TESIS DOCTORAL

Attention and executive function: Development and influence of socio-environmental factors

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Attention and executive function: Development and influence of socio-environmental factors

(Atención y función ejecutiva:
Desarrollo e impacto de factores socio-ambientales)

DOCTORANDA

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Chapter 1.

Theoretical and empirical background

1.1. Introduction: Varieties of attention constructs and measures

In a changing world full of stimulation, attention is vital for making adaptive responses to the social and physical environment in which we are immersed. Since the beginning of Psychology as an experimental science, attention has been a central issue in the effort to understand cognition. Broadly speaking, attention refers to the allocation of processing resources to relevant stimuli; it implies selection of stimulation from the external environment, or internal representations (i.e. thoughts, emotions, memories, etc.), in order to be processed in a conscious mode and controlled when such process are directed toward achieving a specific goal.

There are three main domains that have been extensively studied within the field of attention: alertness, tonic changes of state; selection, priority of processing of one stimuli among others; and, control, goal-directed regulation processes (Posner & Dehaene, 1994).

Alertness includes both a state of tonic arousal (vigilance) and the ability to rapidly respond to warning cues, also known as phasic alertness. It was during World War II that investigation on vigilance opened a rich field of research. Mackworth (1948) addressed the tendency of radar and sonar operators to miss rare irregular events close to the end of their tracking. He designed a task, known as the "clock test", where participants had to detect when a clock hand makes slow jumps (7mm vs. 14mm) within a period of 2 hours. He found that signal detection declined over time, and this reduction dropped faster after the first 30 minutes of the task. From research in vigilance we have learned the limited ability of the cognitive system to maintain an appropriate level of arousal and alertness in conditions of high demands. In contrast, salient and relevant stimuli activate and prepare the cognitive system for a fast response (phasic alertness). Phasic alertness is usually studied using infrequent, unpredictable warning cues before the presentation of a stimulus (Posner, 2008); the difference in reaction time (RT) between trials with presence or absence of a warning cue is a measure of phasic alertness.

Regarding selection, Broadbent (1958) introduced the idea of attention as a filter in his model of early selection at the end of the 1950s. He viewed attention as a filter of sensory stimuli that facilitates selection. According to his model information is selected based on perceptual attributes and semantic or conceptual processing occurs only for selected information. Consequently, Deutsch and Deutsch (1963) proposed their late selection model. They suggested that all stimuli are non-selectively and involuntarily processed to the stage of object identification or semantics, and then selection happens according to how relevant the information is. The late selection model, however, did not take into account the limited capacity of processing of the cognitive system. Triesman (1964) modified Broadbent's model and proposed that attention filtering attenuates, rather than eliminates, the processing of unattended stimuli. According to his model, unattended stimuli can re-enter into the filter for further processing if they are relevant. These theories were pioneers in the study of attention as selection, they contributed to experimental psychology the notion of attention as a mechanism that blocks processing of unselected sources and enhances processing of selected ones. Additionally, the work of Colin Cherry (1953) with the dichotic listening paradigm also supplied important data about the ability to suppress irrelevant information. Two decades later, the investigation in selection of visual-spatial information with monkeys and patients revealed that three elementary process (each related with specific brain regions) take place during visual selection: disengaging from the current focus of attention; movement of attention from its current focus to the new focus; and engagement in the new location or stimuli. These results indicated that a complex neural network is involved in covert shifts of visual attention (Posner, Inhoff, Friedrich, & Cohen, 1987).

The notion of attention as a control mechanism arises from models that intended to distinguish between automatic and controlled processing. Usually well-practiced actions become automatic and require no attention to be performed. During the 1970s and 1980s some experiments were able to separate automatic activation and conscious control in the same event using paradigms as priming and serial reaction time. For example, in a word-nonword classification task, participants recognized a word more quickly when it was immediately preceded by a semantically related prime rather than an unrelated prime (Neely, 1977). With serial RT task, participants have to select a series of response keys either in a fixed or random sequence. RTs decrease under fixed sequence whether the participants were aware of the sequence or not (Nissen & Bullemer, 1987). These findings showed the difference between stimulus driven and voluntary controlled response. Faster responses, due to priming and fixed sequences, appeared to be the result of an automatic activation of a pathway without attention that facilitates faster RTs.

Posner and Snyder (1975) were pioneers of the idea of attention as a cognitive control process. They proposed two distinct components of attention: a fast automatic inhibition-free spreading activation process and a slow limited-capacity conscious attention mechanism. Later, Norman and Shallice (1986) proposed the "Supervisory attentional System" (SAS) as a model of attention for action. They differentiated between automatic and controlled modes of processing. They argued that processing systems rely on a hierarchy of thought and action schemas that can be either activated or inhibited under routine and non-routine demands. The SAS was thought to function as a central executive that manages selection and inhibition of schemas in order to achieve a specific goal. Attention is thus considered a key component in the regulation of thoughts, emotions and behaviors (Rueda, Posner, & Rothbart, 2005). Attention is needed when situations demand complex responses that involve novelty, error detection, planning, problem solving, and inhibition of automatic tendencies (Michael I. Posner & DiGirolamo, 1998).

The three aspects of attention mentioned so far here (alertness, selection, and control), are simultaneously implicated in our everyday behavior. These three functions of attention have been integrated in one model by Posner and his colleagues (Posner & Petersen, 1990). They developed a neurocognitive model of attention that distinguishes three brain networks that support the functions of alerting, orienting and executive attention. This model has been widely supported by data from different domains (e.g. neurochemistry, physiologically, anatomically, and behaviorally) from primates, patients and healthy subjects.

Particularly important for the work presented in this thesis is the notion of control. Conflict resolution, planning, monitoring and inhibition are the cognitive processes included within executive attention network (EAN) in Posner's model. These processes are also related to the several concepts developed in different fields of study, namely the concept of executive function (EF) in the field of Neuropsychology and Cognitive Neuroscience, the concept of self-regulation (SR) within the field of Developmental Psychology, and the concept of Effortful Control (EC) from the field of Temperament. EF refers to goal-oriented cognitive control functions including WM, inhibition and attentional flexibility (Miyake et al., 2000). EC is the dimension of temperament that describes individual differences in the ability to control emotional reactivity and behavior (Rueda, 2012). Similarly, SR is defined as the ability to control own thoughts, emotions and behaviors in order to achieve goals (Vohs & Baumiester, 2011). Adele Diamond describes EF as the functions that enable us to "mentally playing with ideas; taking the time to think before acting; meeting novel, unanticipated challenges; resisting temptations; and staying focused." (Diamond, 2013, pp. 135). Such approach fits well with the concepts of EAN, EC and SR. All of these concepts refer to the effort to reduce discrepancies between our standards of thoughts, emotions and behavior and the demands of the actual situation; the ability to suppress automatic dominant responses when they are not congruent with our goal, and the ability to achieve goals in a flexible way despite temptations and obstacles along the way (Hofmann, Schmeichel, & Baddeley, 2012). Therefore, all these concepts (EAN, EF, EC and SR) refer to similar cognitive control processes under different names given that they have been developed in different disciplines. It has been shown in several studies that these control processes are essential to a number of factors related to quality of life, such as mental, emotional and physical health; academic and professional success; efficient and heartwarming social interaction; and healthy relationships (Diamond, 2013). Cognitive control processes allows us to manage cognitive and emotional resources in a goal-directed way in order to respond to the environment in a form that is coherent with our goals and thus to have an adequate functioning in daily life. During childhood cognitive control is related to socio-emotional adjustment and academic achievements(Checa, Rodríguez-Bailón, & Rueda, 2008).

Another fundamental aspect in our work is development. Humans are not born with the capacity of voluntarily regulating inner states and behaviors, but this capacity develops with time. The development of cognitive control is subject to different factors from genetics, brain development, temperament, environment, and experience. Many studies have shown that the neural mechanisms supporting cognitive control are highly related to the prefrontal cortex (PFC) and the anterior cingulate cortex (ACC). Such structures undergo a long development from infancy until early adulthood, which makes them susceptible to environment for a longer period of time in comparison with other brain structures that have an earlier maturational course. Despite the late maturation of cognitive control processes, there is evidence of an important development throughout infancy and childhood, setting the foundation for further development. There is a great body of literature showing the strong influence of environmental and educational factors over brain development and cognition. Multiple studies with humans and animals indicate that rich environments promote and strengthen brain development and cognitive functioning.

In this introduction, we first describe Posner's neurocognitive model of attention and the classic paradigms used to study attention processes of alerting, orienting and control. Within Posner's model an experimental task has been developed in order to measure the three functions of attention: the ANT. We describe both the structure and the typical measures obtained from the ANT. Next, we outline the electrophysiology of attention, addressing specific ERP components that have been associated with attention functions. Then, we delved a little bit into the concepts of EF and EC to describe the process related to them in the literature. Finally, the section dedicated to cognition ends with a brief review of the development of attention functions, EF and EC. Once the reader is contextualized in the cognitive approach to our research question we present an environmental perspective of cognition. Specifically we discuss the importance of environmental factors during child development. In that section, data from animal models is relevant, since it has contributed with extensive evidence about the effects of the environment in both brain and behavior. We will also talk about findings within the field of human cognitive neuroscience concerning the influence of SES during childhood over both behavior and brain mechanisms related to superior cognitive skills. We hope that the material included in this introduction will provide a sufficient framework to guide the reader in the experimental work described in the following chapters.

1.2. Posner's neurocognitive model of attention

A well accepted approach to the study of attention is the neurocognitive model developed by Posner and colleagues (Posner & Petersen, 1990). Posner proposed three attention networks that implement the functions of alerting, orienting and executive control. These three networks are anatomical and functionally distinct (see Figure 1.1).

Alerting is related to reaching and maintaining of a state of high sensitivity to incoming stimuli (Posner & Rothbart, 2007). The anatomical circuitry related to the alerting network involves frontal and parietal regions of the right hemisphere for tonic alertness, and left hemisphere for phasic alertness. The neuromodulator associated with alerting network is norepinephrine (NE). Changes in alertness are accompanied by activity in the locus coeruleus, the source of the NE (Aston-Jones & Cohen, 2005). Drug studies have shown that the NE release provoked by warning cues increases the speed of response to the coming stimuli (Marrocco & Davidson, 1998).

The orienting network is involved in the selection of stimuli and the shifting of attention for preferential processing. It has been suggested that two partially segregated networks are implicated in these processes. A dorsal network, comprising parts of the intraparietal cortex and superior frontal cortex, is involved in a goal-based stimuli and response selection. Meanwhile, a ventral network, including the temporoparietal junction and inferior frontal cortex (lateralized to the right hemisphere), is specialized for detection of salient or unexpected but behaviorally relevant stimuli (Corbetta & Shulman, 2002). The neuromodulator related to orienting is the acetylcholine (Ach). Monkeys with lesions in the basal forebrain cholinergic system show difficulties orienting attention (Voytko et al., 1994).

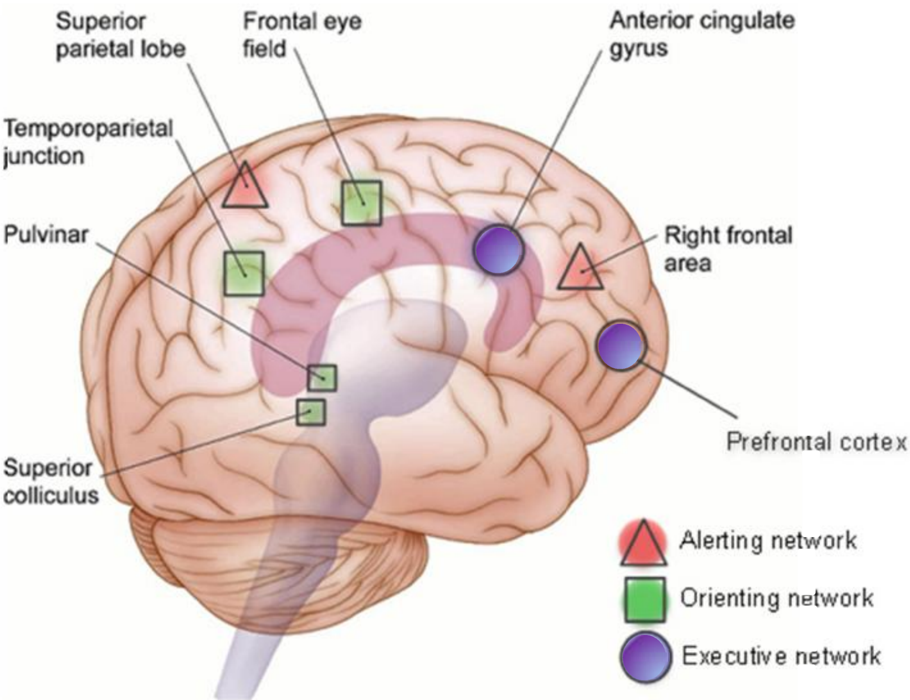

Figure 1.1. Main brain nodes associated with each attention network. From Posner, Rueda, & Kanske (2007)

The EAN is involved in control processes such planning, action monitoring, conflict resolution, response selection, and inhibitory control. EAN activates when automatic responses are insufficient or inadequate to achieve a specific goal. The ACC and the PFC are the structures associated with EAN. The efficiency of EAN is modulated by the neuromodulator dopamine. As a matter of fact, some medications for attention-deficit/hyperactivity disorder (ADHD) acts on dopamine D1-receptors in the PFC to facilitate regulation of behavior and attention (Arnsten, 2006).

1.2.1. Tasks to measure attention functions

Alerting

The presentation of a target preceded by a warning cue is a common way to study phasic alertness. Warning cues induce phasic changes in the level of activation that prepare the system for a fast response (Posner, 2008). The difference in RT between responses in the presence or absence of a warning cue is taken as a measure of phasic alertness. Responses in absence of warning cue are affected by tonic alertness, the ability to voluntarily maintain an inner state in preparation for processing stimuli (Raz, 2004).

Orienting

To study orienting of attention, Posner (1980) developed a cue task. In this paradigm, a cue signals the possible location of the incoming target. The task of the participants is to indicate the location of the target by pressing a key. The cues can be either valid, when appearing at the same location as the subsequent target, or invalid, when appearing at the opposite location as the target. Behaviorally, this task allows RT measures of so-called attentional costs and benefits of moving attention to one location before the target appears. RTs are shorter for targets preceded by valid cues and slower when subjects have to reallocate attention to the actual location of the target after invalid cues were presented. The RT difference between valid and invalid trials is known as the validity or orienting effect.

Executive attention

The EAN has been studied using tasks involving conflict resolution and inhibitory control. Such tasks induce conflict between an automatic response and a controlled response that has to be produced in order to perform the task successfully, while the automatic response has to be inhibited. When performing this type of tasks, participants' responses are slower and less accurate in trials involving conflict compared to conditions in which there is no conflict between the dominant automatic response and the non-dominant but appropriate response. The Flanker and Stroop are very well known and used tasks to assess conflict processing, and Go/No-go tasks is a typical task to evaluate inhibitory control. The Flanker task (Eriksen & Eriksen, 1974) consist on a central target flanked by stimuli that are irrelevant to the task. When flankers suggest a response that is different to that of the central target responses are slower and less accurate. The original version of this task consisted of a set of seven letters, subjects had to respond to the central letter, which was surrounded by either same or different letters (congruent and incongruent conditions respectively). In the Stroop task (Stroop, 1935), names of colors are presented in colored ink and subjects are instructed to respond to the color of the ink as fast as possible. The dominant response that has to be suppressed is reading the color name. The congruent condition in this task is when the ink and the name of the color match (i.e. the word blue written in blue ink). Finally, the Go/No-go task requires participants to respond to a specific stimulus, go condition, but to hold the response when a different stimulus is presented, the no-go condition. To increase the tendency to respond, the go stimulus has a high frequency presentation, while the no-go stimulus has a low frequency presentation. The percentage of responses to the no-go stimulus is taken as index of failure of inhibitory control.

1.2.2. The Attention Network Task (ANT)

To assess attentional networks' efficiency Posner and his team developed the ANT (Fan, McCandliss, Sommer, Raz, & Posner, 2002). This task combines warning and orienting cues with a flanker task to obtain indexes of efficiency of each attention network in a single task. In the original version of this task (Fig. 1.2) the target appeared either above or below a fixation cross. Each target was preceded by one of four cue conditions: no cue, central cue, double cue or spatial cue. Double cue condition acts as warning cue, because informs the participant about the appearance of the target but no about its location; spatial cues served as orienting cues informing about the possible location of the incoming target; central and no cue conditions were used as control conditions to obtain alerting and orienting effects. The ANT was intended to be simple enough to make it appropriate for children, patients and even for non-human animals. Networks' efficiency is evaluated by measuring how RTs are affected by warning cues, spatial cues and flankers. An efficiency score is calculated for each network using the

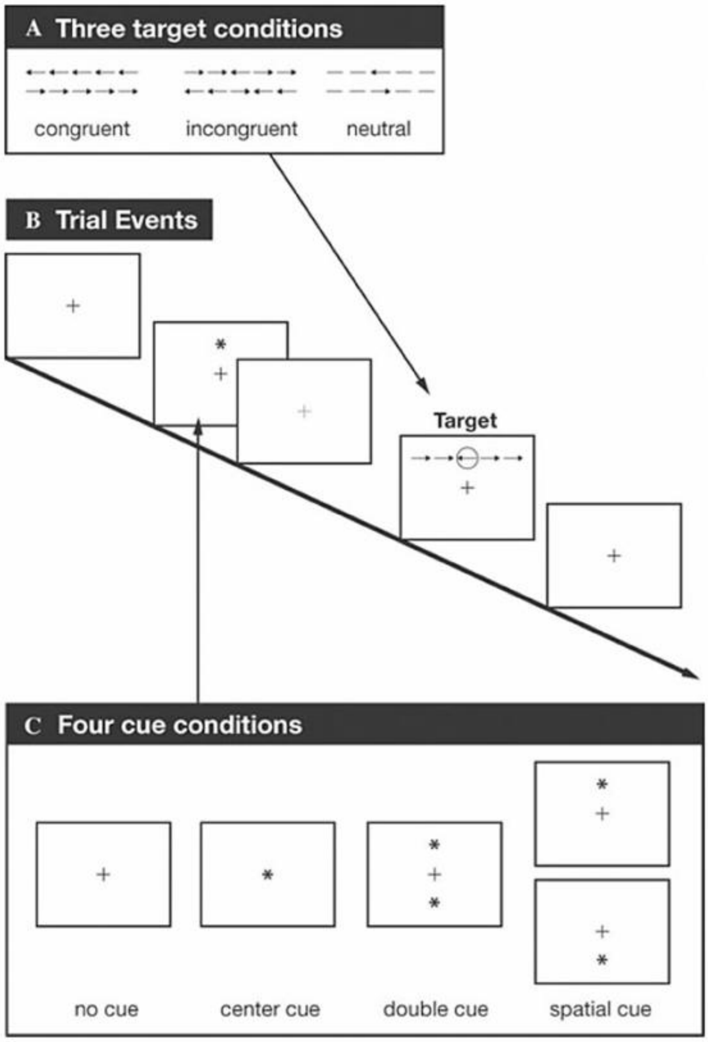

Figure 1.2. Schematic structure of the original version of the ANT. From Posner (2008).

subtraction method (Donders, 1969). Subtraction compared the RT from two experimental conditions, assuming that the only difference between them is that one requires an additional cognitive process to be fulfilled. The alerting score is obtained by subtracting the mean RT of the warning cue condition from the mean RT of the no warning cue condition. The orienting score is calculated by subtracting the mean RT of the spatial cue condition from the mean RT of the center cue. Finally, the executive score is obtained by subtracting the mean RT of congruent condition from the mean RT of incongruent condition. Moreover, the ANT also allows testing possible interactions between the networks. The EAN has been found to be inhibited by activation of the alerting network. With higher alerting states faster although less accurate responses are produced. This is usually interpreted as alerting promoting more automatic and thus faster responses, preventing executive control from engaging in higher level processing (Callejas, Lupiàñez, Funes, & Tudela, 2005). Conversely, orienting attention to the target location facilitates suppression of distracting information conveyed by flankers (Fan et al., 2009). However, with original version of the ANT is not possible to assess the interaction between alerting and orienting networks because alerting and orienting are manipulated with the same trial event.

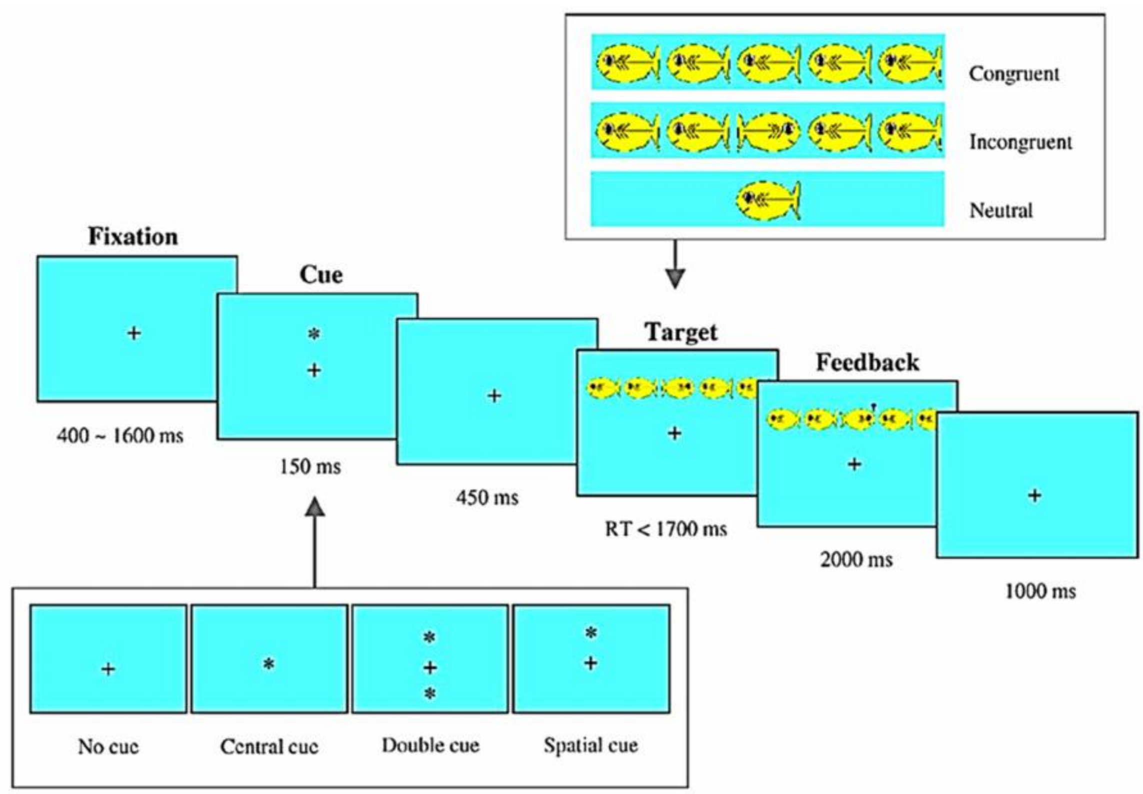

Figure 1.3. Schematic of the child version of the ANT. From Rueda, et al. (2004)

The ANT has been adapted to be used with children by Rueda and cols. (Rueda, Fan, et al., 2004). The child ANT presents a yellow colored line drawing of either one yellow fish or a horizontal row of five yellow fish above or below fixation (see Fig. 1.3). Children are instructed to respond based on whether the central fish points to the left or right by pressing the corresponding left or right button. In order to make the task game-like children are told that a hungry fish would appear on the screen and they have to feed it by pressing the correct button. They are also informed that sometimes the hungry fish would be alone and sometimes the fish would be swimming with some other fish as well. They are instructed to focus on the fish in the middle and feed only that fish and to respond as quickly and accurately as possible.

1.3. Electrophysiology of attention

ERPs are scalp-recorded electrophysiological responses related to specific cognitive processes. ERP waveforms can be divided into basic parts called ERP components, which are "scalp-recorded neural activity that is generated in a given neuroanatomical module when a specific computational operation is performed" (Luck, 2005, pp. 59). Traditionally, ERP components are named according to basic features as polarity, latency and scalp distribution. Usually N stands for negative amplitude and P for positive amplitude components. When only one number follows either the N or P, it indicates the order of appearance of the component. For example N1 refers to the first negative peak and P3 alludes to the third positive peak occurring within the duration of one segment of EGG. On the other hand when a three digit number follow the N or P it indicates approximated time, in milliseconds, in which such component is usually observed. However, these features can vary under different conditions such as experimental manipulations, difficulty of the task and characteristics of the subjects from who ERP are measured. For example, the N170 component denotes a negative peak that typically appears around 170 ms after seeing a face, and it is considered an index of face recognition. Yet, N170 has been found to peak earlier en adults (~150 ms) than in children

(~220 ms). The ERP technique provides an excellent temporal resolution of brain electrical activity and the possibility to distinguish lower from higher-level brain processes. The early components, before ~100 ms. are thought to reflect brain activity related to the processing of perceptual attributes of the stimulus. Thus, this time window is considered to be informative about the integrity of the sensory processing. Later components are believed to reflect more complex cognitive processing. Although the ERP technique is a great source of information about brain timing processing, it lacks in spatial resolution. The actual source of activation inside the brain that is measured by electrodes located in the scalp can only be inferred by means of mathematical models (source localization algorithms).

As mentioned before, warning cues cause a change in alertness. At the electrophysiological level such change is reflected as negative deflection in central areas of the scalp. This shift is called the contingent negative variation (CNV; Walter, 2006). The CNV is thought to reflect the suppression of ongoing activity in order to prepare the system for a rapid response (Posner, 2008). The CNV varies in function of age, suggesting that neural mechanisms related to response preparation process changes throughout development. Studies measuring CNV, as early as 6 years of age, have reported smaller CNV amplitudes in children than in adults (Flores, Digiacomo, Meneres, Trigo, & Gómez, 2009; L M Jonkman, Lansbergen, & Stauder, 2003; L M Jonkman, 2006; Segalowitz & Davies, 2004). Authors attribute this result to incomplete maturation of frontal-parietal structures in children, which are involved in motor regulation.

Using the Posner cue paradigm to examine the orienting network (valid vs invalid space cues), P1 and N1 components show enhanced amplitude over occipital channels for targets that have been validly cued. This effect is believed to reflect a sensory gain in the processing of the target due to anticipated allocation of attention (Hillyard, Vogel, & Luck, 1998; Mangun, 1995). In contrast, validity of the orienting cue modulates the component P3 in an opposite way: enhanced amplitude over parietal channels is observed for invalidly cued targets (Mangun & Hillyard, 1991). This effect suggests implication of parietal structures in the disengagement and reorientation of attention after an invalid cue. Developmental studies of orienting attention using Posner's cueing paradigm have found that both 6–13 years old children and adults show higher P1 amplitude on validly cued trials, whereas latencies of P3 appeared delayed for children with respect to adults under invalid conditions (Flores, Gómez, & Meneres, 2010; Perchet & García-Larrea, 2000).

A very well studied ERP component related to conflict processing is the N2. This component is observed as a negative deflection that peaks around 300-400 ms after target onset; it has a fronto-central scalp distribution and is more negative for trials involving conflict. The neural source that has been consistently related to the N2 is the ACC (Van Veen & Carter, 2002). Adults show the conflict-related N2 component at ~300 ms after target presentation, while preschool and school age children exhibit a late and sustained conflict modulation from ~500 ms post-target (Rueda, Posner, Rothbart, & Davis-Stober, 2004). The difference in amplitude between conflict and no conflict conditions is called conflict effect, and it is generally taken as an index of efficiency in conflict processing, as it reflects differences in brain activation during processing of conflict and non-conflict trials. The delay in latency and duration of the amplitude differences between conflict conditions observed in children has been taken as an indicator of the time course of brain mechanisms underlying monitoring and resolution of conflict during development (Rueda, Posner, et al., 2004)

The error-related negativity (ERN) is another ERP component related to the EAN, it signals neural response to the commission of an error. The ERN is a negative deflection observed in response-locked ERPs that peaks ~50-100 ms after an incorrect response is made. The ERN has a frontocentral scalp distribution and is originated in the dorsal portion of the ACC (Falkenstein, Hohnsbein, Hoormann, & Blanke, 1991; Van Veen & Carter, 2002). It has been proposed that the ERN signals a mismatch between the intended and the actual response. Overall, results from developmental studies show that ERN amplitude does not reach adults levels until about early adolescence (Davies, Segalowitz, & Gavin, 2004). Both the late maturation of the ACC and the key role of this structure in monitoring behavioral responses in cognitive tasks, are believed to explain the late appearance of ERN during development. Another ERP component, the Pe, is also modulated by error commission. The Pe is a late positive component that peaks around 200-500 ms after the commission of an error. It shows a central-posterior scalp distribution and its source is found in the rostral portion of the ACC (Van Veen & Carter, 2002). The Pe is associated with conscious evaluation of an error, as it is greater for perceived than unperceived errors (Falkenstein et al., 1991). Contrary to ERN, the Pe component is shown by children as well as adults, and appears to be relatively stable from 7 to 18 years of age (Davies et al., 2004). Although both the ERN and the Pe are related to action monitoring, neural and behavioral evidence shows that these components are functionally distinct from each other. For instance, even when both Pe and ERN were observed on error trials during a flanker task, contrary to the ERN, the Pe was not influenced by stimulus compatibility and expectancy factors (Bartholow et al., 2005). Additionally, it was reported that the ERN was not significantly reduced by sleepiness, while the Pe was (Murphy, Richard, Masaki, & Segalowitz, 2006).

1.4. Attention and related concepts

1.4.1. Executive Functions

The concept of EF was developed for the most part within the field of Neuropsychology. Research with frontal lobe patients revealed that the prefrontal cortex (PFC) has an important role in planning, organizing and regulating cognition and behavior (Luria, 1966). Later, animal research and neuroimaging studies confirmed these results. EF refers to a group of cognitive abilities involved in the conscious control of thought, emotions and behaviors. EF is required when behavior and cognition cannot run on automatic and PFC must be engaged in order to achieve a specific goal, or when the situation demands unexpected and flexible adjustments. The core processes in EF are: WM, inhibitory control and attentional flexibility (Miyake et al., 2000). These abilities are important for organizing information, planning, problem solving and monitoring of thought and action in goal-directed behavior.

WM refers to the active holding or updating of information over a relatively short period of time (Atkinson & Shiffrin, 1968). WM tasks require remembering information that was presented for a short period of time and is not physically present at the time of recall. This ability to store and manipulate information for short periods is effortful, attention and flexibility-demanding, and it is vital for an effective cognitive functioning in our everyday activities. A wide accepted model of WM (Baddeley & Hitch, 1974) distinguish three systems: a central executive system responsible for regulatory functions that include attention, control of actions and problem solving; and two slave systems responsible for manipulation and retention of information on the phonological and visuospatial domains.

Inhibitory control refers to the ability to override a strong internal- or externally-driven tendency, and instead do what is more appropriate or needed (Diamond, 2013). The function of inhibition is to suppress the response to internal and/or external stimulus than can interfere with the goal at hand. External stimuli and behavioral tendencies influence our behavior powerfully, however, inhibition allows us to exert control over our attention and actions and change them according to our interests.

Finally, the term cognitive flexibility denotes the ability to shifting the focus of attention, and flexibly adjusting to changing demands, rules or priorities (Schmitter-Edgecombe & Langill, 2006). Task-switching paradigms are used to measure this function by assessing the ability to flexibly shift from one task-set to another according to specific rules. Cognitive flexibility builds on both WM and inhibition, as changing from one task set to another requires activating and maintaining rules in WM as well as inhibiting the previous one (Garon, Bryson, & Smith, 2008).

1.4.2. Temperamental effortful control

We are all born with a particular way to react to the environment that surrounds us. These reactions and the mechanisms to regulate them constitute our temperament. Temperament refers to constitutionally-based individual differences in emotional, motor and attentional reactivity and self-regulation, understanding constitutional as the biological composition of the organism, which is influenced by heredity, maturation and experience (Rothbart & Derryberry, 1981). In the temperament literature, self-regulation is associated with the temperament factor of effortful control. According to Rothbart and colleagues the structure of temperament can be explained by means of three factors: Extraversion/surgency, Negative affectivity, and Effortful Control (EC). The first two are related to the reactivity aspect of temperament, behaviors of positive/approaching and negative/avoidance, while EC represent the self-regulatory system of temperament that controls reactivity. EC defines the child's ability to choose a course of action under situations of conflict, inhibit a dominant response in order to perform a subdominant response, to engage in planning, and to detect errors (Rothbart, 2007; Rothbart & Rueda, 2005). EC serves as a general regulation mechanism that activates or inhibits positive and negative emotions, as well as avoiding or approaching behaviors when needed (Rothbart, 2001). Our level of arousal and our tendency to positive and negative emotions determine our actions to a high degree. However, EC allows us to make choices according to the situation at hand and not be always at the mercy of emotions. EC also allow us "to approach situations we fear and inhibit actions we desire, giving a strong self-regulatory basis for action, conscience, and self-control" (Rothbart, 2001; p. 58).

1.4.3. Higher-level Executive Functions

Both EF and Effortful control overlaps with the concept of Executive attention. More specifically, Inhibitory control and Attentional flexibility are the EFs that have been greatly related to the EAN and the temperamental factor of Effortful control (See Fig. 1.4). WM, Inhibitory control and attentional flexibility are the foundation for higher-level processes that implicate creative and abstract thinking, concept formation and problem solving. These higher-level cognitive abilities are referred as "higher-level Executive functions" and involve planning, reasoning and problem solving processes (Collins & Koechlin, 2012). In turn, these higher-level functions are related to the construct of fluid intelligence. The ability of understanding abstract relationships, as well as inductive and deductive logical reasoning are related to both fluid intelligence and higher-level EF. The higher-level EF required the adequate and continuous functioning of the basic EF throughout goal-directed behaviors.

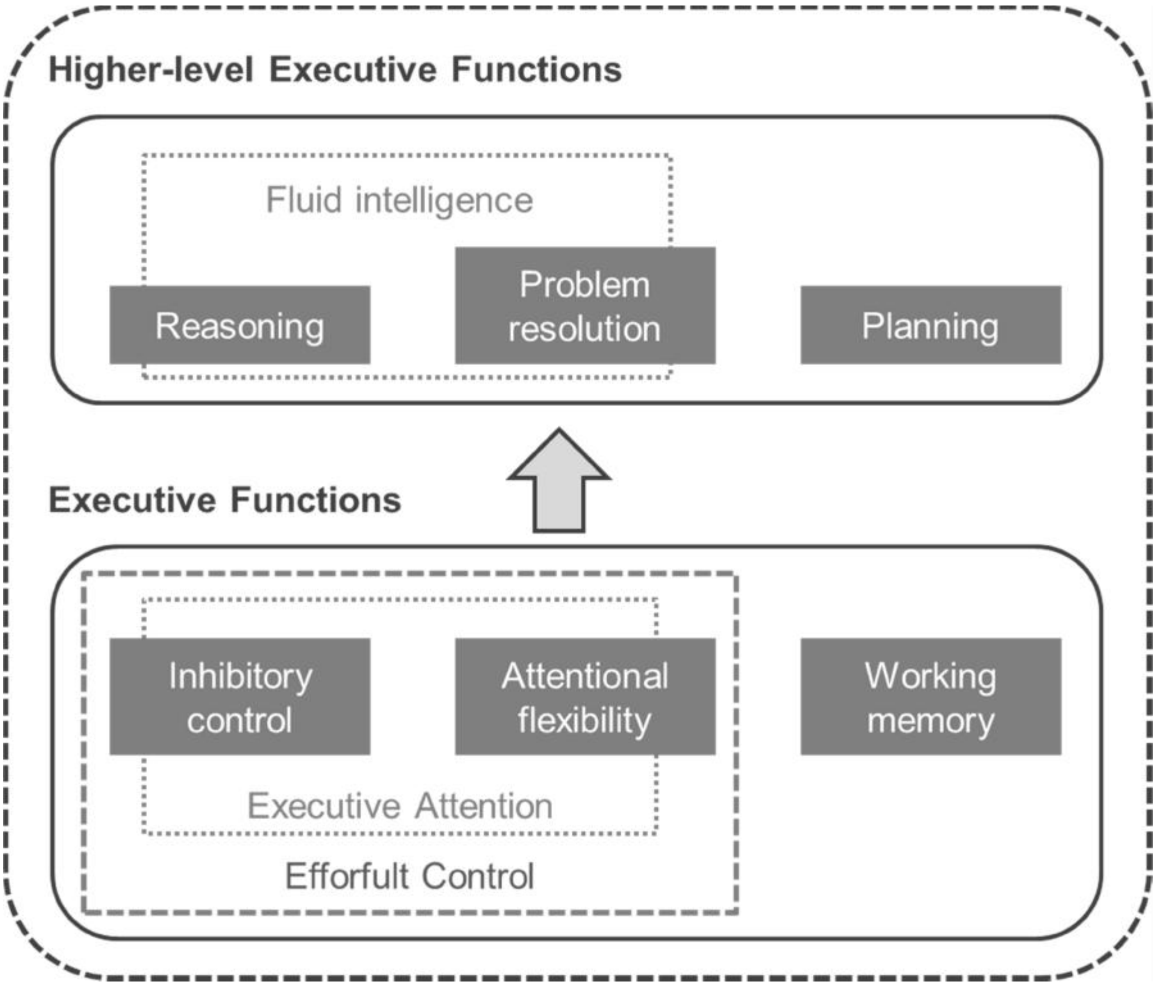

Figure 1.4. EF and related concepts.

