TESIS DOCTORAL

Early Development of Executive Attention

(Desarrollo temprano de la Atención Ejecutiva)

DOCTORANDA

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Diciembre de 2016

Editor: Universidad de Granada. Tesis Doctorales
Autora: Ángela Conejero Barbero
ISBN: 978-84-9163-115-6
URI: http://hdl.handle.net/10481/44949

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Para aquellos que a mi lado, me han acompañado durante esta etapa.

Esto también os pertenece de alguna manera.

Sin vosotros no hubiera sido posible.

AGRADECIMIENTOS

He de empezar dando gracias a todas las familias parte de este estudio y cuyo compromiso ha hecho posible una investigación como la que aquí se presenta. Gracias papás y mamás por vuestro interés y disposición. Gracias a vuestros hijos, por haberme concedido el privilegio de verlos crecer estos años: espero que recuerden la experiencia con cariño y puedan alguna vez leer este trabajo.

Mi agradecimiento a todos y cada uno de los miembros del tribunal, Pío Tudela, Ana Chica, Carmen González, Andrea Berger y Laura Bosch por aceptar revisar este trabajo. Espero que lo disfruten tanto como me ha hecho disfrutar a mí. I would also like to thank professor Mike Posner and professor Laura Visu-Petra for accepting reading this work and their comments on it.

A mis compañeros, porque simplemente no hubiera sido lo mismo sin el olor del café a media mañana, el chiste que te despierta del letargo de un análisis eterno, el consejo a tiempo, los momentos de agobio colectivo, la confidencia a media voz o esas tartas compartidas. Gracias por esos momentos.

A mi familia y amigos, por todas las manos tendidas, por vuestra comprensión infinita, por saberme entender tan bien y fingir tan bien entenderme. Porque a pesar de todo, siempre sabéis cómo arrancarme una sonrisa. Y por encima de todo, porque todo lo que soy os lo debo a vosotros. Vuestros ánimos alentaban mi esfuerzo. Millones de gracias.

Por último, Charo, siempre te estaré agradecida por toda la confianza que pusiste en mí desde el comienzo. Porque me acogiste con los brazos abiertos. Porque cada pequeño paso que avanzaba lo recibías con

entusiasmo. Porque siempre encontraste la forma de estar ahí, haciendo lo imposible por engañar al tiempo. Y porque eres la principal culpable de que un día todo esto comenzara: gracias por descubrirme un campo de la psicología tan fascinante.

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CHAPTER 1: INTRODUCTION

1.1 EXECUTIVE ATTENTION

1.1.1 WHAT IS EXECUTIVE ATTENTION

Everybody in everyday life frequently uses terms that refer to attentional processes. People usually encourage others to “pay more attention” when they are not “concentrated” in the task, identify that a noise is “distracting” them when they cannot avoid to involuntarily “focus” on it, and they exclaim “watch out!” to “warn” someone of a risk in order “to be prepared” to react. Underlying all these expressions there is an intuitive conception of attention as the capacity that allow us to act according to our goals by selecting the relevant information and maintaining a certain mental state. In fact, the term attention is commonly used in ordinary language. This could drive us to the conclusion that attention is a quite clear concept, as conveyed by William James (1890) in his popular sentence: “Everyone knows what attention is”. However, the truth is that numerous authors along the history of Psychology have long debated (if not to say that the debate is still open) about what aspects of cognition and behaviour should be included in the construct of attention.

During the early years of Psychology, authors associated attention with consciousness. That was the case of William James (1890) or Wilhelm M. Wundt (1874), stating that anything in our consciousness was necessarily first attended. Later, some models conceptualized attention as a selection filter. This view of attention fits well with that of Aristotle, who already in antiquity identified attention with a system capable to focus our senses (Robinson, 1989). We are compelled to extract the relevant information from a cluttered world. Filter models were concerned about our limited capacity to consciously process an amount of information at the same time. However, authors did not come to an agreement in the allocation of the filter, and whereas early selection theories defended that information was filtered before processing stimuli (Broadbent, 1958), according to late selection theories the filter operated after cognitive processing (Deutsch & Deutsch, 1963; Norman, 1968).

Later, Kahneman (1973) introduced the idea of a central system (similar to a central processor, probably inspired by the advances of that time in Computer Sciences) able of coordinating the different cognitive systems and assigning priorities depending on the difficulty of every task to be accomplished. Kahneman alluded to a general-purpose mechanism whose main function was to deploy the cognitive resources to optimize performance. Considering the role of attention in controlling cognition and behaviour, this model of attention approximates to what we understand today for executive attention. Other authors continued developing this idea of attention as a mechanism of control. Norman and Shallice (1986) made a distinction between those automatic and controlled processes. According to their model, we generate a repertoire of schemas of action as a product of learning and practice. Different schemas of actions are automatically activated as a default in certain situations, permitting an efficient and quick response. However, there are some situations in which attention control is preferable. Authors identified 4 circumstances in which controlled attention should be exerted: in novel situations, to adjust behaviour after committing errors or to resolve any conflict, to prevent a danger or overcoming any difficulty, and to suppress strong habits, routines or predispositions.

To this point, authors had distinguished three main functions of attention (Posner & Boies, 1971): attention as state, attention as a selection mechanism and attention as a system of control. Attention as state applies to the need of maintaining a high sensitivity to incoming information and it is also referred in literature as vigilance, alert or sustained attention. Attentions as selection mechanism (also identified as selective attention or orienting) represents the ability to ignore some information in order to focus on the most relevant information. Attention as a system of control alludes to the ability to cope with conflicting information or competing responses and inhibiting that inappropriate according to our goals or the contextual demands.

Further developments in experimental psychology and neuroscience confirmed the structure of attention into these three main components. Posner and Petersen (Posner & Petersen, 1990) presented an integrative model of attention that considered attention not as a unitary construct, but as an umbrella construct that encompassed those three different aspects of attention. In their Attention Networks Model, Posner and Petersen differentiated between three different neural networks coinciding with the three previously described functions of attention: alerting network, orienting network and executive control network (see Figure 1.1). The first one, the alerting network, is described as the mechanism responsible for maintaining a mental state that allow individuals to sustain a particular activity in time and be prepared to react to environmental changes. Thalamic, parietal and right frontal structures of the brain have been suggested to conform the alerting network (Fan, McCandliss, Fossella, Flombaum, & Posner, 2005), being modulated by norepinephrine levels (Fossella et al., 2002). The orienting network is the one involved in the selection of information from sensory input and in shifting attention allocation. Evidence has related the orienting network to parietal brain structures, such as superior parietal lobe and the temporal parietal junction, frontal eye-fields and superior colliculus

(Corbetta & Shulman, 2002; Fan et al., 2005). In this case, the neurotransmitter acetylcholine has demonstrated to have key role in regulating this network (Fan, Wu, Fossella, & Posner, 2001). Finally, the executive attention network is contemplated like a control mechanism responsible of the control of sensorial information input, behaviours, thoughts and emotions. Research had associated this network with prefrontal brain structures, in particular to anterior cingulate cortex (Fan et al., 2005; Neuhaus et al., 2010; Westlye, Grydeland, Walhovd, & Fjell, 2011). More recently, in a review of their model, Petersen and Posner (2012) reconsider the initial division of attention into three networks and include a subdivision for the executive attention network. Authors distinguish now between the dorsolateral prefrontal network, implicated in switching between mental sets, and the cingulo-opercular network, responsible of maintaining the mental set. Dopaminergic system has been largely associated with this attention network. Low levels of dopamine in prefrontal areas of the brain has been associated with difficulties in inhibitory control, attention flexibility and conflict resolution (Brocki, Clerkin, Guise, Fan, & Fossella, 2009; Fan et al., 2001; Posner, Rothbart, Sheese, & Voelker, 2012).

Cognitive skills that involve executive attention traditionally has been enclosed under the term of “executive functions” in literature (Diamond, 2013): inhibiting a prepotent or automatic response in favour of another one more adequate to the current context or goal, self-control in arousing contexts, flexibility in adapting to new environmental demands, monitoring changes in upcoming stimulation and own internal states, and the ability to manage with conflicting information. However, executive functions is a broader construct that not only include those cognitive processes related to inhibitory control and cognitive flexibility, but also those related to working memory (Miyake et al., 2000). Thus, executive attention partly overlaps with executive functions, corresponding to executive functions under inhibitory control and cognitive flexibility domains.

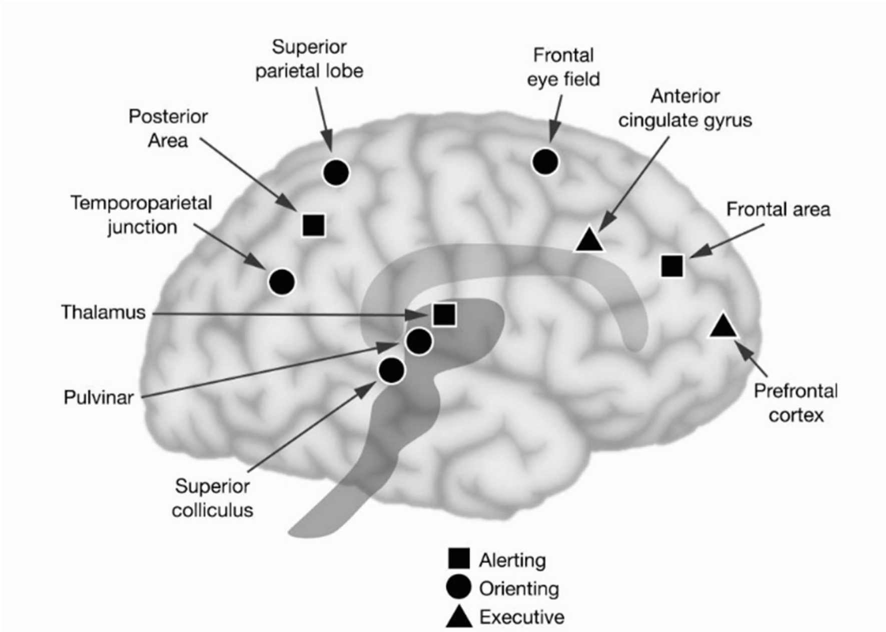


Figure 1.1. Anatomical areas of attention networks (Posner & Rothbart, 2007).

The study of executive attention skills has concerned to numerous researchers in the field of developmental psychology due to its implication in a wide range of developmental outcomes. Executive attention skills are thought to underlie the development of more complex cognitive processes, such as problem resolution and reasoning, which reside at the core of fluid intelligence (Burgess, Gray, Conway, & Braver, 2011; Rose, 2004; Sigman, Cohen, & Beckwith, 1997). In fact, brain structures associate with general intelligence largely correspond to that in the executive attention network (Duncan et al., 2000) and predicts school competence (Purificacion Checa & Rueda, 2011). Likewise, executive attention is thought to be on the basis of the development of self-regulatory skills, sharing common neural substrates (Rothbart, Sheese, Rueda, & Posner, 2011) and predicting later social adjustment, as well as internalizing and externalizing problems (Lengua, 2003). In the next section I will review the evidence on the contribution of executive attention to the development of the different self-regulation mechanisms and its implication for learning and psychosocial adjustment.

1.1.2 Executive attention and self-regulation

As it was already mentioned, one important aspect of executive attention is its implication for self-regulation. Self-regulation refers to the control of thoughts and behaviour according to goals and is implicated in modulating affect, controlling impulses, and behaving according to rules (Baumeister & Vohs, 2004). Importantly, self-regulation has been demonstrated to be a fundamental factor for academic success and social adjustment (Checa, Rodríguez-Bailón, & Rueda, 2008; Gumora & Arsenio, 2002). Poor self-regulation is also predictive of behavioural problems in addition to anxiety and ADHD symptomatology (Lawson & Ruff, 2004).

Self-regulation is a challenging chore that entails executive attention. Self-regulation also involves inhibitory control in “hot” situations, that is highly arousing situations or situations with an emotional component (Ochsner & Gross, 2005). Thus, motivation and emotion are central aspects in the self-regulation concept. In fact, self-regulation and executive attention are considered overlapping constructs to some degree, and it has been suggested that self-regulatory skills are built on the basis of the development of executive attention (Rothbart et al., 2011). According to

Rothbart and colleagues, self-regulation primarily relies on attention orienting mechanisms in early years, such as disengagement of attention. Children develop more complex regulation strategies depending on executive attention as prefrontal structures of the brain develop.

Empirical research has confirmed the suggested close relationship between self-regulation and executive attention. Individual differences in executive attention have been associated with differences in the capacity to self-regulate, with performance in executive attention tasks being positively related to self-regulatory skills in typical delay of gratification tasks (Gyurak et al., 2012; Hongwanishkul, Happaney, Lee, & Zelazo, 2005; Schmeichel & Tang, 2014). Executive attention deficits have been also observed in certain psychopathological conditions characterized by alterations in self-regulation such as anxiety disorders or depression (see Banich et al., 2009 for a review). Moreover, there is evidence showing that training pre-schoolers in executive attention by means of a set of computerized games not only improves children's executive attention, but also transfer to the ability to self-regulate behaviour as measured with an adapted version of the adult gambling task (Rueda, Checa, & Cómbita, 2012). Likewise, mindfulness meditation practice based on the control of attention in order to achieve a state of focused attention, which engages the executive attention network, has also a positive effect on self-regulatory skills (Tang, Posner, & Rothbart, 2014).

