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Voluntary and automatic orienting of attention during childhood development

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Abstract

Selective attention directs cognitive resources to relevant objects or events through either voluntary (top-down) or automatic (bottom-up) control. This paper analyzes voluntary and automatic orienting of attention during childhood development. Seventy-four children (6 to 10 years old) were asked to press a key in response to a visual target presented in a previously oriented position (voluntary orienting; Experiment 1) or after a peripheral unpredictable cue (automatic orienting; Experiment 2). A systematic reduction of reaction times was observed in older children in both experiments. For automatic orienting in Experiment 2, reaction times were shorter in the ipsilateral condition than in the contralateral condition. However, for older children, the differences in reaction times between these conditions decreased. This may be attributable to the appearance of Inhibition of Return as a result of the maturation of the attentional system derived from childhood development, which contributes to more effective exploration of the environment. **Keywords:** attention, development, voluntary orienting, automatic orienting.

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Introduction

Selective attention directs cognitive resources toward objects or events that are relevant to our objectives, through either voluntary (top-down) or automatic (bottom-up) control (Hopfinger, Buonocore, & Mangun, 2000; Petersen & Posner, 2012; Chica, Bartolomeo, & Lupiáñez, 2013). Voluntary orienting can occur intentionally (e.g., when one focuses attentional resources on a particular area of the visual field). In this case, attentional shift is endogenous or intrinsic. The automatic orienting of attention is associated with the reflexive capture of processing resources by stimuli that occur in the environment. In this case, visual stimuli can automatically capture attention. This type of attentional shift is exogenous or extrinsic. The existence of these selection processes allows environmental stimuli to be efficiently processed by the central nervous system, preventing the overload of unnecessary information (Desimone & Duncan, 1995; Knudsen, 2007; Smith & Chatterjee, 2008; Petersen & Posner, 2012; Carrasco, 2011; Chica et al., 2013). Thus, orientation of attention in organism/environment interactions reflects competition between external demands and internal goals (Berger, Henik, & Rafal, 2005; Chica et al., 2013).

The search for possible methods for studying attention and its orienting mechanisms is a vast topic in the neuroscience literature. Many studies have shown that measuring manual reaction time (RT) to a sensory stimulus is a useful quantifiable method to comprehend the influence of attentional and sensory mechanisms involved in processing visual information (Carreiro, Haddad, & Baldo, 2011; Petersen & Posner, 2012; Chica et al., 2013). Thus, studies of the visual orienting of attention using RT measures can contribute to a better understanding of how the nervous system selects relevant information from the environment and the neural circuitries involved (Petersen & Posner, 2012; Carrasco, 2011).

Knowing the previous position of a target can improve the response to stimuli in expected positions, but this also leads to the less efficient processing of stimuli that occur elsewhere in the visual field. The question about how to evaluate the costs and benefits of orienting attention was studied by Posner (1978) and in many recent studies (Knudsen, 2007; Klein, 2009; Carreiro et al., 2011; Chica et al., 2013). In the study by Posner, the position of the target's appearance was indicated by an arrow next to a fixation point. When the arrow correctly indicated the target position (valid), the

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participant's manual response was faster than when the arrow erroneously indicated the target position (invalid) or when no indication was given (neutral). According to Posner (1978), the differences observed in RTs under these conditions might be caused by central mechanisms involved in expectations about the position of target occurrence.

In addition to central cues, the occurrence of an unexpected uninformative stimulus in the periphery of the visual field may decrease RTs to targets that subsequently occur (up to 150 ms) in the same position. With longer intervals (200-1500 ms), an opposite effect is observed (i.e., greater RTs). Posner & Cohen (1984) called the first effect Early Facilitation (EF) and the second effect Inhibition of Return (IOR). For these authors, EF can occur because of the occurrence of a peripheral uninformative visual stimulus that automatically attracts attention to its position. Greater RTs related to IOR are explained as a difficulty returning to previously stimulated positions in the visual field, which facilitates exploratory behavior (Klein, 2000).