1.5. Development of attention and cognitive control

1.5.1. Development of attentional networks

The developmental course of attention functions is intrinsically linked to the maturation of the brain mechanisms that support them. Throughout infancy the three attentional functions considered in Posner's model appear to be less independent (Ruff & Rothbart, 2001). Attention is involved in more automatic engagement and orientation to external stimuli. During early infancy, orienting of attention acts as a regulatory mechanism. Babies' attentional engagement usually has a regulatory effect. In fact, a frequently used strategy to sooth babies' when they are distressed consists on calling their attention toward a source of stimulation. This down-regulation effect of attentional orienting and engagement during infancy is thought to be under the control of executive attention later on, given that this function only emerges around the end of the first year of life. Thus, it is during the toddler and preschool years that the EAN progressively controls attentional process towards a more goal-directed control (Rueda, 2013).

Although the ability to attain a phasic alertness state is achieved during the firsts months of life (Colombo, 2001), the ability to maintain alertness improves with age. At the age of 5 years children show a stable phasic alertness, however, it is until 7-8 years of age that children use warning cues correctly in cue paradigm task, in other words, they can use warning cues to prepare to give a fast response (Querne, 2009). Measured with the alerting score provided by the child ANT, there is a significant decline from age 10 to adulthood, suggesting further development of alerting during late childhood (Rueda, Fan, et al., 2004). Results from simple detection task also support this idea, showing a significant decrease in RT, related to alertness, between 10 and 12 years of age (Drechsler, Brandeis, Földényi, Imhof, & Steinhausen, 2005). These results indicate that young children have difficulties maintaining an adequate level of alertness; they perform poorly when no warning cue is presented, and therefore they benefit more from warning cues.

Orienting network functions as a control mechanism of visual orientation during the first months of age. Around 6 months of age. It is later, around 18 months, when infants are able to voluntary disengage attention (Ruff & Rothbart, 2001). However, the voluntary orienting of attention continues improving during childhood and adolescence. Data obtained with the child ANT show similar orienting score from 6 years till adulthood (Rueda, Fan, et al., 2004), suggesting that, as adults, children also improve their RTs by previously orienting attention to the correct location of the target. Same results have been found using the Posner's cuing paradigm. No differences in validity effect from preschool age up to adulthood are observed, indicating that both children and adults orient attention automatically to the cued position. However, only adults seem to take full advantage of the predictability of the cue, as suggested by an age-related decrease in orienting cost (Enns & Brodeur, 1989). Moreover, preschool age children have difficulties voluntarily adjusting their attentional focus under long intervals between cue and target (Schul, Townsend, & Stiles, 2003), suggesting that processes related to voluntarily disengagement and reorienting of attention continue developing during childhood.

The controlled processed related to the EAN (conflict monitoring and resolution, and inhibitory control), appear to develop greatly during preschool years. The protracted developing of EAN process is associated with the late maturation of the ACC and the PFC (Fuster, 2003). Children get progressively better at suppressing distractors, following relative more complex instructions, regulating impulses and working in long-term goals. However, these processes are not fully mature during preschool age and continue developing until adolescence (Bunge & Wright, 2007). Developmental studies report that the conflict effect in RT (i.e. the difference between conflict and no conflict conditions) decreases with age (Rueda, Fan, et al., 2004; Waszak, Li, & Hommel, 2010) showing that young children are more affected by conflict than older children and adults.

1.5.2. Development of executive function

Inhibitory control significantly improves with age. Inhibiting dominant responses is very difficult for young children. In contrast to 3 year-olds, 5 years old children show a better performance in inhibitory control tasks that demand suppressing a dominant response according to specific rules. Although 3 year-olds understand the rules required to perform the task successfully, they have difficulties suppressing incorrect responses (Bell & Livesey, 1985). Many studies have reported differences in inhibitory control between children, adolescents and adults, suggesting that this process has a protracted maturation. Inhibition is typically measured using task as go/no-go, flankers and Stroop. Despite the differences between these tasks, imaging studies suggest that they activate the PFC and the ACC, important nodes of the executive attention network. Combining Go/No-Go and flanker tasks to assess interference suppression and response inhibition, evidence has shown that 8-12 year-olds are more susceptible to interference and less able to inhibit incorrect responses than adults. Additionally, imaging studies have shown that 8-12 year-olds do not show activation in PFC regions, which were activated by adults (Bunge, Dudukovic, Thomason, Vaidya, & Gabrieli, 2002). Similar results were observed using the Stroop task in an age range from 7-57 years of age (Marsh et al., 2006). Behavioral data from Stroop task also indicate that the development of inhibitory control extends into adolescence (Leon-Carrion, García-Orza, & Pérez-Santamaría, 2004).

The most used measure of WM is memory span. Memory span refers to the maximum amount of information an individual can remember accurately after a short presentation. Span capacity of WM increases with age, with typically a two –to three- fold expansion between 4 and 14 years of age (S. E. Gathercole, 1999). In young children, the phonological loop is limited to phonological store only. Before 7 years of age, spontaneous rehearsal is not consistent, and children rely on the visuospatial sketchpad for maintaining information in WM. Meanwhile, older children use the phonological loop to mediate immediate memory performance and recode visual stimuli into a phonological form via rehearsal (Hitch et al., 1983). On the other hand, developmental changes in the central executive of WM have been studied using what is called complex memory span. This refers to the maximum amount of information an individual can recall in tasks that demand simultaneous processing and storage. Examples of this paradigm are the *listening span* task, where subjects listen to a set of sentences that have to qualify as true or false and remember the last word in the sentence; and the *backward digit span*, where subjects have to repeat a sequence of numbers in backward order (from last to first). Gathercole and colleagues (S. E. Gathercole, Pickering, Ambridge, & Wearing, 2004) worked with an large sample of children from 4 to 15 years of age and multiple tasks to assess the three component systems of WM during development, and to investigate whether or not the structure of WM undergoes changes throughout development. They found that the tripartite structure of WM and the relationships between the three components is stable from age 6, with no evidence of consistent structural changes after this age up to adulthood. However, the capacity of each system increases with age. The measures related to the phonological, visuospatial and central executive systems follow a similar trajectory, showing linear improvement in performance from age 4 to age 15. The developmental changes in the slave systems of WM during childhood and adolescence have been associated with changes in different component processes, such as perceptual analysis, construction and maintenance of a memory trace, retention of order information, rehearsal, retrieval and reintegration. In the other hand, developmental changes in central executive have been attributed to both gains in the efficiency of processing and increased attentional control (Gathercole, 1999).

The Wisconsin Card Sorting Task (WCST; Grant & Berg, 1948) and the Tower of London (ToL; Shallice, 1982) have been broadly used to measure attention flexibility. In the WCST subjects are instructed to sort cards according to rules based on cards dimensions of shape, color, and number of items. The sorting rule change without notice and the participant have to find out the new sorting rule through trial and error. Performance on the WSCT reaches adult levels (measure as rate of perseverative errors and failure-to-maintain set) by 13-15 year of age (e. g., Levin et al., 1991). However, the number of categories completed increase into young-adulthood (Huizinga, Dolan, & van der Molen, 2006). A version of this task suitable for young children is the Dimensional Change Card Sort (DCCS; Zelazo, 2006). In this task, children have to sort a series of bivalent cards, first according to one dimension (e.g., color), and then according to another (e.g., shape). Three-year old children perseverate during the post-switch phase, while 5 year-olds are able to switch when required. On the other hand, the ToL task requires participants to solve spatial problems by moving rings, one by one, from an initial state to a pre-specified state making the less movements possible. The ability of mental planning of the moves improves significantly from age 4 to 5 (Unterrainer et al., 2013). Similar to WCST, performance of ToL, measured as errors and planning time, is shown to reach adult levels by 13-15 years of age. Yet, performance based on errors continue to improve up until young-adulthood (Baker, Segalowitz, & Ferlisi, 2001; Huizinga et al., 2006). Attention flexibility shows a protracted developmental improvement even when memory demands are minimized (Davidson, Amso, Anderson, & Diamond, 2006).

These data clearly show that EF progressively improves with age. Although results from different studies indicate that the three processes associated to EF develop at different rates during childhood, it seems clear that they are still not fully mature by the end of childhood.

1.5.3. Development of effortful control

Despite the constitutional nature of temperament, environment and development also play a role in the unfolding and solidification of the individual characteristics. Individual differences in reactivity (extraversion/surgency and negative affectivity) are observable from the first months of life, whereas EC begins to emerge at the end of the first year.

Although parent-report scales are a common tool to assess children's temperament, conflict and inhibition tasks are a typical way to evaluate EC in lab settings. Kochanska and colleagues (Kochanska, Murray, & Harlan, 2000) developed a battery of tasks to assess EC between 22 and 33 months. They found that EC improves significantly between 22 and 33 months, its coherence increases with age and it is consistent across tasks. Likewise, EC rates obtained by parent's report at age 3 appear to be highly related to children's performance in a spatial conflict task where children had to press a button after presentation of a target that could appear at the same (congruent) or opposite (incongruent) site of the associated button (Gerardi-Caulton, 2000). In this task, children improve with age, and they were 90% accurate at 3 years of age. Nevertheless, it is between 3 to 5 years of age that children become better in tasks that require WM and inhibition, such as day-night (children are instructed to say day when a card picturing the moon is shown, and night when they see a card picturing the sun), tapping (tap once when experienment taps twice, tap twice when experiment taps once), card sorting, Go/No-go, conditional discrimination, theory of mind, false believe and delay of gratification (Diamond, 2011).

Much evidence indicates that EC is stable from childhood to adulthood. For example, in a longitudinal study, Mischel and colleagues (Mischel, Shoda, & Rodriguez, 1989) found that 4-year-old who delayed gratification longer in lab settings developed into more cognitively and socially competent adolescents, achieved higher academic scores (independent from IQ), copied better with frustration and stress, and were less likely to use recreational drugs. They also were rated by parents and peers as more interpersonally competent and intelligent. Other follow-up studies, have reported that the ability to delay gratification in the preschool period predicts goal-setting and self-regulation at the age of 30 (Ayduk et al., 2000).

The improvements in the processes targeted in our work co-occur with important structural and functional neural maturation changes. Myelination and synaptogenesis in the frontal lobes continues until adolescence (e.g. Cummings, 1993) and cellular differentiation does not end until puberty. At the same time, children face more complex scenarios and demands as they develop; they are asked to learn more complex content, and they are also asked to be responsible for their own behavior. Some authors suggest that fundamental changes in the structure of cognition happen during preschool years, and further development in school ages and adolescence consist on an ongoing improvement of those cognitive process as a function of experience and opportunity (Zelazo et al., 2013).

Chapter 2.

Environmental influences on attention and executive functions

2.1. Environment and brain plasticity

There is solid evidence that the brain changes in response to experience (Rosenzweig & Bennett, 1996). Behavioral, cellular and molecular studies in animals have shown that early and extended onset of an enriched environment (EE) promotes significant changes in cognitive abilities, brain biochemistry, synaptic connectivity, dendritic arborization, brain cortex weight and thickness, and neuronal networks functioning (e.g., Nithianantharajah & Hannan, 2009; Petrosini et al., 2009; Rosenzweig, 2003). In animal models (predominantly mice and rats) EE involves sensorimotor, cognitive, and social stimulations via novel and complex stimuli. Constant changes of displays and objects (different in composition, shape, size, texture, smell and color) in the home cages generate opportunities for enhanced cognitive stimulation, fine manipulation skills, formation of tuned spatial maps, and detection of novelty. Additionally, physical training and healthy lifestyle is achieved via exploratory movements in large cages, long-lasting daily activities, correct alimentation, preserved cardiorespiratory functions, and the use of running wheels.

The first report of the effects of EE on animals was provided by Hebb (1949). He found that rats that had the experience of exploring his house for some weeks as pets of his children outperformed regular laboratory rats in problem-solving tasks. He found that this superiority was maintained and even increased during a series of tests. Later, in the 60's, a research team in Berkeley demonstrated structural changes in the rat brain related to experience, first by training and later by exposure to an EE. They found that the levels of the enzyme acetylcholinesterase (AChE) in the rat cerebral cortex was significantly correlated with the ability to solve spatial problems (Krech, Rosenzweig, & Bennett, 1956; Rosenzweig, Krech, & Bennett, 1960). The higher AChE activity in the cortex of trained groups indicated that training modified such activity. To test it, they compared trained and untrained littermates and found that trained rats developed higher cortical AChE than their untrained littermates. After these findings, they housed the animals in different environments that provided differential opportunities for informal learning. They observed that an EE not only caused changes in problem-solving abilities and cortical chemistry but it was also related to increase in weights of neocortex regions (Rosenzweig, Krech, Bennett, & Diamond, 1962).

Since those first findings, mounting research has shown that behavioral changes after EE experience are related to changes in brain neurochemistry and physiology. For example, different hippocampal functions, such as long-term potentiation, neurogenesis, and dendritic spine growth, are enhanced by environmental enrichment (Foster & Dumas, 2001). Furthermore, exposure to EE decreases apoptosis of regenerating neurons (Kempermann, Kuhn, & Gage, 1997) and increases levels of nerve growth factor and brain-derived neurotrophic factor in the cerebral cortex (Ickes et al., 2000). A large volume of literature in this matter comes from animal models of brain injury. The improvements in cognitive abilities related to an EE have been observed in both intact and brain-lesioned animals. For example, the effects of cholinergic depletion (present in many cognitive disorders) on cognitive flexibility and spatial competences were analyzed 1 month after provoking lesion in rats exposed to EE and standard rear environment (Petrosini et al., 2009). Cognitive flexibility was measured using a serial learning task, in which the sequence of correct responses changed daily, requiring rats to forget the learned sequence and learn a new one each day. The mnestic spatial abilities were assessed by means of water and radial arm mazes. Cognitive flexibility and spatial ability were significantly maintained and perseverative behaviors were reduced in enriched-lesioned rats. During the first phase of serial learning task, EE lesioned rats performed similar to intact rats, while standard environment lesioned rats showed impairments in performance. However, the EE lesioned rats were unable to maintain their efficiency in the final phase of the task. As for spatial tasks, the EE lesioned rats exhibited competent explorative strategies and preserved mnestic competencies, as indicated by low rate of errors and long spatial span in the radial arm maze. With regard to brain changes, EE lesioned rats showed similar dendritic spine values in parietal pyramidal neurons (main target of cholinergic projections studied) than EE intact rats. Moreover, EE lesioned rats did not show the proximal shift in dendritic spine distribution exhibited by standard reared rats as compensatory mechanism to brain injury (De Bartolo et al., 2008; Mandolesi, Bartolo, & Foti, 2008).

Exposing animals to adversity and/or poor environment also leads to measurable changes in both behavior and brain. For instance, mice isolated for 2 weeks immediately after weaning showed alterations in PFC function and myelination, specifically, reduction in rates of WM and social behavior with respect to standard rear and EE mice (Makinodan, Rosen, Ito, & Corfas, 2012). Furthermore, several animal studies have reported that PCF and dopaminergic system are sensitive to events during the postnatal period. In rodents, the postnatal social environment, particularly maternal care, can affect significantly the development of the PFC. Rats exposed to maternal separation (MS; usually 3-4.5 hrs a day during the first 2-3 weeks of life) showed a hyperresponsive stress and emotion regulatory systems, as well as higher fearfulness (Caldji, Diorio, & Meaney, 2000; Meaney et al., 1996). At the brain level, these animals showed a reduced capacity for the hypothalamic-pituitary-adrenal axis (HPA) feedback regulation, which is associated with stress via regulation of cortisol levels (Avishai-Eliner, Hatalski, Tabachnik, Eghbal-Ahmadi, & Baram, 1999). Early isolation and MS rats exhibited abnormally high synaptic density in the infralimbic cortex and altered densities of dopaminergic and serotonergic fibers throughout the medical PCF (Braun, Lange, Metzger, & Poeggel, 1999). In contrast, pups that were rear by mothers whose maternal behaviors were stimulated showed a better and stable cognitive state, and a greater feedback regulation of stress and emotion regulatory systems. Good maternal care stimulated the normal right hemispheric lateralization of emotional regulation (Denenberg, 2010) and it was related to enhancement of inhibitory control within the right PFC and hippocampus (Sullivan & Gratton, 2002).

These findings provide strong evidence of the plastic nature of the brain and the important role of the quality of the environment and experience in which for the brain development and function. All these data not only reveal the benefits of a rich stimulation for the brain, but also provide evidence that the harm caused by poor stimulation could be diminished, or maybe even reversed, thru exposure to an EE. Although animal research have some limitations to reproduce human experience, especially that related to language, education, culture and complex social interaction, animal models have offered important insights into the effects of experience and environment in the brain. Prenatal factors, postnatal parental behavior and cognitive, motor and social stimulation are conditions that have been controlled and isolated in animal models allowing the investigation of both direct effects of these factors and interactions between them at different levels of analysis.

2.2. Socio-economic status as an index of family environment

In humans, brain development takes place within a specific context, determined, at least in part, by the material and social conditions of the family. A vast body of literature has used the concept of socioeconomic status (SES) as a measure of the family environment. SES is a multidimensional concept that involves both economic resources and social factors. The majority of the authors agree in three measures of SES: parental education and occupation, and income (Hollingshead, 1975). Generally speaking, SES has been associated with the quality of material resources, nutrition, parental care, housing, health and education services, employment and education, as well as with social connections, social position and level of stress. Since children are dependent on others, their SES is measured by the SES of their families, specifically, through parental attributes. High (HSES) and middle SES (MSES) has been associated with material, cultural and educational resources that potentially provide a rich stimulation and vast learning experiences for children during development. In contrast, low SES (LSES) families are more likely to be headed by single parents, have low education, low earning or unemployment, high levels of stress and deficient nutrition, which is related to a poor stimulation environment (Brooks-Gunn & Duncan, 1997).

2.3. SES and high cognitive skills

Numerous studies have reported that children's family SES impact both brain functioning and cognition (for review see Hackman, Farah, & Meaney, 2010; Lipina & Posner, 2012). Particularly, language and EF have been found to be very sensitive to SES (Hackman & Farah, 2009; Raizada & Kishiyama, 2010). Early language exposure is likely to be diminishing in LSES children. Maternal speech is a strong mediator between vocabulary building and SES during infancy (Hoff-Ginsberg, 1991). The quantity, lexical richness, and sentence complexity of mother's speech to her child vary with SES, and appear to have an important influence on the cognitive development during the child's early years (Hoff, 2003). Additionally, parent-child activities that promote vocabulary exposure, as the leisure time, book reading, and social and cultural events, are also associated with SES. Hart and Risley (2003) reported that LSES children in USA have heard on average 30 million fewer words than HSES children by the age of 3. In the same line, it has been observed that, by the age of 5, the hemispheric specialization in the left inferior frontal gyrus (which includes Broca's area) is higher in HSES children. These results suggest that growing up in an environment with poorer language, as is usually associated with LSES families, influences the neural mechanisms underlying language processing (Raizada, Richards, Meltzoff, & Kuhl, 2008). The dissimilarities in language exposure may account for differences in reading and verbal skill, as well as school readiness and academic achievements consistently found in preschool and school children from different SES (Hoff, 2003; Jefferson et al., 2011; Leseman & De Jong, 1998; Niklas & Schneider, 2013; Noble, Farah, & McCandliss, 2006; Noble, Wolmetz, Ochs, Farah, & McCandliss, 2006).

To examine the impact of SES disparities on diverse neurocognitive systems, Farah and colleagues (Farah et al., 2006; Noble et al., 2006; Noble, McCandliss, & Farah, 2007; Noble, Norman, & Farah, 2005) assessed specific neurocognitive skills in children from different SES backgrounds. They used a complete battery of tasks drawn from neuropsychology to evaluate the left perisylvian/language system, the parietal/spatial cognition system, the medial temporal/memory system, the prefrontal/executive system, and the occipitotemporal/visual system. These systems are anatomically and functionally defined by neuropsychological studies with brain-injury patients and imaging studies in healthy subjects. They found that MSES preschool children outperformed their LSES peers on the battery of tasks as a whole. However, the language and executive systems were the most affected by SES. MSES and LSES preschoolers varied by over a standard deviation in performance on language tasks, and by over two thirds of a standard deviation in the executive control tasks. The other systems did not show vulnerability to SES (Noble et al., 2005). In order to explore in more detail the influence of SES over the executive system, the authors performed another study with first grade children subdividing the prefrontal/executive system into three subsystems, each one with its own tests: lateral prefrontal/MW system, ACC/cognitive control, and ventromedial prefrontal/reward processing system (Noble et al., 2007). As in the previous study, language was highly associated with SES, which accounted for over the 30% of the variance on language tasks performance. Though SES was related to both cognitive control and memory systems, the factors that mediated this relation were different. While the WM–SES relationship was mediated by home and school variables (home literacy environment, daycare/preschool attendance, and elementary school quality), the cognitive control-SES relationship was mediated by language abilities (specifically receptive vocabulary). No association was found between SES and the reward system. It is worth noticing that the same pattern of results was obtained in a similar study with middle school students (Farah et al., 2008), suggesting that influence of SES over language and executive control systems continues during development.

Recent findings indicate that disparities in SES affect brain functioning since early infancy. Tomalski and cols. (Tomalski et al., 2013) found that LSES infants, 6-9 month-olds, showed lower gamma power in frontal areas in resting EEG, compared to HSES. Previous findings linked individual differences in frontal gamma power to differences in language and cognitive skills in 16-36 month-olds. Infants with a familiar risk for language impairment exhibit lower gamma power over frontal regions in comparison to controls. Such differences predicted language development at age 4-5 (Benasich, Gou, Choudhury,

& Harris, 2008; Gou, Choudhury, & Benasich, 2011). In adults, increment of gamma-band activity in frontal areas is related to selective attention engagement (Ray, Niebur, Hsiao, Sinai, & Crone, 2008). In contrast, reduced gamma activity has been observed in children with ADHD (Barry et al., 2010). Lower gamma-power in LSES infants suggests developmental disparities in attention and language related to SES since early years. Other electrophysiological studies have also reported differences in selective attention between high and low SES children. Using ERPs, (Stevens, Lauinger, & Neville, 2009) maternal education was associated to differences in measures of selective auditory attention in children 3-8 years old. Children listened to two stories simultaneously and were cued to respond to one and ignore the other. Low maternal education children showed higher amplitude to the probes in the unattended ear in early stages of stimulus processing (~100 ms), suggesting that they had greater difficulty to suppress irrelevant information. Using tones instead of stories, D'Angiulli and cols. (D'Angiulli et al., 2012; D'Angiulli, Herdman, Stapells, & Hertzman, 2008) found that LSES preadolescents showed similar brain response to attended and unattended tones. Additionally, the greater theta activity in LSES preadolescents accounted for supplementary attentional resources during task performance, also reflecting difficulties to ignore irrelevant information in LSES participants, even though no differences in RT were observed. Similar pattern of results were found by Kishiyama and colleagues (Kishiyama, Boyce, Jimenez, Perry, & Knight, 2009).that reported reduced ERPs' amplitude to novel distracting stimuli in LSES compared to HSES children.

To sum up, the data described in this introduction indicate that controlled process associated with the EAN and EF has a prolonged maturation and is susceptible to the quality of the environment and experiences. Furthermore, individuals' temperament also plays an important role in the level of efficiency of EAN and EF. Therefore, we are facing an interesting scenario that combines cognition, brain, temperament and environment immersed in a diverse and changing dynamic of mutual influence that determines the unique expression and experience of each individual. It is our intention to provide valuable data that may help to better understand the relationship between cognition and environment during preschool years.

Chapter 3.

Questions and hypotheses

The studies reviewed in the introduction indicate that both attention and EF go through a protracted development along childhood, and that the environment in which development takes place affects them. Based on this research , our interest was to further understanding of two main questions. First, the developmental course of neural mechanisms underlying attention functions of alerting, orienting and executive attention; and second, the influence of the environment on preschoolers' cognitive control processes both at behavioral and neural levels. The three experimental series presented in this dissertation aimed to shed some light on these topics. In the next paragraphs I will present in detail the objectives of each series as well as the experimental approach we followed in order to answer these research questions.

3.1. What are the neural mechanisms underlying the development of attention networks?

What are the neural mechanisms underlying the development of alerting, orienting and executive attention? Also, do attentional networks interact in the same way during childhood and adulthood?

To examine the developmental course of attention networks and their interaction across development we used a modified version of the ANT in an age range sample from 4 to 13 years, and a group of adults. The ANT provides measures of the efficiency of the three attentional networks by combining a flanker task with presentation of different cues intended to activate alerting and orienting functions. In the original ANT orientation of attention is triggered by presenting valid spatial cues that direct attention to the location in which the target is likely to appear. Individuals are faster and more accurate in trials in which the target is preceded by a valid cue. This is called the validity effect, and it reflects a facilitation of target processing by allocation of attention in the location where the target appears. Developmental studies reveal that the validity effect is present since preschool years, suggesting that young children benefits from orienting attention to a valid location. However, processes of disengagement and re-orientation of attention, also part of the functions of the orienting network, appear to maturate later in childhood (Schul et al., 2003; Waszak et al., 2010). Such processes cannot be examined with the original ANT because in that task only valid and neutral (central) cues are used. Moreover, in the original version of the ANT alerting and orienting cues are manipulated within the same trial event, in which one of four equally likely types of cues (i.e. no-cue, double, central, or spatial cue) is presented. This design prevent from measuring possible interactions between the alerting and orienting networks.

To address our research questions we used a modified version of the ANT (Callejas, Lupiáñez, & Tudela, 2004) that separates alerting (auditory tone) and orienting (valid and invalid visual cues) events within each trial in order to investigate all possible interactions between the attentional networks. We adapted the ANT into a child-friendly version, where the target consisted of a raw of five cartoon yellow fish, one in the middle (i.e. target) surrounded by four flankers (distractors), two each side, that were pointing to the same or opposite direction (congruent and incongruent trials, respectively) to that in the middle. These experimental manipulations not only allow the assessment of attentional networks' efficiency and interactions, they also provide the possibility to address disengagement and re-allocation of attention both at behavioral and neural levels.

To evaluate neural mechanisms underlying attentional functions we used event-related potentials (ERP). This technique uses electroencephalographic recording to obtain brain measures of electrophysiological activation related to specific cognitive processes. The increase in speed of processing is one of the major developmental phenomena that occur along the life span. It is well characterized that children progressively increase the velocity of information processing up until late adolescence and early adulthood, and later on, in elderly, there is a decline in speed of processing. This has been associated to general maturational processes, such as myelination, which allows neural signals to propagate more swiftly and with less signal loss, as well as synaptic proliferation (Johnson, 2005). ERPs provide excellent temporal resolution, and thus allow a fine examination of brain mechanisms in the time domain. On the down side, this technique does not provide detailed information on the anatomy of brain activations. However, the ease of application of EEG/ERPs (as opposed to other brain imaging techniques such MRI or PET), as well as the developmentally relevant information they provide, makes it an important technique to examine the relationship between brain development and cognition.

We expected to find different developmental courses for each attentional network at both behavioral and electrophysiological levels of analysis. From this standpoint, it is likely that the way attention networks interact also change across development. It has been reported that attention networks are less differentiated during the firsts two years of life and becomes more differentiated later on (Posner, Rothbart, Sheese, & Voelker, 2014). As far as we know, no prior studies have been carried out to address changes in the interactions between attention networks with age. Our first study intended to fill that lack. By assessing interactions between attention functions we might help explaining inconsistent data about the developmental course of each function. Given that alerting and orienting functions appear to have an earlier developmental course to that of executive attention, we expected to observe modulation of these networks over executive control from early childhood. Also, we expected that this modulatory effect would have greater impact when less efficient forms of executive control are likely to be observed, as in early compared to middle or late childhood. We hypothesized that at early ages the executive system may largely benefit from conditions that facilitate filtering out irrelevant information.

Likewise, only some studies have examined neural underpinnings of the development of attention functions. For the most part, these studies have focused on particular functions and have examined neural processes for each attention function separately. To our knowledge, no other study has addressed age-related neural changes in alerting, orienting and executive attention using the ANT. By previous findings we know that the modulation of ERP components by conditions differing in attentional requirements are delayed in and more sustained in children in comparison to adults' (e. g. Rueda, Posner, Rothbart, & Davis-Stober, 2004). Thus, we expected to find amplitude differences between experimental conditions to be more sustained for younger children, and to become less prolonged in time as age increases. Also, it was expected that some ERP components will be delay in children, and absent in some cases, especially in the youngest children.

Overall, behavioral and electrophysiological data were expected to further understanding of the development and functioning of the three attentional networks throughout childhood.

3.2. Does SES influence young children's neural mechanisms of conflict and error processing?

Do disparities in SES impact brain functioning? Are conflict and error processes in preschool children influenced by SES?

In this last experimental series we aimed at examining the connection between macro-level measures (i.e. at the social and family level), such as SES, and micro-level measures (i.e. neural mechanisms), related to the efficiency of EAN. We were interested in exploring whether differences in SES would be expressed at the electrophysiological level. For this purpose we used a child-friendly modified version of the flanker task designed to separately address brain activation associated with target and response processing (Checa et al., 2014). The N2, N450, ERN and Pe ERP components were employed as electrophysiological markers of conflict and error processing, and we focused on disparities between SES groups in conflict-related and error-related amplitude differences in the ERP components mentioned above.

Although the literature concerning brain functioning related to SES is quite limited, the data suggest that SES impacts brain development. Some authors propose that HSES environment promotes brain maturation during childhood (D. A. Hackman & Farah, 2009). Consequently, our main hypothesis was that ERP from HSES children would show more mature pattern of brain activation during performance of the flanker task. Specifically, we expected to observe earlier and less sustained conflict-related amplitude differences related to conflict processing. With regard to error processing, Checa et al., (2014) have shown that the ERN in response to errors in a flanker task is not observed until about 7 years of age. Given that we were going to use the same task used by Checa and colleagues with preschoolers, our hypothesis was that children raised in HSES families would show brain reactions to errors more similar to that shown by older children, whereas LSES children were expected to not show this early brain reaction to errors.

3.3. Do home environment factors predict preschoolers' high cognitive skills over and above the influence of temperament?

Are home environment variables, like socio-economic status (SES), predictive of differences in cognitive skills after controlling for individual characteristics, such temperament, age and gender? What about other home environment variables, such as parenting, or frequency of attendance to cultural activities? Does family environment interact with the child's characteristics to define differences in cognitive skills?

The second experimental series of the current work focused on the impact of environmental factors on a range of cognitive skills within the umbrella of executive functions (EF). As mentioned in the introduction, the preschool years constitute a period of significant development. Then, it is expected that environment exert a great influence during these years. There is an important amount of data indicating that SES affects cognitive development. However, we were interested in exploring the impact of other variables that are potential indicators of the richness or poorness of the social and cognitive stimulation within the family environment in which children develop. We elaborated a questionnaire to obtain information about a wide range of aspects related to the family environment, involving the family demography, activities in which the children usually get involved in a daily basis, interaction with adults and peers, as well as access to technology and didactic resources. We intended to have a richer index of the family environment beyond the traditional measures of SES consisting of an average of parental education, parental occupation and per-family-member income.

Also pointed out in the introduction, cognitive control processes are studied under different names. For the aims of this series we decided to use the concept of EF, since it is widely used in the cognitive neuroscience literature, and the tasks used to measure it are also well established. Then, under the framework of EF we aimed to gather a rich collection of cognitive measures including: speed of processing, conflict resolution, inhibitory control, WM, and emotion regulation. In addition we included measures of verbal and fluid intelligence.

It is also well documented that temperament is highly associated with differences in EF. We incorporated measures of temperament in order to explore to what extent SES accounts for differences in EF after controlling for age, gender and temperament, which we labeled as child's characteristics.

In order to assess the influence of SES in our behavioral measures after controlling for individual characteristics and other environment variables, we used hierarchical linear regression analyses. Nonetheless, it is very likely that measures of EF are influenced by interactions between environment and child's characteristics. To elucidate this possibility we carried out moderation analyses to observe how our variables affect each other to explain the variance observed in our data.

According to previous research, we expected that both temperament and SES would predict individual differences in EF. Though, differences in the amount of variance accounted by characteristics of the child and environment were expected to differ from one cognitive measure to another. Moderation effects were also expected. We are not aware of other studies addressing this topic, thus we do not have a reference framework to hypothesize if the impact of SES on EF processes would diminish or stay constant once temperament is taking into account.

An additional goal for this study was to establish a link between the SES and the temperament literature with the purpose of better understanding the interplay that takes place between environment, temperament and cognition during children development.

Chapter 4.

Electrophysiological correlates of attention networks in childhood and early adulthood

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4.1. Introduction

Attention serves as a basic set of mechanisms that underlie our awareness of the world and the voluntary regulation of thoughts and feelings (Posner & Rothbart, 2007). In the past decades, Posner and colleagues (see Petersen & Posner, 2012; Posner & Petersen, 1990) have developed a neurocognitive model of attention, in which three differential neural networks and neuromodulators are assumed to subserve different functions. The alerting network serves the function of reaching and maintaining the state of alertness. It has been associated with frontal and parietal regions of the right hemisphere for sustained or tonic alertness, and the left hemisphere in conditions in which the level of alertness is increased by warning cues (Bekker, Kenemans & Verbaten, 2004; Coull, Frith, Büchel, & Nobre, 2000). The orienting network is involved in shifting attention and selecting sensory events for preferential processing. This network comprises a number of frontal and parietal structures, such as the superior parietal lobe, the temporal-parietal junction, the frontal eye fields and ventral frontal cortex that are differentially involved in top-down and bottom-up control of attention (Corbetta & Shulman, 2002). Finally, the executive attention network is involved in control processes, such as conflict monitoring, error detection and response selection when competing alternatives are available. The anterior cingulate cortex is the main node of this network (Posner & Rothbart, 2007), which also includes areas of the lateral prefrontal cortex.

Within the framework of Posner's model of attention, an experimental paradigm, the Attention Network Task (ANT), was developed several years ago with the purpose of measuring functional efficiency of each attention network (Fan, McCandliss, Sommer, Raz, & Posner, 2002). This task combines presentation of orienting and alerting cues (Posner, 1980) with a flanker-type task (Eriksen & Eriksen, 1974) in order to measure alerting, orienting, and executive attention by means of time and accuracy of responses. Alerting is measured by comparing RT/Accuracy in trials with and without warning cues. Orienting of attention is examined by comparing trials with cues that direct attention to a location where the target will appear later on (valid cues) to trials without such cues. And, finally, executive attention is measured by comparing trials in which the target is surrounded by congruent flankers to trials with incongruent flankers. Since it was developed, the ANT has been utilized in many studies in order to characterize attention function with a wide variety of populations (e.g. Fan, Wu, Fossella, & Posner, 2001; Jennings, Dagenbach, Engle, & Funke, 2007; Posner et al., 2002; Rueda et al., 2004a). The ANT has also been adapted to children as young as 4 years of age and some cross-sectional studies have been conducted in order to study the development of attention networks during childhood (Mezzacappa, 2004; Rueda, et al., 2004a; Rueda, Posner, Rothbart, & Davis-Stober, 2004b).