Furthermore, neuroimaging studies indicate that activation of the executive attention network underlies self-regulation efforts. Children's individual differences in conflict processing and error monitoring at the electrophysiological level predict individual differences in self-regulation measured by delay of gratification and inhibitory control tasks (Abundis-Gutiérrez, Checa, Castellanos, & Rueda, 2014). Furthermore, studies using fMRI usually link activation of the ACC, a main node of the executive attention network, with self-regulation. For instance, research indicates that activation of the ACC precedes the reduction of amygdala response towards emotional stimuli, indicating a role in emotional regulation (Dolcos, Iordan, & Dolcos, 2011; Oschner & Gross, 2005).

Overall, the links between executive attention and self-regulatory skills has been established in this section. The section that follows moves on to introduce the primary measures of executive attention and self-regulation.

1.1.3 Measuring Executive Attention

Researchers in the field of cognitive psychology have ideated diverse methods to assess executive attention skills over the past years. A variety of experimental paradigms were designed with the purpose of dissociating between the different functions of executive attention permitting to observe individual differences. Thanks to the advances in computer sciences and the popularization of computers, experimental psychologists were able to include in their studies computerized tasks that allowed registering participants' reaction times with millisecond precision. In addition to new tasks, new versions of the old paper-based tasks were also produced. In the following lines, main experimental paradigms and tasks will be described in order to provide the reader with a general overview.

1.1.3.1 Conflict tasks

Conflict tasks measure the ability of individuals to manage conflicting information. In this kind of tasks, participants have to overcome cognitive conflict, ignoring some interfering information in order to achieve the main goal of the task. A conflict index is obtained by calculating the difference in performance between a congruent condition (where no interference is generated) and performance in an incongruent condition (where conflicting information is presented). Differences of smaller magnitude either in reaction time or accuracy between congruent and incongruent conditions are considered to reflect the more efficiency in resolving cognitive conflict, and thus, better executive attention. Subsequently, Stroop (Stroop, 1935), Flanker (Eriksen & Eriksen, 1974) and Simon (Simon, 1990) tasks are reviewed as the three more extensively experimental paradigms used to measure conflict processing. Figure 1.2 illustrates stimuli and procedure in each experimental paradigm.

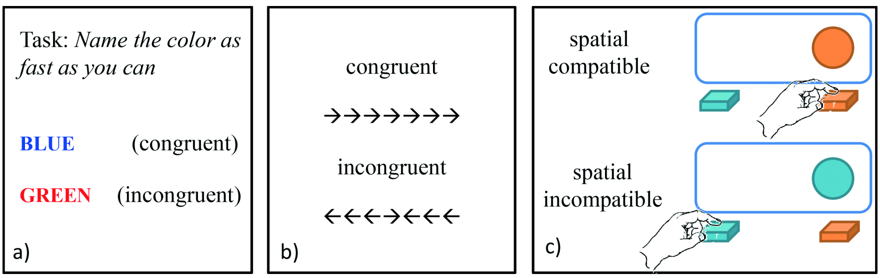


Figure 1.2. Illustration of congruent and incongruent conditions in the Stroop task (a), the Flanker task (b) and the Simon task (c).

The Stroop task consists on presenting participants with a list of words with the particularity that all the words in the list were names of colours. The ink in which each colour name is printed is manipulated, thus usually about half of the words are printed on the colour designated by the word (congruent condition), whereas the other half is printed on a different colour (incongruent condition; see Figure 1.2 a). Participants are asked to report the colour of the ink. In general, people are slower in the incongruent condition, as they need to ignore word meaning to avoid any interference with the task of naming ink colour.

In the Flanker task participants have to respond to a central stimuli while ignoring a set of stimuli located at both sides of the central stimuli, that is, flanker stimuli. In the classic flanker task designed by Eriksen and Eriksen (1974) stimuli consisted in a set of letters, with target letter placed in the central position. Letters were associated with different directional responses, so that participants' executive attention has to deal with the incongruence between target and flankers when associated with opposite directions. In a posterior version of the task arrows pointing either to the left or to the right are used as stimuli (Kopp, Mattler, & Rist, 1994; see Figure 1.2 b). In that case, participants have to respond to the central arrow by pressing the key that indicates the direction to what arrow is pointing. Half of the times, flanker arrows point in the opposite direction that central arrow. Fan and colleagues (2002) modified the original flanker task to measure not only executive attention, but also orienting and alerting networks. The task was called Attention Networks Test (ANT) and has been extensively used in research. Authors of the ANT added orienting cues and warning cues in the design of the task. Thus, apart from the index of executive attention, the task provides an index of orienting and alerting networks. First, the index of executive attention is obtained from comparing performance in the incongruent and congruent conditions. Then, the index of the orienting network is obtained by contrasting performance when stimuli are preceded by a valid vs. an invalid cue. Lastly, the index of alerting network is attained by contrasting performance in the presence and absence of warning cues.

Cognitive conflict typically generated in Stroop and flanker tasks require ignoring some stimulation that interferes during the encoding of the target stimuli. However, the conflict can be generated at the level of response selection. That is the case of the spatial conflict tasks such as the Simon task (Hommel, 2011). In the Simon task, participants are told to press the right button for stimuli A and left button for stimuli B (see Figure 1.2 c). Both stimuli could appear either on the right or on the left. Despite position being irrelevant for the task, people are typically slower when stimuli appear in the contralateral location and must press the button in the opposite side. When spatial incompatibility occurs between stimulus and response people have to inhibit the natural tendency of giving a response congruent to the location in order to address the identity of the stimuli.

1.1.3.2 Cognitive Flexibility tasks

Tasks measuring cognitive flexibility are designed to obtain a measure of how efficiently a person adapt to different situations. Cognitive flexibility experimental paradigms require participants to either alternate between two or more tasks (task switching paradigms) or alternate attention between different features of stimuli (set shifting paradigm). Prominent among these measures are the classical Task-switching paradigm (Jersild, 1927) and Wisconsin Card Sorting Test (WCST; Grant & Berg, 1948).

In the task-switching paradigm, performance between two types of bocks, single task blocks, and mixed blocks, is compared. During mixed blocks, two single tasks are combined and instructions change trial by trial. For instance, the experimenter could ask participants to report the colour of the stimuli in a first block, report the shape of the stimuli in a second block and finally in a mixed block, participants would have to report either colour or shape of stimuli as rule randomly change from trial to trial. An index of switching cost is obtained by subtracting the performance in the single task block from the mean performance in alternating tasks block.

The WCST explores the ability to change of mental set, contrasting to task-switching paradigms that require updating task demands on a trial-by-trial basis. In the WCST, participants have to categorize a set of cards that could be sorted according to three dimensions: colour, shape and quantity. However, participants ignore the dimension according to which cards have to be classified and they only get a feedback about whether a particular match is right or wrong. Once participants show that they learned and use a certain sorting rule, the rule is changed. Participants should be able to detect the change in the rule throughout the feedback provided, stop following the old rule, and try to find the new rule. Perseverative errors, that is, errors made because participants continued ordering cards following a rule that is no longer valid, are indicative of poor cognitive flexibility.

In both experimental paradigms, the task-switching paradigm and the WCST, people are generally slower and have a greater probability of committing an error after switching. Thus, there is a switching cost in performance that represents an index of cognitive flexibility. Reduced switching costs are indicative of greater cognitive flexibility and therefore, of the more effective use of executive attention.

1.1.3.3 Error monitoring and error detection tasks

Regarding error monitoring and error detection, instead of a specific task it would be better to consider the elements that make a task apt for the assessment of those processes. In the case of tasks measuring error monitoring, difficulty of the task is usually adjusted to individuals' performance in order to ensure that participants will make a minimum percentage of errors (Gehring, Liu, Orr, & Carp, 2011). Variations of the flanker task and go/no-go tasks have been commonly used to investigate error monitoring (Pailing, Segalowitz, Dywan, & Davies, 2002; Scheffers, Coles, Bernstein, Gehring, & Donchin, 1996). Authors normally find that participants slow down after an erroneous response presumably as a consequence of applying more control to reduce their probability of committing a new mistake (Dutilh et al., 2012; Jentzsch & Dudschig, 2009). In contrast, error detection paradigms do not necessarily require participants to actively give any response to stimuli, involving the identification of erroneous information. Error detection could be observed in a context where participants are asked to identify an error, such as incorrect solutions to simple equations (Tzur & Berger, 2009) or to notice when a third person gives a wrong response (Picton, Saunders, & Jentzsch, 2012), but also implicitly by introducing irrelevant spelling mistakes while performing a classic Stroop task (Mesika, Tzur, & Berger, 2014). In both, self-error monitoring and error detection tasks, associated brain responses are usually registered. The characterization of the brain response is particularly relevant in the case of error detection given that this is not related to participants' performance but to their perception of some mistaken information, and therefore, no adjustment of behaviour is observed.

1.1.3.4 Inhibitory control tasks

The withholding of a prepotent response is characteristic of inhibitory control tasks. In these tasks, participants need to supress a previously automatized response. Two different experimental paradigms have been predominantly used to measure inhibitory control: Stop-signal and Go/No-go tasks (see Figure 1.3 for a schema of the tasks). In stop-signal tasks participants have to perform a given task that has to be interrupted in the presence of a stop signal (Verbruggen & Logan, 2008). Stop signal could be just an additional stimulus (e.g. a sound) that appears together with target stimuli indicating participants to withhold the response. Once stop signal disappears, participants should continue doing the task. In the case of Go/No-go tasks, either go or no-go stimuli can randomly appear in each trial (Mostofsky et al., 2003). Participants should press a button when go stimuli appear (e.g. a circle appears in green), whereas they should not in the case of no-go stimuli (e.g. circle appears in red). To produce a tendency to make a response, go trials occurred in a higher proportion than no-go trials. False alarms (also called commission errors) take place when participants failed in inhibit the response during no-go trials or in the presence of a stop signal. A low proportion of false alarms indicate that participants applied inhibitory control efficiently.

1.1.3.5 Self-regulation tasks

These tasks typically observe the capacity that people show to prevent their impulses and control their behaviour in highly arousing settings. Tasks measuring self-regulation often manipulate the value of rewards in order to elicit the desired level of excitement and motivation (Pessoa, 2009). That is the case of the Delay of Gratification task (Casey et al., 2011; Walter Mischel & Metzner, 1962). This task entail the ability to resist the temptation of an immediate reward in order to get later a bigger reward. In Mischel and Metzner (1962) original task they used a marshmallow as stimuli as it was designed to be used with children. In the case of adults, marshmallows are typically substituted by hypothetical monetary rewards (Critchfield & Kollins, 2001; Madden, Petry, Badger, & Bickel, 1997) in order to make the reward as meaningful for adults as it is for children.

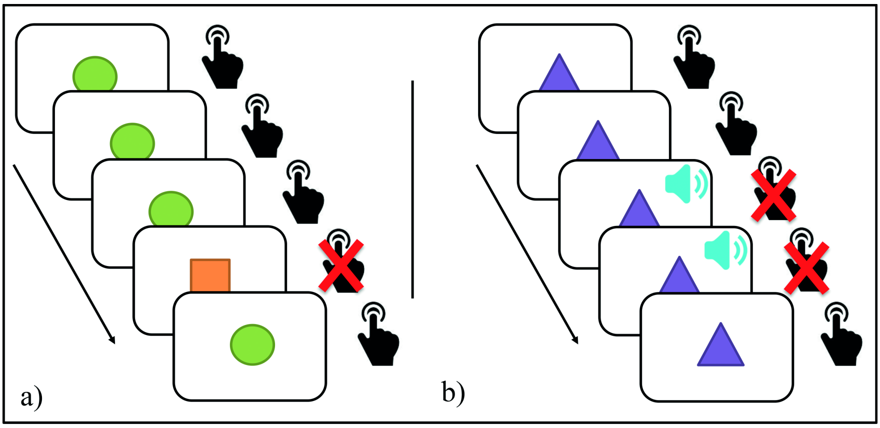


Figure 1.3. Illustration of the Go/No-Go task (a) and the Stop-signal task (b).

It has been also measured by self-report through instruments designed to determine the general tendency of a person to delay in time in order to achieve greater goals. For instance, Ray and Najman (1986) elaborated a simple 12-yes/no-items scale in which asked people whether they take decisions thinking in long-term outcomes (e.g. saving money for the future). Likewise, the Academic Delay of Gratification scale (Bembenutty & Karabenick, 1998) measure the capacity to inhibit the involvement in other more appetitive activities to get involved in other kind of activities that go after the achievement of greater academic goals. People may choose in a 4-poins-Likert scale how probable they would, for example "Go to a favourite concert, play, or sporting event and study less for this course even though it may mean getting a lower grade on an exam you will take tomorrow" instead of "Stay home and study to increase your chances of getting a higher grade." Both scales provide an index of the general capacity to delay in daily life.

Along this section I have presented different tasks measuring executive attention. These tasks not only allowed to explore executive attention functioning throughout behavioural indicators but also have serve to investigate brain mechanisms of executive attention when combined with neuroimaging techniques. I turn now to review the principal findings regarding the neural substrates of executive attention.