The effects of directing attention voluntarily and automatically have been extensively studied in adults. However, comprehension of how these processes are related to childhood development is not fully understood. Colombo (2001) provided an overview of the development of visual attention in childhood using four attentional functions: alertness, spatial orienting, attention to object features, and endogenous attention. He suggested that forms of attentional functions that have been documented in adults appear to exist during the first year of life. Furthermore, the fact that these functions exhibit different developmental courses indicates that they can be dissociable in childhood and adulthood.

Plude, Enns, & Brodeur (1994) reviewed and discussed findings about infancy-childhood and adulthood, outlining research on selective attention within a lifespan developmental framework. They found in the child development literature that the RT method was used to study the covert orienting of attention, even in early childhood. Smith & Chatterjee (2008) stated that the ability to orient to salient visual stimuli emerges in the first few months of life and continues to evolve through childhood. Brodeur & Enns (1997) examined covert visual orienting over the span of a human life, ranging from 6 to 73 years of age, using an abrupt stimulus cue and voluntary information cue and measuring RTs in discrimination tasks. The authors found few age differences in stimulus-cued orienting but important differences when orienting was intentional. Compared with young adults, children were less able to sustain orienting over time, and senior adults required more time to process information given by the cue. Waszak, Li, & Hommel (2010) used Posner-type orienting tasks with valid and invalid cues to investigate gains and losses in the ability to use exogenous cues to shift attention covertly and ignore conflicting information in individuals aged 6 to 89 years. They found that the ability to deal with conflicting information improved more slowly during early life than the ability to covertly orient attention.

Dye & Bavelier (2010) found that attentional skills improve with increasing age, but little is known about the factors that promote this development and its exact timeline. The present study explored this issue by analyzing the voluntary and automatic orienting of attention during childhood development in children from 6 to 10 years of age and examined the effects of IOR and EF.

Methods

Participants

Seventy-four children aged 6 to 10 years (42 girls and 32 boys) who were enrolled in a private elementary school (from 1st to 5th grade) in São Paulo, Brazil participated in the study. They were divided into five age groups (6 years old, n = 15, average age, 6.6 ± .3 years; 7 years old, n = 20, average age, 7.3 ± .3 years; 8 years old, n = 19, average age, 8.5 ± .4 years; 9 years old, n = 9, average age, 9.5 ± .3 years; 10 years old, n = 11, average age, 10.6 ± .3 years). Teachers from the school were asked to select eight children (four boys and four girls) from each of 15 classes in different grades. Selected students received an invitation letter that requested the presence of a parent at a meeting scheduled by the school at which the research and evaluation process were explained.

The following inclusion criteria were used: (1) parental consent, (2) score on Attention Deficit Hyperactivity Disorder Scale version for teachers (Benczik, 2000) that did not indicate attention deficits or hyperactivity, (3) intellectual level within or above average according to an estimated Intelligence Quotient (IQ) assessed using the Vocabulary and Block Design subtests of the Wechsler Intelligence Scale for Children, 3rd edition (WISC-III; Mello, 2011), and (4) absence of clinical or borderline signs of behavioral problems both in parental reports on the Child Behavior Checklist (CBCL; 6/18) and teachers' responses on the Teacher's Report Form (TRF; 6/18; Achenbach & Rescorla, 2001). All methodological procedures were approved by the Committee on Research Involving Human Subjects at Mackenzie Presbyterian University (CEP/UPM 1229/04/2010 and CAAE 0037.0272.000-10).

Materials and procedure

Measures of RT to visual targets were used according to classical procedures that Posner (1980) described and used in attention research (Smith & Chatterjee, 2008; Carreiro et al., 2011; Chica et al., 2013). For stimulus presentation and data collection, we used an Infoway Itautec laptop computer (Pentium Dual Core 2.10 GHz, 3 GB RAM). The computer routines for stimulus generation and response recording were controlled by E-Prime version 2.0 software

(Psychology Software Tools). The stimuli were designed as white on a black background. All stimuli were presented under suprathreshold and photopic conditions. The stimuli could be easily distinguished from the background. Data were collected in a room at the school that had reduced noise and the presence of the researcher and participant. Two test sessions of 40 min each were conducted. In the first session, IQ was estimated. In the second session, the computer tests were performed (Experiments 1 and 2).

