Journal of the International Neuropsychological Society (2014), **20**, 434–443.

doi:10.1017/S1355617714000150

Asymmetric Attention Networks: The Case of Children

Sarit Yaakoby-Rotem AND Ronny Geva
Department of Psychology, Bar Ilan University, Ramat Gan, Israel

(RECEIVED August 8, 2013; FINAL REVISION January 29, 2014; ACCEPTED January 30, 2014; FIRST PUBLISHED ONLINE March 11, 2014)

Abstract

Visuospatial attention-networks are represented in both hemispheres, with right-hemisphere dominance in adults. Little is known about the lateralization of the attentional-networks in children. To assess the lateralization of attentional-networks in children aged 5 years, performance on a Lateralized-Attention-Network-Test specifically designed for children (LANT-C) was compared with performance on the Attention-Network-Test for children (ANT-C). Participants were 82 children, aged 5–6 years (55% boys, middle–class, mainstream schooling). They were examined with both the ANT-C and the LANT-C along with evaluation of intelligence and attention questionnaires. Multiple analysis of variance showed a main effect for network, with high efficiency for orienting and lower executive efficiency (accuracy; $p < .001$; $\eta^2 = .282$). An effect for procedure, elucidated higher efficiency in the ANT-C relatively to the LANT-C (accuracy; $p < .01$; $\eta^2 = .097$). A procedure × network interaction effect was also found, showing that this procedure difference is present in the alerting and executive networks (accuracy; $p < .05$; $\eta^2 = .096$). LANT-C analysis showed a left visual-field advantage in alerting, (accuracy; $p < .05$; $\eta^2 = .066$), while executing with the right hand benefitted executive performance (response-time; $p < .05$; $\eta^2 = .06$). Results extend previous findings manifesting a right-hemisphere advantage in children's alerting-attention, pointing to the importance of lateralization of brain function to the understanding of the integrity of attention-networks in children. (*JINS*, 2014, *20*, 434–443)

Keywords: Attention networks, Children, Hemispheric lateralization, Visuospatial attention, Right-hemisphere dominance, Cerebral dominance

INTRODUCTION

Both hemispheres work in concert to enable efficient cognitive performance, with each hemisphere contributing its own unique input (Hervé, Zago, Petit, Mazoyer, & Tzourio-Mazoyer, 2013). The anatomical structures and networks believed to underlie attention are distributed over both hemispheres. However, the individual components are lateralized (Greene et al., 2008). It has been suggested that, although the anatomical basis of hemispheric dominance for visuospatial-attention is largely unknown, visuospatial-attention is probably a bilateral function, with right-hemisphere dominance in most adults (Thiebaut de Schotten et al., 2011). Research with healthy adults indicates that attention favors the right side of the visuospatial-field (Castro-Barros, Lacerda, Righi, & Ribeiro-do-Valle, 2010). Specifically, (Mesulam, 1990) proposed that a left-hemisphere network controls attention to objects on the right and that a right-hemisphere network controls attention to both the left and the right. Work with individuals with attention-disorders also appears compatible with this assertion (Mesulam, 1990). Little is known on the hemispheric lateralization of attention in children.

Correspondence and reprint requests to: Ronny Geva, Department of Psychology, The Gonda Brain Research Center, The Developmental Neuropsychology lab, Bar Ilan University, Ramat Gan, Israel 529002. E-mail: ronny.geva@biu.ac.il

Developmental View of Hemispheric Asymmetrys

Research shows that hemispheric anatomical asymmetry emerges early on in development. Basic structural lateralization can be assessed as early as the 12th week of gestation (Hervé et al., 2013) and micro-anatomic and physiological inter-hemispheric differences appear as early as the 30th week of pregnancy (Smyser, Snyder, & Neil, 2011). These differences persist into the postnatal period, and continue to develop during late infancy (Dubois et al., 2010; Glasel et al., 2011; Habas et al., 2012; Hill et al., 2010; Kasprian et al., 2011), persisting throughout early and late childhood and on into adolescence (Dean & Anderson, 1997).

Functional lateralization seems to be the result of these anatomical maturational processes (Everts et al., 2009), and task-specific experiences such as during visual search (Everts et al., 2009), the activation of visuospatial memory (Groen, Whitehouse, Badcock, & Bishop, 2012), and processing of linguistic forms and contexts (Karunanayaka et al., 2006). The maturation of hemispheric specialization is associated with improvements in visuospatial and linguistic abilities (Everts et al., 2009) that set the basis for cognitive development (Hervé et al., 2013). These visuospatial experiences drive the development of discrete attention-networks.

Attention-Networks and Their Development

Developmental models of attention suggest that the maturational process of attention-systems can be followed in parallel with the development of various brain regions (Colombo, 2001; Posner & Petersen, 1990). Behavioral expressions and functional magnetic resonance imaging (fMRI) data suggest that attention-systems activate three largely orthogonal networks (Fan, McCandliss, Flombaum, Thomas, & Posner, 2001; Petersen & Posner, 2012):

i. The *vigilance-alerting network* is responsible for the state of alertness while preparing for a response, as indicated by activations in the fronto-parietal cortex and thalamus. This network is thought to be mediated by the norepinephrine system arising in the locus coeruleus of the midbrain. There is evidence that the ability to regulate arousal is related to the alerting-network, which appears to be mediated particularly by right-hemispheric networks (Petersen & Posner, 2012; Posner & Petersen, 1990; Raz, 2004). Basic alerting abilities are present from birth, gradually developing through the first months of life. At early developmental stages, the level of arousal affects both the ability to regulate attention and the extent of reactivity to stimuli (Geva, Yaron, & Kuint, 2013).

ii. The ability to *orient and re-orient visual-attention*, involves a dorsal top-down attention network, consisting of frontal eye fields (FEF) and intraparietal sulcus/superior parietal lobe, and a ventral bottom-up re-orienting sub-network, consisting of the temporoparietal junction (TPJ) and the ventral frontal cortex (VFC) (Petersen & Posner, 2012). Orienting develops from the first months of life (Geva et al., 2013; Rothbart & Posner, 2001; Rueda et al., 2004), and is also correlated with right-hemispheric function, specifically, at the right-sided temporal-parietal junction (Corbetta, Kincade, Ollinger, McAvoy, & Shulman, 2000; Konrad, Neufang, Hanisch, Fink, & Herpertz-Dahlmann, 2006). The orienting-network is responsible for sensory tuning (especially visual tuning), spatial-attention, and transitions between foci of visual stimuli. Orienting-related activations are modulated by the cholinergic system which arises in the basal forebrain. A developmental study by (Rueda et al., 2004) comparing 6- to 10-year-old children and adults showed that orienting develops from infancy and reaches full maturity by 6 years (Rothbart & Posner, 2001; Rueda et al., 2004).