1.1.4 Neural substrates of executive attention

Advances of neurosciences with the introduction of diverse neuroimaging techniques facilitated the study of brain structures and brain activity associated with the different cognitive processes. Neuroimaging permitted to extend the knowledge about the underlying brain mechanisms of the diverse cognitive functions by observing brain activations during the performance in cognitive tasks (Gazzaniga, Ivry, Mangun, & Swaab, 2002). As previously mentioned, the cingulo-opercular network together with the dorsolateral prefrontal network were proposed to underpin executive attention (Petersen & Posner, 2012; Posner & Petersen, 1990). Data from diverse neuroimaging studies provided with empirical support that idea. Figure 1.4 summarized the principal structures and neural mechanisms associated with the executive attention network. Across this section, I review the evidence of neural substrates of executive attention network from studies with electrophysiological brain measures and fMRI data.

EEG studies examining event-related potentials (ERPs) commonly find a fronto-central negativity peaking around 200–300 ms after stimulus onset named N2 (Folstein & Van Petten, 2007; Ibanez, Melloni, Huepe, & Helgiu, 2012). N2 is thought to reflect the processing of conflicting information (Botvinick, Carter, Braver, Barch, & Cohen, 2001; Botvinick, Cohen, & Carter, 2004). Greater amplitude of N2 has been reported for incongruent condition compared to congruent in the Stroop, flanker, and Simon tasks (Folstein & Van Petten, 2007; Larson, Clayson, & Clawson, 2014; Yeung, Botvinick, & Cohen, 2004), as well as when inhibitory control must be applied during no-go trials in Go/No-go and stop-signal tasks (Dimoska, Johnstone, & Barry, 2006; Nieuwenhuis, Yeung, Van Den Wildenberg, & Ridderinkhof, 2003). Smaller differences in the amplitude of N2 between congruent and incongruent conditions have been related to better efficiency in resolving conflict, being linked to a more mature executive attention network (Abundis-Gutiérrez et al., 2014).

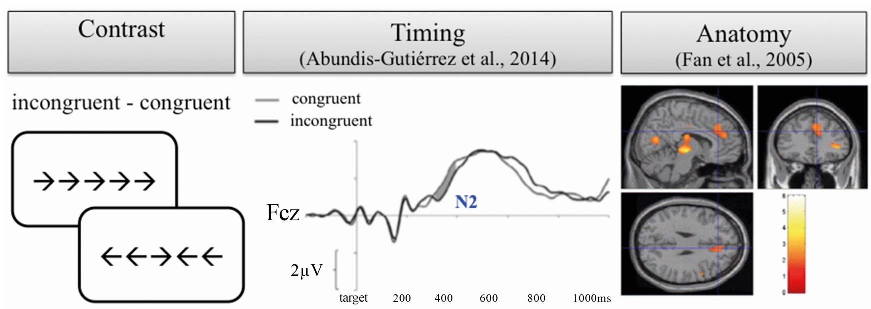


Figure 1.4. Electrophysiology and anatomy of executive attention network.

Another negative component has been generally described between 100–200 ms following the commission of an error with a similar topographical distribution to the conflict-related N2 over the frontal midline (Pailing et al., 2002; van Noordt & Segalowitz, 2012). This ERP component is known as the error-related negativity (ERN; Gehring, Liu, Orr, & Carp, 2012) and it can be observed not only after making an error, but also in response to perceived errors (Bates, Patel, & Liddle, 2005; Mesika et al., 2014; Schie, Mars, Coles, & Bekkering, 2004) or even in the absence of awareness about perceiving the error (Nieuwenhuis, Ridderinkhof, Blom, Band, & Kok, 2001). Some authors have suggested that as N2, ERN may also reflect conflict monitoring given that error detection can be seen as the product of resolving a special type of conflict that involves comparing expected and actual result (Yeung et al., 2004).

In addition to the study of ERPs, it is also possible the spectral decomposition of EEG in different frequency bands throughout the time-frequency analysis. Executive attention has been especially associated with oscillatory changes in theta-band, defined in a range from 3.5 to 7 Hz (Cavanagh & Frank, 2014). Power of theta frequency typically increases over frontal midline regions of the scalp in response to events that evoke cognitive control, such as in conflict and inhibitory control tasks (Huster, Enriquez-Geppert, Lavallee, Falkenstein, & Herrmann, 2013; Nigbur, Ivanova, & Stürmer, 2011), mental set shifting (Enriquez-Geppert, Huster, Figge, & Herrmann, 2014; Sauseng et al., 2006) or during error monitoring (Mesika et al., 2014; Trujillo & Allen, 2007; Tzur & Berger, 2009). Oscillations in theta frequency band have been associated with both N2 and ERN components, as theta power bursts concur in time with the ERPs (Mesika et al., 2014; Nigbur et al., 2011; Schmiedt-Fehr & Basar-Eroglu, 2011). In fact, both N2 and ERN are thought to be the result of a phase alignment of theta-band activity (Cohen et al., 2013; Harper, Malone, & Bernat, 2014; Luu, Tucker, & Makeig, 2004; Trujillo & Allen, 2007).

Executive attention network is thought to be the neural substrate for this brain activity. ACC has been proposed to be the brain source for both the N2 (Bekker, Kenemans, & Verbaten, 2005; Veen & Carter, 2002) and the ERN (Luu et al., 2004; Perry, Swingler, Calkins, & Ann, 2015). Indeed, some data indicate that changes in theta-band oscillations are also generated in the ACC (Luu et al., 2004; Nigbur et al., 2011). This is in agreement with results from fMRI studies that consistently find the involvement of cingulo-opercular executive attention network when inhibitory control must be applied in no-go trials (Kerns et al., 2004; Watanabe et al., 2002), in dealing with conflict information (Botvinick, Nystrom, Fissell, Carter, & Cohen, 1999; Kerns, 2006; Kim, Kroger, & Kim, 2011), after detecting an error (Mathalon, Whitfield, & Ford, 2003) or for initiating a shift in task set (Dosenbach et al., 2006). It has been suggested that ACC may be engaged in signalling the presence of any incongruence and error likelihood, evaluating the need of implementing control (Botvinick et al., 2004; Brown, 2013).

N2, but not ERN, is also correlated with activation of the dorsolateral prefrontal network (Mathalon et al., 2003). A number of fMRI studies show that cognitive conflict induces the activation not only of cingulo-opercular network but also of dorsolateral prefrontal network, although dorsolateral prefrontal network seems to be specially linked to conflict adaptation (Botvinick et al., 2001; Egner, 2011; Kerns et al., 2004). Dorsolateral prefrontal network is particularly involved in cognitive flexibility and is distinctively recruited when switching between rules (Ravizza & Carter, 2008). Thus, cingulo-opercular network and dorsolateral prefrontal network functioning can be dissociated and whereas the first one has been associated with conflict monitoring during the ongoing task, the latter appears to be more implicated in representing attentional demands of the task in order to implement control and maintain the task set (MacDonald, Cohen, Stenger, & Carter, 2000).

1.2 Early Development of Executive Attention

1.2.1 Methods for studying Executive Attention development

1.2.1.1 Designs in cognitive development research

The purpose of developmental research is to investigate the occurred changes in brain and cognition during a certain period of time in life. It may encompass from a few months to the whole life span. Depending on the approach, we can distinguish between two principal kinds of developmental studies: cross-sectional studies and longitudinal studies (Shaughnessy, Zechmeister, & Zechmeister, 2012). Cross-sectional studies regard development of a particular cognitive function across samples of different age groups at the same time. In contrast, longitudinal studies investigated development of the same children for a given period of time. Whereas cross-sectional studies compare typical cognitive skills between groups of age, being appropriate for answering questions of the type “how is a baby cognitively different than an adult”, longitudinal designs are more indicated for addressing the question of how much early cognitive skills foretell about later cognitive outcomes.

In an example of a cross-sectional study, experimenters could measure attention in three different groups of children: a first group of children aged 18 months, a second group of children aged 24 months and a third group of children aged 33 months. Comparing groups, they may conclude that attention skills improve with age since 24 month-olds showed a better performance than 18 month-olds and so did 33 month-olds with respect to 24 month-olds. The same study, but under a longitudinal perspective, would involved recruiting children by 18 months of age, following them at 24 and 33 months. In this case, there is a unique sample that is assessed at different moments during their lives. Given that changes are observed in the same children, longitudinal approach allows not only observing improvements in attention with age but also to investigate developmental trajectories and explore whether attention at time one predicts later attention skills.

Theoretically, longitudinal designs suppose an advantage over cross-sectional designs in the study of development, as they allow not only investigate age-related changes but also help to generate new knowledge about stability and predictive value of cognitive skills in early life. Even so, longitudinal studies are not exempt of some methodological issues (Collins, 2006). This kind of studies generally requires greater investment of time to recollect data compared to cross-sectional studies, varying from several months to years and years of research. As a consequence, loosing participants is a common problem in this kind of research, since people may have different circumstances that can make them to stop collaborating at some point of the study. Experimenters have to try to minimize attrition rate given that high levels of experimental mortality can diminish sample dramatically, biasing data and limiting conclusions about results (van der Kamp & Bijleveld, 1998). Another aspect to be concerned is that longitudinal effects can be attenuated as long as time advances. Because of that, it is recommended to take into account the role of third variables mediating relationship between predictors and outcomes (Selig & Preacher, 2009). Using different tasks can also enhance the predictive validity (Colombo et al. 2004).

All in all, longitudinal studies proved to be fundamental in the understanding of cognitive development. Longitudinal data not only serve to trace the developmental paths of a certain cognitive function, but also have a great value for prevention. Longitudinal research provides with information about typical and atypical developmental patterns that may help to recognize potential risks for a developmental disorder such as autism (Sacrey, Bryson, & Zwaigenbaum, 2013) or to identify variables that could be acting as protective factors.

1.2.1.2 Representative tasks in the study of early development of Executive Attention

Most of the research on early development of executive functions has focused on the preschool years and there is still little published data on executive attention comprising the first years of life (see Hendry, Jones, & Charman, 2016 for a recent review). One of the principal reasons for that is the methodological challenge that supposes adapting experimental paradigms to the characteristics of babies and toddlers. Some tasks are not suitable for those ages because the limited motor skills of infants and toddlers can affect performance, and physical demands of the task can easily overwhelm children’s physical capacity. Language competences at these ages may be also insufficient for understanding the rules and instructions typical of these tasks. Additionally, the shorter attention spans, greater distractibility and the relative facility to which their emotional state can be altered have to be taken into account when designing tasks apt for this range of age. In an attempt to deal with those problems, experimenters in the field of developmental psychology have adapted existing experimental paradigms by simplifying stimuli and making them more child-friendly. Experimenters usually try to make tasks more attention-catching with the use of colourful and dynamic stimuli, look for alternative ways to measure performance that not require of complex motor responses (e.g. registering looking behaviour), and include more breaks or shorten the procedures. Table 1.1 presents a selection of executive attention tasks appropriate for infants and toddlers and equivalent measures in adults grouped by executive attention processes. In the following section I will review principal tasks and measures suitable for assessing executive attention in the first three years of life.

1.2.1.2.1 Tasks suitable for infants

Probably the most used task in the study of early development of executive attention is the A-not-B task (Diamond, 1990b). The simplicity of the procedure allows researchers to use this task from very early on development, extending from infancy to early childhood (Johansson, Forssman, & Bohlin, 2014). The task consisted in hiding a toy in location A in front of children sight (see figure 1.5a). After a delay of a few seconds, experimenter encouraged children to retrieve the toy. Once children learn to retrieve the toy from location A, the toy is hidden in a new location (B). Flexibility of attention permitted children to adapt to that change and look for the object in the new location B. Perseverative errors (that is, searching for the toy in the previous learned location A) indicated poor cognitive flexibility.

The reaching task (Diamond, 1991) represents another example of a behavioural task measuring attention flexibility in infants. In this task, babies are shown an attractive toy in a clear-sided box (see figure 1.5 b). That box is opened only in one side, different from the side that babies are viewing the toy. In order to success in getting the toy, infants need to inhibit the natural tendency of reaching the toy in a direct way and detour the box to retrieve the toy by the open side.

Table 1.1. Summary of Executive Attention measures for infants/toddlers and equivalency with adults' measures.