Experiment 1: Voluntary orienting of attention

Initially, a fixation point (FP) was presented in the center of the computer screen. Along with the FP, two 0.8° boxes were presented 5.5° to the right and left. After a random interval of 800–1800 ms, a cue (i.e., an arrow that pointed to the left or right) was presented beside the FP. After 300 or 800 ms of cue presentation, the target (i.e., a filled square with 0.4° sides) was presented inside one of the two boxes until the emission of a response or 1500 ms elapsed, which interrupted the attempt. The cue and target had two possible correlations. In the valid condition, the target appeared at the location indicated by the cue. In the invalid condition, the target appeared at the opposite position indicated by the cue. The cue was valid in 70% of the presentations and invalid in 30% of the presentations. The participants were asked to fixate on the FP during the entire experiment and instructed to direct their attention to the position indicated by the arrow. Regardless of the place where the target appeared, the participants were instructed to respond to it as soon as possible by pressing the spacebar on the computer's keyboard (Figure 1).

Experiment 2: Automatic orienting of attention

A FP was presented in the center of the computer screen along with two 0.8° boxes, which were presented 5.5° to the right and left. After 700 ms, a first stimulus (i.e., an unfilled square) was presented. After an interval of 100 or 800 ms, the target (i.e., a filled square with 0.4° sides) was presented inside one of the two boxes until the emission of a response or 1500 ms elapsed, which interrupted the attempt (Figure 1). Experiments 1 and 2 were different with regard to the type of attentional orientation involved (i.e., voluntary and automatic, respectively), and different intervals between the cue and target were established for each one. In the experiment that involved voluntary orientation, random intervals occurred until the appearance of the cue followed by 300- and 800-ms intervals to the target. The experiment that involved automatic orientation had 700-ms intervals until the appearance of the cue, followed by 100- and 800-ms intervals that were specific to the effects (i.e., EF, 100 ms; IOR, 800 ms).

The cue and target had two possible correlations in Experiment 2. The target could appear at the same position as the first stimulus (i.e., the ipsilateral condition) or at the opposite position (i.e., the contralateral condition). The participants were instructed to fixate on the FP. They should ignore the first stimulus and respond to the target as soon as possible, regardless of the location of its appearance, by pressing the spacebar on the keyboard.