While the three functions of attention are thought to be present to some degree by the end of the first year of life, they appear to have differential developmental courses throughout childhood and adolescence (Rueda, 2013). Developmental studies addressing alertness have shown that children have greater difficulty processing warning signals compared to adults (Mezzacappa, 2004; Rueda, et al., 2004a). Evidence shows that young children (i.e. 5 years old) need longer warning-to-target intervals in order to benefit from warning cues and are less able to sustain alertness over time compared to older children and adults (Berger & Posner, 2000; Morrison, 1982). On the other hand, children show a progressive increase in orienting speed to valid orienting cues during childhood (Schul, Townsend, & Stiles, 2003). Several studies have shown that the ability to orient attention by means of peripheral as well as central cues seems to reach full maturation by age 10-11 years (Goldberg, Maurer, & Lewis, 2001; Waszak, Li, & Hommel, 2010). However, somewhat longer developmental courses have been observed when disengagement from an invalid location and reorienting to the valid one is needed, particularly under endogenous orienting conditions, as when long intervals between cue and target are utilized (Schul, et al., 2003; Wainwright & Bryson, 2005). Finally, there is much evidence that young children experience more difficulty than older children and adults performing tasks that involve conflict. Executive control is often measured using experimental paradigms involving conflict among stimuli, responses, or stimulus-to-response mapping, such as the flanker and Stroop-like tasks. Using a flanker task adapted to children, Rueda and colleagues have reported a significant development of the ability to suppress interference from distracting stimulation during preschool years (Rueda, et al, 2004a; Rueda, Posner, & Rothbart, 2005). However, in contrast to the other attention networks, executive attention appears to develop more gradually during childhood and adolescence. Waszak and colleagues (2010) found that even 14-15 year olds show larger flanker interference than adults, indicating a protracted development of mechanisms related to executive control.

Numerous studies have used event-related potentials (ERP) to examine the neural basis of alerting, orienting and executive attention (see Posner, Rueda, & Kanske, 2007), but a smaller number have addressed neural mechanisms underlying the development of these functions.

Auditory signals are frequently used to study alertness. Commonly, a series of evoked potentials can be recorded from as soon as ten milliseconds after the presentation of auditory signals (Picton, Hillyard, Krausz & Galambos, 1974). From about 50 to 250 ms following the tone, a midline-distributed series of component with different polarity (i.e., P1, N1 and P2) can be observed, which has been associated with early attentional preparation, reflecting automatic sensory activation/orientation processes (Bekker et al., 2004; Jonkman, 2006). Alerting cues also elicit a slow negative electrical brain wave, called the contingent negative variation (CNV), occurring at the interval between presentation of the cue and the imperative stimulus (Walter, Cooper, Aldridge, McCallum, & Winter, 1964). The CNV is considered an index of the endogenous maintenance of attentional effort during the expectancy period between the warning cue and the target (Brunia & Damen, 1988; Gómez, Vaquero, & Vázquez-Marrufo, 2004), and seems to have two differentiated phases. The early CNV, which emerges around 300-400 ms after the warning cue, appears to be related to stimulus orientation and task anticipation processes. With cue-target intervals of more than a second, a late CNV component has also been observed, which occurs prior to the imperative stimulus, and is thought to reflect motor preparation (Loveless & Sanford, 1974).

Developmental studies have observed no differences in the modulation of early ERP components by warning cues from age 6 to adulthood (Jonkman, 2006). However, several studies using different tasks have shown that the amplitude of the CNV increases with age (Hämmerer, Li, Müller, & Lindenberger, 2010; Jonkman 2006; Jonkman, Lansbergen, & Stauder, 2003; Segalowitz & Davies, 2004). Using auditory cues and targets, Bender, Weisbrod, Bornfleth, Resch, and Oelkers-Ax (2005) found that 6 to 12 year-old children elicited the early CNV component but not the motor component of the CNV, which was only observed for children aged 12 years and adults.

With respect to orienting of attention, studies with adults have reported that visual targets preceded by valid spatial cues elicit brain potentials of enhanced amplitude over occipital leads, in comparison to targets presented at uncued locations (Curran, Hills, Patterson, & Strauss, 2001; Lorenzo-López, et al., 2002; Mangun, Hansen, & Hillyard, 1986; Mangun & Hillyard, 1991). Generally, increased P1 and reduced posterior P3 amplitudes are obtained in validly cued trials with respect to invalid ones. Modulation of the P1 is related to facilitation of early sensory processing by attention (Hawking, et al., 1990; Mangun & Hillyard, 1987). On the other hand, modulation of the P3 has been related to stimulus evaluation processes. The higher amplitude of the P3 for invalidly cued trials appears to signal a mismatch between sensory perception and sensory–motor preparation (Digiacomo, Marco-Pallarés, Flores, & Gómez, 2008; Gómez, Flores, Digiacomo, Ledesma, & González-Rosa, 2008). Developmental studies of orienting attention using Posner's cueing paradigm have found that both 6-13 years old children and adults show higher P1 amplitude on validly cued trials, whereas latencies of P3 appeared delayed for children with respect to adults under invalid conditions (Flores, Gómez, & Meneres, 2010; Perchet & García-Larrea 2000).

Finally, several electrophysiological indexes have been associated with executive control processes. Congruency of distracting stimuli in a flanker task modulates the N2, a negative fronto-parietal component that peaks approximately 200-400 ms post-target. This effect has been related to control processes arising in the anterior cingulate cortex (van Veen & Carter, 2002). N2 amplitude increases in incongruent trials relative to congruent trials, signaling greater effort to suppress irrelevant information in the incongruent condition. In fact, smaller N2 effect has been associated with greater efficiency of executive control over and above the effect of age (Lamm, Zelazo, & Lewis, 2006; Stieben, et al., 2007). Several developmental studies carried out with children as young as 4 years of age have observed conflict-related amplitude modulation of ERP components. Before age 6 years, children show very weak conflict-related modulation in the latency of the N2 (Ladouceur, Dahl, & Carter, 2007; Rueda et al., 2004b). However, young children show larger conflict-related amplitude effects compared to adults in later latencies, from about 600 to 800 ms post-target in anterior mid-frontal leads (Rueda, et al., 2004b). From about 6 to 8 years of age, the conflict-related amplitude effects are observed in more adult-like latencies, and the size of the effect appears to decrease with age (Jonkman, 2006; Lewis & Todd, 2007).

Later ERP components, such as the so-called Slow Positivity (SP) or Late Positive Component (LPC), have also being probed to be sensitive to conflict (Chen & Melara, 2009; Coderre, Conklin, & van Heuven, 2011; Larson, Kaufman, & Perlstein, 2009; Liotti, Woldorff, Perez III, & Mayberg, 2000; West, 2003; West & Alain, 2000). The SP usually occurs between 500 and 600 ms after presentation of the target and, depending on the task difficulty and design, may appear before or after the response (Chen & Melara, 2009; West, 2003). Modulation of the SP has also been associated with implementation of attentional control (Larson et al., 2009; Perlstein, Larson, Dotson, & Kelly, 2006; West, 2003). However, the fact that in some studies with adults the SP effect overlaps with the time of the response (Coderre, et al., 2011; Larson, et al., 2009; West, 2003) suggests that SP could also reflect post-conflict rather than response selection or conflict resolution processes.

The purpose of the current study is to further understand the development of attention during childhood by studying the temporal dynamics of activation of the three attention networks by means of event-related potentials (ERPs) using the child ANT. An important advantage of the ANT is that it provides a measure of all three attention functions in the same individual in a relative short time. It is thus a useful experimental paradigm to assess the developmental course of each attention function over childhood, providing a within-subject measure of each network. Overall, studies reviewed here suggest that the alerting, orienting and executive attention networks have different developmental trajectories throughout childhood. Alerting appears to develop mostly during early childhood, with young children showing larger alerting scores due to more delayed responses when no warning cues are presented. In relation to orienting, we expected to obtain a longer developmental trajectory than that observed by Rueda et al (2004) due to the inclusion of invalid cues. In regard to the executive attention network, there is evidence of an important development of the ability to control attention and interference during preschool years (Rueda, Posner, & Rothbart, 2005), and that this ability enhances throughout middle and late childhood (Davidson, Amso, Anderson, & Diamond, 2006; Band, et al., 2000). Thus, we predicted a major developmental change between early and middle childhood but further differences in efficiency of executive attention between late childhood and early adulthood.

EEG recording during performance of the ANT was used in this study with the purpose of informing about the neural mechanisms underlying the development of each attention function. Age-related changes in electrophysiological correlates of each attention network were expected to parallel developmental courses observed with RT and accuracy results. We predicted that auditory cues would evoke early preparation responses in all participants but CNV of larger amplitude in children showing larger alerting scores. With respect to orienting, we expected to see age-related changes mostly in ERP components linked to processing of invalid cues (i.e. the P3). Finally, in relation to the executive attention network, we expected to observe modulation of the N2 and SP components by flanker interference in adults and a delayed and prolonged modulation of frontally distributed ERP components in children that parallels their greater difficulty to solve conflict.

To our knowledge, this is the first study to examine the development of attention networks in a group of children ranging from 4 to 13 years of age, and also one of the first to examine interactions among attention networks in children. Significant interactions between alerting and orienting, as well as consistent Alerting x Executive and Orienting x Executive interactions have been reported. Alerting appears to accelerate and enhance orientation of attention, whereas efficiency of executive control is impaired under conditions of invalid orientation or increased alertness (Callejas, Lupiàñez, Funes, & Tudela, 2005; Fan et al., 2009). Recent evidence suggests that alerting influences the allocation of attention prioritizing processing of spatial information, thus leading to enhanced processing of distracting stimulation in the flanker task (Weinbach & Henik, 2012). On the other hand, orientation to the location of the upcoming target prior to its appearance, as when valid cues are presented, raises the efficiency of executive control by facilitating focalization on the target and hence the suppression of distracters (Callejas et al., 2005).

To our knowledge, very few studies have addressed interactions between attention networks in children. Using the original version of the ANT with 4 visual cue conditions (i.e. No cue, Central cue, Spatial cue, and Double cue) and 3 flanker conditions (i.e. Congruent, Neutral and Incongruent), no interactions were observed between cue and flanker conditions in experiments involving 6 to 10 year old children (Rueda, et al., 2004a). However, given that adults show a consistent pattern of interactions between networks, we expected that these interactions might also be observed in children. Callejas et al., (2005) modified the original ANT in order to be able to measure interactions between the functions of alerting and orienting. They included an auditory warning cue before presentation of the visual orienting cue that precedes the target. They also included both valid and invalid orienting cues in order to examine processes of disengagement and reorienting of attention. In a recent behavioral study the child ANT was modified following the variations introduced by Callejas and colleagues to study the development of attention networks and their interactions from age 6 to 12 years (Pozuelos, Paz-Alonso, Castillo, Fuentes & Rueda, 2014). Results revealed alerting x orienting as well as orienting x executive attention interactions that were present along the age range studied. Also, the state of alertness affected accuracy of conflict processing, but the direction of this interaction changed with age. For the purpose of the current study, we used the same task as Pozuelos et al. and aimed at extending their results by using a sample of participants with a wider age-range and analyzing brain mechanism underlying interactions among networks. We hypothesized that younger children's executive control efficiency would be more hampered on conditions that impose greater demands of suppression of distracting information, i.e. conditions conveying higher alertness and less focused orientation. Thus, we expected to observe Alerting x Executive as well as Orienting x Executive interactions, and aimed at exploring second order interactions with age. Further, in case interactions between networks would be found at the level of the response, these should also be noticeable at the brain function level. Hence, we expected to find modulation of conflict-related N2 and SP effects by alerting and orienting conditions for those age groups in which interactions would be observed at the behavioral level of analysis.

4.2. Materials and method

4.2.1 Participants

A total of 46 children and 15 adults (mean age: 23.6 years; SD: 2.6 years) participated in the study. Children were divided in three groups: 4 to 6 year olds (n=16 mean age = 4.96 years, SD= 0.87 months), 7 to 9 year olds (n=15, mean age = 8.25 years; SD: 12 months) and 10 to 13 year olds (n=15, mean age = 10.8 years, SD = 17.2 months). Children's caregivers were contacted by phone and invited to participate in the study. They were part of a database of families who participated in prior studies and expressed their wiliness to participate in future studies. Adult participants were under and post-graduate students recruited through the website of the Psychology Department of the University of Granada. Participants had normal or corrected-to-normal sensory capacities, no history of chronic illness and/or psychopathologies and no known neurological disorders, ADHD, ASD or Learning Disabilities, as informed by their caregivers. Participation in the study was voluntary, and both parent of the children and adults gave written consent prior to participation.

4.2.2 Procedure

Participants were tested individually at the Cognitive Neuroscience laboratory of the University of Granada. At arrival, participants were informed of the general procedure of the session and were given a few minutes to get comfortable in the lab setting before starting. Participants were fitted with the 128 channels Geodesic Sensor Net (www.egi.com) and were verbally informed of the instructions to complete the task. The duration of the session was 1 h approximately, including time for instructions and breaks between blocks. Young children received stickers between blocks of trials as incentives to stay motivated and complete the task. The experimenter was present in the testing room throughout the session with children of all ages, but did not provide feedback to participants apart from encouragement to complete the task during breaks. A T-shirt with the logo of the lab was offered to participants at the end of the session in appreciation for their participation in the study.

4.2.3 Experimental task

All participants performed an adapted version of the child ANT (Rueda, et al., 2004a). The sequence of events in each trial is displayed in Figure 4.1. Each trial started with a fixation point of variable duration, which was randomly selected between 600 to 1200 ms. In half of the trials, a 2000 Hz tone was presented as alerting cue during 50 ms. Subsequently, an orienting cue, consisting of an asterisk, could appear above or below the fixation point for 100 ms. The asterisk only appeared in two-thirds of the trials, and no cue was displayed in the other one-third of trials. When presented, the orienting cue appeared in the same location of the subsequent target (valid cue) in half of the trials, and in the opposite (invalid cue) location in the remaining half. Finally, a horizontal row of five line drawing fish was presented above or below the fixation point. Fish flanking the one in the middle pointed to either the same (congruent trials) or the opposite (incongruent trials) direction as the central fish (target). Half of the trials were congruent, and half incongruent. Participants were asked to indicate the direction of the central fish by pressing the right or left bottom in a response box as rapidly and accurately as possible. The target display was presented until a response was made or up to 2500 ms. A feedback was provided 400 ms after the response, which consisted of an animation of the middle fish, showing it happy (blowing bubbles) and saying "yes" for correct responses, or sad (tears coming down the eye) and saying "no" for incorrect or missed trials. All stimuli were presented over a cyan-colored background. Adults completed eight blocks of 36 trials each plus 12 practice trials. Children completed four blocks of 36 trials each, preceded by 12 practice trials. The practice block was ran as many times as necessary until it was clear that the instructions were fully understood. In order to make the task friendly for children, they were told that the middle fish was hungry and they were to feed it by pressing the appropriate button.

4.2.4 Behavioral data analysis

Performance of the ANT allows calculation of scores for each attention network. Three subtractions were performed in order to calculate the alerting, orienting and executive attention scores for each participant using the median RTs per condition. The alerting score was calculated by subtracting the median RT for tone from the median RT for the no-tone condition. The orienting score was obtained by subtracting median RT for the valid cue from the invalid cue condition. Finally, the executive attention score was obtained by subtracting median RTs for congruent trials from median RTs for incongruent trials. Age differences for each network score were assessed with one-way ANOVAs. Additionally, sets of mix ANOVAs including Age-Group as between-subject factor and Alerting Cue (no-tone vs Tone), Orienting Cue (valid, invalid and no-cue) and Flanker Congruency (congruent vs incongruent) with median RT and percentage of commission errors as dependent measures were also conducted. In addition to information about the main effects of each factor, mixed ANOVAs allowed examination of interactions between attention networks, as well as second-order interactions involving Age Group.

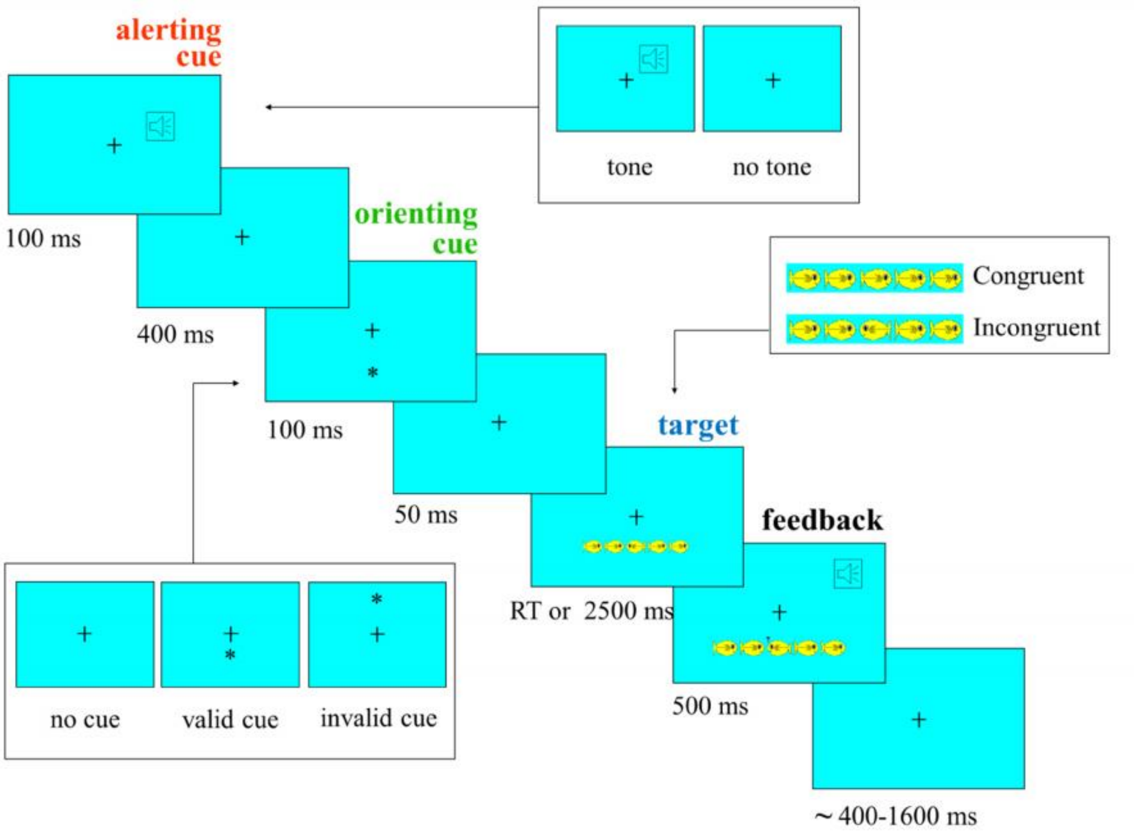


Figure 4.1. Structure of the task utilized in the study.

4.2.5 EEG acquisition and ERP processing

EEG was recorded using a 128-channel Geodesic Sensor Net 4.2 (GSN; Tucker, Liotti, Potts, Russell & Posner, 1993) and processed using Net Station 4.3 software. The EEG signal was digitized at 250Hz. The EEG signal was acquired using a 100 to 0.01Hz band pass filter. Impedances for each channel were kept below 50KΩ during recording. Channels with larger impedances at recording were noted and discarded for processing later on. The average impedance during recording of channels included in further analyses was 23.17 KΩ. Continuous EEG data were filtered by using a finite impulse response (FIR) band pass filter with 0.3 Hz high-pass and 20 Hz low-pass cutoffs (Passband gain: 99.0% (-0.1 dB), stopband gain: 1.0% (-40.0 dB), rolloff: 0.29 Hz). Then, data were segmented into alerting cue-locked (-200 ms to 800 ms around presentation of the alerting cue) and target-locked (200 ms pre-target to 1000 ms post-target) epochs. Segmented files were scanned for artifacts with the Artifact Detection NS tool using a threshold of 70 µV (adults) or 100 µV (children) for eye movements and 70 µV (adults) or 120 µV (children) for eye blinks. Bad channels were rejected and replaced by interpolation form neighbors' channels. Segments containing more than 20 bad channels, eye blinks or eye movements were excluded from further processing. Data for each trial were also visually inspected for each participant. Artifact-free segments for correct responses were averaged across conditions and participants within each age group, and re-referenced to the average of all channels. A per-subject criterion of a minimum of 16 artifact-free segments per experimental condition and 50 good segments among the correctly responded trials was established in order to be included in the grand-average for each age group. The 200 ms preceding the target or alerting cue served as baseline in both alerting cue- and target-locked segments. Event-related potentials (ERP) with the experimental conditions of interest for each attention network were built and plotted in the same graph for each age group.

Two main strategies were used to analyze within and between-groups effects of those conditions in the ERP data. First, peak amplitude values of the ERP components of interest were extracted for each condition and used to carry out analysis of variance with Age Group as between-subjects factor and the conditions of interests as the within-subject factor. These ANOVAs informed about differences in brain potentials relevant for each attention network, and allowed to examine differences between age groups in those effects. Second, in order to examine differences between conditions along the ERP components of interest, we computed amplitude differences at each time point along the entire epoch by mean of pair-wise t-tests. Modulations of amplitudes by experimental manipulations can occur along the entire epoch and not only in the peaks of the components. Analyses with t-tests inform about the extension of those modulations in the time domain. In all ERPs figures, the shadowed areas between ERP waves show the sections of the segments in which amplitude differences between conditions were significant ($p<.05$; uncorrected for multiple comparisons) as analyzed with two-tailed dependent-samples *t* tests ($t>2.145$ ($n=15$) for the 7-9, 10-13 and adult groups, and $t>2.160$ ($n=14$) for the 4-6 years old group). Topographic maps illustrate the distribution over the scalp of the significant amplitude differences between experimental conditions at particular segment times.

4.3. Results

4.3.1 Behavioral results

Omission errors were virtually inexistent (only one omission error committed by one participant), thus accuracy of performance was analyzed with percentage of commission errors. Two participants from the 4-6 years-old group were excluded for further processing due to a high percentage of commission errors (above 40%). Means of the median RT for correct responses and percentage of commission errors for each condition and age group are presented in Table 4.1 and 4.2, respectively.

The network scores for each age group are summarized in Table 4.3. Results from one-way ANOVAs with the networks scores showed no significant effect of Age for the alerting score ($F(3,55)=1.19$; $p=.32$), but significant effects for the orienting ($F(3,55)=3.66$; $p<.05$, $\eta_p^2=0.17$) and executive ($F(3,55)=6.02$; $p<.01$, $\eta_p^2=0.25$) networks scores. Planned contrasts showed no significant differences between groups of children in the orienting score (except for a marginal difference between 4-6 and 7-9 year-olds, $F(1,55)=2.94$; $p=.09$), but 10-13 as well as 7-9 year-olds differed from adults ($F(1,55)=6.29$; $p<.05$,

Age	Median RT		No tone			Tone		
			Invalid	No cue	Valid	Invalid	No cue	Valid
4-6 years	1059,5 (209,8)	Cong	983,18 (338,2)	1076,9 (207,7)	981,64 (180,9)	1002,3 (187,2)	927,86 (153,5)	941,86 (189,9)
		Incong	1142,9 (182,1)	1076,9 (130,1)	1086,4 (311,2)	981,64 (197,1)	1158,7 (237,8)	1002,3 (347,6)
7-9 years	735,5 (147,3)	Cong	706,27 (167)	743,30 (175,1)	684,03 (147,9)	704,67 (149,8)	672,20 (116,0)	623,17 (96,7)
		Incong	844,00 (148)	789,30 (135)	743,13 (164,1)	837,90 (140,6)	789,53 (170,7)	688,40 (157,2)
10-13 years	581,9 (96,9)	Cong	557,77 (92,7)	574,27 (89)	520,33 (91,4)	558,47 (94,3)	547,50 (98,6)	512,57 (79,2)
		Incong	654,07 (90,3)	634,13 (116,2)	573,70 (80,5)	657,47 (74,3)	632,17 (170,4)	560,60 (85,2)
Adults	426,15 (56,7)	Cong	402,90 (49,2)	435,07 (82,65	385,13 (58,8)	396,67 (44,6)	410,50 (55,1)	380,37 (44,3)
		Incong	462,77 (67,4)	466,40 (51,1)	438,53 (71,8)	463,47 (45,8)	452,00 (53,2)	419,97 (57,0)

Table 4. 1. Mean of median RT (SDs) per Age Group and task condition.

$F(1,55)=9.24$; $p<.001$, respectively). Regarding the executive network, we obtained a significant linear reduction of executive attention scores with age ($F(1,55)=17.7$; $p<.001$). Additionally, planned contrasts showed that adults differed significantly from 4-6 year-olds ($F(1,55)=17.47$; $p<.001$) and 7-9 year-olds ($F(1,55)=5.98$; $p<.05$), and marginally from 10-13 year-olds ($F(1,55)=2.85$; $p=.09$). Also, 4-6 year-olds differed from 10-13 ($F(1,55)=6.36$; $p<.05$) and marginally from 7-9 year-olds ($F(1,55)=3.16$; $p=.08$).

Age	Total % errors		No tone			Tone		
			Invalid	No cue	Valid	Invalid	No cue	Valid
4-6 years	9,7 (14,2)	Cong	5,66 (1,8)	9,82 (1,8)	9,82 (2,0)	8,93 (2,3)	11,01 (2,4)	9,23 (1,9)
		Incong	10,27 (2,4)	9,38 (2,2)	6,99 (1,8)	9,52 (2,7)	11,76 (2,6)	12,35 (2,7)
7-9 years	3,2 (5,4)	Cong	1,11 (1,8)	1,67 (1,7)	1,67 (2,0)	2,64 (2,2)	1,53 (2,3)	0,00 (1,8)
		Incong	7,22 (2,3)	2,50 (2,2)	2,78 (1,7)	8,75 (2,6)	4,44 (2,5)	4,30 (2,6)
10-13 years	2,2 (4,2)	Cong	2,78 (1,8)	0,56 (1,7)	1,11 (2,0)	0,56 (2,2)	0,00 (2,3)	1,11 (1,8)
		Incong	4,44 (2,3)	1,67 (2,2)	1,11 (1,7)	6,67 (2,6)	2,78 (2,5)	4,17 (2,6)
Adults	2,9 (3,8)	Cong	1,67 (1,8)	0,42 (1,7)	0,00 (2,0)	1,25 (2,2)	0,83 (2,28)	1,67 (1,8)
		Incong	6,67 (2,3)	2,92 (2,2)	3,33 (1,7)	8,75 (2,6)	5,42 (2,52)	1,67 (2,59)

Table 4.2. Percentage of commission errors (SDs) per age group and task condition.

Separate 4 (Age Group) x 2 (Alerting Cue: no-tone vs. tone) x 3 (Orienting Cue: invalid, valid, and no-cue) x 2 (Flanker Congruency: congruent vs. incongruent) ANOVAs with median RTs and percentage of commission errors as dependent measures were carried out. In both analyses, main effects of all four factors were significant. The main effect of Age Group was significant for both RT and commission errors, indicating a linear reduction of response time ($F(3,55)=79.73$; $p<.001$, $\eta_p^2=0.81$) with age, whereas with percentage of errors the effect was due to a significant difference between the youngest group of children and the rest of the groups ($F(1,55)=3.85$; $p<.05$, $\eta_p^2=0.17$). The main effect of Alerting Cue was significant with both RT ($F(1,55)=16.62$; $p<.001$, $\eta_p^2=0.23$) and percentage of commission errors ($F(1,55)=4.71$; $p<.05$, $\eta_p^2=0.08$). The main effect of Orienting Cue was also significant with both RT ($F(2,110)=19.70$; $p<.001$, $\eta_p^2=0.26$) and

	Alerting	**Orienting**	**Executive**
4-6 yr.	36 (67.6)	53 (86.4)	124 (80.5)
7-9 yr.	37 (39.8)	87 (56.9)	92 (48.3)
10-13 yr.	12 (28.4)	77 (27.5)	78 (21.2)
Adults	17 (32.1)	28 (15.7)	48 (24.3)

Table 4.3. Attention network scores in ms (SD) per age group.

commission errors ($F(2,110)=6.29$; $p<.01$, $\eta_p^2=0.10$). Finally, the main effect of Flanker Congruency was significant with RT ($F(1,55)=122.53$; $p<.001$, $\eta_p^2=0.69$) as well as with percentage of errors ($F(1,55)=39.47$; $p<.001$, $\eta_p^2=0.42$). Additionally, Age Group interacted with Flanker Congruency, an interaction that was significant with RT ($F(3,55)=3.94$; $p<.05$, $\eta_p^2=0.18$) but only marginal with error percentage ($F(3,55)=2.23$; $p=.09$, $\eta_p^2=0.11$). Also, a significant Alerting x Flanker Congruency interaction was found in the RT ANOVA ($F(1,55)=4.50$; $p<.05$, $\eta_p^2=0.08$), which was only marginal ($F(1,55)=3.15$; $p=.08$, $\eta_p^2=0.05$) in the commission errors ANOVA. In order to further explore this interaction, we conducted a second ANOVA in which only trials without orienting cues were considered, because orienting cues convey spatial as well as warning information about the upcoming target, which is likely to affect the preparation effect of alerting cues (see Callejas et al., 2005). In this second ANOVA, the Alerting x Flanker Congruency interaction remained significant ($F(1,55)=7.05$; $p<.05$, $\eta_p^2=0.11$), and the second-order interaction of Alerting x Flanker

Congruency x Age did not reach statistical significance ($F(3,55)=2.06$; $p=.12$). A graph depicting means of median RTs in each alerting and flanker congruency condition for each age group is presented in Figure 4.2. As shown at the figure, the younger groups of children showed stronger modulation of the flanker congruency effect by alerting conditions ($F(1,13)=3.03$; $p=.10$, $\eta_p^2=0.19$; $F(1,14)=5.81$; $p<.05$, $\eta_p^2=0.29$, respectively for 4-6 and 7-9 year-olds) while the effect was not-significant for 10-13 year-olds ($F(1,14)=1.08$; $p=.32$) or adults ($F<1$).

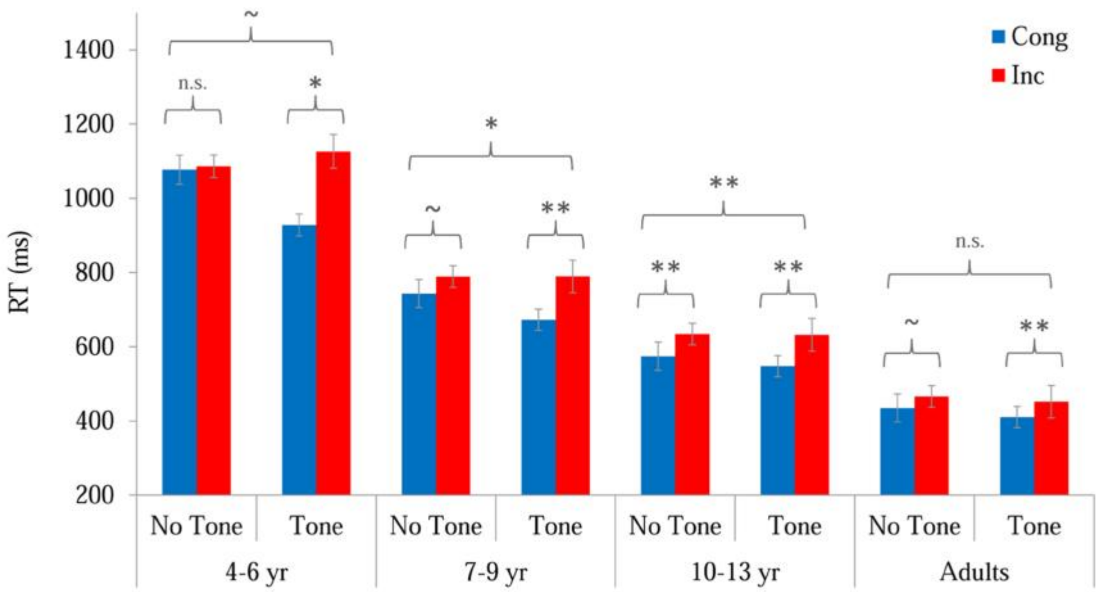


Figure 4.2. Graphical representation of mean RTs (in ms) per flanker congruency (Cong: congruent; Inc: incongruent) and alerting conditions in function of age group.

In addition, a significant Orienting x Flanker Congruency x Age interaction was obtained in the RT ANOVA. This interaction remained significant ($F(3,55)= 3.72$; $p<.05$, $\eta_p^2=0.17$) when trials with no orienting cue were not considered in the analysis, thus including only valid and invalid cues (96 trials for children and 192 trials for adults, from which half (48/96) were validly cued). This interaction, represented in Figure 4.3, indicated that the flanker interference effect was larger under the invalid compared to the valid orienting cue condition for all age groups except the youngest children who showed equivalent interference effects under the two orienting cue conditions ($F(1,14)=5.6$; $p<.05$, $\eta_p^2=0.29$, $F(1,14)=40.85$; $p<.001$, , $\eta_p^2=0.74$, $F(1,14)=6.50$; $p<.05$, $\eta_p^2=0.32$, and $F(1,13)=1.6$; $p=.22$, $\eta_p^2=0.11$ respectively for adults, 10-13, 7-10 and 4-6 year olds).

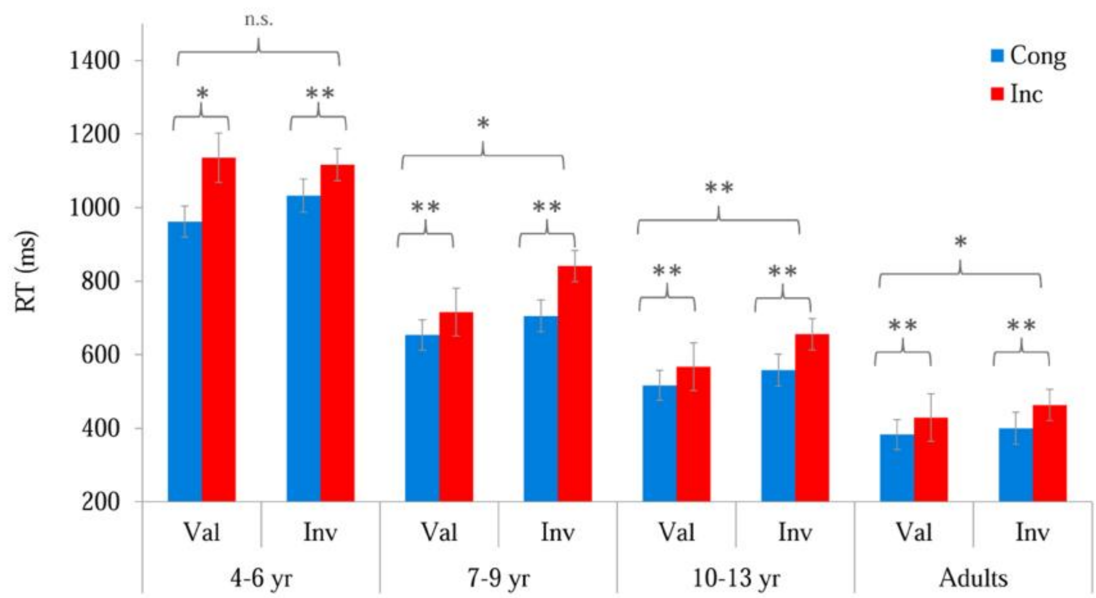


Figure 4.3. Graphical representation of mean RTs (in ms) per flanker congruency (Cong: congruent; Inc: incongruent) and orienting (Val: valid cue; Inv: Invalid cue) conditions in function of age group.

4.3.2 ERPs analyses

Measures of amplitudes for each ERP component, condition and Age Group are presented in Table 4.4. Results of these various ANOVAs are presented below.