	Infants/Toddlers	Adults
Cognitive Conflict	Shape Stroop task (Kochanska, Murray, & Harlan, 2000); Baby Stroop	Stroop task (Stroop, 1935).
	Young-Child ANT (adapted from Rueda et al., 2004).	Flanker task (Eriksen & Eriksen, 1974). Attention Network Test (Fan et al., 2002).
	Spatial Conflict task (Gerardi-Caulton, 2000).	Simon task (Simon, 1990).
Flexibility	A-Not B task (Diamond, 1990b) Detour Reaching task (Diamond, 1990a) Shifting task (Kovács & Mehler, 2009)	Task switching paradigm (Jersild, 1927).
	Reverse Categorization task (Carlson, Mandell, & Williams, 2004); Dimension Card Sorting Test (Zelazo, Frye, & Rapus, 1996).	Wisconsin Cards Sorting Test (Grant & Berg, 1948).
Error monitoring	Arithmetic errors (Berger, Tzur, & Posner, 2006). Unexpected action ending (Reid et al., 2009).	Any of the conflict or inhibitory control tasks adjusting difficulty to provoke errors commission.
Inhibitory control	Anti-saccade paradigm (Csibra, Tucker, & Johnson, 1998a).	Anti-saccade paradigm (Hallett, 1978).
	Freeze-Frame task (Holmboe, Pasco, Csibra, Tucker, & Johnson, 2008). Walk-in-a-line (Kochanska, Murray, & Coy, 1997).	Go-No Go (Mostofsky et al., 2003). Stop-Signal (Verbruggen & Logan, 2008).
Self-regulation	Snack Delay task (Kochanska et al., 2000). Delay of Gratification (Walter Mischel & Metzner, 1962).	Academic Delay of Gratification scale (Bembenutty & Karabenick, 1998)

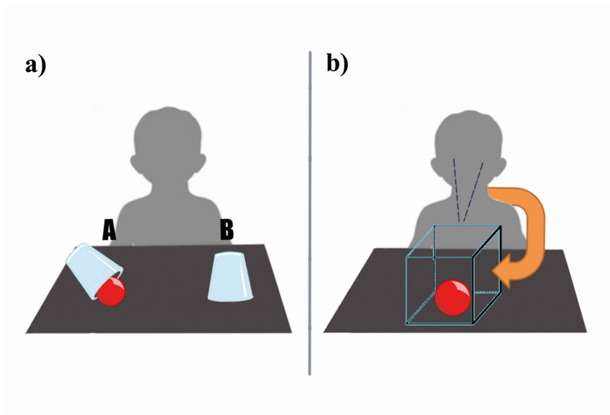


Figure 1.5. Schema of the experimental setting for the A-Not B task (a) and the detour reaching task (b).

Researchers investigating executive attention in pre-verbal infants have recurred to experimental paradigms based on learning contingencies between stimuli, combined with the registration of looking behaviour. That is the case of the anti-saccade paradigm (Csibra, Tucker, & Johnson, 1998b) in which the automatic tendency to look to the cued position have to be inhibited. This task was adapted for being used in babies as young as 3 months of age. As verbal instructions cannot be used with infants, experimenters taught babies to look to the opposite direction of the cued location by reinforcing them with an animated cartoon that appeared in the opposite side every time they did so.

Likewise, in the Visual Expectation Paradigm (Canfield & Haith, 1991) a predictable sequence of visual stimuli is shown to infants repeatedly while infant eye movements are recorded. Anticipatory looks (prior stimuli appearance) and reactive looks are coded. Reactive looks are thought to reflect exogenous control of attention whereas anticipatory looks may involve internal control of attention and is thought to reflect the early functioning of the executive attention network.

Other task measuring inhibitory control during infancy that makes use of the learning of contingencies is the so-called Freeze-frame task (Holmboe et al., 2008). This task was designed to automatically respond to infants looking behaviour with the help of an eyetracking system. Infants have to look to the target stimuli while ignoring other irrelevant stimuli that act as distractors. Babies are rewarded with the animation of the target as long as they looked to it and inhibit looking to the distractors. This task is suitable to be used with preverbal infants and provide a general index of inhibition to distractors and selective inhibition to distractors (depending on whether target was an engaging stimulus or not) that has been related to later performance in conflict tasks.

Similar logic applies to the shifting task designed by Kòvacks and Mehler (2009). This task was conceived to measure flexibility of attention during infancy. In this task, infants learn first to expect a target stimulus in a certain location as it appeared repeatedly in the same side of the screen for a number of consecutive trials. After that, target stimulus start to appear in the opposite side. Infants able to switch attention stop to anticipate stimuli in the previously reinforced location, reallocate their attention, and start to expect target into this new location. Thus, this task provides a measure of infant’s attentional flexibility.

In the case of the study of early development of error detection, researchers have mainly employed violation of expectancy tasks based on the habituation paradigm. In this type of tasks, infants’ looking time to expected and unexpected events is registered. Researchers assume that infants’ longer looking times to unexpected events represent that they are able to anticipate forthcoming events and learn about objects features. This idea was applied to test babies' arithmetic knowledge by means of an experimental paradigm in which researchers presented the resolution of simple equations to infants using puppets as stimuli (Wynn, 1992). As expected, infants looked longer to incorrect solutions. In an attempt to investigate underlying brain mechanisms of error detection in infancy, Berger, Tzur & Posner (2006) used the above mentioned paradigm designed by Wynn to test the ability of babies between 7 and 9 months of age to detect arithmetic errors, but also registering EEG (see figure 1.6). Reid and colleagues (2009) utilized a different paradigm to observe error detection during infancy. They designed a task in which babies were shown a model performing a set of common simple actions. Action sequences could be completed as expected or in an unexpected way (for example, the action of eating finished in the ear instead of in the mouth). A negative component that could be seen as a precursor for the later adult ERN component was observed in infants in response of violation of expectation or error detection in the two studies mentioned.

As we can see, tasks for infancy development research have in common that verbal instructions cannot be used. Nevertheless, children verbal comprehension and motor skills experiment a great progress during the second and third year of life. The unintelligible babbling characteristic of babies gives rise to few words sentences in which children start to express their desires and feelings. Improvements in language are further accompanied with enhancements in physical strength and motor coordination that allowed children to start walking or employ more refined movements. As it will be seen next, these developmental changes will lead to a qualitative change in tasks procedures.

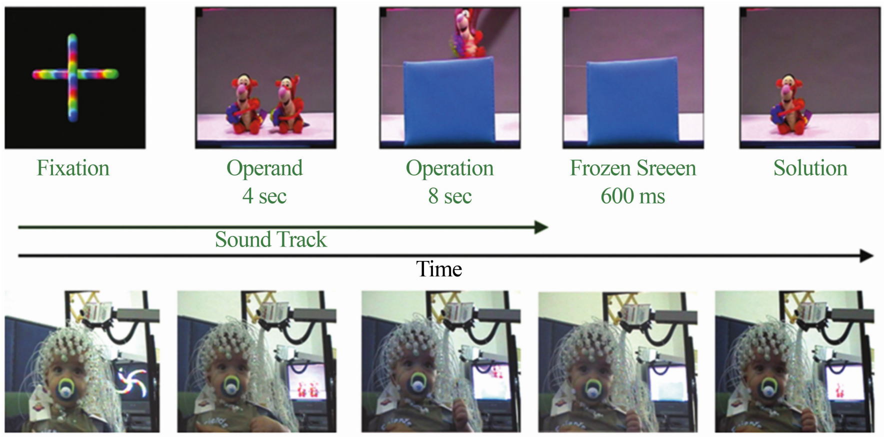


Figure 1.6. Experimental procedure used by Berger et al. (2006) for measuring ERN in babies (Berger, Tzur and Posner, 2006).

1.2.1.2.2 Tasks suitable for toddlers

Toddlers become able to understand simple instructions and follow easy rules, being able of more complex (but not too precise yet) responses. Toddlers can push a button, order different objects, select by pointing among different options or answer simple concrete questions. From this age, measuring the control of impulses become possible as well, existing different self-regulation tasks suitable for toddlers.

As in the case of infancy research, the A-not-B task has been widely used to test attention flexibility in toddlerhood. Concerned about the low difficulty that the original task represents for toddlers, experimenters made an effort for making the task enough challenging for two-year-olds by increasing the delay (Diamond, 1990a), or by including additional possible locations and introducing some means actions necessary to retrieve the toy from a special device (Zelazo, Reznick, & Spinazzola, 1998). Despite those modifications make the A-not-B a task suitable for toddlers, it does not demand too much cognitive flexibility for children older that 24 months, not being enough sensitive for measuring individual differences in flexibility at this age (Carlson, 2005). Reverse categorization task (Carlson et al., 2004) can be a better choice then. In this task, children have to classify a number of blocks according to its size as follows: big blocks in a big bucket, small blocks in a small bucket. After sorting the 12 blocks in this way, rule is reversed and children are told to put big blocks in the small bucket and small blocks in the big one. Errors after changing the rule, as in the case of errors in the A-not-B task, demonstrated low flexibility.

The ability to resolve cognitive conflict is also possible to be assessed by this time. Diverse authors have ideated different Stroop-like conflict tasks that are suitable for toddlers. Kochanska et al. (2000) in their Shape-Stroop task employed a set of three cards depicting three different fruits. Fruits were represented in both big and small size in a way that small fruits were embedded inside the picture of a different big fruit (e.g. a card with a small banana inside a big apple). Children are asked to point to a certain small fruit (e.g. the small banana). A card with the same fruit that experimenter asked for but in the large size, is placed next. Toddlers have to inhibit the prepotent response of pointing to the big fruit, more salient, and search for the small one. In other example of adapted Stroop paradigm, Hughes and Ensor (2005) created the Baby Stroop task in which toddlers were required to feed a mummy doll with a “baby” spoon and baby doll with a “mummy” spoon. Children have to manage the incongruence between doll size and spoon size and avoid the natural tendency of pairing objects by size.

Other example of a conflict paradigm that has been adapted for its use in toddlers is the Spatial conflict task designed by Gerardi-Caulton (2000). This task is based on the Simon effect and unlike the previously described tasks, it can be computerized and is usually presented in touch-screen devices. In this task, children should select the response matching with target stimuli identity, usually a funny cartoon representing an animal (see Figure 1.7). Response buttons are located either on the right or on the left and target can appear either just above the matching response (spatial compatible trials) or in the opposite side (spatial incompatible trials). Likewise adult version of Simon task, incompatible trials are associated with higher proportion of errors and slower reactions times. It is also possible to obtain a conflict index to examine the efficiency of the executive attention functioning by subtracting performance in compatible and incompatible trials. Thus, the greater conflict effect (that is, the larger difference in reaction times or accuracy between conditions), the poorer efficiency of executive attention.

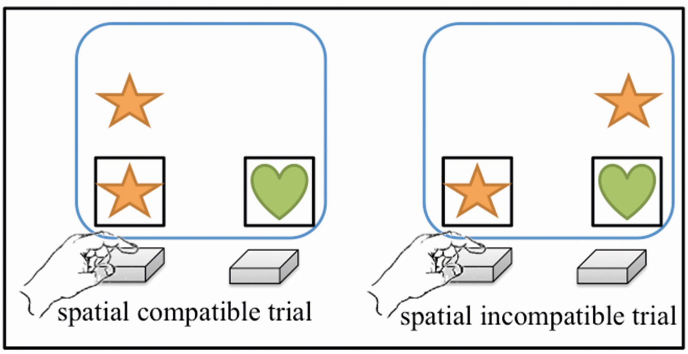


Figure 1.7. Illustration of the spatial conflict task.

Self-regulation also becomes measurable from the second year of age. Self-regulation tasks characteristically involve to supress an impulse towards some appetitive stimuli. Snack Delay task and Gift Delay, both part of the inhibitory control battery task developed by Kochanska and cols. (2000), are representative tasks measuring self-control. In the first one, the Snack Delay task, experimenter locates a tempting snack (usually a cracker) under a transparent cup and asks children to wait to take it until the bell rang. Children have to resist in eating the snack in four trials that progressively increased from 5 to 20 seconds. To get the maximum score, children need to patiently wait during the entire trial and not even move their hands from the mat used to place the snack, whereas eating the snack or even touching it before experimenter rang the bell suppose lower scores.

The Gift Delay task measures the ability of children to override the impulse of opening a wrapped gift. Experimenter gives a wrapped gift to children but leaves the room for some minutes with the excuse of looking for a bow to put on it. Experimenter asks children to wait during that time without opening the gift. Similarly to the Snack Delay task, children that cannot wait and peek the gift are considered to fail in the task, being indicative of poor self-control.

Finally, another task measuring self-regulation in toddlers is the Walk-in-a-line-slowly (Maccoby et al., 1965). In this task toddlers have to inhibit the impulse of walking without any restrictions. Children are asked to walk toward their mum following a line painted in the floor as slow as possible. Time that children spend on walking along the line is registered. A child that usually fails in this task runs right to their mum, not necessarily following the line.

1.2.2 *DEVELOPMENT OF EXECUTIVE ATTENTION DURING INFANCY AND TODDLERHOOD*

1.2.2.1 Early development of executive attention network

For many years, the study of executive functions was limited to adults due to the belief that brain structures in the prefrontal cortex subtending this function did not become mature enough until adolescence (Hughes, 2002). Thanks to the introduction of neuroimaging technics together with novel child-appropriate methods in developmental research, we currently know that development of executive skills occurs much earlier than was previously thought (Dehaene-Lambertz & Spelke, 2015).

Executive attention brain networks are present in infants by term, including fronto-parietal and cingulo-opercular circuits, and already show a similar connectivity pattern to that observed in adults (Doria et al., 2010). The development of brain networks occurs throughout a segregation-integration process in which short-range connections decrease within the network whereas longer-range connections between brain networks increase as long as the brain matures (Dosenbach et al., 2010; Fair et al., 2007). That process starts from birth and is explained by both the myelination of white matter and the synaptic pruning (Huang et al., 2015). Particularly, the first two years of life may be key for the development of executive attention network. A rapid exponential myelinisation growth takes place over frontal cortex areas from the 6th month of life, stabilizing by the end of the first year and reaching adult appearance by 18 months of age (Barkovich, Kjos, Jackson, & Norman, 1988; Dean et al., 2014). Cortical grey volume also increases substantially in the first two years of life, with a faster growth of frontal structures during the second year of age (Gilmore et al., 2012). There is also a peak in cortical thickness in frontal areas of the brain (Lin, Gilmore

& Shen, 2015; Gilmore et al., 2012) and an increment in the thalamo-cortical connections that has been related to cognitive performance in toddlerhood (Alcauter et al., 2014). These structural changes correspond to the restructuring of the network configuration, leading to more efficient and stronger connections that has been also related to a general increase in the modularity of the different brain networks in toddlerhood (Hagmann et al., 2010).