iii. *The executive functions* (EF) network, enables focus on a target signal in complex or conflicting contexts for the purpose of achieving a goal and executing a well-adjusted response, while monitoring automatic responses and inhibiting distracting information in a sustained manner (Petersen & Posner, 2012; Posner & Petersen, 1990). These functions are enabled by the cingulo-opercular control system, which supports across trial maintenance and provides stable background maintenance for task performance as a whole; and the frontoparietal system, which allows task switching and initiation, and real time within trial adjustments. Preliminary signs of executive abilities appear during the first year of life, but show a dramatic advance around the age of 5 years (Berger, Kofman, Livneh, & Henik, 2007; De Luca & Leventer, 2008). The study of lateralization of EF in this age group indicates a right prefrontal advantage (Rolfe, Hausmann, & Waldie, 2006; Rueda, Rothbart, McCandliss, Saccomanno, & Posner, 2005). Studies of response inhibition conducted with healthy children and adolescents show an increase in maturation of right-prefrontal regions with age (Rubia et al., 2001). For example, at the age of 2 years, children show relatively high error rates in conflict-resolution tasks. This tendency gradually decreases in the following months and childhood years (Gerardi-Caulton, 2000; Posner, Sheese, Odludas, & Tang, 2006), reaching a near-plateau adult level at the age of 8 years (Rueda et al., 2004). However, the lateralization of the executive-control attention, ventral and dorsal networks, are not yet well understood.

Evaluating Attention-Networks in Children

The current work is focused on children 5 years of age, based on the findings, showing that this age period serves as an important milestone in the development of the three attentional networks using the ANT-C (Fan, McCandliss, Sommer, Raz, & Posner, 2002; Rueda et al., 2004). Rueda's work with the ANT-C with children from early to middle childhood and adults is indicative of a marked shortening of the gap between the cued condition and the respective non-cued in each network as a potential marker of increased network efficiency as a function of development (Rueda et al., 2004, 2005). This line of research set the ground to study children's network efficiency as a function of hemispheric lateralization.

Assessment of Lateralized Attention-Networks

Attention lateralization testing has been made possible using the LANT developed for adults (Greene et al., 2008). This experimental paradigm, which is based on Posner and Petersen's (1990) model, incorporates hemispheric lateralization in the assessment of attention-networks. Findings from this study with healthy adults indicate that the three attentional functions are represented differently in each of the hemispheres. These preliminary findings suggest that lateralized attention tests extend our understanding of the neuropsychological characteristics of attention-functions, by providing sensitive information, which is less accessible using central stimulus presentations, and a long temporal window of presentation that may activate both hemispheres simultaneously.

Studies combining hemispherical asymmetry research with the LANT procedure are still sparse. Therefore, it is important to broaden the scope of our knowledge in this field, especially with children to improve our ability to understand the hemispheric lateralization of attention-networks in children and to detect neurobiological risk factors for the development of ADHD (Gurevitz, Geva, Varon, & Leitner, 2014) as a function of atypical lateralization (Allen, 2002).

Objectives and Hypotheses

The objective of the current study was to generate an integrated adaptation of the ANT-C (Rueda et al., 2004) and the LANT (Greene et al., 2008) to create a lateralized attention test for children (LANT-C), aiming to study lateralization of attention-systems in children.

The first aim was to compare performance on the ANT-C with results of the LANT-C. The second aim was to study the added value of the LANT-C by studying expressions of each of the three attention-networks as functions of a lateralized stimulus presentation, and lateralized execution. The goal was to understand how the different combinations of stimulus presentation field and executing hand (i.e., different lateralized hemispheric patterns) influence the functioning of the three networks in children.

Network main effects

We hypothesized that the highest efficiency will be found in the orienting-network, while the efficiency of the executive-network would be the least pronounced. In addition, we hypothesized that the alerting-network would manifest intermediate efficiency, relatively to the other two networks. Measures of efficiency were computed in reaction time, accuracy, and number of omission error difference scores for each network.

Main effect of procedures

We hypothesized that the overall efficiency of the three networks would be higher in the ANT-C procedure (using central presentation of stimuli and execution with the right hand), when compared with the more demanding LANT-C procedure, using lateralized presentation of stimuli (right visual field *vs.* left visual field) and execution by each hand (right *vs.* left hand).

Hemispheric lateralization effects

Analysis of performance on the LANT-C would reveal hemispheric differences. These differences would be evident by enhanced efficiency of attention-networks in conditions that stimulate the right hemisphere. Specifically, the functioning of the three networks would be facilitated by the presentation of the target stimulus to the left visual field, relatively to the right visual field. This effect will be most noted in the alerting network (Petersen & Posner, 2012), and will not be over-shadowed by performance with the right (i.e., dominant) hand.

METHOD

Participants

Participants were 82 children (55% boys), 5–6 years old ($M = 65$ months; $SD = 3.31$). Families were recruited through the municipal Institute of Young-Child-Education, as well as from the Sheba Medical-Center, Ramat-Gan, Israel. All families recruited were traditional nuclear families from the middle-class mainstream kindergartens. Children with severe neurodevelopmental disabilities (e.g., blindness, hearing-loss, cerebral-palsy, special-education, $N = 6$) were excluded, and 10 from 100 approached families declined participation. Parental reports concerning laterality indicated that only two participants were left handed. Given their limited number, they were excluded from the analysis.

Ethics

The ethics committee of Bar-Ilan University and the Helsinki Committee of Sheba Medical-Center approved the study. All parents gave written informed consent and their children expressed oral consent.

Procedure

Parents were invited by telephone to participate in a study about child development. Upon arrival, parents gave informed consent and filled out demographic questionnaires, regarding the child and themselves. After a short warm-up session in a play-room, the children were seated 50 cm away from the Tobii 1750 gaze-tracker and were engaged in several tasks. The Tobii tracks eye-gaze in angles up to ±40° measured from the built-in camera. Luminance at eyes as measured with the Lux meter model LX 1010BS was 340 ± 13.6 lux. To confirm that there are no significant differences between the distances of the two eyes from the screen, an analysis of covariance (ANCOVA) with the children's height as a covariate was performed. The analysis showed that there were no significant differences between the distances of the two eyes from the screen during the LANT-C task (mean ± SD right eye 52.97 ± 4.23; left eye 52.62 ± 4.40 cm, $F = .198$; $p < .001$).