	ERP component	4-6 yr NT	4-6 yr T	7-9 yr NT	7-9 yr T	10-13 yr NT	10-13 yr T	Adults NT	Adults T
Alerting effects	P1	1.59 (1.99)	1.78 (1.83)	1.28 (1.61)	2.38 (1.31)	1.15 (0.87)	1.64 (1.59)	0.23 (0.43)	0.29 (0.47)
	N1	-2.29 (1.91)	-2.63 (2.29)	-2.51 (1.31)	-2.93 (2.47)	-2.14 (1.03)	-3.17 (2.53)	-0.81 (0.49)	-3.22 (1.42)
	P2	2.84 (1.50)	3.66 (2.62)	2.80 (1.28)	4.04 (1.87)	1.86 (0.71)	3.79 (2.10)	-0.66 (0.34)	1.75 (1.31)
	CNV	-0.37 (1.22)	-1.41 (1.12)	-0.43 (0.95)	-1.39 (1.47)	-0.59 (0.76)	-1.35 (1.24)	-0.17 (0.36)	-1.02 (1.00)
		VAL	**INV**	**VAL**	**INV**	**VAL**	**INV**	**VAL**	**INV**
Orienting effects	P1	12.28 (6.74)	8.75 (5.09)	23.06 (7.63)	16.91 (5.59)	15.67 (6.18)	12.40 (6.26)	4.13 (3.46)	4.05 (3.32)
	N1	1.74 (5.18)	0.36 (4.06)	7.69 (5.90)	8.24 (5.86)	5.18 (7.83)	7.15 (7.15)	-1.40 (2.64)	-0.67 (2.19)
	P3	1.32 (1.54)	1.79 (1.97)	2.03 (1.55)	2.98 (1.64)	1.80 (1.82)	2.25 (1.73)	0.99 (1.03)	1.03 (0.86)
		C	**I**	**C**	**I**	**C**	**I**	**C**	**I**
Executive Attention effects	N2	-4.24 (1.67)	-4.19 (1.67)	-6.99 (2.97)	-7.05 (3.33)	-7.06 (3.99)	-7.04 (3.34)	-2.15 (1.20)	-2.02 (1.09)
	SP	0.60 (1.82)	1.13 (1.78)	-2.13 (1.99)	3.30 (2.40)	2.47 (2.23)	2.79 (2.36)	1.17 (1.04)	1.41 (1.16)

Table 4.4. Amplitude measures (in µVolts) per experimental condition and age group of the ERP components of interest for each attention network. NT: No tone, T: Tone; VAL: Valid orienting cue, INV: Invalid orienting cue; C: Congruent Flankers; I: Incongruent Flankers. Alerting effects: peak amplitude at channel Fcz was calculated for the P1, N1, and P2 components within a post-alerting cue time window of 10–100 ms, 100–200 ms, and 200–300 ms, respectively, whereas the mean amplitude at channel Fcz within 300–600 ms post-alerting cue was extracted for the CNV component. Orienting effects: peak amplitude averaged over channels Oz, O1 and O2 in post-target time windows ranging from 100–200 ms (P1for all groups and N1 for adults group) and 230-330 ms (N1), as well as the mean amplitude within 250-400 ms post-target window at the average of channels CPz and Pz for P3. Executive Attention effects: N2 is the minimum amplitude at channel Fcz within a post-target time window of 250–400 ms. for adults, and 400-500ms. for children; and SP is the mean amplitude at channel Pz, and P6 for 4-6 year-olds, within a post-target time window of 500–800 ms.

4.3.2.1 Alerting cue-locked ERPs

a. Alerting network

ERPs per alerting condition over mid-frontal leads for each age group are presented in Figure 4.4. Topographic maps at the time of amplitude peaks corresponding to P1, N1, P2 and CNV components show a clear mid-frontal distribution of those components. Therefore, peak amplitude values of the corresponding polarity were extracted for channel Fcz at the following time windows: 10-100 ms for P1, 100-200 ms for N1, 200-300 for P2 and 300-600 ms for the CNV, and sets of 2 (Alerting Cue: tone vs no -tone) x 4 (Age Groups) ANOVAs were performed with those values. The Age Group factor was significant for the P1 ($F(3,55)=4.32$; $p<.01$, $\eta_p^2=0.25$) and P2 ($F(3,55)=9.57$;$p<.001$, $\eta_p^2=0.34$). The effect of Alerting Cue was significant for all the components taken into account: P1 ($F(1,55)=4.74$; $p<.05$, $\eta_p^2=0.08$), N1 ($F(1,55)=16.30$; $p<.001$, $\eta_p^2=0.23$), P2 ($F(1,55)=23.83$; $p<.001$, $\eta_p^2=0.30$), and CNV ($F(1,55)=25.50$; $p<.001$, $\eta_p^2=0.32$). Finally, the Age Group x Alerting Cue interaction was significant only for the N1 ($F(3,55)=3.39$; $p<.05$, $\eta_p^2=0.16$). Further analyses of the interaction revealed that only adults showed a significant effect of Alerting Cue on the N1 ($F(1,55)=21.82$; $p<.01$). This effect was marginal in 10-13 years-olds ($F(1,55)=3.96$; $p=.05$).

4.3.2.2 Target-locked ERPs

b. Orienting network

Figure 4.5 presents ERP for valid and invalid-orienting cue trials (Orienting Network), and Figure 4.6 shows ERP for congruent and incongruent conditions (Executive Attention Network). ERPs per orienting condition for each age group, both at parietal and

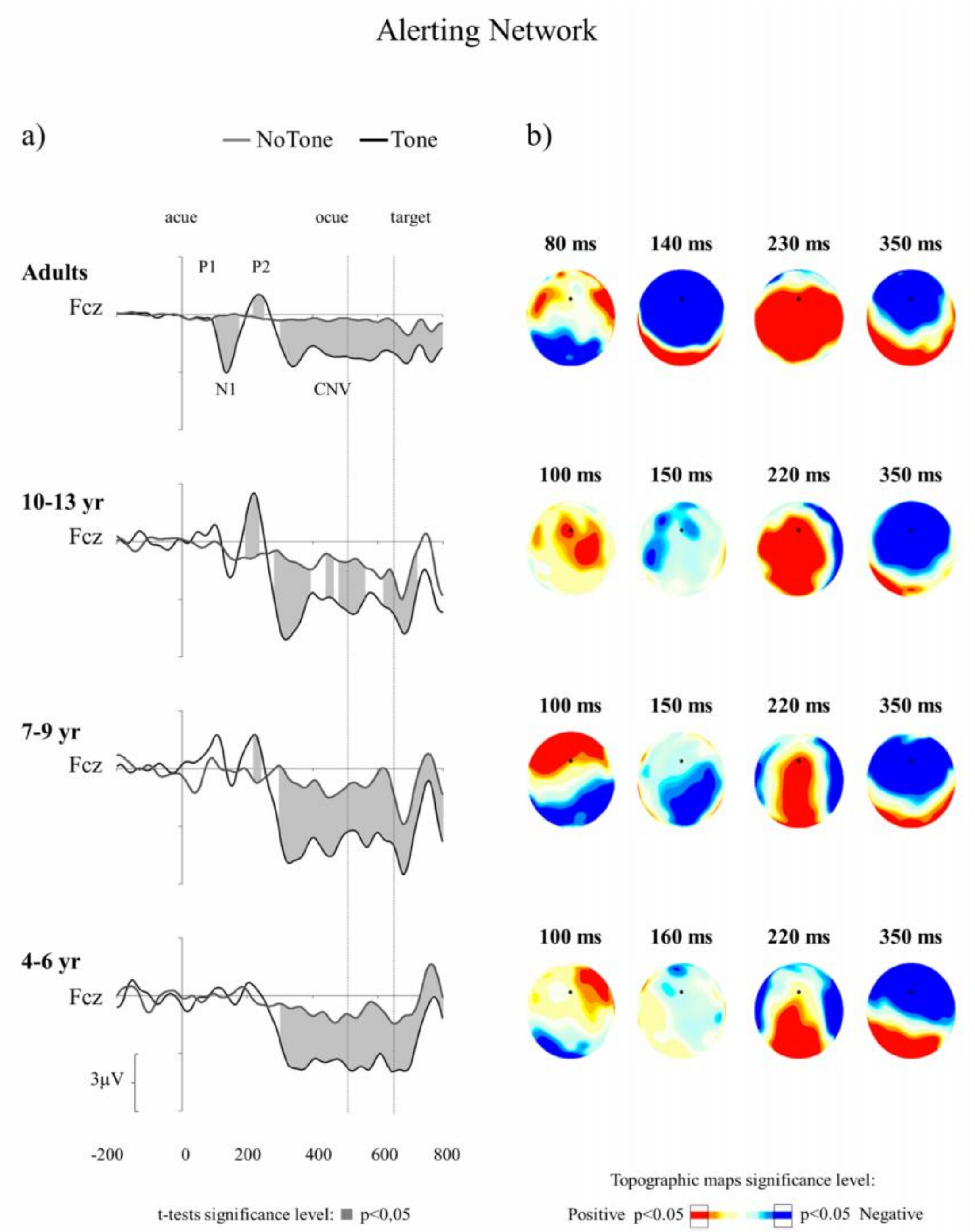


Figure 4.4. Alerting effects on electrophysiological data. Graphs representing alerting cue-locked ERPs for each alerting condition and age group (a). Topographic maps illustrating Tone-NoTone-significant differences at peak times for the P1, N1, P2, and CNV components (b). Gray areas between ERPs indicate time windows with significant ($p<.05$) amplitude differences between conditions computed by two-tailed t-tests. acue: alerting cue; ocue: orienting cue. Note that positivity is plotted upwards.

occipital sites, are presented in Figure 4.5. Peak amplitudes were extracted for each participant at time windows ranging from 100-200 ms, 100-200/230-330 ms (adults/children) and 300-400 ms, respectively for the P1, N1 and P3 ERP components at the average of channels Oz, O1 and O2 (for P1 and N1) and CPz and Pz (for the P3 component). These data were entered in separated ANOVAs including Age Group (4-6, 7-9, 10-13 years-old, and adults) and Orienting Cue (valid- vs. invalid-cue) conditions as factors. The effect of Age Group was significant for each component ($F(3,55)=24.46$; $p<.001$, $\eta_p^2=0.57$ for the P1, $F(3,55)=10.10$; $p<.001$, $\eta_p^2=0.35$ for the N1, and $F(3,55)=9.86$; $p<.05$, $\eta_p^2=0.14$) for the P3). The effect of Orienting Cue was significant for the P1 ($F(1,55)=28.18$; $p<.001$, $\eta_p^2=0.34$) and P3 ($F(1,55)=9.87$; $p<.01$, $\eta_p^2=0.15$), and not significant for the N1 ($F<1$). Also, the Age Group x Orienting Cue interaction was significant for the P1 ($F(3,55)=4.17$; $p<.01$, $\eta_p^2=0.18$). Subsequent analyses of this interaction revealed that the effect of Orienting Cue on the amplitude of the P1 peak was significant for all children groups ($F(1,55)=7.85$; $p<.01$, $F(1,55)=25.58$; $p<.001$, and $F(1,55)=7.22$; $p<.01$, respectively for 4-6, 9-7 and 10-13 years-olds) but did not reach significance in the group of adults ($F<1$).

c. Executive network

Regarding the modulation of ERP by the congruency of flankers, peak amplitude of Fcz for adults within a 250-400 ms and Fcz for children within 400-500 ms after target (when negative deflection was observed), as well as mean amplitude of Pz within a 500-800 ms post-target time window were extracted for each participant (see Fig. 4.6). These data were included in separated ANOVAs with Age Group (4-6, 7-9, 10-13 years-old, and adults) and Flanker Congruency (congruent vs. incongruent) conditions as factors. The effect of Age Group was significant for the N2 component ($F(3,55)=15.27$; $p<.001$, $\eta_p^2=0.45$) but did not reach significance for the SP ($F(3,55)=1.95$; $p=.13$, $\eta_p^2=0.09$). The effect of Flanker Congruency was significant only for the SP ($F(1,55)=16.68$; $p<.001$, $\eta_p^2=0.23$). Finally, the Age Group x Flanker Congruency interaction was not significant in any of the components ($F<1$ for both). We found a lack of flanker interference modulation of the N2 in children. However, amplitude modulation by flanker congruency was observed after 400 ms post-target, as shown by t-tests (see Fig. 4.6).

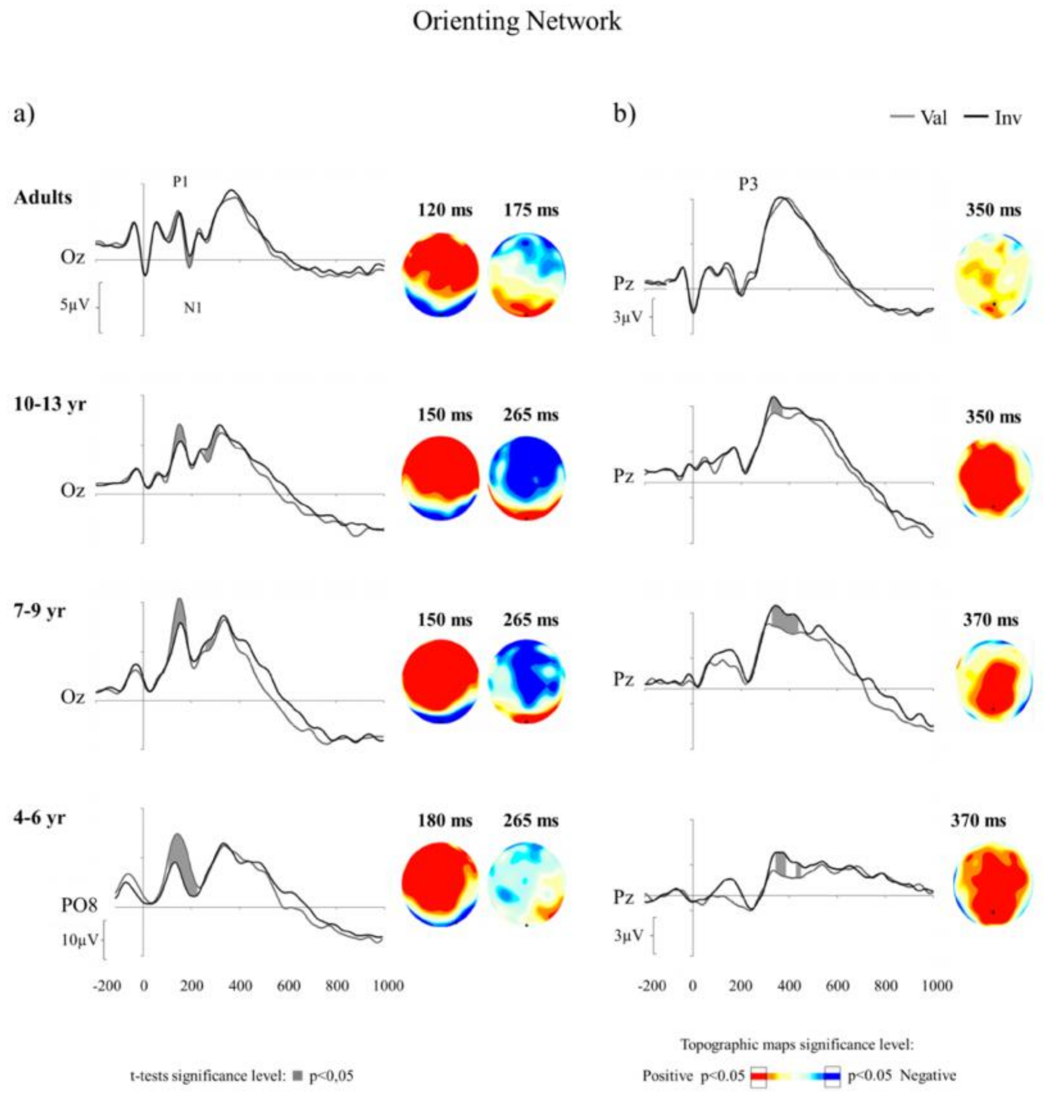


Figure 4.5. Orienting effects on electrophysiological data. Graphs representing target-locked ERPs for each orienting (Val: valid cue; Inv: Invalid cue) condition and age group as well as topographic maps illustrating significant invalid vs. valid differences at peak times for the P1and N1 (a) and P3 (b) components in each age group. Gray areas between ERPs indicate time windows with significant (p<.05) amplitude differences between conditions computed by two-tailed t-tests.

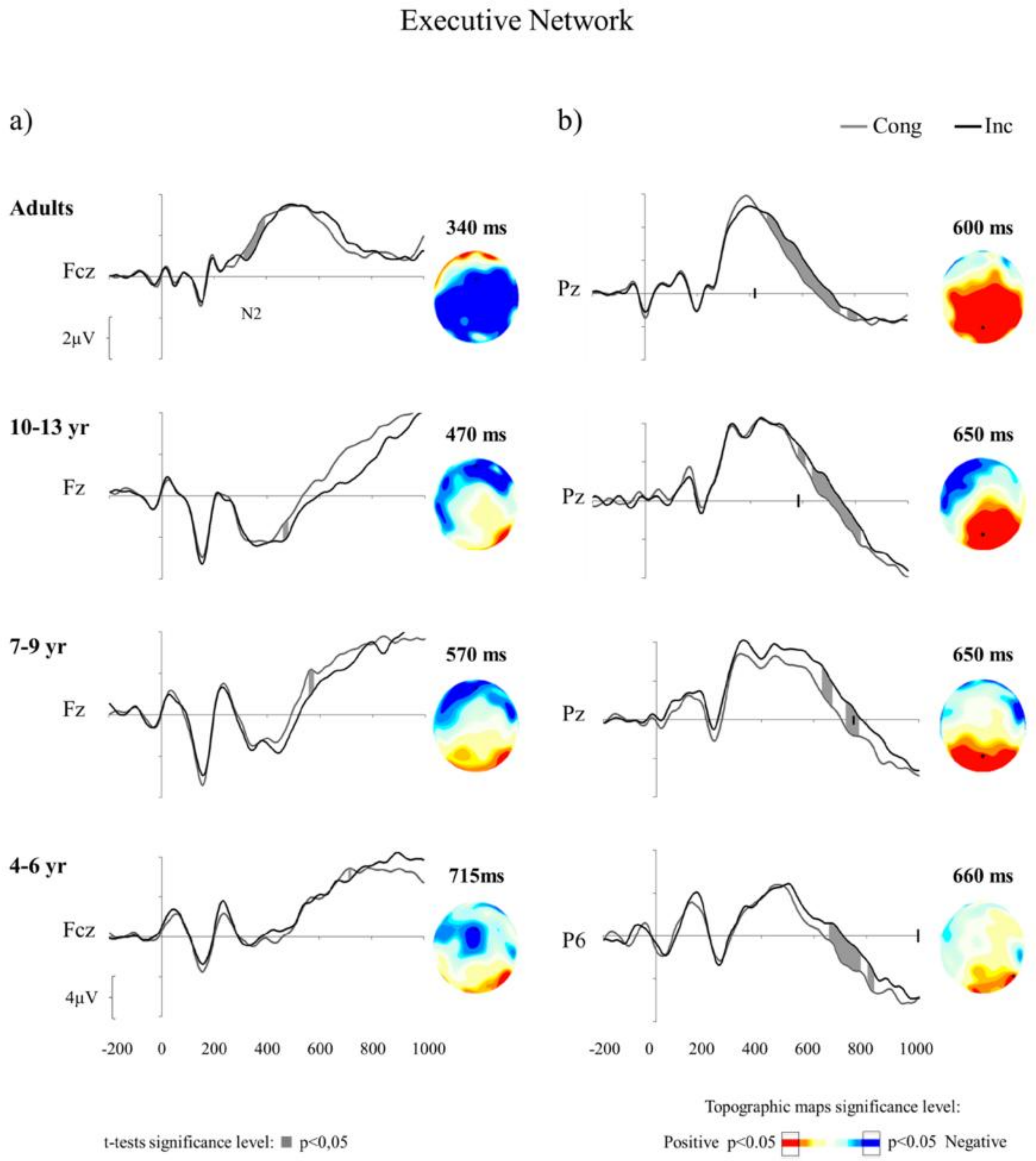


Figure 4.6. Executive attention effects on electrophysiological data. Graphs representing target-locked ERPs for each Flanker Congruency (Cong: congruent; Inc: incongruent) condition and age group as well as topographic maps illustrating significant Incongruent-Congruent differences at peak times for the N2 (a) and SP (b) components in each age group. ▌ At SP graphs indicates median RT for each age group. Gray areas between ERPs indicate time windows with significant (p<.05) amplitude differences between conditions computed by two-tailed t-tests.

d. Interactions between attention networks

Lastly, in order to examine modulation of alerting and orienting conditions on the executive attention effect, ERPs corresponding to congruent and incongruent conditions were averaged separately in function of the conditions of the other two networks. Splitting the data in this way left insufficient artifact-free segments to average across subjects in the children groups, therefore these analyses were only performed with data from the adults' sample, ERPs that resulted from these analyses are presented in Figure 4.7. As before, the shadowed areas between the ERPs corresponding to the congruent and incongruent conditions show time windows with significant amplitude differences between the two conditions as measured by paired-samples t-tests.

To analyze the interaction between alerting and executive attention, two separate 2 (Alerting Cue: tone vs no-tone) x 2 (Flanker Congruency: congruent vs. incongruent) ANOVAs were performed with amplitude of the N2 (minimum amplitude within a time-window of 250-400 ms post-target at Fcz) and SP (mean amplitude within a time-window of 500-800 ms post-target at Pz) components. For the N2, results showed a main effect of Alerting ($F(1,14)=10.56$; $p=<.05$, $\eta_p^2=0.42$) but no effect of Flanker Congruency or Alerting x Flanker Congruency ($F<1$). For SP, a main effect of Flanker Congruency ($F(1,14)=4.86$; $p=<.05$, $\eta_p^2=0.26$) emerged, but no effect of Alerting or interaction between the two factors was found ($F<1$). To analyze the Orienting x Executive networks interaction, two separate 2 (Orienting Cue: valid vs invalid) x 2 (Flanker Congruency: congruent vs. incongruent) ANOVAs were performed, one using the peak amplitude of the N2 at Fcz within a time window of 250-400 ms post-target, and a second one using the mean amplitude at Pz within a time window of 500-800 ms post-target. For the first ANOVA neither main effects nor the interaction between the factors were significant. In the second ANOVA, only the main effect of Flanker Congruency ($F(1,14)=11.60$; $p=<.01$, $\eta_p^2=0.45$) was significant.

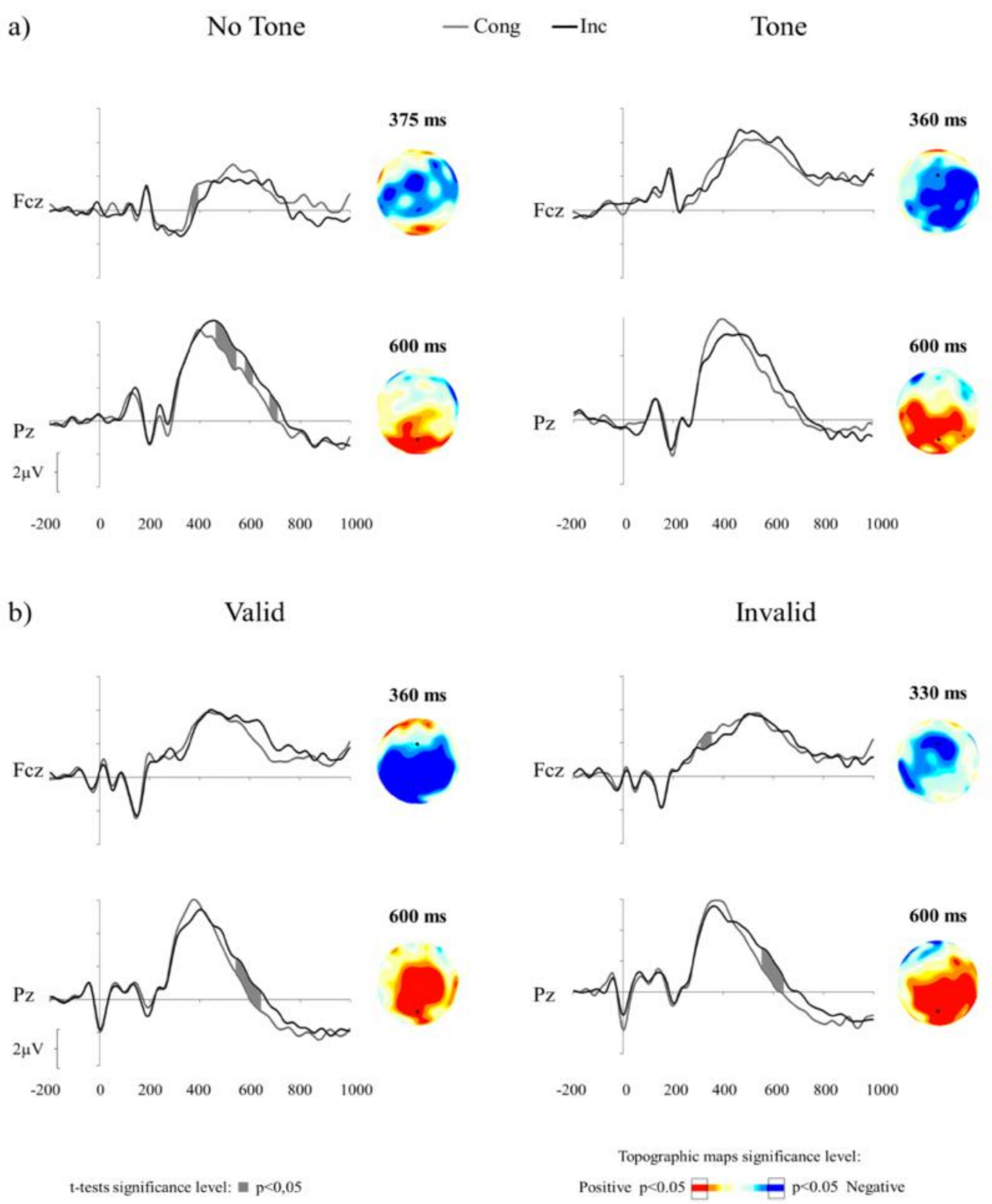


Figure 4.7. Graph depicting Alerting x Executive attention (a) and Orienting x Executive Attention (b) interactions effects on target-locked ERPs in adults (Cong: congruent; Inc: incongruent). Topographic maps illustrating significant Incongruent-Congruent differences at for the N2 and SP components at Alerting (a) and Orienting (b) conditions. Gray areas between ERPs indicate time windows with significant (p<.05) amplitude differences between conditions computed by two-tailed t-tests.

4.4. Discussion

This study examined age-related differences in attentional networks efficiency at behavioral and electrophysiological levels with the goal of understanding cognitive and brain mechanisms underlying the development of attention functions. As expected, age-related changes in the efficiency of attention networks were observed, which, in the age range studied, were more pronounced for the orienting and executive attention networks. We did not find a significant age effect on alerting scores, but there was a trend to larger alerting effects for younger children compared to older children and adults. Orienting scores showed a different developmental trajectory, with no significant differences among the children groups, but significant differences between 7-9 and 10-13 children and adults. Finally, executive attention scores showed a more protracted reduction over the age range studied, indicating a progressive gain in efficiency of conflict processing with age. Overall, the developmental trajectories obtained in this study replicate what was observed before with a similar version of the task (Pozuelos et al., 2014; Experiment 1) and in other studies using different procedures to measure the same functions (Waszak, Li, & Hommel, 2010). Additionally, alerting and orienting conditions modulated efficiency of executive attention in ways that were expected according to previous research (Callejas et al., 2005; Pozuelos et al., 2014). Overall, interference suppression was less efficient after presentation of a warning auditory tone, and also following invalid orienting cues. In the current study, we found that these interactions were qualified by the age of participants, a second-order interaction that was mostly derived from the youngest group of children. The modulatory effect of alerting over executive attention was stronger for the youngest group, who only showed a significant flanker interference effect when a warning tone preceded the target (see Fig. 4.2). Also, the youngest children, contrary to the rest of the groups, showed equivalent interference effects following valid and invalid orienting cues (see Fig. 4.3). In the developmental study conducted by Pozuelos et al. (2014) no second-order interactions with age were observed, which could be due to the fact that the youngest group included in that study was 6 and a half years on average, whereas in this study the average age of youngest group was 5 years. Below we discuss these developmental patterns in relation to ERP data obtained in this and other studies.

4.1 Alerting network

Previous studies have shown that young children (5-year-olds) need more time than older children (8-year-olds) and adults to get full benefit from a warning cue (Berger, Jones, Rothbart, & Posner, 2000), and they also seem to be less able to sustain the optimal level of alertness over time (Morrison, 1982). The fact that alertness is subject to more fluctuations in younger children can in part explain age differences in processing speed because alertness is thought to speed the processing of subsequent events. Using the ANT, Rueda et al. (2004a) found no differences in alerting between 10 year-olds and adults with the child ANT, but the same group of children showed a relatively poor ability compared to adults maintaining the alert state in the absence of a warning signal when using the adult ANT. Separation of the alerting and orienting events, and inclusion of trials with invalid orienting cues, is likely to have made the current version of the child ANT some more challenging than the one used by Rueda and colleagues. Behavioral results in our study showed a lack of age effect for the alerting score. However, ERP analyses revealed a poorer processing of the alerting signal by children below age 9 compared to older children and adults (see Fig. 4.4). While adults showed the usual electrophysiological pattern associated with the early processing of an auditory cue, the AEP complex (Ponton, Eggermont, Kwong, & Don, 2000) followed by the CNV, children data revealed a number of differences compared to adults. First, while the presence of the alerting tone modulated the amplitude of the P1 and P2 peaks in 7-9 and 10-13 year-old children, 4-6 year-olds did not show any differences on amplitude between tone and no-tone conditions until about 300 ms after presentation of the tone. Evidence in the literature indicates that central auditory pathways have a maturational time course that extends into adolescence (Ponton, et al., 2000; Sharma, Kraus, McGee, & Nicol, 1997; Wunderlish, et al., 2006). The AEP complex has been associated to sensory encoding and integration of auditory stimuli (Hegerl, & Juckel, 1993; Jucke, et al, 1997). Developmental studies have found an early maturing P1 and P2 in response to auditory cues, but a later emergence of the N1, which appears around 10 years of age (Čeponien, et al., 2002; Ponton, Don, Eggermont, Waring, & Masuda, 1996; Ponton et al., 2000). Our data are in line with these findings because only adults show a clear N1 peak following the alerting tone. Also, both the size and latency of the P1 decrease with age, whereas the P2 is present from mid childhood, showing a latency and topography similar to that of the adults. Regardless of the differences found in the early processing of the alerting cue, all age groups presented a CNV starting at approximately 300 ms after the presentation of the tone. Bender and colleagues (2005) have reported that children from 6 to 12 years of age do not show the late component of the CNV associated to motor pre-activation. However, the relatively short foreperiod (650 ms) used in our task does not allow drawing further conclusions about possible developmental differences on early and late components of the CNV.

Other studies have also found differences in brain activity during development in response to a target that is followed by a warning cue. In a fMRI study using a modified version of the adult ANT, Konrad et al. (2005) found that adults exhibit the classic fronto-parietal activation in the right ventral prefrontal cortex and the left superior parietal gyrus when processing targets preceded by alerting signals. However, 10-12 year-old children did not show activation in those areas. Instead, they showed increased activity in the right middle occipital cortex and right superior temporal gyrus. These remarkable differences were found in spite of a lack of differences in alerting scores between children and adults. Altogether, data suggest that the alerting network shows a poor early processing of warning signals in early and middle childhood. Further maturational processes of this network that are not observable at the behavioral level may still occur during late childhood.

4.2 Orienting network

Efficiency scores for the orienting network provided in this study, which were obtained subtracting valid- from invalid-cue trials, mostly grasp processes related to disengagement and reallocation of attention (Posner & Cohen, 1984). When development of orienting is examined using only valid cues, no age differences are observed beyond age 5 and adults (Rueda et al., 2004a; Wainwright & Bryson, 2002). However, our data reveal a developmental trajectory of this function that extends to late childhood, which is most likely due to maturation of brain structures involved in disengaging and switching attention from one location to another.

A number of posterior ERP components (i.e., P1, N1, and P3) have been long associated to visual processing (Mangun, 1995; Mangun & Hillyard, 1987). Of those, the P1 and N1 components are related to early sensorial processing. These potentials are typically larger in amplitude after valid than invalid cues when short cue-target intervals (i.e., below 500 ms) are used (see Chica & Lupiáñez, 2009 for a reversed pattern when cue-target intervals that promote inhibition of return are used). The larger amplitude on valid-cue trials is associated with attention-related sensory gain at an early stage of processing of the target (Luck & Hillyard, 1995; Mangun, 1995). Studies of spatial attention have shown that the N1 is enhanced by valid orienting cues on choice RT tasks but not when simple RT tasks are used, while the P1 amplitude is modulated by attention cues independently of the type of task (Mangun & Hillyard, 1991; Luck & Hillyard 1995; Ritter, Simson, Vaughan Jr., & Macht, 1982). This suggests that the P1 is a rather exogenous ERP index of early visual processing, while the N1 may reflect a more complex processing phase, involving discrimination of information conveyed by different cortical processing streams (Vogel & Luck, 2000). In our study, orienting cues produced a consistent early modulation of the P1 amplitude in all age groups (see Fig. 4.5). This indicates that children used the cues to successfully orient attention, as is also suggested by faster RT for valid-cue trials. Additionally, 4-6 year olds did not show modulation of the N1 amplitude. Modulation of this component was expected given that the task used in our study involved discriminating the direction of the central fish. The fact that children below age 7 years do not show modulation of the N1 indicates that attention has greater impact at earlier stages of visual processing in young children, whereas it continues to have an impact on subsequent stages of visual processing in older children and adults.

On the other hand, the P3 shows a rather opposite developmental pattern. This potential is also modulated by validity of the cue, showing larger amplitude at invalid compared to valid-cue trials (Bledowski, Prvulovic, Goebel, Zanella, & Linden, 2004; Gómez et al., 2008), and thus has been related to processes of disengagement and reorienting of attention. In our study, modulation of the P3 by the validity of the cue was larger for the youngest group of children. This result is consistent with data from previous studies (Flores et al., 2010), and suggests that young children engage fronto-parietal structures to a greater extent than older children and adults in order to disengage and move attention from the location of the cue to the location of the target in invalid-cue trials.

In sum, our data suggest that children under 7 years of age are not yet completely efficient when it comes to use valid orienting cues to facilitate the processing of a target. Moreover, when the target is presented at a different location from that of the orienting cue and attention has to be reallocated, even the older children in our study show larger costs than that shown by adults.

4.3 Executive attention network

In line with previous results using similar tasks (Fjell et al., 2012; Ridderinkhof & van der Molen, 1995), we found a linear reduction of conflict scores with age. With a version of the child ANT that only includes valid orienting cues, the executive attention network was shown to reach adults' levels of efficiency after about age 7 years (Rueda et al., 2004a). However, data from the current study suggest a developmental trajectory for this network that extends to late childhood. The inclusion of invalid orienting cues in the current version of the task caused increased interference from flankers, as indicated by the significant Orienting x Executive attention interaction with both RT and commission errors (see Table 4.1 and Fig. 4.3), which likely led to a more protracted development of conflict resolution than was observed with the original child ANT. This interpretation is supported by data from a recent developmental study in which a progressive development of executive attention from 6 to 12 years of age was found using the same version of the child ANT (Pozuelos, et al., 2014, Experiment 1).

As expected, electrophysiological recordings revealed a modulation of the N2 amplitude by the congruency of flankers in adults (see Fig. 4.6). As revealed by t-tests, the modulation is observed in midfrontal channels at about 350 ms post-target. This effect was not observed in children, rather we observed a delayed and more anterior modulation by flanker congruency over central anterior channels. Such difference was sustained for a longer period of time in children compared to adults. Data in the literature about developmental changes in conflict-related modulations of the N2 effect greatly depend on the task being used. Several studies using Go-NoGo tasks have reported larger conflict effects in N2 amplitude by young children compared to older children and adults (Hämmerer, et al., 2010; Lamm et al., 2006). This result suggests that the larger the effect on the amplitude of the N2 the poorer the executive control efficiency. As a matter of fact, Lamm et al. (2006) reported an age-related decrease in N2 amplitude between 7 and 16 years of age. However, using a flanker task with arrows, Ladouceur and colleagues (2007) found that only late adolescents (i.e., older than 14 years) and adults showed larger N2 amplitude in trials with incongruent flankers, while an early adolescents group also included in the study did not show the effect. Our results are consistent with data from this study as well as with those reported by Rueda and cols (2004b) where young children did not show N2 amplitude modulation by flanker congruency but a sustained frontal effect after 500ms post-target.