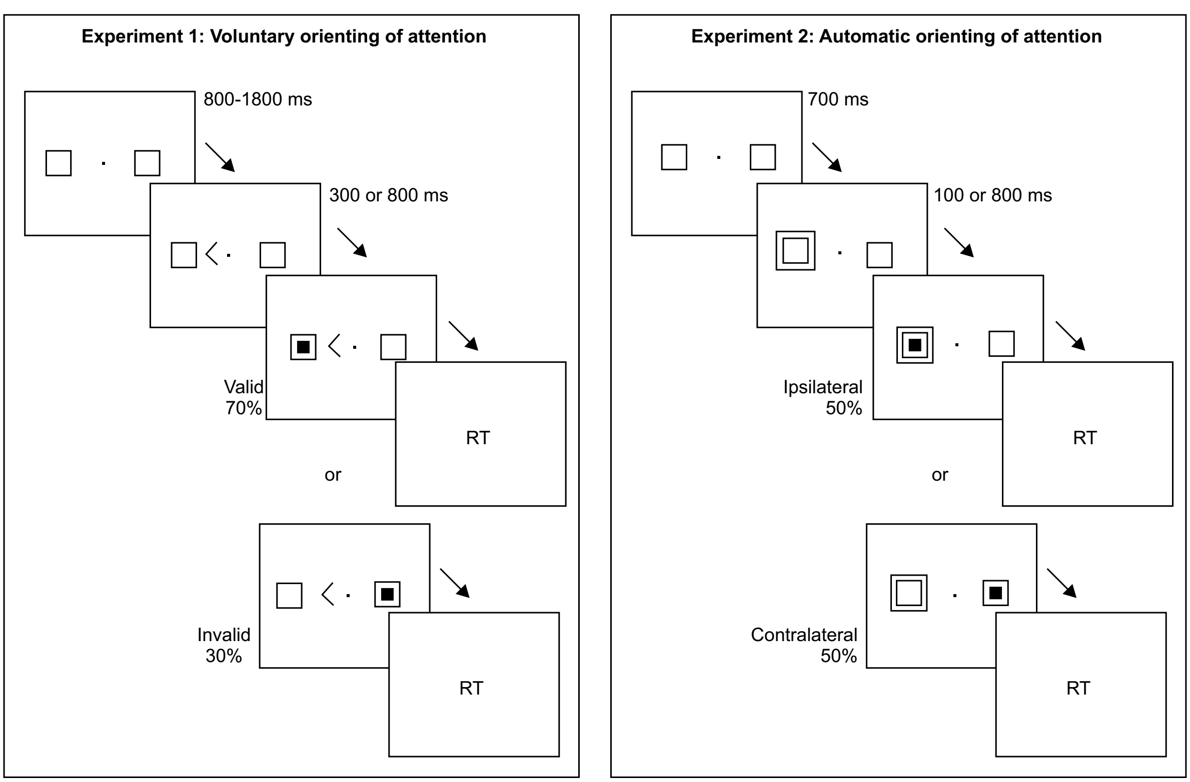

Figure 1. Temporal sequence of stimuli presentation in Experiments 1 and 2.

Statistical analysis

The median RT was calculated for each experimental condition and each participant separately. These values were analyzed using multi-way repeated-measures analysis of variance (ANOVA) followed by pairwise comparisons (Tukey Honestly Significant Difference test). The level of significance was set at 5%.

The median RT in Experiment 1 was analyzed using three-way repeated-measures ANOVA with the following factors: age (between-group; five levels: 6, 7, 8, 9, and 10 years old), cue validity (two levels: valid and invalid), and cue-target interval (two levels: 300 and 800 ms). The median RT for each condition in Experiment 2 was also analyzed using three-way repeated-measures ANOVA with the following factors: age (intergroup factor; five levels: 6, 7, 8, 9, and 10 years old), cue-target spatial correlation (two levels: ipsilateral and contralateral), and cue-target interval (two levels: 100 and 800 ms).

Results

Experiment 1

A significant effect of age was found ($F_{4,69} = 11.066$, $p < .0001$). A systematic reduction of RTs was observed in older children compared with younger children (Figure 2).

A significant effect of cue validity was found ($F_{1,69} = 105.24$, $p < .001$). Reaction times were faster in the valid condition than in the invalid condition. When the target appeared at the location indicated by the cue, RTs were lower than when the target appeared on the opposite side. We also observed an interaction between age and cue validity ($F_{4,69} = 4.0371$, $p = .005$), demonstrating a decrease in RT as a function of increasing age in both the valid and invalid conditions. However, a smaller difference was found between the valid and invalid conditions in older children (6 years old, 72.2 ms; 7 years old, 111.5 ms; 8 years old, 73.9 ms; 9 years old, 57.6 ms; 10 years old, 32.1 ms). Smaller differences between the valid and invalid conditions as a function of increasing age may represent a greater reduction of RTs in the invalid condition. With increasing age, the participants may have become more efficient in perceiving stimuli outside the indicated locations (Figure 2).

A significant effect of cue-target interval was found ($F_{1,69} = 65.295$, $p < .001$). Reaction times were faster for the long (800 ms) cue-target interval than for the short (300 ms) cue-target interval. This difference can be explained by the fact that the 800-ms interval provided more time to direct attention toward the spatial indication of the cue. An interaction between age and cue-target interval was observed ($F_{4,69} = 3.1042$, $p = .0208$), indicating a reduction of RT with increasing age for both the 300 and 800 ms cue-target intervals. Therefore, a smaller difference was found between the valid and invalid conditions in the older students (6 years old, 45.6 ms; 7 years old, 114.6 ms; 8 years old, 68.8 ms; 9 years old, 55.6 ms; 10 years old, 46.9 ms).