Socio-cognitive assessment

General abilities were assessed using the Griffiths-Mental-Developmental Scales-Revised (GMDS; Griffiths, 2006). Two indices were computed using GMDS scores: (a) Motor performance composite score, computed from the Locomotor scale (scale A) and the Eye–Hand Co-ordination scale (scale D); (b) Socio-communicative composite score, computed from the Personal-Social scale (scale B) and Language scale (scale C).

The Young Child ANT procedure (ANT-C)

This computerized task provides a measure of efficiency of the three attention-networks, by computing differences in reaction-time (RT) under different conditions. An ANT-C session (Figure 1) consists of 4 instruction trials, 8 practice trials, and 3 experimental blocks of 32 trials each. Each block includes different target stimuli. In the instruction block, a row of three pictures of fish is presented, above or below a fixation point situated in the middle of the screen. Children were instructed to pay attention to the fish in the middle and to respond (by pressing a key), based on whether the fish was "looking" to the left or to the right. Children were instructed to respond with their dominant hand (e.g., "Press the button with the hand that you prefer writing with"). Two children responded with their left hand, and were thus omitted from the comparative analyses.

For the executive-attention section of the ANT-C (i.e., the conflict task), children were presented with a picture of a fish surrounded by congruent or incongruent flankers. On congruent trials, fish on either side of the middle fish (flankers) "looked" in the same direction, whereas on incongruent trials, flankers pointed in the opposite direction, prompting the incorrect response. For correct responses, feedback was a simple animation sequence of the target fish swimming into a net and making a happy sound. Incorrect responses were followed by a single tone and no animation sequence was shown.

Following instructions, children began practice trials. Each practice trial began with fixation randomly assigned a duration of 400–1600 ms, and was followed by one of four possible warning cue conditions (2.2×1.4 cm) that appeared for 150 ms: (1) a central cue (appearing in the middle of the screen), (2) a double cue (a simultaneously cue above and below the fixation point), (3) a spatial cue (a cue indicating where the target stimulus will appear), or (4) no cue. On any trial, each cue had a 25% appearing probability. After presentation of the cue, there was a second 450-ms-long fixation period, followed by target stimulus presentation (10×1.5 cm). The target stimulus (or stimuli) then appeared for 1700 ms, or until a response was elicited. As for the instruction block, each trial concluded with feedback depending on the accuracy of the response. Experimental blocks resembled the target block; however, the target stimuli (animal) were different.

We used the efficiency measures of the three networks presented by (Rueda, Checa, & Combita, 2012). According to their work, network-efficiency is computed by estimating the effect of the alerting cue (double cue), the orienting cue (spatial cue), and the executive cue (congruent flankers) across all animal blocks, measuring response-time, accuracy, and omission-errors of the child. Lower scores obtained by the child (the gap between the two types of cues), indicated that there is a lesser need for a network-specific cue, thus showing that the efficiency of the network is higher. The computed network specific gaps were: (a) For the alerting-network: No Cue—Double Cue; (b) For the orienting-network: Center Cue—Spatial Cue; and (c) For the executive-network: Incongruent Flankers—Congruent Flankers.

The Young Child LANT procedure (LANT-C)

This adaptation of the ANT-C procedure includes two additional characteristics: presentation-field and response-hand. The procedure (Figure 2) consists of 4 instruction trials, 8 practice trials (which were not analyzed), and 8 experimental blocks of 32 trials each.

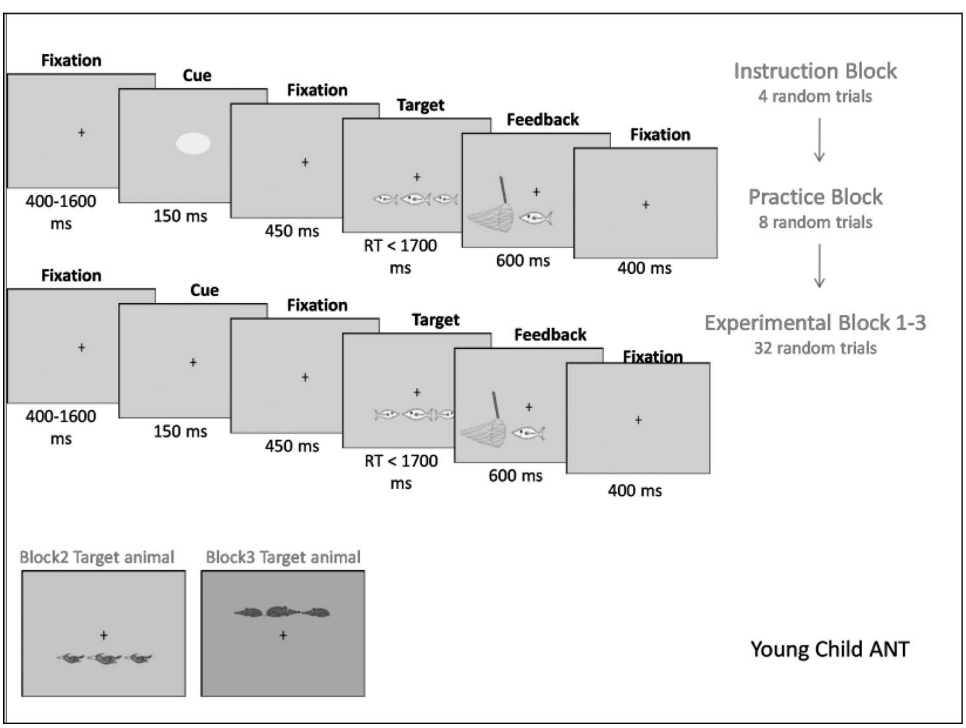

Fig. 1. The ANT-C procedure: examples of stimuli and presentation order.