On the contrary, we found that conflict-related modulation of the SP amplitude was observed in all age groups. It is noteworthy that this potential was observed for the most part after the response in 10-13 year-olds and adults, whereas it was shown around the time of the response (7-10 year olds) or before it (4-7 year olds) for the younger groups. This indicates that the SP potential is somewhat independent of the response and could either be directly involved on conflict resolution or could signal a post-response neural activation for adjustments and sustained control of goal-directed behavior (Coderre et al., 2011). Imaging studies have suggested that executive control is related to the action of two differentiated neural networks, one involved in trial-to-trial response adaptation (adaptive control), and another mostly related to stable control (set maintenance) along the duration of the task (Dosenbach, Fair, Cohen, Schlaggar, & Petersen, 2008). The two systems appear to be functionally segregated in adults but not completely so in late childhood (Fair et al., 2007). It has been previously suggested that, because of children generally slower capacity for processing information, they show conflict-related effects in later ERP components compared to adults (Rueda et al., 2004b). This could explain why children did not show a conflict-related modulation of the N2 component. Instead children showed delayed effects in frontally distributed leads as well as modulation of the SP potential. Determining whether the two ERP components represent waves of activation of the same or different underlying conflict processing systems, and/or whether they reflect equivalent action-control mechanisms, requires further research.

4.4 Networks interactions

Despite their anatomical separation, there is evidence indicating that the attention networks are not functionally independent (Callejas et al., 2005; Fan et al., 2009). It has been previously shown that both alerting and orienting conditions modulate efficiency of the executive attention network (Callejas, Lupiáñez, & Tudela, 2004; Weinbach & Henik, 2012). These modulatory effects were replicated in the current study. Further, in our study, we were able to test whether these patterns of interactions between attention networks change with age along childhood.

Our data revealed that efficiency of executive attention was harmed when a warning tone was presented prior to the appearance of the target. This effect has been interpreted before as indicative of an inhibitory relation between the alerting and executive networks. The idea is that warning signals promote fast and automatic responses over more controlled forms of action (Posner, 1994). Our results show that alerting signals reduced RT mostly in the congruent condition, leading to lager flanker effects in that condition compared to when no alerting tone was presented (see Fig. 4.2). This effect was present in all age groups, although it was somewhat stronger for the youngest group of children. This result agrees mostly with the account of alertness promoting fast and automatic responses. However, it has been also proposed that alerting influences the allocation of attention by prioritizing the processing of spatial information, thus leading to enhanced processing of distracting stimulation (Weinbach & Henik, 2012). According to this hypothesis, larger interference effects are due to the necessity for greater implication of the executive system in order to suppress the influence of distracting stimulation with higher alertness.

The second modulatory effect over efficiency of executive attention was that of orienting cues. The significant Orienting x Executive Attention x Age in our study indicated that the interaction between orienting and executive attention differed among age groups. As can be seen in Figure 4.3, for all age groups except the youngest children, executive scores were higher (i.e., poorer efficiency) when invalid orienting cues were presented prior to the appearance of the target. After invalid cues, reallocation of attention is needed, a process that is thought to engage a fronto-parietal network (Corbetta, & Shulman, 2002) that may partially overlap with structures involved in suppressing irrelevant stimulation (Fan, et al., 2007; Fan, McCandliss, Fossella, Flombaum, & Posner, 2005). It has been suggested that during the interaction between orienting and executive attention a competition for limited attentional resources from shared brain structures takes place (Fan et al., 2009). The lack of interaction in the youngest children, may be related to the fact that conflict processing was difficult for children of this age regardless of the facilitation offered by valid orienting cues. In fact, valid cues only reduced RT in the easiest (i.e., congruent) flanker condition in this age group.

These patters of interactions between attention networks were not observed with electrophysiological recordings. T-test results indicated that warning auditory cues might affect the brain potentials associated with conflict processing in adults. Specifically, presence of the tone appeared to cause larger conflict effect on the SP component, whereas did not seem to affect the size of the conflict effect on the N2 (see Fig. 4.7a). As argued before, greater SP amplitude for displays with incongruent distractors is likely related to stronger activation of the fronto-parietal network involved in sustained attention control (Dosenbach et al., 2008), which is even stronger after warning cues are presented, reflecting the greater effort required to deal with conflict in higher alerting states. ERP results are less clarifying of the neural mechanisms underlying the Orienting x Executive attention interaction. As can be observed in Figure 4.7b, the size of the conflict-related amplitude effect on both the N2 and SP components is similar under valid and invalid orienting conditions. In general, inconsistencies between brain and behavioral measures of interactions between attention networks may be due to the smaller number of trials available to study interactions with brain potentials. Further investigation is needed in order to cast light into the neural mechanisms underlying the pattern of interactions between attention network observed at the behavioral level.

4.5 Limitations of the study

One of the main limitations of the current study relates to the unfeasibility to examine interactions between attention networks on electrophysiological recordings in the children sample. Changes introduced to the task design led to a larger number of conditions in this version (2 alerting x 3 Orienting x 2 Congruency = 12 cells) compared to the original version (4 Alerting/Orienting Cues x 2 Congruency = 8 cells) of the ANT. A larger number of conditions inevitably lead to longer tasks if the number of observations per cell is to remain constant. However, task length can be an issue when running developmental studies because of young children's shorter attention/motivation span compared to adults. In order to minimize the influence of such factors in our study we chose to keep the task as short as possible for the children groups. This derived in an insufficient number of observations to examine networks interactions when trials with incorrect responses and EEG artifacts were discarded. In future studies, it might be useful to examine interactions between networks in separate tasks, thus reducing the number of cells in the design, in order to acquire sufficient data points with reasonable task lengths.

4.6 Summary and conclusions

The main goal of the current study was to examine the electrophysiological patterns of activations underlying the development of attention functions of alerting, orienting and executive control during childhood. For doing so, a modified version of the child ANT was used. In this new version of the task, separate events in each trial were introduced to manipulate alertness, orienting and conflict, as in Callejas et al. (2005) and Pozuelos et al., (2014). In consonance with previous data in the literature, behavioral results indicate that the three attentional functions follow different developmental trajectories during childhood (see Rueda, 2013 for a review). While the alerting function appears adult-like by age 10, both orienting and executive attention showed a more protracted developmental curve. In the current version of the ANT, both valid and invalid orienting cues were used. Invalid cues grasp mostly aspects of attentional disengagement and re-orienting, which lengthen the developmental trajectory of orienting compared to when only valid cues are used (Rueda et al., 2004a). Finally, executive attention exhibited a linear increase in efficiency with age that might go beyond the age range of children included in our study (Fjell et al., 2012; Waszak, 2010).

EEG recordings during performance of the task evinced differences between children and adults related to the activation of all three attention networks. Overall, age-related changes were mostly observed on early ERP components, suggesting that, compared to adults, children exhibit a poorer fast processing of conditions varying in attentional requirements. Young children appear to have poorer early processing of warning cues compared to 10-13 year-olds and adults, judging from the immature AEP complex elicited by warning auditory tones in children below 10 years of age. Also, the youngest groups exhibited a poorer processing of orienting cues in early (N1) as well as late (P3) ERP components, indicating that they are not yet able to obtain a full facilitatory effect from valid cues, and must activate the orienting network to a greater extent in order to shift attention when invalid cues are presented. Finally, the lack of conflict-related modulation of the N2 component in all children groups suggests that the executive attention network is not yet fully mature at 13 years of age.

Results from this study also inform about patterns of interactions among attention networks in adulthood and over development. Both alerting and orienting conditions influence the effectiveness of conflict processing by the executive attention network. Higher alerting states lead to poorer conflict processing in all age groups, an effect that, at least in adults, appear to be associated with less efficient recruitment of the executive attention network following a warning signal. On the other hand, as children gain in executive attention efficiency after the preschool period, resources devoted to reallocating attention when invalid orienting cues are provided also reduce the effectiveness of executive control.

Chapter 5.

Impact of SES on electrophysiological correlates of conflict and error processing in young children

5.1. Introduction

Throughout development, children's ability to flexibly adapt behavior to contextual demands gradually increases with age. Cognitive flexibility is linked to attentional control, an skill that progressively move across the toddler and preschool years from being mostly driven by stimulation to being largely self-regulated (Ruff & Rothbart, 1996). Error detection and conflict resolution are processes related to the ability to control emotions and behaviors in a goal-oriented and effortful manner, which in turn contributes to children's socio-emotional and academic adjustment (Checa, Rodriguez-Bailón, & Rueda, 2008).

Both conflict resolution and error detection are processes related to the executive attention network (EAN) in Posner's neurocognitive model of attention (Petersen & Posner, 2012). The EAN comprises the dorsal part of the anterior cingulate cortex (ACC), lateral and ventral prefrontal cortex (PFC), and basal ganglia, a circuit of regions that has been found to be activated in tasks involving conflict resolution, such as Stroop, flankers, and go/no-go tasks (Botvinick, Cohen, & Carter, 2004; Bush, Luu, & Posner, 2000; Fan, McCandliss, Fossella, Flombaum, & Posner, 2005). During preschool years, children become increasingly capable of solving conflict (Rueda, et al., 2004a), however, developmental studies indicate that EAN follows a long developmental course that extends to early adulthood (Abundis-Gutiérrez, Checa, Castellanos, & Rueda, 2014; Huizinga, Dolan, & van der Molen, 2006; Waszak, Li, & Hommel, 2010). It is thought that the protracted development of EAN is related to the relatively late maturation of the PFC and the ACC (Cunningham, Bhattacharyya, & Benes, 2002; Luna, Garver, Urban, Lazar, & Sweeney, 2004; Segalowitz & Davies, 2004).

Resolving conflict between competing responses requires voluntary control of actions. Conflict resolution implies control of automatic activation when it is not appropriate with the desired outcome (Michael I. Posner & DiGirolamo, 1998). Event-related potentials (ERPs) have been used to assess the brain mechanisms associated to conflict processing. The N2 is a conflict-modulated negative deflection that appears at medial-frontal channels between 200–400 ms post-target presentation and it is more negative in trials that entail conflict (e. g. Jonkman, Sniedt, & Kemner, 2007a; Lamm, Zelazo, & Lewis, 2006; Rueda, Posner, & Rothbart, 2005; Van Veen & Carter, 2002). There is evidence that the neural source of the N2 is the ACC (Van Veen & Carter, 2002). The N2 is elicited in tasks that activate two incompatible response tendencies at the same time and require the inhibition of the pre-potent tendency, such as the go/no-go and Stroop tasks; or the flanker task that involves conflict between congruent and incongruent stimuli. The N2 conflict effect (i.e. difference in amplitude between conflict and no-conflict conditions) has been well characterized as an index of conflict monitoring and resolution in adolescents and adults (e. g. Donkers & van Boxtel, 2004; Heil, Osman, Wiegelmann, Rolke, & Hennighausen, 2000; Yeung, Botvinick, & Cohen, 2004). However, young children do not show a clear N2 effect. Using go/no-go and Stroop tasks, the N2 have been observed in children 5-7 year-olds (Jonkman et al., 2007; Lamm et al., 2006; Lo et al., 2013), and around 9-10 years of age with the flanker task. Before this age children exhibit a later conflict effect (~500 ms) during flanker task performance (Abundis-Gutiérrez et al., 2014; Checa, Castellanos, Abundis-Gutiérrez, & Rueda, 2014; Rueda, Posner, Rothbart, & Davis-Stober, 2004).

Besides conflict resolution, the evaluation of the outcomes of ongoing behaviors is another important function of the EAN. Detection and evaluation of errors is an essential process for adjusting responses in order to achieve a specific goal. An ERP thought to reflect performance monitoring is the error-related negativity (ERN) (Falkenstein, Hoormann, Christ, & Hohnsbein, 2000). The ERN is a fronto-central negativity that appears around 100 ms after the commission of an error (Falkenstein et al., 1991; Gehring, Goss, Coles, Meyer, & Donchin, 1993). The ERN is believed to signal a mismatch between the representation of the correct response and the one finally produced, and has been linked to activation arising from the ACC (for a review see Holroyd & Yeung, 2012) (Van Veen & Carter, 2002).

Another ERP that is sensitive to the commission of errors is the error positivity (Pe). The Pe is a slow positive component peaking around 200-500 ms after incorrect responses (Falkenstein et al., 1991). The Pe exhibits a more posterior scalp distribution than the ERN and is suggested to be generated by the rostral part of the ACC (Kaiser, Barker, Haenschel, Baldeweg, & Gruzelier, 1997; Ullsperger & von Cramon, 2004; Van Veen & Carter, 2002) Falkenstein and colleagues (Falkenstein et al., 2000) have shown that the Pe is notably larger for perceived errors than for unnoticed errors, suggesting that Pe is functionally different from the ERN, and that it may reflect conscious detection of error commission (Nieuwenhuis, Ridderinkhof, Blom, Band, & Kok, 2001).

Commonly, response times are shorter for errors than for correct responses (Davies, Segalowitz, & Gavin, 2004). This pattern of faster RT in errors is thought to reflect a poor response control or impulsive responding during error commission (Pailing, Segalowitz, Dywan, & Davies, 2002). It has been shown that the impulsiveness of error responses (i.e. response time difference between correct responses and errors) decreases with age (Checa et al., 2014; Santesso & Segalowitz, 2008). Accordingly, ERP studies indicate that ERN increases with age and it is not clearly present in children until about late childhood (Checa et al., 2014; Davies et al., 2004; Ladouceur, Dahl, & Carter, 2004; Meyer, Weinberg, Klein, & Hajcak, 2012; Santesso, Segalowitz, & Schmidt, 2006). These developmental differences in error processing are associated with the continued maturation, through childhood and adolescence, of the ACC and its connections with the PFC (Davies et al., 2004).

Though developmental changes of the neural mechanisms underlying error and conflict processing have been addressed, little is known about the degree to which socioeconomic factors impact the development of these processes. A growing amount of behavioral studies have shown that children's cognitive abilities and school achievements are affected by the family socioeconomic status (SES; e. g. Bradley & Corwyn, 2002; Davidse, de Jong, Bus, Huijbregts, & Swaab, 2011; Farah et al., 2008; Lipina, Martelli, Vuelta, & Colombo, 2005; Noble, McCandliss, & Farah, 2007). Furthermore, functions of the EAN -conflict resolution, inhibition and attentional flexibility- have been found to be influenced by SES (Ardila, Rosselli, Matute, & Guajardo, 2005; Farah et al., 2006; Lipina, Martelli, Vuelta, Injoque-ricle, & Augusto, 2004; Lipina et al., 2005; Noble et al., 2007;

Sarsour et al., 2011). However, data on the impact of SES on brain networks involved in cognitive skills are more limited (see Hackman & Farah, 2009; Raizada & Kishiyama, 2010 for review).

Children ERP studies have shown SES differences in brain mechanisms associated with selective attention. Differences in the earliest stages of auditory selective attention processing were observed in 3-8 year-olds from different SES background. Children were cued to attend selectively to one of two simultaneously presented narrative stories. LSES children exhibited ERPs associated with a reduced ability to filter irrelevant information (Stevens et al., 2009). Similar results have been found using pure tones with preadolescent children. ERP data revealed that LSES children attend equally to distracters and to targets, while HSES children ignore distracters (D'Angiulli et al., 2008). Another study assessing ERPs evoked by novel distracter stimuli reported greater degree of PFC recruitment in HSES in contrast to LSES children (Kishiyama et al., 2009). In summary, the ERP literature indicates that SES has an impact in specific brain networks involved in attention. Nonetheless, as far as we know, there is not specific evidence of the impact of SES on the neural mechanisms supporting conflict and error processing.

To investigate the relationship between SES and neural mechanisms of error and conflict processing, the present study used ERPs in a group of healthy preschoolers from low (LSES) and high (HSES) SES backgrounds using a flanker task. Flanker tasks (Eriksen & Eriksen, 1974) have been widely used with children to study conflict processing in the laboratory (e. g. Rueda, et al., 2004a; Santesso & Segalowitz, 2008; Waszak et al., 2010), and provides measures of EAN efficiency. For the purpose of the current study, children performed a child-friendly flanker task while electrophysiological activity was recorded with a high-density EEG system. We aimed at separately assessing brain activation related to target and response processing with the purpose of studying brain potentials related to both conflict and error processing (Checa et al., 2014). Parental education, parental occupation and family income were used as measure of SES, as they are the most common indicators of SES used in the literature (D. A. Hackman & Farah, 2009). SES-related differences in electrophysiological activity in response to conflict resolution and errors were expected. It has been reported that young children (under 6 years of age) show not conflict-related modulation of amplitude before 500 ms. post target (Ladouceur, Dahl, & Carter, 2007; Rueda, et al., 2004b). Using a flanker task, we have found in previous studies that conflict-related modulations of ERPs in preschool children appear over mid-frontal leads after 500 ms post target presentation (Abundis-Gutiérrez et al., 2014; Checa et al., 2014), and that ERN is not present before 7 years of age (Checa et al., 2014). It has been proposed that HSES context favors higher executive function and more mature patterns of brain activity in children (D. A. Hackman & Farah, 2009). If HSES children in our sample exhibit a more mature brain activity, early conflict-related and error-related ERPs are expected in this group.

5.2. Method

5.2.1. Participants

Eighty-nine preschool children participated in our study (48 males; mean age: 63.5 months; SD: 7.2 months). They were recruited from 6 preschools located in the urban area of Granada, Spain. Parents agreed to participate and gave written consent. Prerequisites for participation were having normal or corrected-to-normal sensory capacities, no history of chronic illness and/or psychopathologies and not being under pharmacological treatment.

5.2.2. Procedure

Participants completed a child friendly flanker task while their brain activation was registered using a high-density (128-channels) EEG system (www.egi.com). Fitting the sensor-net on, checking impedances, and completing the computer task took about 40 min, including brief breaks between blocks of trials. One experimenter was present with the children in the testing room throughout the session. No feedback was provided to participants apart from encouragement to complete the task during breaks. Children received plastic coins at the end of each block according to their balance of correct trials.

At the end of the session children selected toys and school supplies in exchange for the plastic coins as a gift for their participation in the study. Sociodemographic questionnaires were filled out by parents of participants while children were evaluated. The experimental session took place at the Cognitive Neuroscience laboratory of the University of Granada.

5.2.3. Tasks and measures

5.2.3.1. Flanker task adapted to children

A child-friendly flanker task was used to assess conflict resolution, error and feedback processing (Checa, Castellanos, Abundis-Gutiérrez, & Rueda, 2014). Each trial started with a fixation cross displayed at the center of the screen for a variable duration, randomly selected between 600 to 1200 ms. A cartoon picture of a row of five robots was presented at the center of the screen either above or below the fixation cross. Participants were asked to indicate the shape of the robot in the middle (either round or square) by pressing the corresponding button. Flanking robots could be of the same (congruent) or different (incongruent) shape as that of the middle robot. Flanking robots were congruent in half of the trials, and the congruency condition was randomly selected for each trial. The response could be made during presentation of the target or up to 800 ms after target disappeared. In order to equate the difficulty of the task between participants, the duration of the target was adjusted in each trial according to the participant's performance in the previous trial. When an error was made, the response was omitted or given off time (in the 800 ms period between target disappearance and feedback presentation), the target duration was increased by 50 ms in the following trial. Alternatively, the target duration in trial n+1 was decreased by 50 ms when the response in trial n was correct. Following the response, a 600 ms-lasting feedback was provided. The feedback consisted of a visual animation of the central figure plus an auditory word ("yes" for correct response, "no" for incorrect response, and "late" for omission or off-time responses). Participants completed 144 trials divided into six experimental blocks, with small breaks between blocks. Figure 1 illustrates the structure of this task.

5.2.3.2. SES

To measure SES, we collected information of three aspects of the family SES: Parental education, Parental occupational and family income. Parents reported information of these aspects by means of a questionnaire. Parental occupation was defined according to the 9 points scale of the Spanish Occupation Classification (CNO-11) from The Spanish National Institute of Statistics (BOE, 2010). Table 5.1 shows scales used to score SES. Parents' scores of education and occupation as well as income-per-family-member ratio (i.e. total income divided by the number of family members) were transformed to z-scores and averaged into a composite index of SES for each participant.

	Parental Education	Parental Occupation	Monthly Income
1	No studies	Elementary occupations	< 750 €
2	Elementary school	Facility and machinery operators and assemblers	751-1200 €
3	Secondary school	Artisans and qualified manufacturing and construction workers (except facility and equipment operators)	1201-1600 €
4	High School	Qualified workers in agricultural, livestock, forestry and fisheries sectors	1601-2200 €
5	Technical College or University Diploma	Salesmen, restoration and security services	2201-3000 €
6	Bachelor degree	Accounting, administrative and office employees	3001-4000 €
7	Postgraduate studies	Professionals of technical support	> 4000 €
8		Technician, scientists and intellectual professionals	
9		Directors and managers	

Table 5.1. Scales used to score each of the three measures of SES

We divided our sample into Low SES (LSES) and High SES (HSES). Z-scores ranged from -2.11 to 0.01 for LSES and from 0.16 to 1.47 for HSES. Table 5.2 shows descriptive data of the three aspects of SES for each group.

	LSES n=33		**HSES n=36**		**t**	***p***	***d***
	Mean	SD	Mean	SD			
Age (months)	63.39	12.4	62.81	6.8	-0.248	0.805	0.06
Parental Education (1-7) *	3.74	1.2	5.89	0.7	9.176	0.000	1.48
Parental Occupation (1-9) *	4.06	2.6	7.15	1.0	6.338	0.000	1.23
Income-per-member *	508.59	219.4	904.61	209.4	7.612	0.000	1.36
SES index (Z-score) *	-0.64	0.6	0.57	0.3	-10.737	0.000	1.58

Table 5.2. Means, SD, t-values, p-values and d-values (effect size) of components of SES for LSES and LSES samples.

5.2.4. EEG recording and data processing

EEG was recorded using a 128-channel Geodesic Sensor Net 4.2 and processed using Net Station 4.3 software (EGI Software: www.egi.com). The EEG signal was acquired using a 100 to 0.01Hz band pass filter and digitized at 250Hz. Impedance for all channels was kept below 50KΩ. Continuous EEG data were filtered by using a finite impulse response (FIR) band pass filter with 0.3 Hz high-pass and 20 Hz low-pass cutoffs (Passband gain: 99.0% (-0.1 dB), stopband gain: 1.0% (-40.0 dB), rolloff: 0.29 Hz). Continuous data were segmented into target-locked (-200 ms to 1000 ms) and response-locked (-600 ms to 400 ms) epochs. Segmented files were scanned for artifacts with the Artifact Detection Net Station tool using a threshold of 100 μV for eye movements and 120 μV for eye blinks. Segments containing more than 20 bad channels, eye blinks or eye movements were excluded from further processing. Bad channels were rejected and replaced by interpolation form neighbors' channels. Each trial was also visually inspected to make sure the parameters of the artifact detection tool were appropriate for each

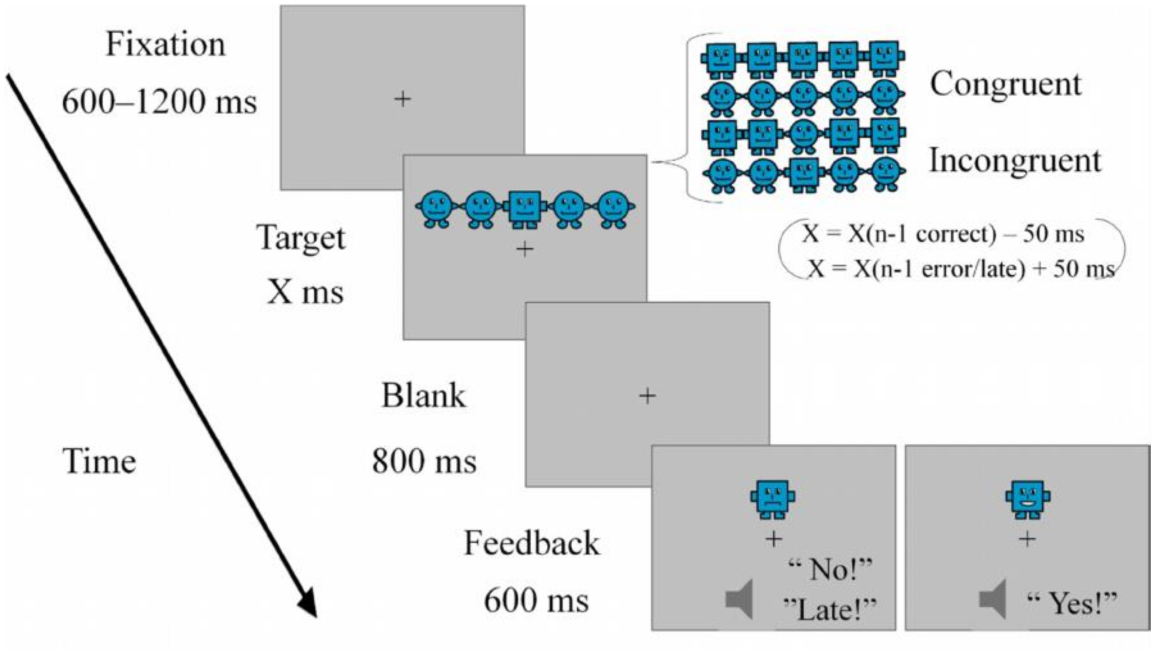


Figure 5.1. Schematic representations of the flanker task used in this study.

participant. Artifact-free segments were averaged across conditions and participants within each SES group, and re-referenced to the average of all channels. A per-subject criterion of a minimum of 12 artifact-free segments per experimental condition was established in order to be included in the grand-average for each age group. A total of 72 children reached that criterion, 33 from LSES and 36 from HSES groups.

5.3. Results

5.3.1. Behavioral results

Three participants (2 from LSES, 1 from HSES groups) were excluded for further analyses because of having a percentage of total errors higher than 2 SDs above the mean (42.2%) of the entire sample.

Two subtractions were performed to calculate conflict interference scores with both RT and percentage of errors. Conflict scores were obtained for RT (median RT of correct responses) and accuracy (percentage of commission errors) by subtracting congruent from incongruent trials. Descriptives of overall performance and conflict interference scores per SES group are presented in Table 5.3.

		LSES	**HSES**	**t**	***p***	***d***
Overall performance	RT	754 (113)	799 (137)	1.668	0.149	0.35
	Er %	17.7 (6.9)	18.9 (6.8)	1.668	0.470	0.18
	Om %	4.6 (3.1)	5.7 (4.6)	1.186	0.239	0.28
Conflict scores	RT	43.4(53.3)	39.4 (54.7)	-0.304	0.829	0.07
	Er%	**7.0 (8.2)**	**2.5 (6.7)**	**-2.480**	**0.016**	**0.58**

Table 5.3. Differences between SES groups in overall performance and Conflict-interference scores. Er% = total percentage of commission errors; Om% = total percentage of omitted responses. Bold fonts indicate significant difference between SES groups.

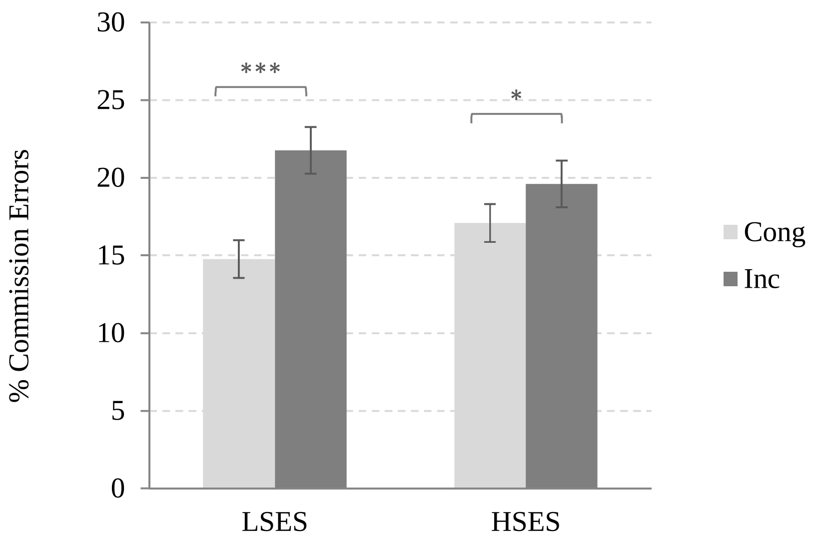


Figure 5.2. Percentage of commission errors per SES group. Cong = Congruent trials; Inc = incongruent trials.

Separate 2 (SES) x 2 (Flanker congruency) ANOVAs with median RTs and percentage of commission errors as dependent measures were performed. For RT, only main effect of flanker congruency was found ($F(1,67)=65.84$; $p<0.01$, $\eta_p^2=0.49$) revealing that RT at incongruent trials were slower than RT at congruent trials. Planned contrasts indicated that the conflict effect (difference in RT between congruent and incongruent trials) was significant for both LSES ($F(1,67)=29.88$; $p<0.01$) and HSES ($F(1,67)=36.28$; $p<0.01$). Regarding the percentage of commission errors, we found a significant main effect of flanker congruency ($F(1,67)=50.71$; $p<0.01$, $\eta_p^2=0.43$), indicating smaller percentage of errors in congruent compared to incongruent trials. The SES x flanker congruency interaction was also significant ($F(1,67)=5.36$; $p<0.05$, $\eta_p^2=0.07$) indicating differences in conflict effect between SES groups: children from the LSES group showed larger conflict effect (see Fig. 5.2).

5.3.2. ERPs Results

Table 5.4 shows amplitude values per condition and SES group in the ERP components of interest.

5.3.2.1. Target-locked ERPs

Figure 5.3 presents averaged ERPs for congruent and incongruent trials. Topographic maps show the distribution of conflict effect (significant difference between congruent and incongruent conditions), as obtained from t-test (t = 2.042). Both SES groups showed negative deflection in central frontal leads around 400 ms post-target (N2) as well as later ERP Flanker congruency modulation after 500 ms post-target. According to topographic maps, conflict effect appeared also in the right and left regions next to midline. Average of Fc (Fc3, Fcz, Fc4), C (C3, Cz, C4), and Cp (Cp3, Cpz, Cp4) locations was

		N2		N450			ERN		Pe	
		Fc	C	C	Cp		Fcz	Cz	Fcz	Cz
LSES	Cong	-8.3 (3.9)	-7.0 (3.4)	2.7 (2.3)	4.5 (2.3)	Co	3.0 (4.2)	4.7 (3.0)	8.7 (4.7)	8.1 (3.8)
	Inc	-7.9 (3.9)	-6.9 (4.1)	1.8 (2.7)	3.2 (2.5)	Er	1.5 (5.2)	3.4 (5.4)	11.8 (5.7)	11.7 (5.3)
HSES	Cong	-6.5 (3.3)	-5.8 (3.3)	4.3 (3.6)	5.4 (3.0)	Co	4.0 (4.8)	6.3 (4.7)	9.1 (4.7)	9.5 (5.5)
	Inc	-7.4 (3.8)	-6.9 (3.4)	2.5 (3.3)	3.8 (2.8)	Er	1.7 (4.1)	4.5 (4.8)	11.0 (5.1)	12.4 (5.8)

Table 5.4. Means (SD) of peak and mean (late effect) amplitudes per ERP component and SES group. Cong = congruent; Inc = incongruent; Co = correct response; Er = error; Fc = average of channels F3, Fz, F4; C = average of channels C3, Cz, C4; Cp = average of channels Cp3, Cpz, Cp4. The time windows considered were: N2 = minimum amplitude within 300-500 ms post-target; N450 = mean amplitude within 500-700 ms post-target; ERN = minimum amplitude within 0 – 100 ms post-response; Pe = maximum amplitude within 130 – 280 ms post-response.

calculated to include left and right channels closer to the one located at the midline. Channels at Fc and C locations were used to analyze the N2 component, whereas the N450 was analyzed at channels C and Cp, given its more posterior distribution. A 2(SES) x 2 (Flanker congruency) x 2 (Fc & C Electrodes location) ANOVA was run using the minimum peak amplitude within a time window of 300-500 ms post-target. A main effect of Location was found ($F(1,60)=13.53$; $p<0.01$, $\eta p^2=0.18$) indicating more negative amplitudes in Fc. Flanker congruency x SES interaction was also observed ($F(1,60)=4.92$; $p<0.05$, $\eta p^2=0.08$). Planned comparison reveled that conflict effect was significant in both Fc ($F(1,60)=4.22$; $p<0.05$) and C ($F(1,60)=6.41$; $p<0.05$) locations for HSES, while no effect was observed in LSES group ($F>1$). ERP modulation by Flanker congruency was also exhibited after 500 ms post-target in more posterior areas. Mean amplitude within 500-

700 ms post-target was entered in a 2 (SES) x 2 (Flanker congruency) x 2 (C & Cp Electrodes location) ANOVA. Main effects of Flanker congruency ($F(1,60)=27.33$; $p<0.01$, $\eta p^2=0.31$) and Location ($F(1,60)=42.38$; $p<0.01$, $\eta p^2=0.41$) were obtained, indicating that amplitudes were more negative for incongruent condition and C location. No SES x Flanker congruency interaction was found. Planned comparison indicated that conflict

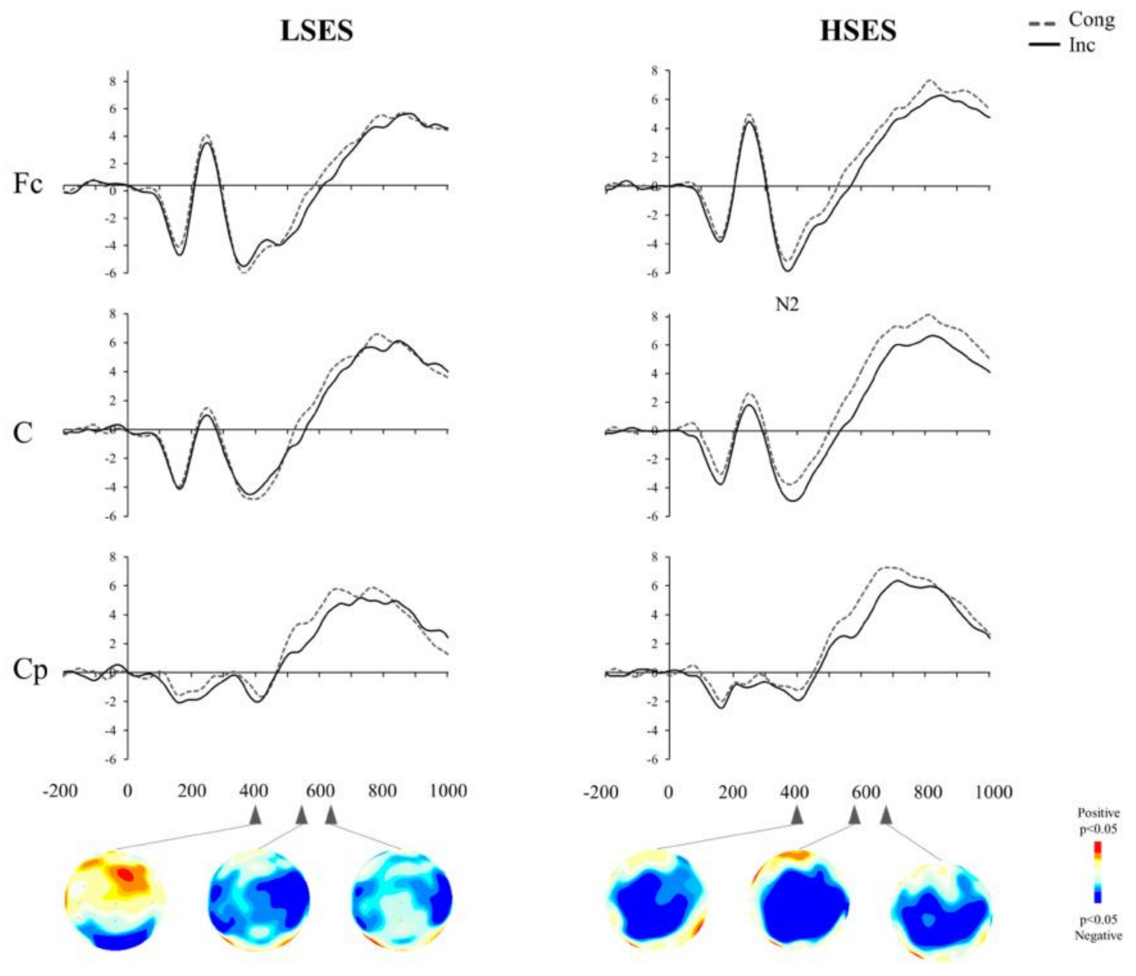


Figure 5.3. Target-locked ERPs for SES groups. Topography shows scalp distribution of significant difference (t = 2.042) between congruent and incongruent conditions at a particular time (indicated by arrows). Waves are the average of left, center and right channels: Fc = Fc4, Fcz, Fc3; C = C3, Cz, C4; Cp = Cp3, Cpz, Cp4.

effect was significant for both LSES ($F(1,60)=4.57$; $p<0.05$ and $F(1,60)=10.69$; $p<0.01$ for C and Cp respectively) and HSES ($F(1,60)= 19.40$; $p<0.05$ and $F(1,60)=18.50$; $p<0.01$ for C and Cp respectively) in both C and Cp Locations. Topographic maps show the distribution of the N450 effect in both SES groups (See Fig. 5.3). Topographic maps illustrate the distribution of significant incongruent – congruent differences in time points related to N2 (400 ms) and N450 effect (around 600 ms; see Fig. 5.3).