Experiment 2

A significant effect of age was found ($F_{4,69} = 11.435$, $p < .001$). A systematic decrease in RTs was observed in older children. Generally, older children had lower RTs than younger children. A significant effect of cue-target spatial correlation was also found ($F_{1,69} = 41.739$, $p < .001$). We also observed a significant interaction between age and cue-target spatial correlation ($F_{4,69} = 5.1855$, $p = .001$). Therefore, a smaller difference between the ipsilateral and contralateral conditions was observed as participants' ages increased (6 years old, 98.3 ms; 7 years old, 44.3 ms; 8 years old, 30.2

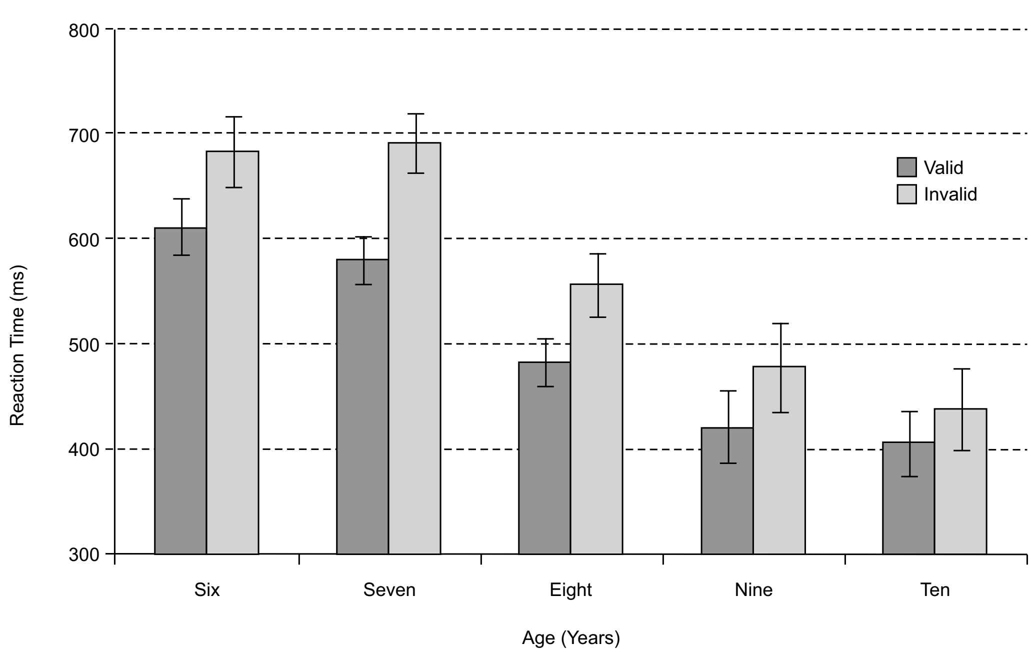

Figure 2. Reaction time in milliseconds (±SEM) for each cue validity condition (valid or invalid) in the five age groups in Experiment 1.