Apart from the structural changes in executive attention network, data from EEG studies suggest that circuits from executive attention network became functional during the first year of life (Posner & Rothbart, 2008). EEG and ERP provide direct measures of the neural activity that has been used to investigate the developmental changes in the functional activity of executive attention network. Studies in early development of functional brain activity usually report a negative ERP component in fronto-central areas over the scalp labelled Nc (Negative Central) about 350–650 ms after stimulus onset with source in ACC, a central structure in executive attention network (Oakes, Cashon, Casasola, & Rakison, 2011). This ERP component has been widely investigated in the field of early development of attention as it could be observed from few weeks after birth (Reynolds, 2015). Larger Nc amplitude it is thought to reflect attention engagement, increasing in response to novel stimuli (Nelson, 1991; Carver, Meltzoff & Dawson, 2006; Reynolds & Guy, 2012), incongruence (Friedrich & Friederici, 2004; Hyde, Jones, Flom & Porter, 2011) or during attentiveness periods (Richards, 2003).

Similarly, a fronto-central negative component comparable to an adult ERN is observed about the 9 months of age (Berger et al., 2006; Reid et al., 2009). Berger, Tzur, y Posner (2006) found that babies showed this ERN-like component in response to perceived errors in simple arithmetic operations represented with puppets. In Reid and colleagues (2009) study, infants showed the negative component after seeing simple action sequences completed in an unexpected way (for example, the action of eating finished in the ear instead of in the mouth). In both studies, infants' brain response was functionally equivalent to that found in adults in the same experimental paradigm with the only difference that ERP component occurred later (about 350–650 ms) and was more extended in time in the case of infants. These results suggest that executive attention network is functional as early as by the end of the first year of life.

The study of oscillations in different brain frequencies, particularly in theta band, has also provided to be a useful tool in the understanding of infants' executive attention development (Saby & Marshall, 2012). Theta band comprises frequencies in a range between 4–7 Hz and has been related to cognitive control (Cavanagh & Frank, 2014). Recent research suggests that frontal theta is an important mechanism supporting changes in white matter fibbers. Evidence from animal and human studies show increases in myelination and connectivity following bursts of frontal theta mediated by activation of the protease calpain (Posner, Tang, & Lynch, 2014). Frontal theta activation in young children may thus be an important mechanism promoting the development of optimal structural connections between regions within the executive attention network. Indeed, there is an increase on theta power with age during infancy that may indicate a development of the cortical pathways that supports the executive attention associated with a more internally controlled attention (Stroganova, Orekhova, & Posikera, 1998; Orekhova, Stroganova, & Posikera, 1999).

In short, brain circuits corresponding to executive attention network start to be ready to assume certain functions from very early on. It does not mean that we could not observe developmental changes later in time.

Contrary to that, the development of executive attention network extends along infancy to adulthood. However, the observed changes in the brain structure and brain functioning bring support for the observed cognitive and behavioural changes occurring during these first three years of life.

1.2.2.2 Development of executive attention: behavioural evidence

The described changes in the executive attention network at structural level can account for the behavioural changes during these early years. In fact, first signs of executive attention could be observed from the first months of life. About the third-forth month of age, babies start to show an endogenous control of attention (Colombo, 2001). Before that age, babies' attention is considered as essentially reactive, responding preferentially to exogenous events and relying in low-level arousal mechanisms (Posner, Rothbart, & Rueda, 2013). During this time, babies experiment what has been called "obligatory attention" or "sticky fixation". This phenomenon consists in a great difficulty to disengage attention from one object to redirect attention to a new one once the first became uninteresting or boring (Hood, 1995). This impairment in disengaging attention has been suggested to happen because reallocation of attention during this age is carried out by the superior colliculus (Johnson, Posner, & Rothbart, 1988). Disengagement of attention may require the maturation of prefrontal structures, like the frontal eye fields (Johnson et al., 1988) that would inhibit colliculus in order to allow infants to voluntary control attention. By 3 months of age babies are able to disengage from a central stimuli (Atkinson, Hood, Wattam-Bell, & Braddick, 1992; Johnson, Posner, & Rothbart, 1991), significantly diminishing the time needed to disengage between 4 and 6 months of age (Hunnius, Geuze, & Van Geert, 2006). Additionally, infants from 6 months attended differently to stimuli depending on whether the stimuli was boring (habituating more rapidly) or engaging (increasing the time they expend looking to it), also reflecting an endogenous control of attention (Courage, Reynolds, & Richards, 2006).

Infants further demonstrate that they can flexibly adapt their attention behaviour from very early on. By 4 months of age, infants learn to anticipate their attention to the location in which a particular stimulus embedded in a fixed sequence will appear (Canfield & Haith, 1991; Clohessy, Posner, & Rothbart, 2001; Haith, Hazan, & Goodman, 1988). The fact that babies anticipate their attention is thought to involve executive attention too, as it can be considered that babies oriented voluntarily towards a certain location according to a learned sequence. Indeed, the proportion of anticipatory looks that babies produce during the task is correlated to genes that regulate the levels of dopamine in frontal brain structures, related to executive attention network (Voelker, Sheese, Rothbart, & Posner, 2009). About the end of the first year of life, there is an improvement in attentional flexibility so that infants become able to pass the A-not B task, a task that requires to inhibit searching a toy in the location that was initially hidden to learn to retrieve it from a new one (Diamond, 1990b). Similarly, 7-months olds can learn to redirect attention to the opposite side that was previously rewarded (e.g. with an animated cartoon), with infants raised in a bilingual context showing a better performance compare to monolinguals (Kovács & Mehler, 2009). There is also evidence that 9 months old infants are also able to inhibit attention to irrelevant stimuli that try to distract them from a target stimulus in the so-called Freeze-frame task (Holmboe, Fearon, Csibra, Tucker, & Johnson, 2008). By this time, babies also demonstrate a more flexible behaviour and they are able to inhibit directly reaching a toy presented in a transparent box (open by only one side) to detour the box and retrieve the toy by the open side instead (Diamond, 1990a).

During toddlerhood, development of executive attention becomes more apparent. By two years of age, children are able to overcome a more sophisticated version of the detour-reaching task that requires performing a means-action before they can reach the desired object (McGuigan & Núñez, 2006). The enhancement in executive attention also results in an improved performance in a set of executive function tasks they failed before that age, like a multiple hiding locations A-not-B task or the forbidden toy task (Miller & Marcovitch, 2015). All these changes in executive attention are accompanied of an increased self-regulation. Infants regulation is focused on reducing reactivity levels and mainly rely on caregiver’s skills or the use of simple mechanisms of self-regulation to reduce distress such as disengagement of attention and distraction (e.g. looking away from distressful stimuli) and self-comforting (Rothbart, Ziaie, & O’Boyle, 1992; Stifter & Braungart, 1995). Toddlers not only regulate reactivity but also guide behaviour according to goals and concern about social demands. They can regulate their behaviour according to rules, first with the need of some external aid and parents guidance, but becoming more independent and self-regulated about the two years of age as long as their inhibitory control increases (Kochanska, Coy, & Murray, 2001; Kopp, 1982).

Later, between the second and the third year of life, children become more and more efficient in resolving cognitive conflict. Using a child-friendly version of the spatial conflict task, Gerardi-Caulton (2000) compared performance of children of 24, 30 and 36 months of age. Children become more competent in resolving the spatial conflict with age, first making fewer errors and then doing it faster and faster. There is also an enhancement in inhibitory control and attention flexibility between the second and third year of age (Blakey, Visser, & Carroll, 2016). Children of these ages also improve in switching between different rules in a simplified version of the dimensional sorting task that presented only distracting information instead of conflicting information that could make them to perseverate. It will be by 3 years of age that some children will be able to complete the original dimension card-sorting test, although they already commit a great proportion of perseverative errors (Zelazo et al., 1996). Interestingly, those 3-year-olds who presented a better performance activated prefrontal areas significantly more than the rest of children during the task (Moriguchi & Hiraki, 2009). At the same time, there is a significant improvement in self-regulation between the second and the third year of age. At this age, the improvements in self-regulation are specially noticeable in contexts where children are required to sustain an unpleasant activity whereas self-regulation in don't contexts (that is, when children are required to inhibit certain behaviour) seems to develops more rapidly (Kochanska et al., 2001).

All in all, during the first three years of life we can see great changes in the ability of children to resolve different executive attention related tasks that reflect the development of executive attention network. Over the next section, I will present how individual differences in the early development of executive attention may predict later executive attention skills and related outcomes.

1.2.3 Early signs of executive attention and prediction of developmental outcomes

Provided that individual differences in cognitive skills can be traced back to the early infancy (Bornstein, Hahn, & Wolke, 2013), it seems reasonable to consider the longitudinal study of executive attention and related outcomes starting from this point in development. Research indicates that executive attention play a key role in children's social adjustment (Hughes, 2002; Rhoades, Greenberg, & Domitrovich, 2009) and academic performance (Clark, Pritchard, & Woodward, 2010; Rueda, Checa, & Rothbart, 2010), being also involved in a range of developmental disorders such as autistic disorders or ADHD (Corbett, Constantine, Hendren, Rocke, & Ozonoff, 2009; Happé, Booth, Charlton, & Hughes, 2006; Margari et al., 2016). Early detection of executive attention deficits seems to be fundamental for prevention and early intervention (Dawson, 2008; Ramey & Ramey, 1998). Nevertheless, longitudinal studies from infancy and toddlerhood that extend over childhood are still scarce. In the following lines I review literature on that subject in order to provide with a general overview.

1.2.3.1 Early predictors of executive attention

Some early measures of attentional processes have proven to be indicative of later executive attention. One of these measures is the duration of infants' attention fixations when encoding a stimulus. According to this, is possible to divide infants in two different attentional styles: short-lookers and long-lookers (Colombo, Mitchell, Coldren, & Freeseman, 1991). Shorter fixations are thought to reflect a more efficient processing (Colombo, 2001). In fact, long-lookers usually have more difficulty in disengaging attention compared to short-lookers (Frick, Colombo, & Saxon, 1999). Infants classified as short-lookers by 5 months of age also exhibit better executive attention skills (e.g. inhibitory control, attention flexibility, conflict resolution) than long-lookers later by 2, 3 and 4 years of age. Predictive value of fixations durations extends even longer. Duration of fixations by 7 and 12 months of age predicts shifting and working memory also at 11 years of age (Rose, Feldman, & Jankowski, 2012). Likewise, shorter duration of fixations during infancy is related to better inhibitory control during adolescence (Sigman et al., 1997). Overall, duration of fixations demonstrate to be a quite reliable predictor of executive attention development.

Similarly, attention focusing in infancy has been associated with later development of executive attention. Infants' levels of focused attention in a free-play context are associated with less distractibility later by 4 years of age (Holly A Ruff & Lawson, 1990). More recently, Johansson, Marciszko, Gredebäck, Nyström, and Bohlin (2015) that also measured 12-month-olds sustained attention during free play, found that it predicted both children's attention flexibility in the A-not B task and effortful control by 2 years of age. Additionally, focused attention by 9 months of age predicts inhibitory control (measured with a battery of behavioural tasks such as the snack delay task) by 24 months, although no longer predicts inhibitory control later by 33 months of age (Kochanska et al., 2000).

Early differences in inhibitory control also predict later executive attention. Holmboe and colleagues (2008) found that 2-year-olds ability to resolve conflict in a spatial conflict task is predicted by the ability to inhibit attention to distractors at 9 months of age. Interestingly, those infants that differentially inhibited attention depending on the interest on the target (that is, that inhibited attention to distractors more when an engaging target was presented compared to boring targets, reflecting more endogenous control of attention) were the ones that resolved spatial conflict more efficiently later by 2 years of age. In the same way, toddlers that demonstrate a greater inhibitory control by 14 months of age and wait longer for touching a toy that were told not to touch, also show better general executive attention skills at 17 years of age (Friedman, Miyake, Robinson, & Hewitt, 2011).

1.2.3.2 Early executive attention and social and behavioural adjustment

Early measures of executive attention in infancy and toddlerhood can also serve as early indicators of later social outcomes and behavioural adjustment, predicting academic competence and psychological well being. More efficiency of attention habituation at 4 months account for higher IQ at 18 months and 8 years of age as well as for less behavioural problems by 3 years of age and greater academic achievement at age 14 years (Bornstein et al. 2012). These authors proposed that attention development in early infancy had an indirect effect on academic achievement at 14 years of age following a system of cascades in which early attention development effect on academic would be mediated by IQ and behaviour problems. In line with those results, selective attention at 7–12 months of age predicted IQ and academic achievement at age 21 years (Fagan, Holland, & Wheeler, 2007).

In a recent study, authors observed that toddlers' "hot" and "cool" executive attention skills contributed in predicting different developmental outcomes (Mulder, Hoofs, Verhagen, van der Veen, & Leseman, 2014). Hot executive attention referred to the attentional control applied in emotional arousing contexts or highly motivating situations (e.g. resist eating a tempting snack), closely related to self-regulation. In contrast, executive attention skills refer to attentional control exerted in emotionally neutral settings typical of classic experimental tasks. Mulder and colleagues found that executive attention at 24 months of age predicted academic performance and behavioural problems at age 3 years, whereas hot executive attention skills only predicted behavioural problems. Given that, it is possible to think that although related, hot and cool executive attention have similar but separate developmental courses from very early on.