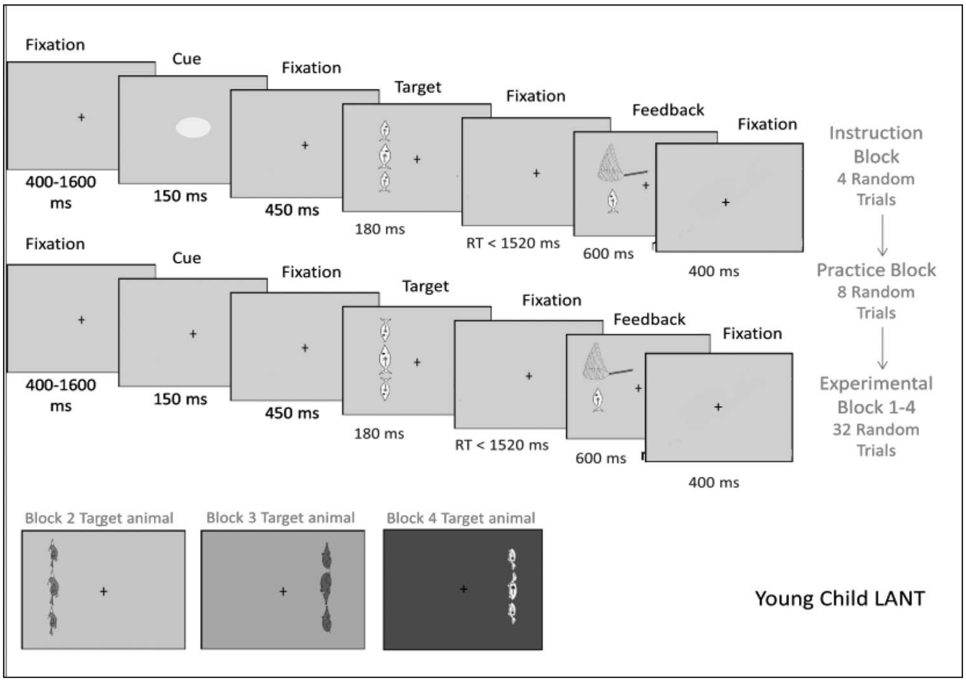

Fig. 2. The LANT-C procedure: examples of stimuli and presentation order.

Each block has different target stimuli; fish, mice, birds, or turtles. The added stimulus in the LANT-C was visually similar to the stimuli in the ANT-C. The two procedures, the ANT-C and the LANT-C, are comparable in the number of trials in each block (32). Mean scores were calculated for each block incorporating the number of trials and stimuli, so that a comparison between the ANT-C and the LANT-C would be possible.

In the instruction block, a line of three fish was presented, on the right or the left of the fixation point. Children were asked to use a different hand for responding on every block. Each trial block began with fixation randomly assigned a duration of 400–1600 ms and was followed by one of the four previously mentioned cueing conditions. The presentation of the cue, followed by a second fixation period (450 ms), and by presentation of the target stimuli (10.3×1.5 cm). The target stimuli were shown for 180 ms, and children were given 1520 ms for responding. Each trial concluded with feedback (happy sound or single tone) as previously described. The LANT-C stimuli consisted, as mentioned, of a line of three animals pointing either upward or downward, and presented either on the left or the right of the fixation point. The order of the tasks was randomized between participants. Each test instrument took approximately 20 min to complete and was administered individually in a quiet room by a qualified clinical psychologist.

RESULTS

Demographic characteristics of the participants are reported in Table 1. These include parental health and education measures, GMDS motor-performance and socio-communicative scales (Griffiths, 2006), CBQ (Putnam & Rothbart, 2006), CBCL (Achenbach & Rescorla, 2001), DSM-IV-TR ADHD scores (American Psychiatric Association, 2000), and measures of birth-maturity, birth-week, birth-weight, and age, weight, and height at test.

To examine the first two hypotheses regarding the main effects of network and procedure, a two-way multiple analysis of variance (MANOVA) was carried out with procedure (ANT-C, LANT-C) and network (alert, orient, conflict) as independent variables, and RT (ms), accuracy, and omission-errors (OE) as dependent variables. The results showed effects of both network and procedure, and a network × procedure interaction, as described below.

Network Main Effects

Our first hypothesis was that there would be differences in the functioning of the three networks. Consistent with this hypothesis, this analysis yielded a significant main effect for network, $F(2,61) = 6.08$, $p < .01$, $\eta^2 = .166$, with RT as the dependent measure. To identify the source of the effect, a *post hoc* analysis was carried out showing a significant difference between the three network indices, such that the lowest difference score was shown in the orienting network ($M = 18.82$; $SD = 8.39$), in comparison with the difference scores in the alerting network ($M = 61.49$; $SD = 10.93$), and in the executive-network ($M = 50.47$; $SD = 6.62$). However, the differences between the alerting and executive networks were not significant.

A main effect for network was also found for accuracy, $F(2,70) = 13.38$, $p < .001$, $\eta^2 = .282$. A *post hoc* analysis revealed that the orienting network evoked the lowest

Table 1. Demographic Data

Measure	Descriptives (mean ± *SD*)
Gender (%male)	54.9%
Maturity (%*)	58.5%
Age at test (months)	65 ± 3.31
Corrected age (months)	65.44 ± 3.42
Weight at test (kg.)	20.01 ± 3.57
Height at test (cm.)	111.56 ± 5.17
Gestation Age (weeks)	36.58 ± 3.68
Birth weight (g.)	2611.67 ± 892.99
Sum DSM hyperactivity~	2.27 ± 2.50
Sum DSM inattention~	1.60 ± 2.07
CBCL External T-Score°	44.26 ± 12.50
CBCL Internal T-Score°	50.22 ± 14.30
CBQ – Activity Level^	3.98 ± 1.02
CBQ – Attentional Focusing^	5.29 ± .95
CBQ – Impulsivity^	4.07 ± .85
CBQ – Inhibitory Control^	5.04 ± .93
GMDS** Socio-communicative %ile†	70.65 ± 19.25
GMDS Motor scales %ile††	46.33 ± 21.15
Paternal education (% higher academic degree†††)	60.2
Maternal education (% higher academic degree)	70
Maternal health (% healthy)	84.3
Paternal health (% healthy)	84.3

*Term age = gestation age >36 weeks; **GMDS = Griffiths Mental Development Scales %ile score for chronological age; †Average percentile score of scale B and C; ††Average percentile score of scales A and D; ††† = percent of parents with above high school academic degrees. ~DSM- questionnaire clinical cutoff requires 6 or more symptoms; °CBCL Clinical cutoff requires a T-score of 70 or more; ^using a scale of 1–7, averages fall within one standard deviation of those reported in Rothbart et al. (2001).

difference-score ($M = 1.13$; $SD = .98$), the alerting network has shown an intermediate difference-score ($M = 3.81$; $SD = .95$), and the executive network yielded the highest difference-score ($M = 7.28$; $SD = .81$).