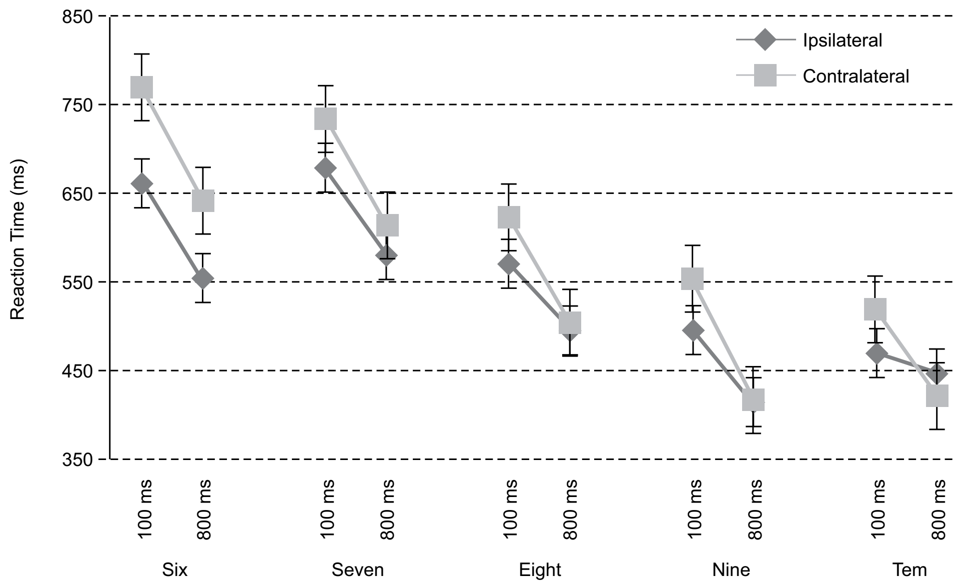

Figure 3. Reaction time in milliseconds (±SEM) for each cue-target spatial correlation (ipsilateral and contralateral) and cue-target interval (100 or 800 ms) in the five age groups in Experiment 2.

ms; 9 years old, 29.5 ms; 10 years old, 11.6 ms). This distinction may have been caused by differences in RTs related to the 800 ms interval.

A significant effect of cue-target interval was found ($F_{1,69}$ = 133.66, p < .001). Reaction times with the 800 ms interval were shorter compared with the 100 ms interval. A significant interaction between cue-target interval and cue-target spatial correlation was observed ($F_{1,69}$ = 10.813, p < .002), demonstrating that RTs in the ipsilateral condition with the 100 ms interval were reduced compared with the contralateral condition. No difference was found between the ipsilateral and contralateral conditions for the 800 ms interval.

Discussion

In Experiment 1, we observed a systematic reduction of RTs in older children who generally had lower RTs than the younger children. With increasing age, improvements in attentional skills led to better performance on the tasks. This might be related to the maturation of neural networks associated with attentional control (Colombo, 2001).

We also found that RTs were faster in the valid condition than in the invalid condition. These results are consistent with previous studies and show that valid cues enable previous shift of attention to the spatial position indicated by the cue (Brodeur & Enns, 1997). This shift facilitates target detection and consequently improves the response expressed by the RT (Posner, 1978; Araújo & Carreiro, 2009; Petersen & Posner, 2012; Carrasco, 2011). These results are also consistent with Plude et al. (1994) who found an age-related decrease in orienting cost in which older subjects switched attention to invalid conditions more efficiently than younger subjects. Dye & Bavelier (2010) studied the impact of normal maturation on the ability to deploy attention over space, time, and objects. They found that different paradigms revealed their own rates of development and could rely on different neural resources.

In Experiment 2, we observed that RTs were faster in the condition in which the cue and target appeared at the same position (ipsilateral condition) than in the condition in which the cue and target appeared on opposite sides (contralateral condition). Such results can be explained by the automatic capture of attention that occurs with the unexpected and abrupt presentation of a stimulus in the periphery of the visual field as initially described by Posner & Cohen (1984). They showed that the occurrence of a stimulus in the periphery of the visual field (when it is uninformative and unexpected) may cause RTs to decrease for subsequent targets at the same position (i.e., EF) when the interval between them is short (up to 150 ms). With longer intervals (200–1500 ms), an opposite effect (i.e., IOR) causes the slowing of RTs when the cue and target occur at the same position. This EF may occur because of the automatic attraction of attention to the position indicated by the peripheral uninformative cue. Moreover, IOR, as explained by Posner & Cohen (1984), impairs the return of the attentional system to previously stimulated positions of the visual field, enabling the search for new positions and facilitating exploratory behavior (Klein, 2000).

When analyzing the modulation of RTs in ipsilateral and contralateral conditions, differences were found according to age. A facilitation of the ipsilateral condition was found for both the 100- and 800-ms intervals in younger children (6 or 7 years old). Moreover, in older children (9 or 10 years old), RTs increased with the 800-ms interval, giving rise to an inhibition process (Figure 3). These results may be associated with the description of EF and IOR by Posner & Cohen (1984). Our results highlight this discussion, demonstrating that these processes depend on the maturation of the nervous system expressed by childhood development related to increasing age. Brodeur & Enns (1997) found evidence of inhibition in a group of young adults who presented faster responses in invalid trials than in valid trials with a long interval (800 ms). The difference between the results of Brodeur and Enns and the present results may be related to differences in the experimental designs. Brodeur & Enns (1997) used discrimination tasks, whereas we used simple RT tasks.