1.2.3.3 Early executive attention deficits and developmental disorders

Assessment of executive attention in infancy might serve as screening tools for early detection of those children at risk for deficits in executive attention and developmental disorders. This is for example the case of siblings of children that had been diagnosed with autism. A difficulty to disengage attention has been consistently report in literature for children diagnosed with autism (Landry & Bryson, 2004; Zwaigenbaum et al., 2005). Infants that have a familiar antecedent of autism generally show longer latencies to disengage in a gap-overlap task (Elsabbagh et al., 2009). Moreover, longer latencies to disengage predict who of the children at risk will later develop autism by 3 years of age (Elsabbagh et al., 2013; Sacrey et al., 2013). However, before 12 months of age it seems too early to forecast the later development of autism with this task. Only children that showed impairments in disengaging attention at the end of the first year of life and continued to show that impairment during the second year were later diagnosed with autism (Sacrey et al., 2013).

In the same way, the duration of attention fixations in infancy significantly predicted hyperactivity-inattention with those infants classified as long-lookers where the ones that showed a greater proportion of hyperactivity-inattention symptomatology between the 3 and 4 years of age (Papageorgiou et al., 2014). Likewise, sustained attention between the first and the second year of life is also a predictor of hyperactivity symptoms observed at 3 years of age (Lawson & Ruff, 2004). These results suggest that individual differences in development of attention may serve to detect attention deficit disorders as early as by infancy.

All in all, these results suggest that individual differences in executive attention can help to the identification of the first signs of some developmental disorders such as autistic spectrum disorders or attention deficit disorders that are characterized by alterations in executive attention. This may promote prevention by starting detection and intervention as early as by infancy. However, other variables that may modulate early development of executive attention (either as protective factor or as a potential risk factor) have to be also contemplated. In the next section, I present the evidence on different variables that may act as a source of variability in the development of attentional skills, considering not only constitutional but also environmental factors.

1.3 Influence of constitutional and environmental factors in early development of Executive Attention

1.3.1 Temperament and Executive Attention development

Temperament refers to those observed differences in motor, emotional and attentional reactivity, as well as the mechanisms involved in regulating such reactivity (Rothbart & Bates, 2006). Temperament is contemplated as a constitutional-based characteristic of children, being stable throughout development even from early years (Casalin, Luyten, Vliegen, & Meurs, 2012; Stifter, Putnam, & Jahromi, 2008). It can be distinguished three main temperament factors: surgency/extraversion, negative affectivity and regulation/effortful control (Rothbart & Bates, 2006). The first one, surgency/extraversion, refers to a tendency towards positive affect and is characterized by high activity levels and impulsivity. The second one, negative affectivity, is a temperamental disposition to experiment negative emotions. Children characterized by a high negative affectivity are often described as high irritable children that are easily frustrated, and with an extreme fear towards novel stimuli, being very difficult to be calmed once is distressed. Finally, regulation/effortful control apply to the ability of voluntarily regulate attention in order to down-regulate high reactivity levels, either surgency or negative affectivity.

Individual differences in behavioural, emotional and attention reactivity can be observed from very early on development. Parents distinguish whether their children are, for example, more or less irritable or active even from infancy (Rothbart, Sheese, Rueda, & Posner, 2011). Different temperamental profiles have been related to differences in children's executive attention. On the one hand, higher levels of temperamental reactivity, either surgency/extraversion or negative affect, have been associated with poorer executive attention skills. (Davis, Bruce, & Gunnar, 2002; Gerardi-Caulton, 2000; Wolfe & Bell, 2004; Wolfe & Bell, 2007). Even from infancy, higher negative affectivity is related to difficulties in disengaging attention (Johnson et al., 1988; McConnell & Bryson, 2005). In fact, efficiency of attention processing in infancy predicts individual differences in temperamental reactivity later in childhood. Infants that fixated attention for longer times (considered an indicator of poorer attentional control) were the ones that present higher surgency levels (Papageorgiou et al., 2014; Papageorgiou, Farroni, Johnson, Smith, & Ronald, 2015).

On the other hand, better executive attention has been found among children that show greater effortful control. Executive skills have been also associated with self-regulation of positive and negative affect (Rothbart et al., 2011; Simonds, Kieras, Rueda, & Rothbart, 2007). The ability of infants to disengage attention has been also related to greater soothability (Johnson et al., 1991). Infants' control of attention is also related to regulation of distress at 10 months of age (Morasch & Bell, 2012), predicting effortful control at childhood (Papageorgiou et al., 2014).

Interestingly, interaction between both temperamental reactivity and regulation during infancy predicted executive attention in early childhood (Ursache, 2013). Children that exhibited higher levels of emotional reactivity but also applied more regulatory strategies to calm-down during infancy develop higher levels of executive attention later in childhood, whereas temperament and regulation in infancy was unrelated to later executive attention development in the case of low reactive children. In fact, developmental changes in executive attention (specifically in conflict resolution and inhibitory control) during the third year of life are also correlated with parent reports of temperamental effortful control (Gerardi-Caulton, 2000; Kochanska et al., 2000).

1.3.2 Environmental factors and early development of Executive Attention

Executive attention network has been consistently observed to be quite sensitive to environmental features (Lipina & Posner, 2012). Developmental studies have mainly centred their interest in the effects of family socioeconomic status (SES) and parenting on executive attention. There is a growing body of literature that recognises the importance of SES and parenting influence in cognitive development, but mainly focused in its effects during childhood and adolescence (Duncan, Yeung, Brooks-Gunn, & Smith, 1998; Hackman et al., 2014). Over the next sections, I will review evidence on the influence of those two environmental factors in early development of executive attention from infancy to toddlerhood and its implication for later development.

1.3.2.1 Influence of SES

Children raised in families from lower-SES contexts generally show poorer performance in executive attention-related tasks (Duncan et al., 1998; Mezzacappa, 2004; Noble, McCandliss, & Farah, 2007), being linked to reduced cortical thickness and lower white matter density in prefrontal brain structures of the executive attention network, like cingulate cortex (Farah & Hackman, 2012; Hackman & Farah, 2009; Lawson, Duda, Avants, Wu, & Farah, 2013). Hence, SES seems to affect later cognitive development and thus, academic achievement (Duncan et al., 1998; Duncan, Ziol-Guest, & Kalil, 2010; Noble et al., 2007; Noble, Wolmetz, Ochs, Farah, & McCandliss, 2006).

Few studies have investigated the influence of SES on executive functions and brain mechanisms that develop throughout infancy (Clearfield & Jedd, 2013; Hanson et al., 2013; Lipina, Martelli, Vuelta, & Colombo, 2005; Noble et al., 2015; Tomalski et al., 2013). However, there is evidence that precisely during the first years of life the influence of family SES on the development of cognitive abilities seems to be particularly relevant. The SES-cognitive outcomes relationship strengthens during this time, weakens after the 4th year of age (Mollborn, Lawrence, James-Hawkins, & Fomby, 2014). Infants coming from low-SES families show poorer performance in the A-not-B task, perseverating more than high-SES infants (Lipina et al., 2005). Low-SES infants also show greater inattention in a free-play context compared to high-SES infants (Clearfield & Jedd, 2013).

These early differences in attention development due to disparities in SES can be also observed at the level of brain function. There is some recent evidence showing that children from low-SES backgrounds show diminished grey matter volume in frontal and parietal regions during the first years of life (Hanson et al., 2013). Reduced grey matter volume in structures within the executive attention network may contribute to the poorer functional efficiency of this network. Likewise, infants raised in low-SES families show reduced power in frontal gamma oscillations while seeing video clips with familiar objects (Tomalski et al., 2013), an oscillatory activity thought to support processes related to object perception and attention (Engel, Fries, & Singer, 2001).

Together, these studies indicate that lower SES is related to a poorer performance in executive control, being associated with differences in early development of brain structures that support executive attention network. This influence of SES on executive attention can be observed as early as from infancy, suggesting that early experience may have a key role in the early development of that cognitive function.

1.3.2.2 Influence of parenting

Another environmental aspect that has been related to the efficiency of executive attention is the way that parents-child interactions are established, including attachment, caregiver sensitivity to children needs or parenting style. Concerning the last one, parenting style, previous studies have already shown that low-quality parenting could also have a negative impact on children’s executive attention from very early on (Fay-Stammbach, Hawes, & Meredith, 2014). Inconsistent parenting strategies, low sensitivity to children's needs and a coercive patenting style have been related to poorer executive attention and later behavioural problems (Bindman, Hindman, Bowles, & Morrison, 2013; Morrell & Murray, 2003; Rioux et al., 2015). In contrast, high-quality parenting can act by benefitting executive attention. It has been observed that when caregivers support toddlers by promoting their autonomy (for instance, teaching them strategies appropriate to their competence and giving them the opportunity to use them) children exhibit later a better performance in attention flexibility tasks (Bernier, Carlson, & Whipple, 2010). Similarly, children whose parents make use of scaffolding when involved in a common activity (that is, encouraging children to be independent and at the same time that provide them support and some feedback about their performance) regulate attention more efficiently (Robinson, Burns, & Davis, 2009).

Parenting may also help to shape self-regulation during these first years of life. Supportive parenting has been positively related to toddlers' inhibitory control in a delay task (Spinrad, Eisenberg, & Gaertner, 2007). Moreover, positive parenting practices during infancy and toddlerhood predicted fewer externalizing behaviour problems in childhood (Boeldt, Hyun, & Dilalla, 2012; Lahey et al., 2008). It has been suggested that those positive parenting strategies may foster the development of self-regulatory skills given that they promote self-reflection and the active control of impulsive responses (Fay-Stammbach et al., 2014). Conversely, parents that exert an excessive control over children behaviour may cause impairment on children to develop regulation skills, as they do not have the chance of applying regulation strategies by their own. Conway and Stifter (2012) found that the ability of toddlers to regulate in a delay task was reduced for those children more inhibited when mothers have a general tendency to redirect children's attention.

There is also some evidence that indicates that high quality parenting can be a protective factor in the case of children raised in deprived environments (Gutman & Feinstein, 2010; Mayo & Siraj, 2015). Parenting also seems to interact with intrinsic characteristics of children during infancy and toddlerhood such as temperament, genes or brain structures. Some authors have proposed that individual differences may cause a differential susceptibility to the external influence induced by parents, being necessary to know children characteristic to estimate the impact that parenting would have in development (Belsky & Pluess, 2009). For instance, in the case of hot-tempered infants, maternal warmth predicts self-regulation at 5 years of age (Razza, Martin, & Brooks-Gunn, 2012). Quality of parenting also interacts with variations in COMT (a dopamine-related gene) to explain individual differences in a measure of executive control of attention by 2 years of age (Voelker, Sheese, Rothbart, & Posner, 2009). In the same line, infants with a shorter corpus callosum whose mothers used more positive discipline (i.e. based on support) show fewer problems associated with difficulties in inhibitory control (Kok et al., 2014). These results suggest that constitutional factors may also be considered in order to understand the influence of parenting on early development of executive attention.

Together, all this evidence demonstrates the importance that experience may have in modulating the early development of executive attention. This suggests that neural networks, and thus cognitive skills, are malleable as early as from infancy and with the appropriate experiences and intervention we can promote the optimal development of executive attention and even help to prevent deficits in executive attention from very early on.

1.3.3 RESEARCH AIMS

The principal aim of this research was to explore the development of executive attention during infancy and toddlerhood. The previous sections of this introductory chapter present a theoretical background on executive attention mechanisms and measures, summarizing the main findings relating to the early development executive attention. As indicated in those previous sections of the introduction, executive attention can been observed as early as by the end of the first year of life (Holmboe et al., 2008; Diamond, 1990a). Furthermore, according to the reviewed literature, some notable changes undergo in the prefrontal cortex during infancy and toddlerhood (Huang et al., 2015) that seems to be related to the observed improvements in different domains of executive attention. Following that, we focused our research in the study of executive attention development from infancy to the third year of life.

We decided to address this question longitudinally in order to investigate changes in executive attention over time. As was pointed out in the introduction, longitudinal studies allow exploring individual differences in developmental trajectories and predicting later outcomes. We proposed a four-waves study, testing children executive attention at 9–12 months (T1), at 16–18 months (T2), at 2 years (T3) and at 3 years of age (T4). We selected a variety of tasks appropriate for each age to measure diverse executive attention processes: attention flexibility, error detection, conflict processing and inhibitory control. With this longitudinal design we intended to investigate whether early indicators of executive attention predicted executive attention skills throughout the studied developmental period. We expected that the different measures of executive attention would be correlated over time.

We were also interested in the neural mechanisms underlying executive attention. As we already mentioned in the previous sections, there is evidence of the functionality of executive attention network as early as by 7–9 months of age, activating in response to errors in a similar way to that in adults (Berger et al., 2006). We registered electrophysiology of brain during an error detection paradigm at T2 in order to have a neural marker of executive attention network. We hypothesized that brain activation associated with error detection would be related to the performance in a concurrent executive attention task. Likewise, we expected that neural response to errors would predict executive attention at T3 and T4.