5.3.2.2. Response-locked ERPs

Figure 5.4 shows averaged ERPs for correct and error responses and topographic distribution of significant differences in each SES group. We used residualized values of ERN obtained from linear regression analyses to partial out the variability of ERN due to the preceding positive peak (see Santeso & Segalowitz, 2008; Santeso, Segalowitz & Schmidt, 2005). Peak amplitude of positive peak before response (-100 to 0 ms pre-response) was entered as predictor of the ERN (0 – 100 ms post-response) and residual values were used in further analyses. Residual values thus provide a measure of ERN amplitude that is independent of the preceding positive peak. Results form 2 (SES) x 2 (Response type) x 2 (Fcz & Cz Electrodes location) ANOVA reveled main effect of both Response type ($F(1,60)=8.90$; $p<0.05$, $\eta p^2=0.13$) and Electrode Location ($F(1,60)=31.02$; $p<0.01$, $\eta p^2=0.34$), indicating that peak amplitude was more negative for errors than correct responses, as well as more negative amplitudes in Fcz with to respect to Cz. No interactions were observed. Planned comparisons showed that the difference in residual value between error and correct responses was significant in both Fcz and Cz Locations for the HSES group ($F(1,60)=6.87$; $p<0.05$, and $F(1,60)=4.37$; $p<0.05$ for Fcz and Cz respectively) but not in LSES group ($F(1,60)=2.77$; $p<0.01$, and $F(1,60)=2.25$; $p<0.01$ for Fcz and Cz respectively). Furthermore, both SES groups showed the Pe component. This ERP was analyzed using peak amplitudes within a time window of 130 – 280 ms post-response in a 2 (SES) x 2 (Response type) x 2 (Fcz & Cz Electrodes location) ANOVA. We found a significant main effect of Response type ($F(1,60)=23.57$; $p<0.01$, $\eta p^2=0.28$)

indicating a more positive amplitude for errors than for correct responses. The Response type x Electrode Location interaction was marginal ($F(1,60)=3.10$; $p=08$, $\eta p^2=0.05$), showing a tendency to larger Pe effects at the Cz location. Planned comparisons revealed that both SES groups showed a significant difference between ERP for correct and error responses at Fcz and Cz locations (LSES: $F(1,60)=12.79$; $p>0.01$, and $F(1,60)=15.32$; $p>0.01$; HSES: $F(1,60)=4.97$; $p<0.5$, and $F(1,60)=9.47$; $p<0.01$, for Fcz and Cz respectively).

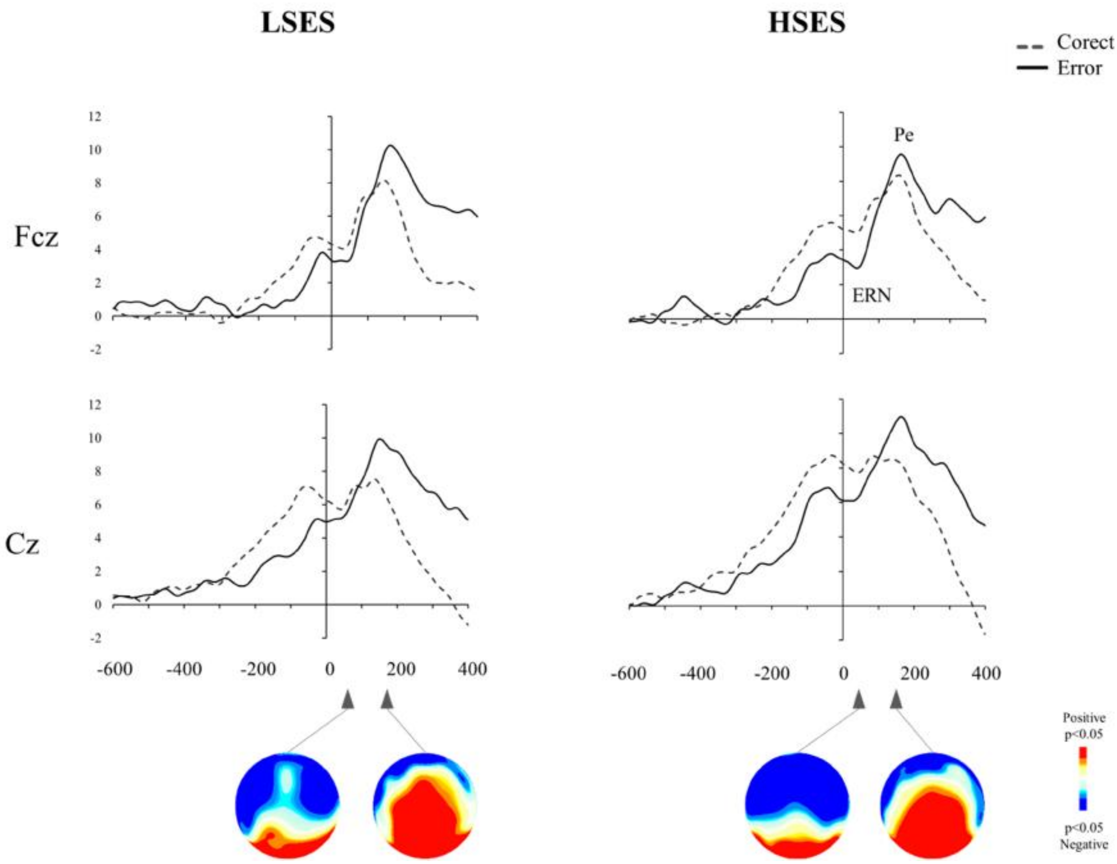


Figure 5.4. Response-locked ERPs for SES groups at frontal midline. Topography shows scalp distribution of significant difference between correct and incorrect responses at 40 ms and 150 ms post response (indicated by arrows).

5.4. Discussion

Our results show that disparities in SES impact children's EAN efficiency. The main goal of this study was to examine differences in neural activation related to conflict and error processing in preschoolers with different SES backgrounds by means of event-related potentials (ERPs) using a flanker task. Several ERP components were used as markers of conflict processing (N2 & N450) and response evaluation (ERN & Pe). At the behavioral level, our results replicate differences in executive control between LSES and HSES children (Hackman & Farah, 2009; Lipina & Posner, 2012). Our electrophysiological results provide data on the neural mechanisms underlying this difference in efficiency of the EAN. HSES children showed ERP related to faster engagement of EAN on conflict and error processing compared to LSES children.

5.4.1. Behavioral findings

Behavioral results showed similar overall performance in our sample regardless of SES background. We believe that, due to the urge for fast responses in order to successfully perform the task, participants from different SES had similar RT and errors rate. Moreover, the task was designed as to adjust target duration to response times and accuracy in an individual basis, making sure that the overall difficulty was equated across participants. However, we found that SES groups differed in conflict scores as calculated with errors of comission. LSES children showed a larger difference between congruent and incongruent trial errors. Thus, despite the similar overall performance, LSES were less accurate in solving conflict. This suggested that LSES children were more susceptible to flanker interference when solving conflict in order to give a correct response. This result is consistent with previous data from other studies that suggested that the executive control is one of the primary neurocognitive systems associated with differences in SES (Farah et al., 2006; SJ Lipina et al., 2005; Sebastián J Lipina & Posner, 2012; K G Noble et al., 2006; K G Noble, Norman, & Farah, 2005). For example, Lipina et al. (2005) found that LSES infants committed more errors associated with impairments of inhibitory control; Mezzacappa (2004) reported differences in EAN related to SES using a flanker task; and Noble et al. (2005) found that HSES preschoolers performed better than LSES on a neuropsychology test of executive system. Brain electrical recordings in the current study help to understand the neural mechanisms underlying the differences between groups observed in task performance.

5.4.2. ERP findings

5.4.2.1. Conflict processing

In order to assess the neural basis of conflict processing in different SES backgrounds, we analyzed conflict-related modulation in amplitude of the N2 and N450 components. In the present study, only HSES children showed significant difference between congruent and incongruent conditions at the N2 peak (N2 effect). As reveled by *t*-test, conflict effect in HSES group had a central distribution and was sustained from 370 – 450~ ms post target. In contrast, LSES children did not present N2 effect. It has been proved that the N2 is very sensitive to the degree of response conflict and to the control adjustments needed in order to produce the appropriate response (Forster, Carter, Cohen, & Cho, 2011). Conflict modulation of the N2 in children depends greatly on the task been used. For instance, the N2 have been observed as early as 35 month-olds using Dimensional Change Card Sort (DCCS) (Espinet et al., 2012), and from 5 years using Go/No-go task (Lo et al., 2013; Spronk, Jonkman, & Kemner, 2008). Nonetheless, several studies have found that when using the flanker task, the N2 is not shown until later in development. For example, in one study using a fish version of the flanker task, no N2 conflict effect was found for 4-5 year-olds children, and it was observed only after 6 years of age (Buss et al., 2011). Additionally, Brydges et al (Brydges, Fox, Reid, & Anderson, 2014) found that not all children from a 7 to 9 years of age group presented the N2, and results of a study by Ladouceur and cols (2007) with arrows reveled that early adolescents did not show N2 effect in contrast to late adolescents and adults. In consonance with this, in previous studies, we did not find an N2 effect in 4-9 year-olds (Abundis-Gutiérrez et al., 2014; Checa et al., 2014). This delay of appearance of the N2 effect during early childhood has been related to the immaturity of ACC during development (Ladouceur et al., 2007). Showing the N2 effect during childhood has been interpreted as an indicator of EAN efficiency, reflecting faster engagement of the brain circuit underlying response monitoring and conflict processing. In the other hand, conflict modulation in brain activity at preschool age is commonly observed from 500 ms~ after target presentation while performing a child-friendly flanker task (Abundis-Gutiérrez et al., 2014; Checa et al., 2014; Rueda, et al., 2004b). This difference appears in the form of a slow potential over central areas. It has been suggested that the relative long duration of this effect may reflect the time course of brain mechanism supporting conflict resolution in young children (Rueda, et al., 2004b). In our data we observed that the LSES group presented this late conflict modulation pattern. Due to immaturity of the EAN during the preschool period, the N2 effect is not expected at these years. However, our data showed that HSES children exhibited N2 effect, suggesting a more mature pattern of brain activation, and hence a more efficient processing of conflict, which was reflected in better accuracy in conflict resolution at the behavioral level. This suggests that the difference shown by LSES and HSES children is mostly due to a boost in maturation produced by the enriched environment found in HSES families. In summary, the difference in conflict processing related to SES was observed in early stages of conflict processing. The appearance of the N2 effect during development reflects earlier recruitment of EAN in order to process conflict.

5.4.2.2. Error processing

Regarding neural processing of errors, our data revealed significant differences between SES groups on the ERN. HSES group showed the ERN in central midline channels, while the effect was less clear in LSES children. Prior data from developmental research suggest that the ERN is a late maturing component that emerges around middle childhood (Checa et al., 2014; Davies et al., 2004; Ladouceur et al., 2007; Santesso et al., 2006; Segalowitz & Davies, 2004). The common finding is that ERN is fully defined after early adolescence (Checa et al., 2014; Davies et al., 2004; Ladouceur et al., 2007; Segalowitz & Davies, 2004). Activation causing the ERN has been consistently localized at the dorsal portion of the ACC (Falkenstein et al., 1991; Van Veen & Carter, 2002; Yeung et al., 2004). Therefore, due to late maturation of the ACC it is expected to find absence of ERN during preschool years. In a recent developmental study carried out with exactly the same task as was used in the current study and children of three age groups (4-7, 7-10, and 10-13 year olds, besides a group of adults), the ERN was not observed for the youngest group (Checa et al., 2014). However, the ERN shown by 7-10 year olds is strikingly similar to the effects shown by the HSES children in the current study (see Fig. 4 at Checa et al., 2014, and Fig. 5.4 in the current paper). Therefore, our data show that HSES children show an ERP pattern associated with a more mature neural response to errors.

The ERN is thought to reflect activity of a response-monitoring system that signals a mismatch between the actual response and the intended response (Falkenstein et al., 1991; Yeung et al., 2004). Both behavioral and electrophysiological data suggested that HSES children deal more efficiently with conflict and errors, since they appeared to show more mature neural signaling to the commission of an error as well as earlier neural response to conflict.

Additionally, both SES groups showed the Pe component and no differences were observed between groups. The Pe reflects additional error processing related to subjective/emotional error evaluation (Falkenstein et al., 2000). It has been suggested that the presence of Pe and absence of the ERN observed in young children is due to different neural sources of these components (Davies et al., 2004): while ERN is generated in dorsal ACC, Pe has its source in the ventral ACC (Van Veen & Carter, 2002). Hence, it seems that the emotional evaluation of errors has an earlier developmental trajectory and thus is less subject to environmental factors at this age.

5.4.3. SES and differences in brain activation

We found ERP differences between SES groups and behavioral differences related to efficiency of EAN. Topography and waveform ERPs suggested that children from HSES exhibited a more mature pattern of brain activation when facing conflict and error processing. Other studies have also found impact of SES on ERP indexes. For example, using a selective attention task, ERP differences between SES groups suggested that LSES children showed greater difficulty to suppress distractors (D'Angiulli et al., 2012, 2008; Stevens et al., 2009). Also differences in theta band (4 to 7 Hz) has been associated with differences in cognitive control between LSES and HSES adolescences (D'Angiulli et al., 2012). In general, ERP data suggest that disparities in SES are related to differences in recruitment of neural resources during cognitive processing, even when behavioral differences are not found (D. A. Hackman & Farah, 2009). Or data, also suggest a difference between LSES and HSES children in the speed with which neural circuits are recruited. Moreover, interpreting our data in the context of the developmental literature, LSES children appear to show a typical ERP pattern for their age, while HSES children exhibit a pattern similar to what is observed in older children. Because of the high association between the N2 and ERN with ACC and PFC, our findings suggest that higher education and financial resources boost maturation of executive attention system.

Further research is needed in order to understand the impact of SES on neural mechanisms supporting cognitive process throughout development. To our knowledge, most of the ERP studies assessing neural differences related to SES have been done with school age children and adolescents. Hence, there is no evidence of the impact of SES on brain functioning neither during preschool years, nor about the evolution of such impact on cognition as children develop. It is also important to bear in mind that the nature of the results in the literature on SES and cognitive development are greatly determined by the social context in which the study is carried out. Considerations of LSES may vary considerably from one social context to another.

Chapter 6.

Influence of temperament and home environment variables on high cognitive skills during the preschool period.

6.1. Introduction

The early development of executive functions (EF) plays an important role in socio-emotional and academic adjustment during childhood and beyond (Rueda, Checa, & Rothbart, 2010). EF refers to a set of processes involved in the regulation of thoughts, feelings and responses in a goal-directed and effortful manner (Best & Miller, 2010; Diamond, 2013). Working memory (WM), attentional flexibility and inhibitory control are the core processes within the EF concept. During preschool years important components of EF develop, laying the foundations for the development of higher cognitive processes well into adulthood (Garon et al., 2008; Jones, Rothbart, & Posner, 2003).

Using an extensive sample of EF tasks and participants between 2 and 6 years of age, Carlson (2005) found age-related changes in 11 EF tasks out of a total of 13. Her data showed a significant improvement in EF from age 3 to 4, as well as from age 4 to 5, suggesting that during preschool period important age-related improvement happen in relatively short time. On the other hand, gender has also been related to individual differences in EF. Several studies have found that girls tend to outperform boys in tasks of EF (Else-Quest, Hyde, Goldsmith, & Van Hulle, 2006; Naglieri & Rojahn, 2001).

Besides age and gender, it is also known that temperament is associated with children's differences in EF (e. g. Fox, Henderson, Marshall, Nichols, & Ghera, 2005; Henderson & Wachs, 2007; Posner & Rothbart, 2007; Rueda et al., 2005). Temperament refers to individual differences in reactivity and self-regulation (Rothbart & Derryberry, 1981). Reactivity denotes positive/approaching and negative/avoiding characteristics; while self-regulation refers to the processes that modulate reactivity, through facilitation or inhibition (Rothbart, 1989). Rothbart and colleagues (Rothbart, Ahadi, Hershey, & Fisher, 2001) have proposed a structure of temperament based on three factors: effortful control (EC), negative affectivity (NA), and extraversion/surgency (E/S). EC is the core of self-regulation; it is defined as the child´s ability to use attentional resources and to inhibit behavioral responses in order to regulate emotions and behaviors. NA refers to the rate of recovery from intense arousal, and the expression of frustration, fear, discomfort and sadness. Finally, E/S describes risk taking and pleasure seeking behaviors (Rothbart, 2007). The cognitive control processes included within the concept of EC (inhibition, response modulation and monitoring) are also conceived within the notion of EF (Michael I Posner & Rothbart, 2009; Rueda et al., 2005). This conceptual overlapping between EC and EF explains that great part of the literature relating EF and temperament is focus on EC. Numerous studies have consistently shown a positive correlation between EF and EC (Barkley, 2001; Bridgett, Oddi, Laake, Murdock, & Bachmann, 2013; Carlson & Wang, 2007; Murdock, Oddi, & Bridgett, 2013; Posner & Rothbart, 2009). However, the study of reactivity also provides a framework for studying individual differences in EF during development (Henderson & Wachs, 2007). For instance, impulsivity, which is related to E/S, has been associated with poor cognitive performance in inhibition tasks (Bari & Robbins, 2013; Davidson et al., 2006; Spronk et al., 2008). Moreover, longitudinal data have shown that fear reactivity is also related to poor performance on EF tasks in early childhood (Hill-Soderlund & Braungart-Rieker, 2008).

Thereby, age, gender and temperament are inherent characteristics to children that influence individual differences in EF during development. However, children characteristics appear to be also affected, to a large extent, by the environment in which the child develops. The socio-economic status (SES) of the family is believed to exert some influence on brain development during childhood. A broad body of studies have reported association between differences in SES and language (e. g. Fish & Pinkerman, 2003; Jednoróg et al., 2012; Noble, McCandliss, & Farah, 2007; Noble, et al., 2005; Raizada, Richards, Meltzoff, & Kuhl, 2008), intelligence quotient (IQ) (Capron & Duyme, 1989; Fitzpatrick, McKinnon, Blair, & Willoughby, 2014; Kishiyama et al., 2009; Vernon-Feagans et al., 2008), WM (Lipina et al., 2013; Stevens, Lauinger, & Neville, 2009), inhibitory control (Lipina, Martelli, Vuelta, & Colombo, 2005) and attentional flexibility (Bernier, Carlson, Deschênes, & Matte-Gagné, 2012; Clearfield & Niman 2012; Hackman et al., 2010; Sarsour et al., 2011). These data indicate that low SES (LSES) children tend to lag behind their high SES (HSES) peers in tasks of EF, as well as in school achievement

(Hackman, Farah, & Meaney, 2010; Lipina & Posner, 2012; Mezzacappa, 2004; Noble, Norman, & Farah, 2005).

Although SES is a complex concept, it is usually taken as a measure of individuals' overall status and position in society (Hackman et al., 2010). The most widely used measures of family SES are parental education, parental occupation and family income. These three aspects are frequently taken in the literature as indicators of the material and psychological environment in which children grow up. It is assumed that, compared to LSES, high SES (HSES) families have increased access to good nutrition, health care, structural resources (e.g. good housing), stimulating cognitive materials and experiences, as well as parental actions and social connections that create a supportive environment that benefit the child development (Bradley & Corwyn, 2002).

Parenting is another factor reported to be related to EF during development. Positive parenting has been suggested to be of great benefit for the cognitive and psychosocial development of the child (Whittle et al., in press; Woolley & Grogan-Kaylor, 2006). For example, Eshel and colleagues (Eshel, Daelmans, de Mello, & Martines, 2006) reported that responsive parenting (adequate interpretation of child's behavior and actions to meet the child's needs) is positively associated with language, cognitive and psychosocial development. In line with this, Bernier and cols. showed, in a longitudinal study, that parenting contributed to differences in EF after controlling for their child cognitive functioning and maternal education (Bernier, Carlson, & Whipple, 2010). Likewise, Whittle and cols. (Whittle et al., 2014) found that warm and supportive parenting was associated to more optimal pattern of brain development in areas related to EF during early adolescence.

Although there is a great bulk of evidence showing that both child characteristics and family factors influence individual differences in EF, very few studies have examined those factors together in the same sample. Due to the importance of both child characteristics and environment in the study of EF, this research aimed to examine the impact of environment variables on EF during preschool age after controlling for children's age, gender and temperament. We expected to find an impact of environmental factors on EF over and above child's characteristics. It was also expected that child characteristics also predict differences in cognitive performance. We intended to examine to what extent SES (as the composite of parental education, occupation and income) is a strong predictor of EF after controlling for children characteristics. We hypothesized that environmental variables and child characteristics influence EF processes at different magnitudes. We also were interested in assessing the predictive power of SES on EF when other environmental variables are included in the model. Much of the researches assessing this topic do not include other environmental variables (besides education occupation and income) that are likely affecting behavioral outcomes. Some authors that have suggested that, even when the classic measures of SES are methodologically correct, they could exclude other perspectives that allow for a more complete view of disparities in SES (Bradley & Corwyn, 2002; Lipina, Simonds, & Segretin, 2011). In the current study, we intended to incorporate other measures that are potential indicators of the richness or poorness of the social and cognitive stimulation in the context of family environment, such as activities children possibly do with their parents and other children, as well as parenting style. Furthermore, it is likely that both temperament and environment affect each other in their association with EF. To better understand the relations between EF, environment and temperament we also examined the interactions between environment and temperament and its contribution to differences in EF.

6.2. Method

6.2.1. Participants

One hundred and seven children (58 males; mean age: 60.1 months; SD: 7.3 months) participated in our study. They were recruited from different preschools located in the urban area of Granada, Spain. Parents agreed to participate and gave written consent. Prerequisites for participation were having normal or corrected-to-normal sensory capacities, no history of chronic illness and/or psychopathologies and not being under pharmacological treatment.

6.2.2. Procedures

Each participant completed a battery of six tasks aimed at examining cognitive and emotional control in two evaluation sessions. Both sessions were conducted individually. During the first session, carried out in a quiet room at the school, all participants completed a set of pen and paper tasks including: WM number span, K-BIT, delay of gratification, and a child version of the gambling task. The second session took place at the Cognitive Neuroscience laboratory of the University of Granada, where children performed a computer based Go/No-go (GNG) task and a child-friendly version of the flanker task. At arrival, participants were informed of the general procedure of the session and were given a few minutes to get comfortable in the lab setting before starting. The second session lasted approximately 1 hour, including time for instructions and breaks between blocks of trials. Children received stickers between blocks of trials as incentives to stay motivated and complete the tasks. One experimenter was present in the testing room throughout the session with the children, but did not provide feedback to participants apart from encouragement to complete the task during breaks. Toys or school supplies were offered to participants as a gift at the end of the session in appreciation for their participation in the study. Parents filled out a temperament and socio-demographic questionnaire during the second session while children were evaluated.

6.2.3. Tasks and Measures

***6.2.3.1. Working Memory Span Subtest of the* WISC (Wechsler, 1991).**

Children are instructed to listen and repeat series of digits in the same (Forward) or reverse (Backward) order of presentation. The task includes a total of 8 experimental blocks with two trials (series of numbers) each. The amount of numbers gradually increases in each block up to 9-digit-long series. Two practice trials using two-digit long series were administrated for the forward condition. For the backwards condition, practice trials included two and three-digit long series. The task terminated once the child committed two consecutive errors within the same block. The number of correct trials (series of digits correctly remembered) was registered for each condition and used as dependent variable (DV).

6.2.3.2. Kaufman Brief Intelligence Test **(K-BIT; Kaufman & Kaufman, 1990).**

This test provides scores for two intelligence subscales: Fluid reasoning (Matrices) and Crystallized (Verbal) IQ, as well as a composite intelligence IQ score. Direct scores for each subscale were standardized and used as DV.

6.2.3.3. Delay of Gratification **(***DoG)*

The DoG task administered in this study was a modified version of the task designed by Thompson and colleagues (Thompson, Barresi, & Moore, 1997). Children were instructed to choose between getting one prize immediately or waiting until the end of the task in order to (a) get two prizes instead of one or (b) get one prize for themselves and let the experimenter get one prize too. Three scores were calculated in this task to measure the self-regulation response: percentage of delay choices for oneself, percentage of delay choices for other, and percentage of total delay responses.

6.2.3.4. Children Gambling Task

A modified version of the Iowa Gambling Task designed by Kerr and Zelazo (2004) was used in this study. In this task, children were presented with two decks of 50 cards and instructed to pick one card at a time from any of the two decks in order to win candies. The number of smiling and sad faces printed on the cards indicated the amount of candies that the child would win or lose, respectively. The two decks varied in the win-to-loss ratio. The advantageous deck provided a reward of one or two candies and a losing amount of zero, one or two. The disadvantageous deck provided a higher reward (four or six candies) but the probability to lose was also higher (2, 4, 6, 7 or 8) candies per card. Four practice trials (two for each deck) were provided to convey the instructions. A total of 50 experimental trials were administrated after the child had understood the instructions.

6.2.3.5. Go/No-Go Task

Participants were asked to press a button every time a traffic light presented in the middle of the screen was of green color as fast as possible, but hold the response when the light was red. Trials consisted of a 500 ms fixation cross, followed by presentation of the stimulus, followed by a 500 ms inter-trial. Target presentation was terminated once the response was made or after 1000 ms. Go trials were the 75% of 160 total trials, divided in two blocks.

6.2.3.6. Flanker Task

We designed a child-friendly flanker task. A cartoon picture with a row of five robots was presented at the center of the screen either above or below the fixation point. Participants were asked to indicate the shape of the robot in the middle (either round or square) by pressing the corresponding key. Flanking robots could be of the same (congruent) or different (incongruent) shape as that of the middle robot. Flanking robots were congruent in half of the trials, and the congruency condition was randomly selected for each trial. The response could be made during presentation of the target or up to 800 ms after it disappeared. In order to adjust the difficulty of the task to the participant's performance level, the duration of the target was adjusted in each trial according to the participant's performance in the previous trial. Following the response, a 600 ms-lasting feedback was provided. The feedback consisted of a visual animation of the central figure plus an auditory word ("yes" for correct response, "no" for incorrect response, and "late" for omission or off-time responses). Participants completed 144 trials divided into six blocks with small breaks between them.

6.2.3.7. Parenting style (Bauermeister, Salas & Matos, 1995)

In this 37 items scale parents reported frequency of situations within their relationship with their children. Scale goes from 0 (never or rarely), 1 (sometimes), 2 (frequently), and 3 (very often). Items are divided into two categories: 22 items for acceptation-sensibility (approbation, affection, dialog) and 15 items for coerced style (inconsistency, control based on coercion, love withdrawal). The index for parenting was the subtraction of average of coerced items from the average of acceptation-sensibility items. Hence, greater index in this task indicate a more assertive parenting style.

6.2.3.1. SES

To measure SES, we collected information of three aspects of the family: 1) parental education; 2) parental occupation, and 3) family income. Parent reported information of these aspects by means of a questionnaire. Parental occupation was defined according to the 9 points scale of the Spanish Occupation Classification (CNO-11) from The Spanish National Institute of Statistics (BOE, 2010). Table 6.1 shows the scales used to score SES. Parents' scores of education and occupation as well as income-per-family-member ratio (i.e. total income divided by the number of family members) were transformed to z-scores and averaged into a composite index of SES for each participant.

	Parental Education	Parental Occupation	Monthly Income
1	No studies	Elementary occupations	< 750 €
2	Elementary school	Facility and machinery operators and assemblers	751-1200 €
3	Secondary school	Artisans and qualified manufacturing and construction workers (except facility and equipment operators)	1201-1600 €
4	High School	Qualified workers in agricultural, livestock, forestry and fisheries sectors	1601-2200 €
5	Technical College or University Diploma	Salesmen, restoration and security services	2201-3000 €
6	Bachelor degree	Accounting, administrative and office employees	3001-4000 €
7	Postgraduate studies	Professionals of technical support	> 4000 €
8		Technician, scientists and intellectual professionals	
9		Directors and managers	

Table 6.1. Items and scale used to score SES.

6.2.3.9. Family environment

We were also interested in collecting data from environmental factors that may influence children's development beside the traditional SES measures (education, occupation and income). For this purpose we designed a questionnaire including demographic information of the family, time the child spent with adults, didactic resources, educational and entertainment activities and type of games. Table 6.2 depicts the scales and items considered in each of these aspects.

Family demography	Daily time with adults	Didactic resources	Activities	Game type
	1 = less 6 hrs. 2 = 2-4 hrs. 3 = 4-6 hrs. 4 = more 6 hrs.	1 = yes 2 = no	0 = never 1= < 1 per month 2 = 1-2 per month 3 = 1 per week 4 = >1 per week	0 = NA 1 = > 1 hr. day 2 = 1-2 hrs. day 3 = 2-3 hrs. day 4 = >3 hrs. day
Presence of both parents	daily time with mother	Books	Extracurricular	Videogames or computer based
Income-provider members	daily time with father	Computer	Book reading to child	Playing with other children
Number of children	daily time with grandparents	Internet	Art and culture (galleries, expositions)	Playing alone (other than computer-based)
Number of siblings	daily time with take giver	Studio	Entertainment (circus, theater, concerts)	TV
Position of the participant in the family				

Table 6.2. Scale and items used to obtain children´s environment variables.

6.2.3.10. Temperament

We used the parent-report short version of the Children Behavioral Questionnaire (CBQ) (Putnam & Rothbart, 2006). The CBQ consist of a number of questions about children's reactions in daily life situations that can be grouped onto three main factors: Effortful control (EC), Extraversion/Surgency (E/S), and Negative Affect (NA).

6.2.4. Data analysis strategies

In order to explore how child's characteristics and environment predict EF in our sample, we carried out the following analyses: 1) Principal component analysis (PCA) to ensure that the items included in our questionnaire grouped as we intended, and to reduce the set of data obtained from our questionnaire; 2) correlation analysis to observed the relation between children characteristics, environment and EF; 3) hierarchical regression analyses to obtain an estimate of the unique variance in behavioral outcomes accounted for environment variables after variance accounted by child's characteristics was considered; and 4) modulation analyses to explore the role of interactions among our variables in the relationship between environment, temperament and EF.

From the six tasks used in the current study a total of nine measures were selected for analyses:

1. Working Memory index (WM) as the total of correct trials on forward modality. We found small variability on backward condition in our sample. It appears that backward fashion is of a high level of difficulty task for preschoolers;
2. Verbal IQ (vIQ) and fluid IQ (fIQ) indexes as obtained from the subscales of vocabulary (crystallized intelligence) and matrices (fluid reasoning) from K-BIT test;
3. Flanker interference: average of z-scores of conflict-interference score for RT and commission errors at flanker task. Score was obtained by the subtraction of congruent trials from incongruent trials, for both RT and errors. This index reflect the distance in RT and errors, between congruent and incongruent trials, hence, the smaller the index the better the performance.
4. Inhibitory control: percentage of No-go errors in GNG task;
5. Slow after error (SAE) from GNG task. SAE was calculated by subtracting the mean RT for correct Go trials preceded by correct response from the mean RT for

correct Go trials preceded by error trials. SAE was taken in this study as an indicator of response-based behavioral regulation.

6. Response time: mean RT to Go trials.
7. 4 consecutive advantage cards (ADV): number of trial at which 4 cards from the advantageous deck were chosen consecutively for the first time during gambling task. The first 10 choices were not accounted for this measure. We took this measure as indicator of a reward-based behavioral regulation.
8. Self-based DoG: percentage of self-delayed gratification trials. This measure was also taken as reward-based regulation indicator.

6.3. Results

6.3.1. Participants

Eighteen participants were excluded due to incomplete SES information, leaving us with a final sample of 89 children (48 males; mean age 63.53 months; SD: 7.2). None of the participants in the final sample fell more than two standard deviations on either side of the mean on all measures included. Scores were converted to z-scores relative to the entire distribution of 89 children.

6.3.2. Data Reduction

Due to a high range of missing for "daily time spent with grandparents" and "daily time spent with caregivers" these variables were excluded for further analysis. The variables "position of child in the family", "presence of both parents", "income-provider members" and "didactic resources" were also eliminated due to lack of variability along our sample. In addition, we found that "number of siblings" and "total of children in the family" gave similar information, thus we decided to only use "total of children in the family" in the subsequent analyses.

Parenting style, total of family members, number of siblings, income-per-family member, maternal and paternal education, maternal and paternal occupation, daily time with mother and father, monthly frequency of book reading, cultural, entertainment and extracurricular activities, daily hours of TV, videogames, playing alone and playing with other children, were submitted to a principal component analysis (PCA). Daily time with mother and father, and hours of playing videogames, of playing alone and playing with other children were excluded from PCA analyses due to high loading in more than one component or single variable component result. A relatively high Kaiser-Meyer-Olkin measure of sampling adequacy (KMO = 0.7) confirmed the validity of using a factor analysis for structure detection. The PCA analysis yielded a four-factors solution (Eigenvalues: 4.33, 1.95, 1.45 & 1.20) that accounted for the 68.72 % of the total variance. In order to interpret the contribution of each variable towards a factor, component loadings greater than a value of 0.5 were designated as significant and named according to the main concepts captured. The four PCA factors in descending order of eigenvalue were as follows. The first component, named "SES," contributed 33.3% of the total variance and included parenting style, maternal and paternal education and occupation, income-per-family member, and book reading. Factor two, designated "activities" contributed 15.0% of the overall variance and included cultural and outside entertainment activities. Factor three, contributing 11.12% of the total variance, was named "Family demography" and consisted of the total of family members and number of siblings. Component four, imputed as "TV & extracurricular" accounted for 9.24% of the cumulative variance and encompassed by extracurricular activities and hours of TV. Factor loadings are indicated on Table 6.3.

Next step was to test the internal consistency of our components (measured by Cronbach's alpha). Following the classic concept of SES, we included maternal and paternal education and occupation plus income-per-family member to test internal reliability for SES component, dismissing parenting styles and book reading. The internal reliability of the components calculated in our sample was: SES α=.84, Activities α=.85, Family demography α=.83 and TV & extracurricular α=.14. Internal reliability was high except for “TV & extracurricular”. Since extracurricular activities add more variability to our sample than TV we decided to exclude TV and take only extracurricular activities as a single measure for further analyses. Same with parenting styles and frequency of book reading, they were also used as singular measures in all analyses. Internal reliability for temperamental factors in the whole sample of participants was: EC α=.80, E/S α=.76, NA α=.71.

	1. SES	**2. ACT**	**3. F.D.**	**4. TV/Ex**
Parenting style	**0.529**	-0.242	-0.059	0.023
Mother Education	**0.697**	-0.215	0.388	-0.183
Father Education	**0.745**	-0.237	0.208	-0.112
Mother Occupation	**0.635**	-0.162	0.307	0.018
Father Occupation	**0.601**	-0.370	0.160	0.034
Income-per-family member	**0.850**	-0.254	-0.011	0.097
Total family members	-0.600	-0.149	**0.707**	-0.089
Number of siblings	-0.608	-0.097	**0.701**	-0.038
Monthly book reading	**0.689**	0.454	0.054	-0.078
Monthly outside entertainment	0.293	**0.855**	0.224	-0.039
Monthly cultural activities	0.414	**0.761**	0.223	0.068
Monthly extracurricular activities	0.197	-0.102	0.037	**0.764**
Daily hours of TV	-0.143	0.079	0.198	**0.734**

Table 6.3. Factor loading from PCA. ACT = activities; F.D. = family demography; TV/Ex = TV & extracurricular activities.