Some studies, such as those cited in the review by Colombo (2001), described characteristics associated with IOR in the first year of life. However, as indicated by this author, a need still exists for further studies to more precisely establish the processes related to the course of attentional development. Varga, Frick, Kapa, and & Dengler (2010) examined the development of IOR in 3- to 6-month-old children using three cue-target intervals (200, 300, and 600 ms) and analyzed video recordings of their eye movements. All of the age groups presented facilitation with the 200-ms interval, whereas 6-month-old children presented inhibition with the 600-ms interval. Some differences among studies of IOR in childhood may be derived from the type of tasks used to analyze the effect, including response time, eye movement, and manual response time. Varga et al. (2010) also indicated that additional studies are necessary to elucidate this issue.

MacPherson, Klein, & Moore (2003) developed a study based on the suggestion that the time course of IOR depends on factors that might affect the efficiency with which attention is removed from the cued location. They compared the performance of young children (5 to 10 years old) with the performance of older children and adolescents (11 to 17 year old) in single- and double-cue procedures. Overall, the results indicated that the time-course of the appearance of IOR varies with age and cue condition. The present results indicate the occurrence of IOR as a function of age, especially in manual RT measures, contributing to a better understanding of this phenomenon.

A systematic age-related reduction of RTs was found in both experiments in the present study (voluntary and automatic orienting of attention). Younger children presented higher RTs than older children. This fact can be explained by the correlated functional development of attention associated with nervous system maturation. Rueda at al. (2004) used the Attention Network Test and found that RT and accuracy could be improved at different ages with regard to different aspects of attention. They described that alertness shows evidence of changes up to 10 years of age, and conflict scores appear to stabilize after 7 years of age. Posner (2012) also described studies that showed evidence of the sparse connectivity between structures during infancy and a strong increase at 2 years of age. He suggested that some structures related to executive attention or effort control, for example, may be present in infancy but can only be totally effective when their connectivity is formed later in childhood.

Posner (2012) reviewed the contributions of different methods including neuroimaging to describe the brain networks related to attention. With regard to orienting attention, Posner (2012) highlighted the contribution of structures related to the dorsal stream, including the frontal eye field and inter parietal sulcus. The temporoparietal junction was identified as an important structure that switches attention related to miscued targets. Other more ventral networks including the temporoparietal junction were more active following the target. Chica et al. (2012) reviewed publications on neural systems that modulate endogenous and exogenous spatial attention and suggested that these two attentional systems are implemented in overlapping, although partially segregated, brain circuits. Chica et al. (2012) suggested that some kind of interaction between dorsal and ventral systems is needed for the attentional system to work properly. Prefrontal lateral components were described as a possible site for this convergence. Other regions and connectivity between them also appear to be important for organisms' interactions with the environment. Chica et al. (2012) stated that frontoparietal areas involved in attentional control can modulate the activity of the occipital cortex and occipitotemporal cortex to process and recognize objects. Therefore, the source of the attentional system is integrated within a frontoparietal network, whereas the neural effects involved in attention may be modulated by perceptual areas in the brain.

Another result consistent with the literature was found in Experiment 1 (voluntary orienting of attention) in which the factor "cue validity" differentially affected RTs at different ages. As age increased, there was a narrowing of differences between valid and invalid conditions, possibly making the participants more efficient in perceiving stimuli outside the designated locations. Similarly, in Experiment 2 (automatic orienting of attention), RTs were shorter in the ipsilateral condition than in the contralateral condition. However, for older children, differences in RTs between these conditions decreased. This may be attributable to the appearance of IOR as a developmental consequence in older children. Smith & Chatterjee (2008) described that orienting behavior during the first 6 months of life evolves as discrete neural pathways that control oculomotor activity develop. They also explained that as the parietal lobes are being integrated into attentional networks, infants' control of saccades to retinotopic coordinates or even a second saccade is directed toward a remembered location indicating a development of covertly orienting. Additionally, the involvement of frontal areas even later can contribute to a volitional plan to orient attention and to compose a more efficient system to more effectively explore the environment.

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