A network main effect was also noted using the OE dependent measure, $F(2,70) = 7.41$, $p = .001$, $\eta^2 = .175$. A *post hoc* analysis revealed that the OE difference score in the orienting-network ($M = -.32$; $SD = .87$) was significantly lower in comparison with either the alerting-network ($M = 2.47$, $SD = .80$) or the EF network ($M = 3.61$; $SD = .66$). There was no OE difference in the alerting and EF networks efficiency and no network differences using the overall RT measure.

Procedure Main Effects

The second hypothesis postulated that the LANT-C procedure would elicit higher scores in comparison with the ANT-C, indicating lesser efficiency beyond the three networks. In line with this hypothesis, results showed a significant main effect for procedure in the analysis of response accuracy, $F(1,71) = 7.61$, $p < .01$, $\eta^2 = .097$, showing that the overall score was higher in the LANT-C procedure ($M = 5.42$; $SD = .82$) in comparison with the ANT-C procedure ($M = 2.72$; $SD = .72$), indicating a higher efficiency in all three networks in the ANT-C procedure. The differences between the two procedures with RT and OE as dependent measures were not significant.

Procedure × Network Interaction Effect

The current analysis has also yielded a significant Procedure × Network interaction effect for accuracy, $F(2,70) = 3.70$, $p < .05$, $\eta^2 = .096$. To explore the source of this effect, a simple-effect *post hoc* analysis was conducted (Figure 3), showing that participants presented higher efficiency in the alerting network while performing the ANT-C procedure ($M = .81$; $SD = 1.28$) compared with the LANT-C ($M = 6.81$; $SD = 1.46$). Similarly, in executive network higher efficiency was shown in the ANT-C ($M = 5.73$; $SD = 1.29$) in comparison with the LANT-C ($M = 8.83$; $SD = 1.12$). However, no procedure differences were found in the orienting network. RT and OE measures did not yield comparable interaction effects.

Assessment of Lateralized Network Function Using the LANT-C

The third hypothesis was that activation of the right hemisphere would result in a higher efficiency of all three networks, manifested by lower test scores. To explore this hypothesis, we first analyzed the three dependent variables, RT, accuracy and OE, using a 2*2 ANOVA within the LANT-C task, for each network.

This analysis revealed main effects and no Field × Hand interactions. The first main effect was found for field in the alerting network with accuracy as the dependent measure, $F(1,72) = 5.09$, $p < .05$, $\eta^2 = .066$. Specifically the analysis showed that a presentation to the left visual field yielded higher efficiency of the alerting network ($M = 4.73$; $SD = 1.60$) than a presentation to the right visual field ($M = 9.83$;

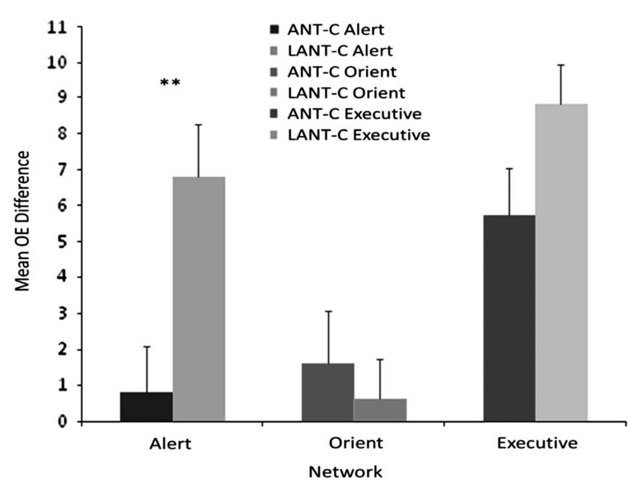

Fig. 3. Response error difference as a function of network and procedure.

$SD = 2.02$), as presented in Figure 4. No differences in the alerting network were found for RT or OE.

In the executive network, a significant main effect for hand was found, with RT as the dependant measure, $F(1,68) = 4.26$, $p < .05$, $\eta^2 = .06$, showing that the efficiency of the executive network was higher when a response was made with the right hand ($M = 18.21$; $SD = 10.37$) than when the response was made with the left hand ($M = 47.83$; $SD = 11.29$). These effects are presented in Figure 5. A similar effect was found in the executive network with OE as the dependant variable, $F(1,72) = 7.03$, $p = 0.01$, $\eta^2 = .09$, with the efficiency of right hand response ($M = 1.54$; $SD = 1.22$), significantly higher than that of the left hand ($M = 5.27$; $SD = .98$), as shown in Figure 6. No significant differences were found in the executive network for the accuracy measure. Furthermore, no significant differences were found in the orienting network.

These results seem to highlight a right hemispheric lateralization that is particularly evident in the alerting network irrespective of pressing hand, in a manner that is different from that seen in the executive networks—where the executing hand made a difference.

In summary, lateralization differences were found in the alerting network and in the executive networks. The alerting efficiency was higher when presenting to the LVF in accuracy and the efficiency of the executive network was significantly higher when the responding hand was the right hand irrespective of visual field in response time and OE.

DISCUSSION

The objective of the current work was to broaden understanding regarding the functioning of the attention-networks (Posner & Petersen, 1990), by studying lateralization of attention in children. Our work focused on attentional mechanisms in 5-year-olds as a function of visual-field and response-hand; specifically, we compared a new task

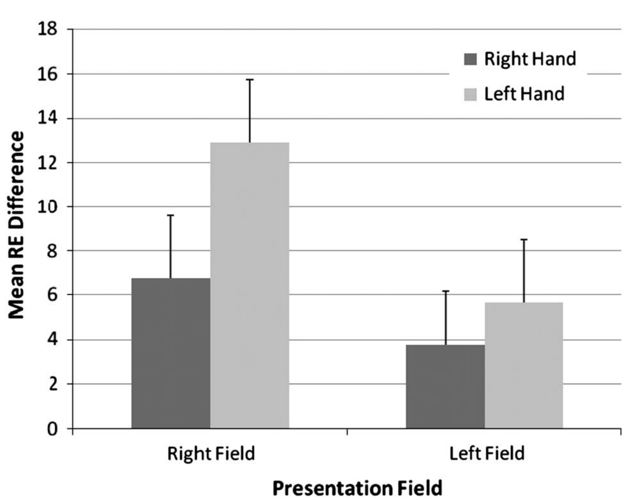

Fig. 4. Accuracy difference in the alerting network as a function of response hand and presentation field.