Due to the changes in SES component and the decision of using some environment variables as a single measure, we considered appropriated not to use the factors from PCA in further analyses, instead, we used an average of z-scores of the variables grouped for SES, activities and family demography. The final environment variables used in following analyses were: SES, activities, family demography, frequency of book reading, extracurricular activities, and parenting styles.

6.3.3. Hierarchical regression analyses

Table 6.4 presents correlation results among the variables used in our study. Our first goal was to examine the amount of unique variance accounted for environment variables after controlling for the variance explained by individual characteristics. We also were interested in assess to what extend SES is predictor of behavioral outcomes after controlling for other environment variables. For this aim a series of hierarchical linear regressions were conducted for each of the behavioral measures. In hierarchical regression analysis some variables are introduced into the analysis before others. The order in which independent variables are introduced establish the priority that is given to them, typically for theoretical reasons. Therefore, variables entered first are allowed to capture variance in the absence of competition from variables to be introduced subsequently. This analysis allows us to compare the amount of variance explained by child's characteristics with the variance explained by environment. Since we were interested in knowing how much variance is explained for each variable, nice models were entered: one for each independent variable. First we include child's characteristics: gender, age, temperament and IQ (age was not considered a predictor for vIQ and fIQ because we used standardized age scores). Since it has been found that EC is the temperamental factor more related to EF (Rothbart, 2007) it was introduced before E/S and NA. Subsequently, environment variables were introduced in the following order: parenting style, frequency of book-reading and SES. According to the literature SES is a powerful predictor of EF, however it was the last model introduced in the analyses in order to control it for other environment variables, (in this case parenting and book-reading). Because the variables activities and extracurricular activities did not correlate with any behavioral measure they were excluded from regression analyses. The F value was used as Stepping method criteria (4.0 – 2.79; 1,88 df, $p < .05$). Hierarchical regression

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
1. Gender	-																				
2. Age (months)	-	-																			
3. IQ	-	-	-																		
4. EC	-	-	**.22**	-																	
5. E/S	-	-	*-.19*	**-.23**	-																
6. NA	-	-	-	-	-	-															
7. SES	-	**-.22**	**.48**	*.20*	**-.24**	**-.24**	-														
8. F. Demography	-	-	-	-	*.18*	-	**-.30**	-													
9. Book reading	-	-	**.40**	**.23**	-	-	**.49**	*-.19*	-												
10. Activities	*.21*	-	-	-	-	-	-	-	**.53**	-											
11. Extracurricular	-	-	-	-	-	-	-	-	-	-	-										
12. Parenting	-	-	-	**.38**	*-.21*	*-.21*	**.37**	-	**.31**	-	*.19*	-									
13. WM	-	**.28**	-	-	-	-	**.29**	-	**.26**	-	-	**.23**	-								
14. vIQ	-	-	**.89**	-	-	-	**.50**	-	**.40**	-	-	*.21*	*.20*	-							
15. fIQ	-	-	**.81**	**.26**	-	-	**.30**	-	**.27**	-	-	-	-	**.45**	-						
16. Executive Att.	-	-	**-.31**	-	**.26**	-	-	-	-	-	-	-	-	**-.30**	**-.23**	-					
17. Inhibitory C.	**.34**		-	-	-	**-.27**	-	-	-	-	-	-	-	-	-	-	-				
18. SAE	-	*.18*	-	-	-	-	-	-	-	-	-	-	-	-	-	-	**.21**	-			
19. Response Time	**-.23**	**-.30**	-	-	**-.22**	*.19*	**.28**	-	-	-	-	-	*.18*	*.19*	-	-	**-.40**	**-.33**	-		
20. 4 ADV consectv	-	*.18*	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
21. Self-based DoG	-	**.28**	-	-	-	-	-	-	-	-	-	-	*.18*	-	-	-	-	-	-	-	-

Table 6.4. Correlation for all variables included in our study. Bold and italic fonts indicate statistically significant and marginal differences respectively. Gender was dummy coded, 1 for boys and 0 for girls.

	Executive attention					Inhibitory Control					Working Memory				
	ΔR^2	F ch	*B*	*SE B*	β	ΔR^2	F ch	*B*	*SE B*	β	ΔR^2	F ch	*B*	*SE B*	β
Child characteristics															
Gender	.00	.830	-.04	.17	-.03	**.12**	**.002**	**.68**	**.21**	**.34**	.01	.424	.18	.22	.09
Age	.00	.622	-.04	.09	-.06	.14	.183	-.14	.11	-.14	**.08**	**.013**	**.26**	**.11**	**.26**
EC	.01	.763	.03	.09	.04	.14	.503	-.07	.11	-.07	.09	.432	.09	.11	.09
E/S	**.08**	**.018**	**.21**	**.09**	**.28**	.15	.472	-.08	.11	-.08	.09	.906	-.01	.11	-.01
NA	.08	.605	-.04	.09	-.06	**.20**	**.026**	**-.24**	**.10**	**-.24**	.09	546	.07	.11	.07
IQ	**.18**	**.004**	**-.26**	**.09**	**-.35**	.20	.641	-.05	.12	-.05	*.14*	*.061*	*.22*	*.12*	*.22*
Child environment															
SES	.19	.599	-.07	.12	-.07	.22	.172	-.22	.16	-.18	**.24**	**.002**	**.50**	**.15**	**.40**
Book-reading	.19	.665	-.04	.10	-.06	.24	.315	.12	.12	.12	.26	.243	.14	.12	.14
Parenting	.21	.153	.14	.10	.18	.25	.354	.11	.12	.11	.27	.230	.14	.12	.14
Activities															
Extracurricular A.															

	Response time					Verbal IQ					Fluid IQ				
	ΔR^2	Sig. ΔF	*B*	*SE B*	β	ΔR^2	Sig. ΔF	*B*	*SE B*	β	ΔR^2	Sig. ΔF	*B*	*SE B*	β
Child characteristics															
Gender	**.05**	**.036**	**-.47**	**.22**	**-.23**	.02	.230	.27	.22	.13	.00	.962	-.01	.22	-.01
Age	**.13**	**.010**	**-.28**	**.11**	**-.28**										
EC	.13	.850	.02	.11	.02	.04	.204	.14	.11	.14	**.07**	**.020**	**.26**	**.11**	**.26**
E/S	**.17**	**.046**	**-.22**	**.11**	**-.22**	.06	.185	-.15	.11	-.15	.08	.357	-.10	.11	-.10
NA	.20	.128	.16	.10	.16	.06	.944	-.01	.11	-.01	.08	.479	.08	.11	.08
IQ	.20	.620	.06	.11	.06										
Child environment															
Parenting	.21	.719	-.04	.12	-.04	.08	.161	.17	.12	.17	.09	.427	-.10	.12	-.10
Book-reading	.21	.603	.06	.12	.06	**.20**	**.001**	**.36**	**.11**	**.36**	**.15**	**.028**	**.25**	**.11**	**.25**
SES	**.28**	**.012**	**.44**	**.17**	**.35**	**.31**	**.001**	**.51**	**.15**	**.41**	**.19**	**.042**	**.33**	**.16**	**.26**

	Slowing after error					Reward regulation					Delay of gratification				
	ΔR^2	Sig. ΔF	*B*	*SE B*	β	ΔR^2	Sig. ΔF	*B*	*SE B*	β	ΔR^2	Sig. ΔF	*B*	*SE B*	β
Child characteristics															
Gender	.03	.135	.33	.22	.17	.01	.436	-.17	.22	-.09	.02	.249	-.25	.22	-.13
Age	.05	.140	.16	.11	.16	*.04*	*.089*	*.19*	*.11*	*.19*	**.11**	**.006**	**.30**	**.11**	**.30**
EC	.06	.875	.02	.11	.02	.04	.793	-.03	.11	-.03	.11	.498	-.07	.11	-.07
E/S	.08	.172	-.16	.11	-.16	.04	.927	-.01	.11	-.01	.12	.390	.09	.11	.09
NA	.08	.721	-.04	.11	-.04	.05	.593	-.06	.11	-.06	.13	.446	-.08	.11	-.08
IQ	.08	.888	.02	.12	.02	.06	.293	-.13	.12	-.13	.13	.587	.07	.12	.07
Child environment															
Parenting	.08	.694	.05	.13	.05	.07	.389	.11	.13	.11	.13	.790	.03	.12	.03
Book-reading	.08	.858	-.02	.13	-.02	.10	.152	-.18	.13	-.18	.14	.265	.14	.12	.14
SES	.09	.431	-.15	.19	-.12	.10	.940	.01	.19	.01	.15	.382	.16	.18	.13

Table 6.5. Summary of hierarchical regression analyses on measures of EF and intelligence with variables of child's characteristics and environment as predictors. Reward regulation stands for the measure of 4 consecutive advantage cards in gambling task. Sig. ΔF = significant change in F.

results (Table 6.5) revealed that Response Time, Intelligence and WM were predicted for environment after controlling for child's characteristics. SES predicted variance in Response Time, vIQ, fIQ and WM after controlling for parenting and book-reading (accounting for 7%, 9%, 4% and 5% of the total variance respectively). Meanwhile the variance in Flanker interference and Inhibitory Control was accounted only by children's characteristics. Although a marginal effect of SES on Inhibitory Control was observed, adding 4% to the total variance explained. Neither child's characteristics nor environmental variables predicted the variance in Reward-based and response-based regulation variables, except for an effect of age on self-delay of gratification, adding 9% of variance explained.

6.3.4. Moderation analyses

To further explore the influence of child's characteristics and environment on EF we tested whether associations between environment and behavioral outcomes systematically differed when measures of child's characteristics change. For this purpose new environment x child's characteristics interaction variables were added to multiple regression analyses to test for moderation effects. For easier interpretation of moderation effects, results were plotted using a 2-ways standardized template (from http://www.jeremydawson.co.uk/slopes.htm). This template uses the unstandardized regression coefficients to calculate the predicted values of the dependent variable under high and low values of the moderator in order to show the predicted relationship between the independent and the dependent variable at different levels of moderation (Dawson, 2013). High and low values of the independent variable shown in the graphics below correspond to one standard deviation above and below the mean.

6.3.4.1 Temperament x Environment interaction

We found that temperament factors moderated the association between SES and, Flanker interference and WM. Figure 6.1 shows that low EC children appear to be more affected by SES in conflict resolution. Low EC children from HSES had less flanker interference than low EC from LSES, while differences in flanker interference for high EC children did not differed in function of SES. Figure 2 illustrates that WM digit span scores were not modulated by SES in low E/S, however, SES modulated high E/S children´s performance in a positive relation, meaning LSES obtained lower WM scores. We also found a parenting modulation effect for WM and vIQ. Parenting scores were the result of a subtraction of coerced style from assertive style, therefore, the lower the score, the more coerced parenting style. Figure 3 shows that vIQ score was not moderate by parenting in high EC children, yet, low EC children performed equal to their high EC peers when exposed to assertive parenting, while low EC under coerced parenting showed lower vIQ score. In figure 4 we observe that WM score of low NA was unaffected by parenting style, though high NA children exposed to a more assertive parenting performed better in WM digit span task. Although this last modulation effect was statistically marginal (p=0.58) it shows an interesting trend of relationship between WE and temperament.

Fig. 6.1

Executive attention

	R^2	*B*	*SE B*	β
	.10*			
SES		-.16	.14	-.13
EC		.01	.12	.01
SES x EC		.32*	.13	.27

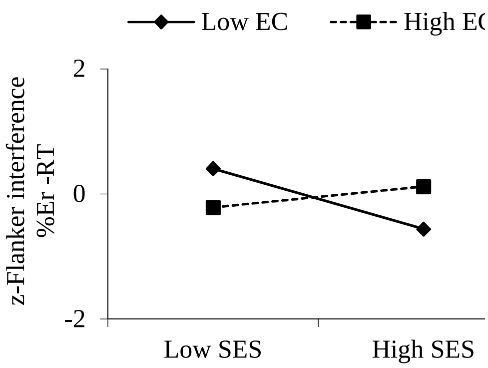


Fig. 6.2

Working Memory

	R^2	*B*	*SE B*	β
	.15**			
SES		.36*	.16	.24
E/S		-.06	.13	-.05
SES x E/S		.43*	.1	.27

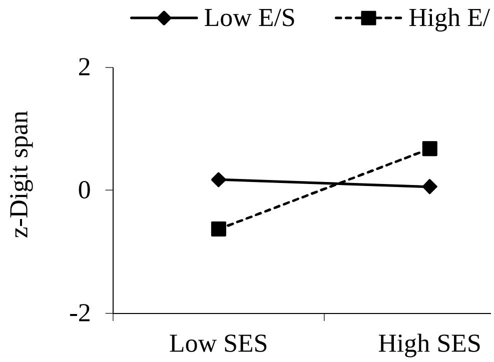


Fig. 6.3

Verbal IQ

	R^2	*B*	*SE B*	β
	.10*			
Parenting		.14	.11	.14
EC		.09	.11	.09
Parenting x EC		-.22*	.11	-.22

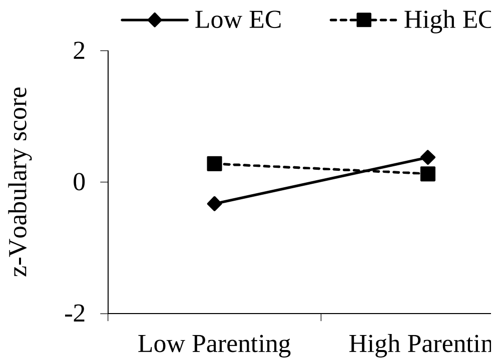
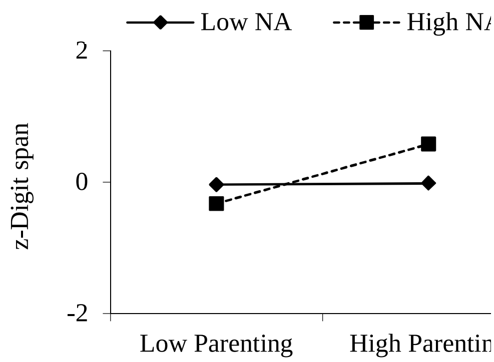


Fig. 6.4

Working Memory

	R^2	*B*	*SE B*	β
	.10*			
Parenting		.23*	.11	.23
NA		.08	.11	.08
Parenting xNA		.22~	.12	.21



Figures 6.1-6.4. Plotted results of moderation effects of temperament in the environment-cognitive performance relationship. Behavioral outcomes are z-score-based scaled.

6.3.4.2 Gender x SES interaction

Figure 6.5 shows the interaction Gender x SES for vIQ. In general HSES children obtained higher score in vIQ in comparison to LSES children. However, girls were the most affected by LSES, showing the lowest vIQ score of the entire sample.

Verbal IQ

	R^2	*B*	*SE B*	β
	.30***			
SES		.85**	.16	.69
Gender		.20	.18	.10
SES x Gender		-.48*	.23	-.27

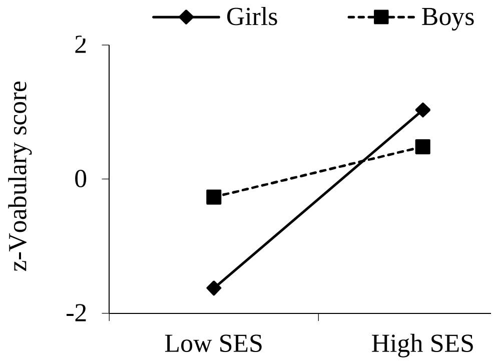


Figure 6.5. Plotted moderation effect of gender on the SES-vIQ relationship. Behavioral outcomes are z-score-based scaled.

6.3.4.3 Gender x Temperament interaction

Gender played a moderator role in GNG task measures. Differences in EC did not influence boys' Go RT neither No-go errors. However, high EC girls committed less No-go errors (Fig. 6.6) and emitted slower RT to Go trials (Fig. 6.7).

Fig. 6.6

Inhibitory control

	R^2	*B*	*SE B*	β
	.18**			
EC		-.35*	.15	-.34
Gender		.66**	.20	.33
EC x Gender		.49*	.20	.35

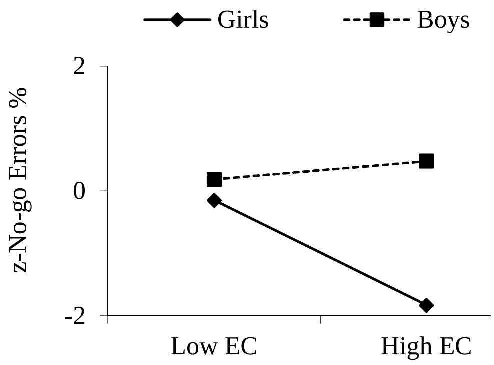


Figure 6.6. Plotted moderation effect of gender on the Temperament-Inhibitory Control relationship. Behavioral outcomes are z-score-based scaled.

Fig. 6.7

Response speed

	R^2	*B*	*SE B*	β
	.06~			
EC		.17	.15	.17
Gender		-.47*	.21	-.23
EC x Gender		-.38~	.22	-.27

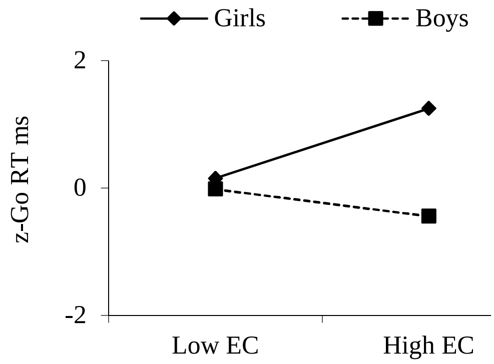


Figure 6.7. Plotted moderation effect of gender on the Temperament-Response speed relationship. Behavioral outcomes are z-score-based scaled.

6.3.4.4 Age x Temperament interaction

Age moderated the influence of temperament in WM. Our data indicate that high EC and low E/S are related to better WM performance. However, this association between temperament and WM performance was seen only in the older children of our sample (see Fig. 6.8 and 6.9). Apparently, temperament did not influence WM performance in young children.

Fig. 6.8

Working Memory

	R^2	*B*	*SE B*	β
	.16**			
EC		.09	.10	.09
Age		.26*	.10	.26
EC x Age		.25*	.10	.26

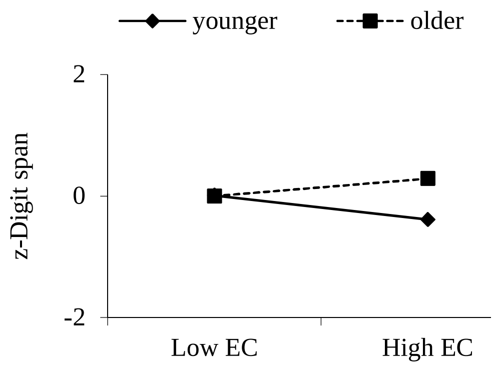


Fig. 6.9

Working Memory

	R^2	*B*	*SE B*	β
	14*			
E/S		-.09	.11	-.09
Age		.27**	.10	.27
E/SxAge		-.23*	.11	-.22

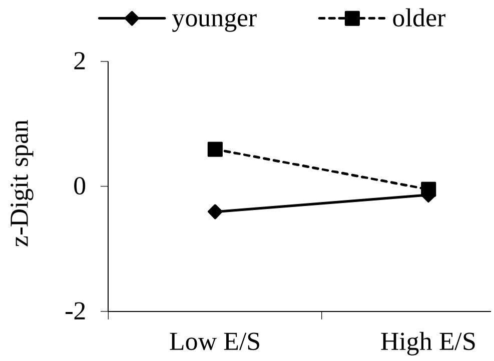


Figure 6.8-6.9. Plotted moderation effect of age on the Temperament-WM relationship. Behavioral outcomes are z-score-based scaled.

6.3.4.5 Age x Environment interaction

A similar pattern of results was found in regarding to environment. Children showed an age-related improvement in WM performance only when exposed to HSES (Fig. 6.10) and book-reading (Fig. 6.11).

Fig. 6.10

Working Memory

	R^2	*B*	*SE B*	β
	.25**			
SES		.35**	.13	.28
Age		.35**	.10	.35
SESxAge		.30*	.13	.23

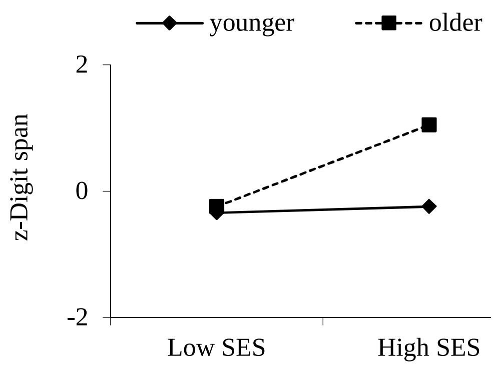


Fig. 6.11

Working Memory

	R^2	*B*	*SE B*	β
	.23**			
Read		.31**	.10	.31
Age		.32**	.10	.32
Read x Age		.28**	.10	.28

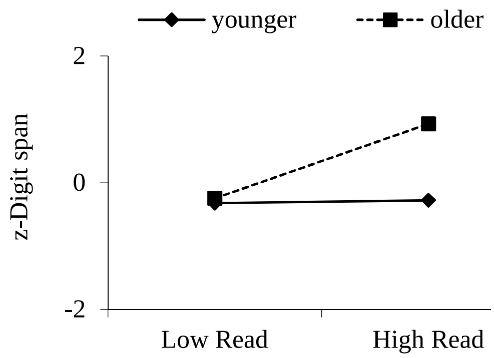


Figure 6.10-6.11. Plotted moderation effect of age on the Environment-WM relationship. Behavioral outcomes are z-score-based scaled.

6.4. Discussion

Our study replicates previous findings that relate SES to differences in cognitive performance. We found that SES is a strong predictor of differences in some EF process after controlling for children's characteristics and other environment variables. Our results also indicate that temperament not only predicts differences in EF measures, but also interacts with environment, age and gender, to moderate behavioral outcomes of EF and intelligence. Many studies have shown that both SES and temperament are related to differences in cognitive performance during childhood. Both LSES and low EC have been considered risk factors for cognitive development, scholar achievements and behavioral problems (Blair, Denham, Kochanoff, & Whipple, 2004; Letourneau, Duffett-Leger, Levac, Watson, & Young-Morris, 2011; Morris et al., 2013). Our data add a link between SES and temperament literature that may contribute to understand the dynamics through which environment, temperament and cognition interact to affect children development.

6.4.1 Environment and EF

SES alone accounted for 9%, 11%, 4%, 5% of the total variance in Response Time, vIQ, fIQ, and WM respectively, after controlling for child's characteristics, parenting and book-reading. Those tasks mentioned above, except for vIQ, required holding information in mind, abstract reasoning and the ability to inhibit irrelevant or distracting information while simultaneously focusing on a specific goal, theses process are considered high order executive functions (EF). Disparities in EF related to SES during childhood have been well documented (Bradley & Corwyn, 2002; Hackman & Farah, 2009; Lipina, Martelli, Vuelta, Injoque-ricle & Augusto, 2004; Noble et al., 2007). Specifically, it has been found that SES affects neurocognitive systems underlying EF and language (D. A. Hackman & Farah, 2009). The amount and quality of input provided by different SES backgrounds during childhood impact the development of prefrontal areas, which are implicated in EF.

Our data also replicate previous results that show that language is highly susceptible to SES (D. A. Hackman & Farah, 2009). The robust influence of SES on language is expected, since language depends on environmental input to develop. This association between SES and language in children is a very consistent finding in the literature (Ardila, Rosselli, Matute, & Guajardo, 2005; Fish & Pinkerman, 2003; Hart & Risley, 1992; Hoff, 2003; Noble et al., 2007). Facilitative maternal behavior, parental education and school-oriented home environment are factors associated with cognitive development and language exposure, that have been found to differ in different SES contexts (Ardila et al., 2005; Reynolds & Fish, 2010).

Book-reading was another environment variable that predicted intelligence after controlling for child's characteristics. The relationship between book reading and vIQ is clear; since, books provide wide range of content, more complex vocabulary and grammar, and the opportunity to discuss the associated text (Topping, Dekhinet, & Zeedyk, 2013). A quantitative meta-analysis of parent-preschooler reading and outcome measures, (Bus, van IJzendoorn, & Pellegrini, 1995) showed that book reading was related to language growth, emergent literacy and reading achievement in preschool age children. Therefore, book reading is an activity that promotes cognitive development beyond vocabulary growth, as it is shown in our data by a statistically significant positive relation between book-reading and fIQ, and statistically marginal with WM.

Although our results did not show direct effects of parenting style on EF processes, we found a modulation effect of parenting in the relationship between vIQ and WM and temperament. Previous studies have shown that higher-quality parenting is related to EF in infants (Bernier et al., 2010) and better impulse control and conflict resolution at age of 3 (Bernier et al., 2012). It is thought that high quality parenting not only provides emotional warm (approbation, affection, sensibility and dialog) but also implies guidance to problem-solving, and training in social and cultural values, that are important aspects in the development of self-regulation. (Bernier et al., 2012; Jennings et al., 2008; Kochanska et al., 2000).

6.4.2. Temperament and EF

Links between high cognitive process and EC have been very well established. EC and EF are overlapping constructs associated with common outcomes (e. g. Diamond, 2013; Rueda, et al., 2005). EC is the aspect of temperament that supports the emergence and exercise of self-regulation. In the field of cognitive neuroscience, self-regulation refers to the ability to modulate one´s behavior according to the cognitive, emotional and social demands of a specific situation (Ruff & Rothbart, 1996). Flanker interference is a typical measure used to assess EC and EF, however, in our sample, we did not find a direct effect of EC on conflict resolution. Rather, we found that E/S predicted flanker interference: high E/S children were more affected by conflict in flanker task. Several studies have linked E/S with externalizing behavior (Rothbart, 2007), which in turn, has been related to impulsivity (Deyoung, 2013). Impulsivity refers to the tendency to respond immediately to external cues, without thinking about the consequences (Gray, 1987). In addition, extraversion is also linked to reward sensitivity (Depue & Fu, 2013). We hypothesized that these two characteristics, impulsivity and reward sensitivity, explain our results. The manipulations made to the flanker task used in the current study required a constant rate of fast responses in order to successfully perform the task. This situation promotes an urge to give a response. Moreover, correct responses were rewarded with fake coins that were exchanged by a gift at the end of the task. Children were encouraged to collect as much coins as possible. Such conditions are likely to evoke impulsive behavior in extravert children, due to impulsivity and reward seeking traits. Some studies have found association between extraversion and EF (e. g. Campbell, Davalos, McCabe, & Troup, 2011). In contrast to introverts, under low reward conditions extraverts are under-aroused and seek out more stimulation, which facilitates performance in EF task. However, our task was a potentially high reward condition, which may over-aroused extraverts and incites impulsive responses in order to obtain a reward. Yet, EC modulated the strength of the relationship between Flanker Interference and SES. These results suggest that differences in EC impacted on flanker task performance in our sample; however, this impact was influenced by SES.

It has been proposed that fluid intelligence is equal to the reasoning and problem-solving subcomponents of EF (Diamond, 2013). Previous studies have found that EC is an important aspect that account for individual differences in intelligence (Kane & Engle, 2002; Kane, Hambrick, & Conway, 2005). Furthermore, it has been found that PFC and ACC, structures linked to EF, activate in tasks of "general intelligence", suggesting that EF and intelligence share common neural networks (Duncan, et al., 2000). In contrast to the traditional conception of fluid intelligence, our results suggested that fIQ is an ability influenced by both individual and social conditions. Findings from other studies indicate that fIQ can be improve after cognitive training (e.g. Klingberg et al., 2005; Rueda, et al., 2012; Rueda et al., 2005) suggesting that fIQ is subject to change.

NA added 5% of the variance in No-go Errors. GNG task has been widely used to study inhibitory control. The tendency to respond, created for the high frequency of Go trials, must be inhibited in No-go trials. Accuracy on no-go trials is taken as a measure of inhibitory control. Some studies suggest that inhibition may be important for regulating NA expression (Liew, Eisenberg, & Reiser, 2004). As mention before, NA refers to the rate of recovery from intense distress, excitement, or general arousal, aside from the experience and expression of frustration, fear, discomfort and sadness. For instance, using Simon says and the disappointing gift, Carlson and Wang (2007) found that preschool children showing better inhibition control had fewer/less intense expressions of negative affect. Nonetheless, in our data we observed an opposite pattern: a negative relation between NA and No-go errors, that is, children that scored high in NA committed less no-go error, indicating that high NA children exercised better inhibitory control on GN task. It is possible that fear or frustration associated with error commission may promote a careful performance in high NA children in order to avoid negative emotions related to failure. Further research is needed to unravel this result.

6.4.3 Gender and EF

Gender was also found to modulate the relationship between SES and vIQ. We found that girls performed slightly better than boys within the HSES group, however, while LSES boys' vIQ was lower than children in the HSES group, LSES girls appeared to be more affected for LSES, showing the lowest vIQ among all children in our sample. Many researchers have found gender differences in verbal abilities during childhood, reporting that girls do better than boys in verbal tasks (Ardila, Rosselli, Matute, & Inozemtseva, 2011; Naglieri & Rojahn, 2001). Our data suggested that LSES girls in our sample have not been exposed to a rich environment that supports vocabulary growth. Maybe LSES boys, in comparison to LSES girls, have more opportunities to socialize and to get involved in activities that stimulate language development.

6.4.4 Gender and Temperament

Temperament x Gender interaction was also found in measures of GNG task. After controlling for temperament, girls showed the greater variability in GNG measures. High EC girls were slower and more accurate than the rest of children, suggesting that the former were more efficient at inhibitory control. This finding is in consonance with a meta-analysis focus on gender differences in temperament during childhood. Else-Quest et al. (Else-Quest et al., 2006) found consistent gender differences, favoring girls, within the factor of EC. They concluded that girls display a stronger ability to regulate attention and inhibit impulses. In general, in our data, boys' RT to Go trials and percentage of No-go Errors did not change in function of temperament. In other words, boys' differences in EC did not affect boys RTs and inhibitory control. It is possible that the nature of the task explains the differences between girls and boys in GNG performance, since boys tend to be more active than girls (Eaton & Enns, 1986). It has also been proposed that the gender difference in EC may suggest a male maturational delay that persists through middle childhood (Else-Quest et al., 2006).

6.4.5 Age and EF

WM appeared to be more susceptible to age than the other measures used in this study. Moderation analyses reflect that the improvement related to rich environment and temperamental characteristics associated with more efficient EF, such HSES, book-reading, high EC and low E/S, are observable as children grow up. This implies that young children in our sample, close to 4 years of age, did not benefit from advantageous conditions as older children did. Developmental studies have found that WM improves with age (S. Gathercole & Hitch, 1993). For instance, Gathercole and cols. (Gathercole, Pickering, Ambridge, & Wearing, 2004) found that the basic structure of WM (phonological and visuospatial storage, and a central executive) is stable from 6 years of age, and that the WM capacity increases linearly from age 4 to early adolescence. Our results suggest that WM capacity is favored by both age and rich environment.

6.4.6 Conclusions

Our results highlight the importance of considering children's temperament and its interactions with environment when assessing EF at preschool age. Moderation analyses provide valuable information for better understanding and characterizing the interactions taking place within the complex relationships among environment, EF and children's characteristics.

Book reading appeared to be a strong candidate to predict differences in EF, suggesting that the frequency with which parents read to children has an important effect in cognitive development, beyond verbal skills.

Noteworthy is the fact that reward processing measures, such as delay of gratification and gambling, were influenced by neither child's characteristics nor environment factors. Other studies have found that reward processing is not influenced by SES. For example, Noble and cols. (Noble et al., 2005; Noble et al., 2007) found that SES predicted variance in language, WM, cognitive conflict and visuospatial performance, but not reward processing, in both preschoolers and firs-grade children. However, some studies have found an association between reward processing and temperament. Specifically, extraversion is highly related to reward seeking (Lucas, Diener, Grob, Suh, & Shao, 2000). Nonetheless, we did not find any association between reward-regulation measures and temperament.

The data presented in this study support the hypothesis that SES disparities are related to differences in EF. Children from HSES background appeared to be more efficient in EF, reasoning and verbal abilities. However, EF processes are affected by environment and temperament at different rates. Our results also support the notion that the late development of prefrontal structures leads to a significant opportunity for environmental impact on cognitive development (Bernier et al., 2012; Noble et al., 2005). Such impact has the potential to be constructive or detrimental. In consonance with several other studies, our data highlight the plasticity of EF during preschool years, opening the window to many possibilities in the implementation of strategies and/or programs directed to boost typical cognitive development or mend detrimental effects of developmental pathologies or suboptimal environment.

Chapter 7.

General discussion

The goal of the current work was twofold: 1) Studying the development of attention networks along childhood and underlying electrophysiological mechanisms; and 2) Examining the impact of environmental factors, such as SES, parenting and family activities, on the development of high cognitive skills in preschool children at the behavioral and neural level. In the next sections, I will discuss the contributions to these two main objectives made by our studies.

7.1. Development of attention networks

In the first study of the current thesis a modified version of the ANT task was used to examine the development of attention networks from early to late childhood. The new task provided improved measurement of a) the orienting network by including invalid cued trials, and b) interactions between alerting and orienting networks. Prior results on the development of attention networks with the original child ANT (children aged 6 to 10 years; Rueda et al., 2004) showed separate developmental trajectories for each network. Alerting scores showed stability across childhood, although children obtained higher alerting scores than adults; there were no difference in orienting scores between children and adults; and, executive score was similar from age 7 years to adulthood. Data from study 1 in the current work show that alerting network is adult-like from 10-13 years of age; orienting appeared to have a prolonged development when processes of disengagement and reallocation of attention are measured, as indicated by 10-13 year-olds being not as efficient as adults; finally, the executive network showed a linear improvement along childhood, and data suggested a further development between late childhood and adulthood, as there were significant differences between these two groups.

Data from the new study replicate the developmental trajectory of the alerting network that was observed before. However, with the new version of the task we found an extended developmental trajectory of orienting. Disengaging attention from an attended location or object and shifting attention to a different object or location involves activation of a parieto-frontal brain network, which function is not fully developed until about late childhood-early adolescence. Our data also showed a more protracted developmental trajectory of executive attention as compared to prior studies running the original ANT task (Rueda et al., 2004).

Further studying interactions between networks is useful to understand the extended development of executive attention. We found that both alerting and orienting conditions modulate executive attention efficiency. Despite the relative independent neuroanatomy and neurochemistry involved in each attention function (Petersen and Posner, 2012), all three attention networks reside in the same brain and thus they are likely to interact when it comes to respond to external an internal stimulation. As in adults (see Callejas et al., 2005), children show a facilitation of flankers suppression and hence conflict resolution when attention is oriented to the target location before it appears (as when valid orienting cues are provides). On the other hand, conflict resolution is impaired in conditions of higher alertness (Callejas et al., 2005; Weinbach & Henik, 2012), except on 4-6 year-olds, who were more accurate on tone trials. Thus, opposite to older children and adults, warning cues facilitated conflict resolution in 4-6 year-olds, reflecting a difficulty to maintain an adequate level of activation at this age when there is no cue. Including conditions that reduce efficiency of executive attention (i.e. invalid cues and warning tones) in our study may have caused a more protracted development of this function with respect to prior studies with other versions of the ANT.

Our electrophysiological data capitalizes on the high temporal resolution of ERPs to identify at which stages of processing differences between children and adults emerge. ERP results revealed that most developmental differences between children and adults appear in early stages of processing. We found that the early components associated to the processing of both for alerting and orienting cues were delayed in children, and, in some cases, absent in 4-6 year-olds. Although children and adults are more alike in slow processing, children exhibit delayed and more sustained ERP effects, as shown by children's extended P3 and N2 in relation to processing of orienting cues and flanker interference, respectively.