We further examined the role of executive attention in the development of self-regulation. We included measures related to self-regulatory skills such as disengagement of attention from emotional stimuli, emotional processing or inhibitory control in delay tasks. First, we expected that early measures of self-regulation would be associated with self-regulatory skills by two and three years of age. Given the close relationship between executive attention and self-regulatory mechanisms (Rothbart, Sheese, Rueda, & Posner, 2011), we also expected that self-regulation would be related to executive attention. We hypothesized that the greater executive attention, the more efficiency in self-regulation. We also expected that changes in self-regulation over time would be predicted by individual differences in executive attention.

Finally, we observed the influence of environment and temperament on the development of executive attention. Regarding environmental factors, we measured SES and parenting style. Families informed about SES in the first visit to the laboratory and about parenting strategies when children were 2 years old. Parents also reported children's temperament at T1, T3 and T4. Providing the reviewed evidence indicating that both, SES and parenting may modulate executive attention, we expected that 1) temperament to be stable across time, 2) both environmental and temperament factors would influence executive attention development even from infancy, 3) temperament and environment factors would interact to predict executive attention and self-regulation.

CHAPTER 2
GENERAL METHOD

CHAPTER 2: GENERAL METHOD

2.1 DESIGN

We employed a longitudinal design, as we were interested in observing the change in executive attention over time. Four testing waves: a first testing session (T1) when babies were between 9 to 12 months of age, a second session (T2) at 16-18 months of age, a third session (T3) at 26-28 months of age, and a forth session (T4) at 36-38 months of age (see Figure 2.1). Children performed a number of executive attention tasks adapted to children's age in each session. The length of each session, including breaks between tasks, is displayed in the figure. Additionally, caregivers provided information on their child temperament, home environment and parenting strategies by filling-up questionnaires at every session. General procedure and the tasks and instruments run in each session are described below.

2.2 PARTICIPANTS

Participants were initially informed about the study by means of advertisements in nurseries located in different socio-demographic areas (from wealthy to socio-economically deprived neighbourhoods) of the city of Granada, local newspapers, local radio programs and the university website. Parents who expressed willingness to participate were contacted by phone and informed of the general purpose of the study. Only children whose caregivers gave informed written consent to participate were included in the study. A total of 70 infants were recruited at the age of 9–12 months. At T2, 29 more children were additionally recruited at age 16–18 months. From a final sample of 99 children, 61 continued at 26–28 months of age in T3 and 57 at 36–40 months of age in T4.

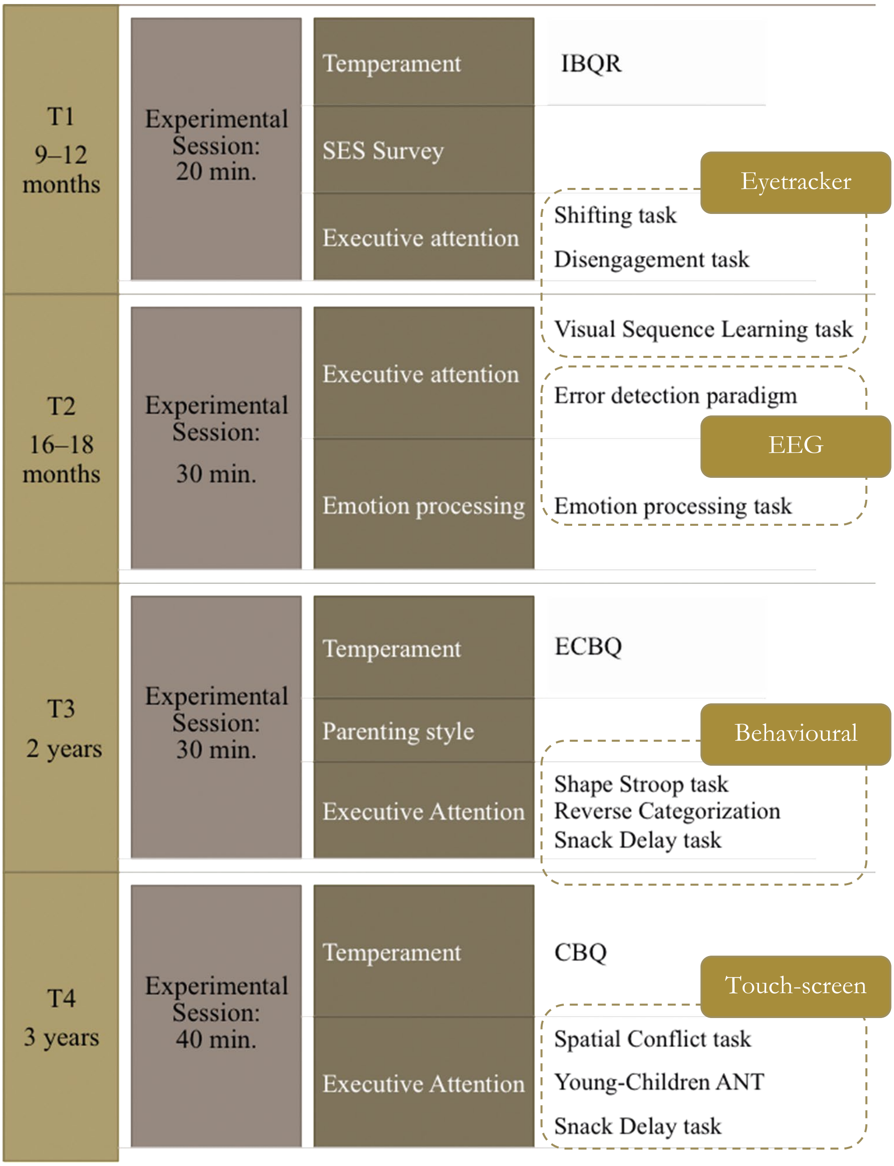


Figure 2.1. General design overview.

Children born prematurely (n=3), or either did not have quality data because of fussiness before or during the experiment or did not reach the minimum of computable trials per condition were excluded from analyses (see Table 2 for valid sample for each experimental task). Children received a 10 € gift card to a local educative toys store per session in appreciation for their participation in the study, and parents received a report with the general results and data of their child at completion of the study.

In addition, 14 adults (13 females) between 18 and 25 years of age (mean= 21.93; *SD*=2.34), recruited through the website of the Experimental Psychology Dept. of the University of Granada, who gave signed consent to be involved in the study and participated in exchange of course credits. This adult group served as a comparison group for the error detection task at T2 were electrophysiological brain activity was registered.

2.3 General procedure

Experimental sessions were held at Developmental Cognitive Neuroscience laboratory in the Mind, Brain and Behaviour Research Centre at University of Granada. As long as children reached the appropriate age to participate in each experimental session, parents were contacted one week in advance in order to schedule an appointment. Upon arrival to the laboratory, parents were informed about the general procedure and aims of the study and asked to sign the consent form. Children and caregivers were received and given a few minutes to get comfortable with the experimenter as well as the lab setting. Once children were ready, we started with the experimental session. Given children age, parents were present during testing. Parents were instructed to not interact with their children in order to not interfere with children's performance in experimental tasks. The study obtained the University of Granada ethics committee approval.

Over the next chapters, I will present the detailed procedure and results of the different waves of the study. Data from each session is described in a different chapter, having a final chapter dedicated to the longitudinal analyses including data from the four waves.

Table 2.1. Sample per session and experimental task.

	Task	Valid n	Age (months) mean (*SD*)
T1 N=70 (36 female)	Shifting task	59	11.04 (1.55)
	Disengagement task	55	
	Temperament IBQR	65	
	SES	91†	
T2 N=88 (43 female)	Visual sequence learning	46	16.77 (.61)
	Error detection paradigm	52	
	Emotion processing task	61	
T3 N=61 (35 female)	Shape Stroop	57	26.64 (.90)
	Reverse Categorization	54	
	Snack Delay	58	
	Temperament ECBQ	56	
	Parenting IPC	55	
T4 N=57 (29 female)	Spatial Conflict	54	37.74 (2.44)
	Young-Child ANT	45	
	Delay of gratification	54	
	Temperament CBQ	56	

† some of the families started their participation in the study in the second session and SES was collected then.

CHAPTER 3

EXECUTIVE ATTENTION IN INFANCY

The content of this chapter is prepared for publication as Conejero, A. & Rueda, M.R (in prep). *Contribution of temperament and socio-economic factors to attention regulation in infancy*

CHAPTER 3: EXECUTIVE ATTENTION IN INFANCY

3.1 INTRODUCTION

The ability to flexibly and voluntarily regulate attention is key to learning and is a central aspect of self-regulation (Posner & Rothbart, 2007). Mastering the regulation of attention requires learning to monitor changes in stimulation, coping with conflicting information and ignoring irrelevant stimulation (Ruff & Rothbart, 2001). This function of attention is associated with a network of brain areas, the executive attention network, which involves frontal and parietal structures as well as basal ganglia (Posner & Rothbart, 2007; Rueda, Pozuelos, & Cómbita, 2015). Individual differences in attention regulation in childhood has been demonstrated to predict academic outcomes (Gawrilow et al., 2014; Zimmerman & Kitsantas, 2014) and social competence (Spinrad et al., 2006). Also, children with poor attention regulation skills show increased probability of suffering both internalizing and externalizing behaviour problems (Eisenberg et al., 2001) and are more vulnerable to psychopathologies, including anxiety disorders (Suveg & Zeman, 2004) or deficit of attention (Martel, 2009).

Existing research suggests that early mechanisms of regulation of attention can be observed already in the first months of life. Attention flexibility and disengagement of attention are two mechanisms involved in regulating attention that appear early in development (Ruff & Rothbart, 2001). The first one, attention flexibility, refers to the ability of switching the focus of attention towards the stimuli we want to process adapting to changing conditions in the environment (Stahl & Pry, 2005). This ability to switch attention is key for learning, since it allows children to explore the environment more broadly and react to perceived changes in stimulation considering diverse response options. In fact, attention flexibility is strongly related to academic success and school readiness during childhood (Blair & Razza, 2007; Bull & Scerif, 2001; Vitiello, Greenfield, & Munis, 2011; Yeniad, Malda, & Mesman, 2013). Prior research shows that babies can flexibly adapt their attention behaviour from very early on. By 4 months of age, infants learn to anticipate their attention to the location in which series of stimuli presented in a fixed temporo-spatial sequence will appear, showing a good initial endogenous control of attention (Canfield & Haith, 1991; Clohessy, Posner, & Rothbart, 2001). About the end of the first year of life, infants are able to search for some attractive object in a new location after learning to retrieve it from a previous one (i.e. A not B task), showing the capacity to inhibit searching in previously rewarded locations (Diamond, 1990a). The ability to flexibly switch attention to different locations has been considered as an early indicator of the function of the executive attention network, a circuit of brain structures modulated by dopamine (Sheese, Rothbart, Posner, White, & Fraundorf, 2008). Indeed, toddlers' attention anticipatory skills to new locations have been related to genes that regulate the levels of dopamine in frontal brain structures involved in the control of attention (Voelker et al., 2009).

On the other hand, disengagement of attention refers to the ability of cease attention from a currently attended location or stimulus in order to redirect attention to a new one (Frick et al., 1999). This ability appears to be functional very early in development. By 3 months of age babies are able to disengage from a central stimuli (Atkinson, Hood, Wattam-Bell, & Braddick, 1992; Johnson et al., 1991), significantly diminishing the time needed to disengage between 4 and 6 months of age (Hunnius, Geuze, & van Geert, 2006). Disengagement may also require the maturation of prefrontal structures, such as the frontal eye fields. It has been suggested that in the early developmental stages attention is controlled by superior colliculus, which causes engagement of attention to salient stimuli. The control of attention by the colliculus causes infants' greater difficulty to disengage from stimuli, whereas later on the inhibition of colliculus by prefrontal structures facilitates the disengagement attention (Johnson et al., 1991). Thus, the two mechanisms, switching/flexibility and attention disengagement, may rely on the functional development of the executive attention network of the brain.

Attention is particularly driven by the relevance and saliency of stimuli, being especially difficult to disengage from stimuli with some emotional content, particularly those that involve some degree of fear or threat (Biggs, Kreager, Gibson, Villano, & Crowell, 2012). Infants between 5 to 7 months of age already show larger latencies to disengage from fearful faces compared to neutral or happy faces (Peltola, Hietanen, Forssman, Leppänen, & Leppänen, 2013). It has been argued that disengagement from emotionally salient stimuli is an important component of emotional regulation, and that the development of more complex strategies for emotional regulation are built on the basis of disengagement (Todd, Cunningham, Anderson, & Thompson, 2012). In fact, decreased ability to disengage from threatening stimuli has been associated with psychopathological conditions characterized by difficulties in attention regulation, such as anxiety disorders (Fox, Russo, Bowles, & Dutton, 2001; Georgiou et al., 2005; Leleu, Douilliez, & Rusinek, 2014). Hence, greater abilities to disengage attention from emotionally salient stimuli can be considered a precursor of later emotional regulation.