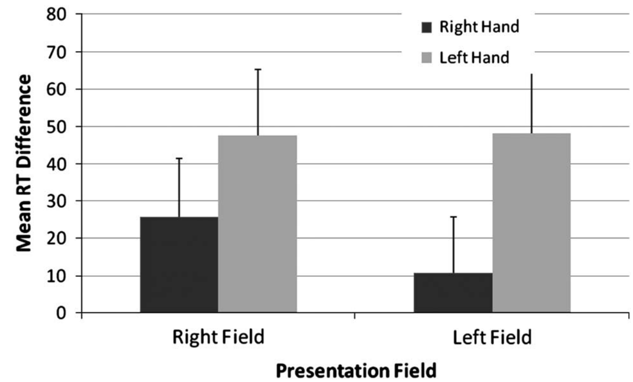

Fig. 5. RT difference in the executive network as a function of response hand and presentation field.

particularly designed for the current project, the LANT-C, with the known attention-network-test for children (Rueda et al., 2004).

The current findings extend the literature in three ways. First, research indicates that in adults each hemisphere has the capacity to be involved in all three attention-networks. Consistent with these adult studies using the LANT (Greene et al., 2008), we found that for children, both the ANT-C and the LANT-C reveal specializations for all three attention-networks. That is, the three attention-networks, alerting, orienting and executive attention are independently represented, in a manner that is compatible with the study of (Rueda et al., 2004). This pattern is supported by findings that the three networks are mediated by different brain structures (Fan et al., 2001).

A main effect of network was found in the current study with children, showing that at least for 5-year-olds, network efficiency is not uniform. As hypothesized, we found differences in the functioning of the three networks, so that, the orienting-network showed higher efficiency while the executive-network showed lesser efficiency. This finding at 5 years of age, complements other developmental findings that showed a dramatic development of the executive abilities at the age of 4–6 years, as demonstrated by ANT-C scores, EEG records, and questionnaire data (Rueda et al., 2005).

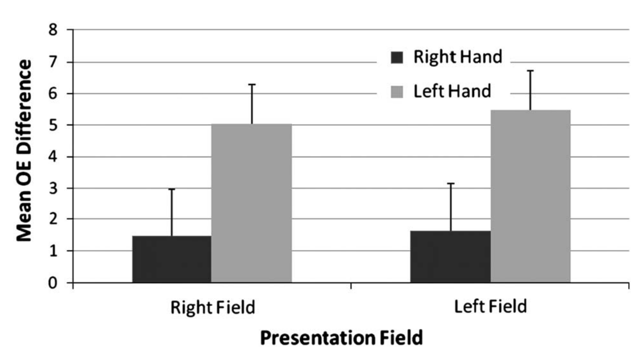

Fig. 6. OE difference in the executive network as a function of response hand and presentation field.

Our second aim was to examine the hypothesis that lateralized performance would be less efficient than performance that engages both hemispheres. Current comparison of children's performance on the classic ANT-C (using a central presentation of stimuli and execution with the right hand) to the results of the new LANT-C (using rapid lateralized stimuli presentation and execution by each hand), showed that the overall efficiency of the three networks was higher in the ANT-C condition, as expressed in a smaller network effect in ANT-C relative to the LANT-C. This finding may indicate that activation of both hemispheres while using the dominant hand, as in the ANT-C increases attention efficacy and points to the utility of bi-hemispheric attention representation to increase attention efficacy. This differs from the LANT-C that probes each hemisphere unilaterally using brief unilateral visual field exposure and alternation of executing hand.

The third aim of the current study was to examine lateralization effects in the three attention networks, using an adapted version of the LANT for children—the LANT-C. We hypothesized that the function of all three networks would be more efficient in conditions that activate the right hemisphere for information processing, especially in the alerting network, based on the conviction that this network is largely focused in right-hemispheric regions (Petersen & Posner, 2012). The current data support this hypothesis for the first time in children, Highlighting right hemisphere involvement, particularly in the alerting network, in a manner compatible with the recently suggested extended framework by Petersen and Posner (2012) in adults. By using lateralized stimuli presentation, we were able to show a right hemispheric advantage in the alerting network, by documenting higher alerting efficiency when the target stimulus was displayed to the LVF, in comparison with conditions in which the left-hemisphere processed the stimulus (RVF). This set of results is compatible with research highlighting the role of the right hemisphere in attentional functions. For example, Fan et al. (2002) presented evidence associating the alerting-network with right fronto-parietal regions. Our findings are also consistent with studies that used both behavioral and functional imaging techniques with adults and showed right-hemispheric dominance for the different attentional-functions and stronger activation of right cortical regions during target detection (Corbetta et al., 2000; Petersen & Posner, 2012; Posner & Petersen, 1990). Thus, the current study contributes to the accumulating base of knowledge associating the function of attention-networks with the right hemisphere (Loo & Barkley, 2005; Rolfe et al., 2006), by showing comparable behavioral data with children.

The right hemisphere advantage seen in the current study may fit with a right hemisphere susceptibility noted in children with attention deficit disorders (ADHD). Brain imaging studies of children diagnosed with ADHD show neuro-functional abnormalities related to hemispheric asymmetry in evoked response potentials (Konrad et al., 2006). Moreover, ADHD DSM-IV diagnosis correlates with activities controlled by the right hemisphere and cerebral networks associated with regions in the right hemisphere (Hale et al., 2005; McAlonan et al., 2007; Posner & Dehaene, 1994; Rolfe et al., 2006). The mechanism involved is still rather speculative. Of interest, MRI studies using voxel mapping of children with brains of children with ADHD reveal significantly lower gray matter volume in the right hemisphere as compared to that of a non-ADHD group (McAlonan et al., 2007). Lower white matter volume in the right prefrontal lobe was also observed for the diagnosed group. Since this study underscores the importance of right hemisphere activation, particularly for alerting attention, future LANT-C studies with children with ADHD may improve diagnosis accuracy and treatment management.