Thus, our data indicate that the timing of processing during development appears to be based on slower and more sustained brain responses in children compared to adults. Such timing pattern of brain response has been associated with immature brain connectivity during childhood (Johnson, 2005). Developmental neuroimaging studies have revealed two patterns in brain structure development: 1) higher-order association cortices mature after lower-order somatosensory and visual cortices; 2) phylogenetically older regions of the cortex mature earlier than more recent ones (Gogtay et al., 2004). During childhood and adolescence a reduction in gray matter occurs due to synaptic pruning and axon myelination that provokes changes in density and structure of white matter (Sowell, Thompson, Tessner, & Toga, 2001). Myelin enhances the speed of axonal conduction, and therefore facilitates the processing in cortical networks. However, the frontal connections such as fronto-occipital, fronto-temporal and superior longitudinal fasciculi continue to develop during adolescence reaching maturity around 20 years of age (Lebel, Walker, Leemans, Phillips, & Beaulieu, 2008). As structural and functional changes occur in the brain, the connections between structures become more specific and differentiated. Several studies have found that brain development is supported by a shift in patterns of activation, from diffuse to more focal (e.g. Gaillard et al., 2000). In fact, it has been reported that the development of networks associated with cognitive control (fronto-parietal and cingulo-opercular networks) involves both decrease of short-range connection and increase of long-range connections between the structures compromised. In studies examining functional connectivity between brain regions at rest, young children (age 7 to 9 years) show reduced functional connectivity from parietal to prefrontal areas implicated in executive control. (Fair et al., 2007). This is an important piece of data for our work because high-level cognitive processes, such as executive attention and EF, require long-distance communication between frontal and parietal structures. As children grow, connections between these regions both develop and become faster. These maturational processes of structural nature likely underlie the differences found in the time domain between children and adults.

There are some developmental neuroimaging studies showing different patterns of activation for children and adults while performing the ANT (Konrad et al., 2005). However, as far as we know, there is not previous works characterizing the neural response, in time domain, in each attentional network during development. We believe that these data offer important information to better understand the development of attention, and may serve as a framework to investigate a vast range of subjects, from typical to atypical development. Knowing the brain basis of attention function may help understanding the mechanisms that underlie developmental pathologies involving attention and executive control, providing a better clinical evaluation and understanding of attention functions and their alterations. Furthermore, information of this sort is useful for designing and implementing intervention and training programs. Given that the child ANT is a very widely used task in different disciplines, our data on the normative development of the attention network scores and the neural processes underlying them offer many opportunities for the practical and theoretical use of these data.

7.2. Impact of environmental factors

The second aim of this thesis was to examine the influence of environment over high cognitive skills in general and executive functions in particular. Our first research question was: are neural mechanisms related to conflict and error processing impacted by differences in SES during preschool age?

To answer this question we carried out a study with a child-friendly version of the flanker task that was run by 4 to 6 year old children while EEG was recorded. This child-friendly version of the task provided separated EEG measures of target and response processing and was previously used in research conducted in our lab (Checa, et al., 2014).

Previous research has mainly addressed the relationship between SES and cognition by assessing behavioral outcomes. Very few neuroimaging and electrophysiological studies have explored the cerebral mechanisms underlying cognitive outcomes in children exposed to different SES backgrounds. However, there is a very consistent literature in non-human animals that evinces the impact of the environment on brain development and functioning, particularly, it has been found that frontal structures are very susceptible to the environment.

Our results showed different patterns of brain response to conflict and error processing in children raised in families with SES differences. HSES children showed brain activation related to a more efficient functioning, in contrast to their LSES peers. The N2 conflict effect (i.e. significant difference between ERP amplitude in congruent and incongruent conditions) was present in HSES children but absent in the LSES group, whom exhibited later conflict-related amplitude modulation, and only the HSES group exhibited the ERN in midline channels.

Both the N2 and ERN are late maturation ERP components associated with activation of the ACC. Most of the developmental studies using conflict resolution tasks consistently find absence of the N2 and ERN in preschool children (Abundis-Gutiérrez et al., 2014; Checa et al., 2014; Davies et al., 2004; Rueda, Posner, et al., 2004). These components are not clearly shown by children until late childhood, or even until adolescence (e.g. Checa, Castellanos, Abundis-Gutiérrez, & Rueda, 2014; Davies, Segalowitz, & Gavin, 2004). Behavioral data from developmental studies indicate that children process the error information, but they may not use frontal structures to process this information as adults do (Davies et al., 2004). In the case of conflict, it is thought that children engage frontal structures later than adults and that the processing of conflict implies more effort, which is reflected in a more sustained conflict effect.

The data obtained in the second study of the thesis show that differences in timing of processing associated with executive control and error processing are influenced by environmental factors. HSES preschool children showed a timing of processing similar to that observed in older children and adults in our prior experiment. The fact that we have found N2 conflict effect and incipient ERN in preschool children from HSES background suggests that HSES provides some elements that boost maturation of EAN, which is involved in action monitoring and conflict resolution processes.

As mentioned earlier, electrophysiological data are informative of the time domain, and only indirectly about structural activation. Although the N2 and ERN are linked to the activation of the ACC, the development of a particular cognitive function is supported not only by the functioning of a particular brain region, but also by the way a network of areas are connected functionally and anatomically. We mentioned earlier that important brain changes take place during childhood. It has been suggested that such changes can be of two types: 1) quantitative: changes (increase or decrease) in activation of particular regions with age; and/or 2) qualitative, changes in the particular set of brain regions involved in the function of interest (Bunge & Zelazo, 2006). This shows that brain development is a very complex process involving a dynamic interaction between maturation mechanisms of diverse nature. These changes influence the speed of processing, which is an important index of cognitive efficiency. Therefore, ERPs constitute a very useful technique for characterizing neural changes that accompany development along childhood, and to assess the impact that factors such as family environment may cause in those changes.

The second research question regarding the influence of environment over EF posed in the current thesis had to do with the extent with which SES predict individual differences in a wide range of superior cognitive skills, and whether SES influences the development of such skills over and above the effect of other individual factors, such as temperament, also shown to be related to high cognitive functions.

So far our data indicate that SES impacts neural processes underlying EF. However, the influence of the environment over EF is also influenced by the child's individual characteristics. As children develop, they show individual differences in their ability to regulate their reactions according to personal goals, likes, social norms, rules and context demands. They become more efficient in flexibly approaching situations they fear and inhibiting inappropriate behaviors (Ruff & Rothbart, 1996). The temperamental factor of EC has been constantly related to school competences and social adjustments, as well as to EF (M. R. Rueda, 2012). Attentional focusing, inhibitory control, perceptual sensitivity and low-intensity pleasure are the dimensions included in the temperamental factor of EC (Rothbart, 2007). Consequently, it is not surprising that many studies have reported that better performance in conflict tasks is related to high EC (e. g. Checa et al., 2008; Rothbart et al., 2003).

Both temperament and SES have been proved to affect children's superior cognitive skills, such as intelligence and EF. The drawback here is that these findings have been obtained in separated research fields with little, or null, communication between them. Very little is known about how SES and temperament intermingle to impact EF processes. In our third study we addressed this topic by taking measures on various dimensions related to temperament, family environment, as well as several measures within the umbrella of superior cognitive skills. Our results indicated that response speed, WM and intelligence are cognitive skills particularly influenced by SES, while conflict resolution and inhibitory control were primarily predicted by children temperament. Moderation analyses provided valuable information to better understand the interplay between cognition, environment and temperament. Executive attention (conflict resolution) was indeed affected by SES, but this influence was modulated by temperamental EC. Furthermore, parenting styles, that did not predict any behavioral outcome independently, modulated the impact of temperament over verbal IQ and WM. Interestingly, age was an important modulator on WM for both temperament and environment: WM performance reflect the benefits or disadvantages of environment and temperament as children grow older. This set of data indicates that the three processes under the concept of EF are influenced by temperament and environment in different ways.

Working memory, inhibitory control and attentional flexibility are functions linked to the PFC. Given the partially overlapping neuroanatomy one may expect to observe similar susceptibility to the environment and temperament in EFs. However, the PFC is a structure of protracted development that is rich in connections along other cortical and subcortical structures. Neuroimaging studies show that children recruit different brain areas than adults during performance of cognitive tasks. Increased recruitment of PFC, parietal cortex and striatum during development is related to better performance in a range of cognitive tasks (Bunge & Zelazo, 2006). For instance, it has been found that adults relied on dorsal lateral PFC and parietal regions for visuospatial WM task, while children showed limited activation of those structures and activation of a more diffuse network, primarily ventromedial regions for the same task (Scherf, Sweeney, & Luna, 2006). It has been also found that children do not recruit a region in the right ventrolateral PFC that adults engage for inhibition in flanker and go/no-go tasks (Bunge et al., 2002). According to these data, children rely on different brain structures than adults to perform EF tasks. These data suggest that the different skills may be subject to slightly different maturational processes involving distinct regions of the PFC. These differences may explain the disparity in the degree to which EF processes are influenced by temperament and environment shown in our third study.

It is important to notice that LSES is not necessary synonym of poverty. According to the United Nations, poverty involves more than the lack of income and productive resources to ensure a sustainable living, it includes hunger and malnutrition, limited access to education and other basic services, social discrimination and exclusion, as well as the lack of participation in decision making (http://undesadspd.org/Poverty.aspx). In our sample, the children within the group of LSES mostly came from a disadvantageous socioeconomic context rather than from poor families. Furthermore, due to the current economic situation in Spain, many families have experienced changes in their quality and style of life in the last years. It is possible that some families categorized in our study as LSES did not have a history of LSES. Therefore, our results cannot be generalized to children living in poverty. It has been emphasized that the timing, depth and duration of children's poverty experience has a substantial influence on their development, over and above current poverty (Brooks-Gunn & Duncan, 1997). We believe that this notion also applies to high SES: the timing, depth and duration of exposure to rich or poor environment determine the impact of such conditions in children development. For example, some evidence suggests that the duration of the effects of cognitive training are influenced by the duration and complexity of the training (Rueda et al., 2012). Nonetheless, it is worth to notice that we found differences between SES groups in neural response and behavioral outcomes even though the differences in SES were not extreme.

Traditionally, temperament was conceived as a static constitutionally-based construct that is subject to relatively little change throughout the life span. Currently, temperament is viewed as a predisposing set of characteristics that expresses according to the nature of the context in which the individual is functioning, much more defined by the interplay between genetic disposition and environmental factors, with the potential to systematically change over time (Wachs, 2006; Rothbart, 2011). It is likely that the SES acts as a contextual factor that favors or reinforces some temperamental characteristics and disgraces others. Jansen and colleagues (2009) found differences in temperament during infancy related to family stress and maternal psychological well-being, suggesting that SES plays a role in temperament since early years (Jansen et al., 2009). In our study sample, we did not control for differences in temperament between SES groups. More research is needed in order to know whether our results were or not affected by possible differences in temperament associated with SES.

7.3. Conclusions and future directions

Four to six year-olds show the slowest overall brain response among all age groups. At this young age, children have difficulties maintaining an adequate level of alertness during performance of cognitive tasks. Disengaging and shifting attention, suppressing distractors and solving of conflict, is challenging for them. In contrast, 7-9 year-old children show similar behavioral and brain activity patterns to 10-13 year-old children when it comes to processing warning and spatial cues. This pattern of results suggests the existence of an important developmental step in the attentional system during the first years of primary school. An important improvement in the efficiency of the attentional networks both at behavioral and neural level, was observed from 7-9 years of age, coinciding with the first years of primary education. In contrast to preschool, primary school involves a more constrained environment with richer and more complex information, which demand greater self-regulatory skills. Although preschool years constitute a period of great development, our data suggest that the beginning of primary school is also a period of developmental improvement in the attentional system. Nonetheless, as shown by our results and other prior studies, the EAN continues maturation throughout late childhood and adolescence (Rueda, 2014).

We also show evidence of the plasticity of the EF during the preschool period, and the significant improvements children obtained when they are exposed to rich environments. Children from HSES background appeared to process conflict and errors using a more efficient recruitment of neural resources than LSES. At the behavioral level, HSES was also associated with better performance in EF tasks.

Only recently SES has been included as an independent variable in the study of cognition. Most of what we know about cognitive development has been obtained from data that have not taken into account the influence of the environment. Even more, it is very likely that studies about typical development have been done with samples from middle and high SES populations, which usually have more access to institutional resources and information and may also be more prone to participate in researches. Despite the complexity that is intrinsic to the concept of SES, it seems to be a stable indicator of the environment of the family in which the child develops. This concept clearly captures family differences in at least three pieces of information: parental education, parental occupation, and income. According to our data, these factors are stronger predictors of differences in EF and intelligence above other environmental variables included in our study, such as family demography, leisure activities or extracurricular activities.

Not that recent in the study of cognition is the topic of temperament as a way to study individual differences in behavior and cognitive performance. However, little is known about how temperament and environment interact to impact EF. We found that EF processes are influenced in different degrees by temperament and environment. WM was the EF process more affected by environment, while inhibitory control appeared to be mostly influenced by temperament. Nonetheless, SES moderated the relationship between temperament and conflict resolution, indicating that SES is particularly important for children showing poor regulatory skills. These results highlight the importance of including both SES and temperament as variables to control for in the research of child development.

EF and intelligence are of great importance in daily activities throughout life. Planning, monitoring, shifting attention from one focus to another, solving problems, flexibly changing strategies when needed and suppressing temptation and automatic responses when they are not appropriated, are basic and complex operations that we have to perform in a daily basis. Such processes are in the foundation of the regulation of our thoughts, emotions and behaviors, which allow us to successfully cope with the demands of others and our own goals. Our results are consistent with a big body of literature that indicates that EF is very malleable during childhood. We found that the environment not only directly affects intelligence and other EF processes, but it also moderates the relationship between cognition and temperament. Moreover, our work connects neural, cognitive, temperamental, and behavioral levels of analysis providing data that help to better understand individual differences in EF during preschool years. Both the behavioral and neural results obtained in our studies offer information that can be used in the implementation of adequate experiences and scenarios that boost the development and improvement of EF processes during preschool years.

Chapter 8.

Resumen en español

8.1. Introducción

El trabajo presentado en esta tesis tiene dos vertientes: 1) estudiar el desarrollo de las redes atencionales a lo largo de la infancia y los mecanismos electrofisiológicos subyacentes; y 2) examinar el impacto (a nivel comportamental y neuronal) de factores ambientales tales como nivel socioeconómico (NSE), estilos de crianza y las actividades familiares, en el desarrollo de altas habilidades cognitivas en niños prescolares.

Esta tesis tiene como marcos teóricos de referencia el modelo neurocognitivo de la atención de Michael Posner (Posner & Petersen, 1990) y el concepto de función ejecutiva propuesto por Miyake y colaboradores (Miyake et al., 2000) y el modelo de temperamento de Mary Rothbart (M. Rothbart, 1989).

El modelo neurocognitivo de Posner propone tres redes atencionales que sustentan las funciones de alerta, orientación y atención ejecutiva. Estas redes son neuroánatómicamente independientes. En términos generales la alerta se relaciona con vigilancia y alerta tónica (capacidad de responder rápidamente a estímulos salientes y/o relevantes); la orientación implica tanto la orientación a estímulos que han sido seleccionados para ser procesados, como la habilidad de desenganchar la atención de un punto de focalización y re-orientarla a un nuevo foco de atención; y la atención ejecutiva se encarga de procesos de alto nivel, como resolución de conflicto, control inhibitorio, planificación y monitorización (Petersen & Posner, 2012).

Por otra parte, el concepto de función ejecutiva se relaciona con procesos de control inhibitorio, memoria de trabajo y flexibilidad atencional (Miyake et al., 2000). El control inhibitorio denota la habilidad para suprimir respuestas automáticas y dominantes cuando éstas no son adecuadas; memoria de trabajo alude a la capacidad de mantener y actualizar información durante un periodo de tiempo relativamente corto; y flexibilidad atencional es la capacidad para ajustar el comportamiento a las demandas de la situación de forma flexible, y de cambiar de una tarea a otra según determinadas reglas.

Finalmente, el modelo de Rothbart utiliza tres factores para explicar el temperamento en la niñez: extraversión, afectividad negativa y control con esfuerzo. Los dos primeros están relacionados al aspecto de reactividad del temperamento, conductas de aproximación positiva y evitación negativa, respectivamente, mientras que el control con esfuerzo es aspecto de auto-regulación del temperamento que se define como la habilidad del niño para resolver conflicto, inhibir respuestas dominantes, planificar y detectar errores (M. K. Rothbart & Rueda, 2005). Es sabido que las características temperamentales influyen patrones y estrategias de procesamiento cognitivo (Checa, Rodríguez-Bailón, & Rueda, 2008).

Como el lector habrá dado cuenta, hay solapamiento conceptual entre los conceptos de atención ejecutiva, función ejecutiva y control con esfuerzo. Los tres conceptos implican procesos de control cognitivo y son medidos con tareas similares en el contexto de laboratorio, específicamente tareas que implican resolución de conflicto e inhibición de respuesta. Se ha demostrado que estas funciones de alto nivel cognitivo maduran contantemente durante la niñez, experimentando un progreso importante durante la edad prescolar (Carlson, 2005; Huizinga, Dolan, & van der Molen, 2006). Además, los tres conceptos se asocian a la activación de la corteza prefrontal y el cíngulo anterior, las cuales tienen un desarrollo tardío, llegando a la madurez después de la adolescencia (Luna, Garver, Urban, Lazar, & Sweeney, 2004).

Debido a tardía maduración de la corteza prefrontal y el cíngulo anterior estas estructuras son susceptibles a la influencia del ambiente por un periodo prolongado, mayor que el de otras estructuras cerebrales que maduran antes. Actualmente el estudio de la influencia del ambiente en la maduración y funcionamiento cerebral ha ganado terreno. Especialmente modelos de investigación animal evidencian el impacto del entorno en medidas cerebrales micro, desde nivel anatómico hasta molecular (Sale, Berardi, & Maffei, 2009). Contextos cognitiva y emocionalmente enriquecidos estimulan maduración cerebral y eficiencia de procesamiento. Por el contrario, ambientes cognitiva y emocionalmente pobre impactan negativamente a nivel neural, cognitivo y comportamental. Datos obtenidos con humanos van en la misma dirección (Hackman &

Farah, 2009). El NSE es una medida típica usada en el estudio del impacto del ambiente durante el desarrollo (Bradley & Corwyn, 2002). Educación, ocupación e ingreso, son los tres indicadores clásicos de NSE.

En base en lo hasta aquí expuesto surgen las siguientes preguntas de investigación:

1. Cuáles son los mecanismos neurales subyacentes al desarrollo de las redes atencionales?

2. ¿El nivel socioeconómico afecta mecanismos neurales relacionados con el procesamiento del conflicto y errores?

3. ¿Es el ambiente familiar un predictor de habilidades cognitivas de alto nivel más allá de la influencia del temperamento?

8.2. Los correlatos electrofisiológicos de las redes atencionales en la niñez y la adultez temprana.

Para responder a la primer pregunta de investigación utilizamos la ANT (por sus siglas en ingles Attentional Networks Task) en una versión modifica (Callejas, Lupiañez, & Tudela, 2004) y adaptada para niños en un rango de edad de 4 a los 13 años (n=46) y en un grupo de adultos (n=15). Mientras que los participantes realizaban la tarea registramos su electroencefalograma (EEG) para hacer análisis de potenciales evocados (ERP por su siglas en ingles; Event Related Potentials). Con el fin de estudiar diferencias en el desarrollo dividimos nuestra muestra en 4 grupos de edad: 4-6, 7-9 y 10-13 años de edad, más un grupo de adultos jóvenes. La tarea ANT ofrece medidas de eficiencia de cada una de las redes atencionales ya que combina una tarea tipo flancos con la presentación de distintas señales de alerta y orientación. La versión de la ANT utilizada proporciona una mejor medida de a) la red de orientación mediante la inclusión de pruebas con claves inválidas, y b) las interacciones entre las redes de alerta y orientación.

Datos anteriores a nuestro estudio, usando la ANT infantil original (Rueda et al., 2004) en niños de 6 a 10 años y adultos, mostraron trayectorias de desarrollo independientes para cada red. Las puntuaciones de alerta mostraron estabilidad en la infancia, aunque los niños obtuvieron puntuaciones de alerta más altas que los adultos; no hubo diferencias de puntuación en la orientación entre niños y adultos; y, la puntuación de atención ejecutiva fue similar desde la edad de 7 años hasta la edad adulta.

Nuestros datos indican que: 1) la eficiencia de la red de alerta en niños de 10-13 años de edad es similar a la de adultos; 2) la orientación mostró un desarrollo prolongado cuando se miden los procesos de desenganche y la re-orientación de la atención: niños de 10-13 años de edad fueron menos eficientes que los adultos; 3) la red de atención ejecutiva mostró una mejora lineal a través de desarrollo, sin embargo, no está completamente madura hacia el fin de la infancia.

Usando la versión modificada de la ANT encontramos una trayectoria prolongada en de desarrollo de la orientación. El desenganche de la atención de un lugar u objeto y el cambio de atención a un objeto o lugar diferente implica la activación de una red cerebral fronto-parietal, cuya función no se desarrolla completamente sino hasta la infancia tardía o la adolescencia temprana. Más aún, encontramos que, contrario a niños mayores y adultos, las señales de alerta facilitaron la resolución de conflicto en niños de 4-6 años de edad, lo que refleja la dificultad de mantener un nivel adecuado de activación en esta edad cuando no hay señal.

En cuanto a las interacciones entre las redes atencionales encontramos que tanto las condiciones de alerta como de orientación modulan la eficiencia de la atención ejecutiva. Al igual que en los adultos (ver Callejas et al., 2005), los niños muestran una facilitación para la supresión de flancos y, por tanto, la resolución de conflictos, cuando orientan la atención a la ubicación en la que el target aparecerá (como cuando se proporcionan señales de orientación válidas). Por otro lado, la habilidad para la resolución de conflicto se afecta en condiciones de alto nivel de activación, como es el caso en la presentación de señales de alerta (Callejas et al, 2005; Weinbach y Henik, 2012). Sin embargo, los niños de 4-6 años fueron más precisos en los ensayos con señal de alerta. El hecho de incluir en nuestro estudio condiciones que reducen la eficiencia de la atención ejecutiva (es decir, las señales no válidas y los tonos de aviso) podrían explicar la inconsistencia de nuestros resultados con resultados anteriores obtenidos con otras versiones de la ANT.

Nuestros resultados de ERP revelan diferencias de desarrollo entre los niños y adultos en el procesamiento rápido. Los componentes tempranos tomados como índice de procesamiento de señales de alerta y orientación, aparecieron atrasados en niños, y, en algunos casos, ausentes en niños de 4-6 años de edad. Aunque los niños y los adultos son más parecidos en el procesamiento lento, los niños muestran retraso de respuesta electrofisiológica y efectos más sostenidos, como se muestra por el P3 extenso en niños relacionado al procesamiento de señales de orientación y el N2 tardío en niños de 10 a 13 años de edad, relacionado al procesamiento de la interferencia de flancos.

En conclusión, los datos de nuestro primer experimento indican que el tiempo de procesamiento durante la niñez parece estar basado en las respuestas cerebrales más sostenidas y más lentas, en comparación con los adultos. Tal patrón de tiempo de procesamiento se asocia con una conectividad inmadura durante la infancia.

Nuestros hallazgos en este primer experimento constituyen una herramienta útil para el diseño e implementación de programas de entrenamiento y/o intervención durante la infancia que tengan como objetivo impactar procesos atencionales y de control ejecutivo. Dado que la ANT es una tarea ampliamente usada en distintas disciplinas, nuestro resultados suponen una aportación tanto teórica como práctica en el estudio del desarrollo cognitivo. Adicionalmente, profundizar en las bases neuronales de la atención contribuye en el entendimiento de los mecanismos que subyacen a patologías del desarrollo que involucran la atención y control ejecutivo, ayudando tanto en la evaluación clínica, como en el entendimiento de las alteraciones de la atención.

8.3. El impacto del nivel socioeconómico en los correlatos electrofisiológicos de procesamiento del conflicto y error en niños prescolares.

El objetivo de esta serie experimental fue el establecer una conexión entre medidas de nivel macro tales como nivel socioeconómico y medidas de nivel micro, tales como la activación cerebral. Para ello, usamos una versión modificada de la tarea de flancos adaptada al uso con niños, la cual fue diseñada para evaluar de forma separada la activación asociada al estímulo objetivo y la activación asociada al procesamiento de la respuesta. 69 niños participaron en este estudio, 33 de bajo NSE y 36 de alto NSE. Los componentes de activación cerebral N2, N450, Negatividad Asociada al Error (ERN por sus siglas en ingles) y Pe, fueron utilizados como marcadores electrofisiológicos del procesamiento del conflicto y el error. En esta parte nos enfocamos en las diferencias de amplitud de la activación entre los grupos de nivel socioeconómico en los componentes de activación mencionados más arriba.

Encontramos diferentes patrones de respuesta neural al procesamiento del conflicto y el error en nuestros grupos. Los niños be alto NSE mostraron una activación cerebral relacionada con un procesamiento más eficaz. Solo el grupo de alto NSE mostró efecto de conflicto en el componente N2, igualmente, solo el grupo de alto NSES mostró el ERN. Cabe señalar que estos componentes generalmente aparecen al final de la niñez, incluso hasta la adolescencia (Checa, Castellanos, Abundis-Gutiérrez, & Rueda, 2014; Davies, Segalowitz, & Gavin, 2004).

Nuestros datos sugieren diferencias en el dominio del tiempo de procesamiento entre niños prescolares de bajo y alto NSES. Nuestros resultados sugieren que el contexto provisto por un alto NSE favorece la maduración de procesos cognitivos de alto nivel, como lo sugieren el hecho de que el grupo de alto NSE mostró tiempos de procesamiento similares a los observados en niños mayores.

Los cambios en tiempo de procesamiento parecen ser una herramienta importante en el estudio de las bases neurales del desarrollo. Los ERP ofrecen información valiosa para caracterizar los cambios neurales que ocurren durante la niñez, y de esta forma poder evaluar cómo otros factores, como el NSES, impactan en el desarrollo.

8.4. Influencias del temperamento, el nivel socioeconómico y otras variables ambientales en habilidades cognitivas de alto nivel

Existe una gran cantidad de estudios que indican que el nivel socioeconómico afecta el desarrollo cognitivo de los niños. Sin embargo, nosotros estábamos interesados en explorar el impacto de otras variables que pueden ser un indicador potencial de la riqueza o pobreza de la estimulación social y cognitiva en el ambiente familiar en el que los niños se desarrollan. Para ello, elaboramos un cuestionario con el objetivo de tener un índice del ambiente familiar que fuera más allá de las medidas tradicionales de nivel socioeconómico (educación u ocupación de los padres, ingresos económicos).

Para esta serie experimental recogimos una gran variedad de medidas cognitivas incluyendo: inteligencia verbal y fluida, tiempo de reacción, resolución del conflicto, control de la inhibición, memoria de trabajo y regulación emocional.

Además, se sabe que el temperamento esta asociado con diferencias individuales en las funciones ejecutivas. Por esta razón, también hemos incluido medidas de temperamento con el objetivo de explorar de qué forma el nivel socioeconómico puede explicar diferencias en las funciones ejecutivas, una vez se ha controlado por lo que hemos denominado "características del niño" que en este caso incluyen edad, genero y temperamento.

Con el objetivo de evaluar la influencia del nivel socioeconómico en nuestras medidas comportamentales después de controlar por las características del niño y otras variables ambientales, usamos un análisis de regresión jerárquica. De todas formas, es muy probable que las medidas de función ejecutiva se ven influenciadas por la interacción entre variables ambientales y las características del niño. Para evaluar esta posibilidad, hemos implementado un análisis de moderación para observar cómo las variables elegidas se relacionan entre sí para explicar la varianza en nuestros datos.

Nuestros resultados indican que tiempo de reacción, memoria de trabajo e inteligencia son influenciadas por el NSE, mientras la resolución de conflicto y el control inhibitorio son principalmente predichos por el temperamento de los niños. Los resultados de análisis de moderación proporcionan amplían el dato permitiendo obtener una visión mas amplia de la relación entre cognición, medio ambiente y temperamento. Encontramos con que la resolución de conflicto se vio afectada por el NSE, pero esta influencia fue modulada por el factor temperamental de control con esfuerzo. Los estilos de crianza (que no predijeron la varianza en ninguna de nuestras medidas cognitivas), modularon el impacto del temperamento sobre la inteligencia verbal y la memoria de trabajo. Además, la edad fue un importante modulador del efecto del temperamento y el medio ambiente en la memoria de trabajo. Según nuestros resultados la memoria de trabajo es afectada o beneficiada por el entorno y el temperamento a medida que los niños crecen. Este conjunto de datos indica que los tres procesos bajo el concepto de EF están influenciados de forma diferente por el temperamento y el medio ambiente.

En resumen, nuestros datos muestran evidencia de la plasticidad de la función ejecutiva durante edad prescolar y el mejoramiento significativo que los niños obtienen cuando se desarrollan en ambientes cognitivamente ricos. Aparentemente, niños de alto NSE procesan el conflicto y el error presumiblemente mediante un reclutamiento neuronal mas eficiente que los niños de bajo NSE. Esta disparidad en eficiencia también se observó a nivel comportamental.

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Appendix

Universidad de Granada

LNCD
Laboratorio de Neurociencia Cognitiva del Desarrollo

CUESTIONARIO PARA FAMILIARES

Estimado Familiar,
Permítanos **agradecerle una vez más su disponibilidad** para participar junto con su hijo/a, en este estudio. Gracias a su colaboración podemos profundizar en el conocimiento del desarrollo de la atención en niños en edad pre-escolar. Aunque este estudio implica principalmente la realización de actividades por parte de su hijo/a, necesitamos alguna información adicional que sólo usted puede proporcionarnos. Para ello, hemos diseñado este cuestionario para que no le ocupe demasiado tiempo. Recuerde que **toda la información que nos proporciona es de carácter confidencial** por lo que sólo será conocida por los profesionales que forman parte de nuestro equipo y en ningún momento será utilizada de modo que usted o su hijo/a puedan ser identificados.

A rellenar por el personal:
Num. Exp. ____________________

Fecha de hoy D____ M____ A_____

DATOS DEMOGRÁFICOS

Ciudad de nacimiento del niño _________________ Provincia___________________

País__________________ Curso en el que se encuentra_________________

Si no nació en España, ¿A qué edad llegó a España? _______________

INFORMACIÓN SOBRE LA UNIDAD FAMILIAR

Señale cuántas personas conviven en la casa:

Adultos ☐

Niños ☐

Señale cuáles (con una *X*):

Padre____ Madre____ Hijos ____ Otros____

¿Cuáles? ______________________________

¿Cuántos hermanos tiene el niño/a? ☐

¿Qué posición ocupa entre los hermanos? ☐

¿Qué idioma se habla habitualmente en casa?

____

Señale cuál es su situación:

Solo padre o madre (o tutor) convivo con el niño/a ☐

Padre y madre convivimos con el niño/a ☐

¿Cuánto dinero diría usted que ingresa su familia en total al mes (ingreso mensual neto)? Indique el total de TODOS LOS INGRESOS, incluyendo becas, ayudas, aportaciones de pareja divorciada, etc.

Menos de 750€	751-1200	1201-1600	1601-2200	2201-3000	3001-4000	Más de 4000€
☐	☐	☐	☐	☐	☐	☐

¿Cuantas personas hacen aportes a este ingreso? __________

ENTORNO FAMILIAR

Indique cuánto tiempo pasa a diario con su hijo
(Déjelo en blanco si alguna de las opciones no aplica)

	Menos de 2 horas	Entre 2 y 4 horas	Entre 4 y 6 horas	Más de 6 horas
Madre				
Padre				
Abuelos				
Cuidadores/Familiares (diferentes de padres o abuelos)				

En casa…

1. Tenemos libros, revistas, novelas	SI	NO
2. Tenemos ordenador	SI	NO
3. Tenemos conexión a internet	SI	NO
4. Contamos con un espacio de estudio	SI	NO

Señale con que frecuencia se realizan las siguientes actividades:	Nunca	Menos de una vez al mes	Una o dos veces al mes	Al menos una vez por semana	Más de 3 veces por semana
1. Leemos libros, cuentos, novelas con el niño					
2. Visitamos exposiciones, centros culturales con nuestro hijo					
3. Realizamos actividades culturales con el niño (ir al teatro, conciertos, al circo)					
4. El niño asiste a una actividad extraescolar (deporte, aprender a tocar un instrumento)					

SOBRE SU HIJO

Indique la cantidad de tiempo que su hijo invierte a diario haciendo…
(Señale la casilla "no aplica" si su hijo no realiza esa actividad)

	Menos de una hora	Entre una y dos horas	Entre dos y tres horas	Más de tres horas	No Aplica
1. Ver la televisión					
2. Jugar con videoconsola u ordenador					
3. Jugar con otros niños (hermanos o amigos)					
4. Jugar solo con juguetes diferentes al ordenador (puzzles, pintar)					

Sobre el periodo de gestación y parto

1. ¿Su hijo nació a termino? SI NO

En caso negativo, ¿cuantas fueron las semanas de gestación? ___________

2. ¿Hubo problemas en el parto? SI NO

En caso afirmativo, indique cual ____

3. Indique si su hijo ha presentado o presenta alguna dificultad o patología que haya sido diagnosticada por un profesional
SI NO

En caso afirmativo, indique cuál(es)____

INFORMACIÓN SOBRE EL PADRE O TUTOR

La información que se pide a continuación se refiere al **padre del niño/a, si mantiene contacto con el niño/a,** aunque no viva con él (por ejemplo, los fines de semana). **Si el padre NO mantiene ningún contacto con el niño, déjelo en blanco.**

Rodee con un círculo todos los cursos que haya realizado. No importa si ha obtenido el título o no.

Primaria/ EGB	1° 2° 3° 4° 5° 6° 7° 8°
ESO	1° 2° 3° 4°
Bachillerato/BUP/ COU	1° 2° 3° COU
FP	1°FP1 2°FP1 1°FP2 2°FP2 1°FP3 2°FP3
Ciclo Formativo	Medio 1 Medio 2 Sup1 Sup2
Universidad	1° 2° 3° 4° 5°
Otros (Cuáles)	

Señale qué títulos tiene:

- Certificado de Estudios Primarios ☐
- Graduado Escolar o en Educación Secundaria ☐
- Formación profesional Primer Grado (FP1) ☐
- FP2 o Ciclo Formativo de Grado Medio ☐
- FP3 o Ciclo Formativo de Grado Superior ☐
- BUP ☐
- COU o Bachillerato ☐
- Diplomatura Universitaria ☐
- Licenciatura Universitaria ☐
- Otros, ¿Cuál? ☐

____

¿Dónde nació?

Provincia___________________________

País_________________________________

¿Qué idioma/s habla habitualmente?
(Aunque no sea en casa)

____

¿Cuál es su situación laboral actual?

- Trabajo indefinido o funcionario ☐
- Trabajo temporal ☐
- Desempleado/a ☐
- Jubilado/a, incapacidad laboral permanente o retirado ☐
- Estudiante ☐
- Amo/a de casa ☐
- Otro ☐

Indique cuál__________________________

Ocupación

¿Cuál es el nombre de su puesto (o en el que trabajó por última vez si está desempleado o jubilado)? (por ejemplo, técnico administrativo, gerente, mecánico, etc.)

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¿Dónde trabaja actualmente (o trabajó por última vez si está desempleado o jubilado?) (por ejemplo, en un taller de automóviles, en un hospital, en una tienda, etc.)

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INFORMACIÓN SOBRE LA MADRE O TUTORA

La información que se pide a continuación se refiere a la **madre del niño/a, si mantiene contacto con el niño/a,** aunque no viva con él (por ejemplo, los fines de semana). **Si la madre NO mantiene ningún contacto con el niño, déjelo en blanco.**

Rodee con un círculo todos los cursos que haya realizado. No importa si ha obtenido el título o no.

Primaria/ EGB	1° 2° 3° 4° 5° 6° 7° 8°
ESO	1° 2° 3° 4°
Bachillerato/BUP/ COU	1° 2° 3° COU
FP	1°FP1 2°FP1 1°FP2 2°FP2 1°FP3 2°FP3
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- BUP ☐
- COU o Bachillerato ☐
- Diplomatura Universitaria ☐
- Licenciatura Universitaria ☐
- Otros, ¿Cuál? ☐

____

¿Dónde nació?

Provincia_________________________

País______________________________

¿Qué idioma/s habla habitualmente?
(Aunque no sea en casa)

____

¿Cuál es su situación laboral actual?

- Trabajo indefinido o funcionario ☐
- Trabajo temporal ☐
- Desempleado/a ☐
- Jubilado/a, incapacidad laboral permanente o retirado ☐
- Estudiante ☐
- Amo/a de casa ☐
- Otro ☐

Indique cuál________________________

Ocupación

¿Cuál es el nombre de su puesto (o en el que trabajó por última vez si está desempleado o jubilado)? (por ejemplo, técnico administrativo, gerente, mecánico, etc.)

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