It is notable that the current paradigm did not elicit right-field lateralization effects in the orienting and executive network. This finding is in line with Petersen and Posner's (2012) recent article regarding the lack of a robust lateralization for the executive dorsal and ventral networks, yet this finding may be at odds with reports of lateralization in the orienting network (Petersen & Posner, 2012) and with imaging findings associated the executive network with the right superior cingulate gyrus (Fan et al., 2002). The LANT-C findings concerning the executive network indicated an advantage to the right, albeit dominant, hand. This right hand advantage was not present in the other two networks. The executive network requires processing of fine detail, and executing a counter-intuitive rule based output. It is plausible that in children the efficiency this network relies most pronouncedly on the efficacy of the executing motor system given this entailed cognitive load, and thus benefits from executing using the dominant hand. Future work that will examine the effect of motor dominance may deepen the understanding of this notion.

The current findings from a healthy group of pre-school children may serve as a baseline for future diagnostic and therapeutic work with at-risk groups. This will enable to shed light on the mechanisms underlying attention-related disorders and improve differential diagnosis of specific clinical populations, since the attention-networks might be unilaterally impaired (Loo & Barkley, 2005). Moreover, fMRI studies with the LANT-C may elicit unilateral attention related deficits in children with attention disorders, neurological pathologies or acquired brain injury.

Methodological Limitations

For purposes of the current study, given the limited cognitive resources of young children and the need to administer both the ANT-C and the LANT-C to the same participants, it was not possible to add more conditions to our study paradigm. This resulted in limitations to conducting a full comparison between the ANT-C and the LANT-C, to examine fine differences between both tasks in stimuli processing duration: the LANT-C- uses brief stimuli exposure, while the ANT-C stimuli were presented until a response was made. Furthermore, in the ANT-C, the children responded with their dominant-hand, whereas the LANT-C requires increasing demand by alternating between hands, as in the Greene et al. (2008) protocol. Future work may consider a requirement to use RH and LH randomly in ANT-C as well to examine the effect of this requirement on performance. The effects found in the current results may be attributed in part to these differences.

The current findings show the importance of presentation field even while controlling for response hand and provide an effective paradigm to examine these effects. It may be useful to examine the effect sizes of presentation field and executing hand in certain clinical cases.

CONCLUSION

The current work highlights the importance of considering lateralization of children's attentional-networks. In particular, findings underscore the advantage of right-hemisphere processing in children's visuospatial-attention, an advantage that manifests differentially for the alerting-network. This involvement of the right-hemisphere in alerting children's attention to stimuli in the environment, may serve to increase the efficiency of their adaptability to dynamic environments.

ACKNOWLEDGMENTS

We thank the participating families, the medical team at the Sheba Medical Center Department of Neonatology and the members of the Developmental Neuropsychology lab at the Gonda Brain Research Center. We thank Prof. Eran Zaidel and Dr. Anat Barnea for sharing the LANT program with us and for their invaluable consultation. The project was partly funded by the Israel Science Foundation grant awarded to Dr. Ronny Geva. The authors declare no conflict of interest. Portions of this study were presented at the Biennial meeting of the Society for Research in Child Development, Seattle, April 2013.

REFERENCES

Achenbach, T.M., & Rescorla, L.A. (2001). *Manual for the ASEBA School-Age Forms and Profiles*. Burlington, VT: University of Vermont, Research Center for Children, Youth, and Families.

Allen, M.C. (2002). Preterm outcomes research: A critical component of neonatal intensive care. *Mental Retardation and Developmental Disabilities Research Reviews*, *8*, 221–233.

American Psychiatric Association (2000). *Diagnostic and statistical manual of mental disorders* (4th ed., Text Rivision). Washington, DC: American Psychiatric Association.

Berger, A., Kofman, O., Livneh, U., & Henik, A. (2007). Multidisciplinary perspectives on attention and the development of self-regulation. *Progress in Neurobiology*, *82*, 256–286.

Castro-Barros, B.A., Lacerda, A.M., Righi, L.L., & Ribeiro-do-Valle, L.E. (2010). Lateral asymmetry of voluntary attention orienting. *Brazilian Journal of Medical and Biological Research*, *43*(8), 745–758.

Colombo, J. (2001). The development of visual attention in infancy. *Annual Review of Psychology*, *52*, 337–367.

Corbetta, M., Kincade, J.M., Ollinger, J.M., McAvoy, M.P., & Shulman, G.L. (2000). Voluntary orienting is dissociated from target detection in human posterior parietal cortex. *Nature Neuroscience*, *3*(3), 292–297.

De Luca, C.R., & Leventer, R.J. (2008). Developmental trajectories of executive functions across the lifespan. In P. Anderson, V. Anderson, & R. Jacobs (Eds.), *Executive functions and the frontal lobes: A lifespan perspective* (Vol. 3–21). Washington, DC: Taylor & Francis.

Dean, R.S., & Anderson, J.L. (1997). Lateralization of cerebral functions. In J.A.M. Horton, D. Wedding, & J. Webster (Eds.), *The neuropsychology handbook foundations and assessment* (Vol. 1, pp. 139–198). New York: Springer Publishing Company.

Dubois, J., Benders, M., Lazeyras, F., Borradori-Tolsa, C., Leuchter, R.H., Mangin, J.F., & Hüppi, P.S. (2010). Structural asymmetries of perisylvian regions in the preterm newborn. *Neuroimage*, *52*(1), 32–42.

Everts, R., Lidzba, K., Wilke, M., Kiefer, C., Mordasini, M., Schroth, G., … Steinlin, M. (2009). Strengthening of laterality of verbal and visuospatial functions during childhood and adolescence. *Human Brain Mapping*, *30*(2), 473–483.

Fan, J., McCandliss, B.D., Flombaum, J.I., Thomas, K.M., & Posner, M.I. (2001). *Comparing images of conflict in frontal cortex.* Paper presented at the Annual meeting of the Cognitive Neuroscience Society, New York.

Fan, J., McCandliss, B.D., Sommer, T., Raz, A., & Posner, M.I. (2002). Testing the efficiency and independence of attentional network. *Journal of Cognitive Neuroscience*, *14*, 340–347.

Gerardi-Caulton, G. (2000). Sensitivity to spatial conflict and the development of self-regulation in children 24–36 months of age. *Developmental Science*, *3–4*, 397–404.

Geva, R., Yaron, H., & Kuint, J. (2013). Neonatal sleep predicts attention orienting and distractibility. *Journal of Attention Disorders*. doi: 10.1177/1087054713491493

Glasel, H., Leroy, F., Dubois, J., Hertz-Pannier, L., Mangin, J.F., & Dehaene-Lambertz, G. (2011). A robust cerebral asymmetry in the infant brain: The rightward superior temporal sulcus. *Neuroimage*, *58*(3), 716–723.

Greene, D.J., Barnea, A., Herzberg, K., Rassis, A., Neta, M., Raz, A., & Zaidel, E. (2008). Measuring attention in the hemispheres: The lateralized attention network test (LANT). *Brain and Cognition*, *66*(1), 21–31.

Griffiths, R. (2006). *The abilities of young children – Revised.* London: Child Development Research Center – The Testing Agency.

Groen, M.A., Whitehouse, A.J., Badcock, N.A., & Bishop, D.V. (2012). Does cerebral lateralization develop? A study using functional transcranial Doppler ultrasound assessing lateralization for language production and visuospatial memory. *Brain Behavior*, *2*(3), 256–269.

Gurevitz, M., Geva, R., Varon, M., & Leitner, Y. (2014). Early markers in infants and toddlers for development of ADHD. *Journal of Attention Disorders*, *18*, 14–22.

Habas, P.A., Scott, J.A., Roosta, A., Rajagopalan, V., Kim, K., Rousseau, F., … Studholme, C. (2012). Early folding patterns and asymmetries of the normal human brain detected from in utero MRI. *Cerebral Cortex*, *22*(1), 13–25.

Hale, T.S., McCracken, J.T., McGough, J.J., Smalley, S.L., Phillips, J.M., & Zaidel, E. (2005). Impaired linguistic processing and atypical brain laterality in adults with ADHD. *Clinical Neuroscience Research*, *5*, 255–263.

Hervé, P.Y., Zago, L., Petit, L., Mazoyer, B., & Tzourio-Mazoyer, N. (2013). Revisiting human hemispheric specialization with neuroimaging. *Trend in Cognitive Science*, *17*(2), 69–80.

Hill, J., Dierker, D., Neil, J., Inder, T., Knutsen, A., Harwell, J., … Van Essen, D. (2010). A surface-based analysis of hemispheric asymmetries and folding of cerebral cortex in term-born human infants. *Journal of Neuroscience*, *30*(6), 2268–2276.

Karunanayaka, P.R., Holland, S.K., Schmithorst, V.J., Solodkin, A., Chen, E.E., Szaflarski, J.P., & Plante, E. (2006). Age-related connectivity changes in fMRI data from children listening to stories. *Neuroimage*, *34*(1), 349–360.

Kasprian, G., Langs, G., Brugger, P.C., Bittner, M., Weber, M., Arantes, M., & Prayer, D. (2011). The prenatal origin of hemispheric asymmetry: An in utero neuroimaging study. *Cerebral Cortex*, *21*(5), 1076–1083.

Konrad, K., Neufang, S., Hanisch, C., Fink, G.R., & Herpertz-Dahlmann, B. (2006). Dysfunctional attentional networks in children with attention deficit/hyperactivity disorder: Evidence from an event-related functional magnetic resonance imaging study. *Biological Psychiatry*, *59*(7), 643–651.

Loo, S.K., & Barkley, A.R. (2005). Clinical utility of EEG in attention deficit hyperactivity disorder. *Applied Neuropsychology*, *12*, 64–76.

McAlonan, G.M., Cheung, V., Cheung, C., Chua, E.S., Murphy, D.G.M., Suckling, J., … Ho, T.P. (2007). Mapping brain structure in attention-deficit hyperactivity disorder: A voxel-based MRI study of regional grey and white matter volume. *Psychiatry Research: Neuroimaging*, *154*, 171–180.

Mesulam, M.M. (1990). Large-scale neurocognitive networks and distributed processing for attention, language, and memory. *Annals of Neurology*, *28*(5), 597–613.

Petersen, S.E., & Posner, M.I. (2012). The attention system of the human brain: 20 years after. *Annual Review of Neuroscience*, *35*, 73–89. doi: 10.1146/annurev-neuro-062111-150525

Posner, M.I., & Dehaene, S. (1994). Attentional networks. *Trends in Neurosciences*, *17*, 75–79.

Posner, M.I., & Petersen, S.E. (1990). The attention system of the human brain. *Annual Review of Neuroscience*, *13*, 25–42.

Posner, M.I., Sheese, B.E., Odludas, Y., & Tang, Y. (2006). Analyzing and shaping human attentional networks. *Neural Networks*, *19*, 1422–1429.

Putnam, S.P., & Rothbart, M.K. (2006). Devlopment of short and very short forms of the children's behavior questionnaire. *Journal of Personality Assessment*, *87*(1), 103–113.

Raz, A. (2004). Anatomy of attentional networks. *The Anatomical Record*, *281B*, 21–36.

Rolfe, M.H.S., Hausmann, M., & Waldie, K.E. (2006). Hemispheric functioning in children with subtypes of attention-deficit/hyperactivity disorder. *Journal of Attention Disorders*, *10*, 20–27.

Rothbart, M.K., Ahadi, S.A., Hershey, K.L., & Fisher, P. (2001). Investigations of temperament at three to seven years: The Children's Behavior Questionnaire. *Child Development*, *72*(5), 1394–1408.

Rothbart, M.K., & Posner, M.I. (2001). Mechanism and variation in the development of attention networks. In C.N.M. Luciana (Ed.), *Handbook of developmental cognitive neuroscience* (pp. 353–363). Cambridge, MA: MIT Press.

Rubia, K., Taylor, E., Smith, A.B., Oksannen, H., Overmeyer, S., & Newman, S. (2001). Neuropsychological analyses of impulsiveness in childhood hyperactivity. *British Journal of Psychiatry*, *179*, 138–143.

Rueda, M.R., Checa, P., & Combita, L.M. (2012). Enhanced efficiency of the executive attention network after training in preschool children: Immediate changes and effects after two months. *Developmental Cognitive Neuroscience*, *2*, 192–204.

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.

Rueda, M.R., Rothbart, M.K., McCandliss, B.D., Saccomanno, L., & Posner, M.I. (2005). Training, maturation, and genetic influences on the development of executive attention. *Proceedings of the National Academy of Sciences of the United States of America*, *102*, 14931–14936.

Smyser, C.D., Snyder, A.Z., & Neil, J.J. (2011). Functional connectivity MRI in infants: Exploration of the functional organization of the developing brain. *Neuroimage*, *56*(3), 1437–1452.

Thiebaut de Schotten, M., Dell'Acqua, F., Forkel, S.J., Simmons, A., Vergani, F., Murphy, D.G., & Catani, M. (2011). A lateralized brain network for visuospatial attention. *Nature Neuroscience*, *14*(10), 1245–1246.