Researchers interested in individual differences of attention and self-regulation have established a link between executive attention and temperament along development (Rothbart & Rosario Rueda, 2005; Rothbart et al., 2011). Temperament has been defined as differences in emotional, motor, and attention reactivity along with the self-regulatory processes that modulate such reactivity, being intrinsic to individuals and observable by birth (Rothbart & Bates, 2006). It can be distinguished between three main temperamental factors: surgency/extraversion (SUR), referring to a tendency towards high activity levels and impulsivity; negative affectivity (NA), applied to a disposition to experiment negative emotions; and effortful control (EC), that comprises the regulatory mechanisms that help to down-regulate high reactivity levels (Putnam, Gartstein, & Rothbart, 2006). Thus, we can differentiate between a reactive system (NA and SUR) and a self-regulatory system (EC). Whereas emergence of self-regulatory system seems to occur later in concurrence to the development of the underlying prefrontal structures, reactivity system is functioning from the first months of life, being possible to clearly distinguish individual differences in temperamental reactivity from very early on (Rothbart, 2007). Regulation of temperamental reactivity is closely related to the development of attention regulation (Rothbart et al., 2011). In particular, NA has been related to a difficulty to regulate attention to emotional stimuli. Infants characterized as high in NA are highly irritable, easily frustrated, show extreme fear towards novel stimuli, and have a hard time to be calmed once distressed. Similarly to adults, infants rated as high in NA usually show poorer attention skills (McConnell & Bryson, 2005; Morasch & Bell, 2012) as well as a greater bias towards threatening stimuli (Nakagawa & Sukigara, 2012) and poorer emotional regulation (Kim, Stifter, Philbrook, & Teti, 2014; Smith, Diaz, Day, & Bell, 2016). However, there is some evidence that regulation of attention can act as a protective factor for the development of externalizing behavioural problems in children with highly negative reactive temperaments (Lawson & Ruff, 2004; Moran, Lengua, & Zalewski, 2013).

In addition to the temperament literature, there is a growing body of evidence suggesting that the nurturing environment play an important role in the development of cognitive skills including executive attention. It has been shown that children raised in low-socioeconomic status (SES) environments exhibit poorer executive control, performing not as well as high-SES children in tasks involving attention control (Duncan et al., 1998; Noble et al., 2007). Although research has mainly studied the impact of SES on attention during childhood and adolescence, a few studies have recently shown that home environment and experience impact the development of attention skills from infancy (Clearfield & Jedd, 2013; Lipina et al., 2005; Noble et al., 2015). Although research indicates that both temperament and environment factors contribute to the emergence of individual differences in the ability to regulate attention, few studies have included the two types of variables to test how they relate in early development. Highly reactive children seem to be more vulnerable to environmental influence (Cummings, El-Sheikh, Kouros, & Keller, 2007; El-Sheikh, 2005). It has been suggested that particularly children with higher levels of negative reactivity can be specially sensitive to stressful events which in turn are more likely to occur in socio-economic deprived environments (Rothbart & Bates, 2006). These results suggest that individual differences in temperamental reactivity may mediate the effect of environment on executive attention development.

The goal of the T1 wave of the general longitudinal study was to investigate individual differences of regulation of attention in infancy. On the one hand, we were interested in studying the involvement of attention flexibility in the disengagement from emotional salient stimuli as a precursor of later emotional regulation. On the other hand, we aimed at examining both temperamental and environmental factors that could influence individual differences in attention regulation.

For these purposes, we measured infants' flexibility of attention using the switching task designed by Kòvacks and Mehler (2009). In this task, a target stimulus appears always in the same side for a number of trials so that infants learn to anticipate gaze to that location before the appearance of the stimulus. Then, target location is changed to a new location. How easily children reallocate their attention and start to anticipate attention to the new location provides a measure of infant's attention flexibility. In addition, we measured disengagement of attention from emotional faces with an emotional version of the gap-overlap task (Peltola, Leppänen, Palokangas, & Hietanen, 2008). This task allows measuring the latency to disengage from a central target consisting of faces expressing different emotions in order to look to a peripheral target. Larger latencies and less probability to disengage from fearful faces compared to neutral or happy faces are consistently observed in infants (Leppänen et al., 2011; Peltola et al., 2008).

We hypothesized that both types of attention regulation mechanisms, attention flexibility and disengagement from emotional stimuli, will be related to each other given that both has been associated with maturation of frontal brain structures and involve the endogenous control of attention. We expected that babies able to switch their attention in a more flexible way would also show better capacity to regulate attention to emotionally salient stimuli, disengaging more easily from fearful faces.

We further hypothesized that temperament reactivity will mediate the impact of environment on infant's attention regulation skills. More specifically, we expected that highly reactive infants would show poorer attention regulation when raised in a low-SES context. Finally, we anticipated that infants with higher NA would also have greater difficulty to regulate attention to emotional stimuli, showing increased difficulty to disengage attention from fearful faces. We expect this association to be particularly robust for infants with poor attention flexibility skills.

3.2 METHOD

3.2.1 PARTICIPANTS

The sample consisted of 70 infants between 9 to 12 months of age (31 males, 34 females; mean age 332.67 days; *SD:* 45.95 days). All infants included in the study were born at full term (37 - 41 weeks of gestation) with normal weight (>2500 gr) and had no history of developmental delay. A total of 3 infants were excluded due to prematurity. Infants were recruited from the city of Granada and surrounding areas by means of adverts at the University of Granada webpage and local newspapers as well as distributing information sheets among local nurseries, covering various districts of Granada differing in socioeconomic background.

3.2.2 PROCEDURE

All infants participating in the study conducted two experimental tasks, a shifting and a disengagement task, in which their gaze was monitored with the eye-tracker device described earlier. The entire experimental session was about 15 minutes long, including a brief break between tasks and time for calibration. Experimenter monitored infants' performance from a contiguous room. Parents were provided with a description of the study and were asked to sing the consent form. The study obtained the University of Granada ethics committee approval. The experiment was conducted in a semi-dark room. Infants seated on their parents lap, in front of the display screen at approximately 60 from the monitor. Parents were asked not to interact with their infants during experimental tasks. The shifting task was presented always first, followed by the emotional disengagement task were presented, always in this order. Calibration of eyetracker was conducted prior the recording of each task.

3.2.3 INSTRUMENTS AND APARATUS

3.2.3.1 Temperament questionnaire

We used the Spanish version of the Infant Behaviour Questionnaire Revised (IBQ-R; Gartstein & Rothbart, 2003) to collect information about infants' temperament. This questionnaire measures temperament in 15 scales grouped in 3 factors: Surgency/Extraversion (SUR), Negative Affectivity (NA) and Orienting/Regulation (REG). Parents were asked to rate in a 7-point scale the frequency of some concrete infant's behaviours in different situations during the previous week or 2 weeks. Cronbach's alphas were above .7 for all the scales. Data from 5 children were not provided by parents as they did not return the questionnaire.

3.2.3.2 Socio-economic status survey

Information about the family SES was obtained with a parent-reported questionnaire at the end of the experimental session. The questionnaire includes information about parental education, parental occupation and family income (see Table 3). Parental education was rated from 1 to 7 as follows: 1) no studies; 2) Elementary school; 3) Secondary School; 4) High School; 5) Technical College / University diploma; 6) University Bachelor degree; and 7) Postgraduate studies. Professional occupation was categorized according to the 9-points scale of the Spanish Occupation Classification (CNO-11) from the Spanish National Institute of

Statistics (BOE, 2010) that ranged from 1 (unemployed) to 9 (manager). Finally, we calculated the family income-to-need ratio by dividing the total annual family income per official poverty threshold provided by National Institute of Statistics of Spain (http://www.ine.es). The three components were positively correlated (Pearson's correlations: Parents Education – Parents Occupation: $r=.42$, $p<.01$; Parents Occupation – Family Income: $r=.53$, $p<.001$; Parents Education – Family Income: $r=.43$, $p<.01$). A general SES index was calculated averaging the z-transformed-scores of the three measures for each participant. We did not obtained information from 5 children whose parents did not return the questionnaire.

3.2.3.3 Eyetracking system

SensoMotorics Instruments (SMI) corneal-reflection eyetracker RED 250 with iView X Hi-Speed (SensoMotorics Instruments, Teltow, Germany) system was used to record infants' looking behaviour. The system has temporal resolution of 250 Hz and a spatial resolution of .03°according to manufacturers. Stimuli were displayed in a 1024 × 768 pixels, 19-inch monitor (60 Hz). Experiment Centre software (SensoMotoric Instruments, Teltow, Germany) was used to control presentation of the stimuli. A 5-point child-friendly calibration (consistent in colourful looming points with sound located in the corners and centre of the screen) was performed before starting each task.

3.2.4 Experimental tasks

3.2.4.1 Shifting task

The shifting task was similar to the task used in a previous research by Kovács and Mehler (2009). Task is illustrated in figure 3.1. Task consisted of two white boxes (size: visual angle of 18ºx18º) in a black background presented in both sides of the screen at 15º eccentricity. These boxes remained visible throughout the entire trial. An animated star with music was presented in the centre of the screen to attract babies' attention at the beginning of each trial. The trial started automatically once the baby looked to the attractor for at least 200 milliseconds in order to get detected by the eye-tracker. After one second delay (anticipatory period), an animated cartoon accompanied by funny sounds appeared in one of the boxes and remained visible for 2 seconds. The initial location of the cartoon (left or right) was counterbalanced across participants. After 9 trials appearing in the same place, the cartoon appeared in the opposite side for another 9 trials. Premature babies (n=3) and babies who completed less than 50% of trials or had poor-quality data (n=8) were excluded from final analysis.

3.2.4.2 Emotional disengagement task

The emotional disengagement task (Figure 3.2) was the one developed by Leppänen et al. (2011). Happy, fearful and neutral faces of two different identities (female and male) from NimStim set (Tottenham et al., 2009) were presented to babies in a computer monitor. Scrambled faces were presented as a control condition. All faces subtended a visual angle of 15.2º x 11.1º. Each trial started automatically after babies looked to a centrally located attention grabbing stimuli for at least 200 milliseconds. Then, a face from any of the 4 experimental conditions appeared randomly on the centre of the screen. A second later, a new stimulus (peripheral target) appeared 13.6º from the central face either on the right or the left side of the screen. The peripheral target consisted of either a black and white check-board pattern or vertically arranged circles (15.4º x 4.3º size). Both stimuli, the face and peripheral target, remained for 2 more seconds. The complete task involved a total of 32 trials. If babies became fussy or bored, the experimenter stopped the task. Only trials in which babies remained looking at the screen during the 2 seconds that the peripheral target was present were considered as valid trials. There was a mean of 6.8 valid trials per condition. Only babies that completed at least 4 trials per condition and had enough quality data were included in the analysis (n=55).

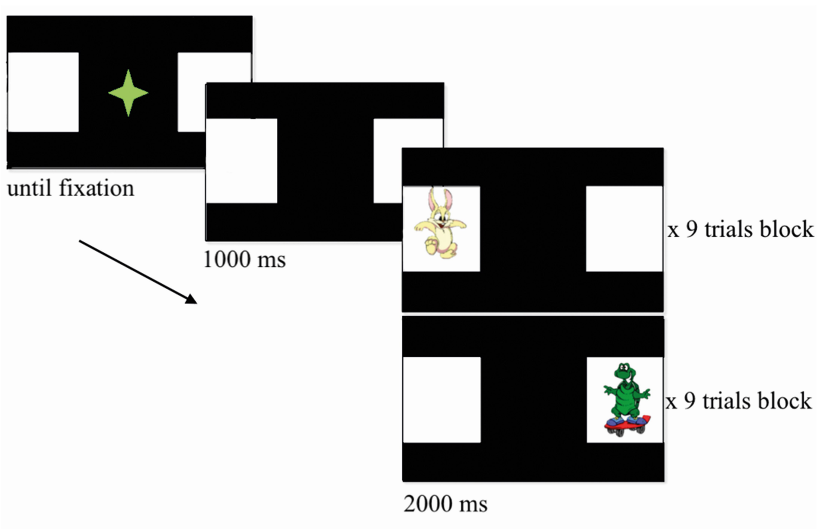


Figure 3.1. Schema of Shifting task procedure. After a first block in which a reward (animated cartoon) appeared in one of the two white boxes for 9 consecutive trials, the reward appeared in the opposite side in a second 9-trials block.

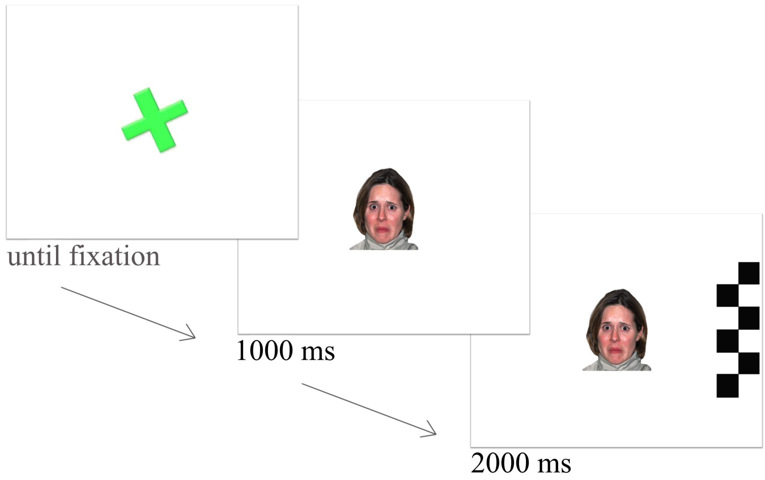


Figure 3.2. Illustration of the Attention Disengagement Task. A distractor appeared 1 second after the appearance of the central target (either a fearful, happy, neutral or scrambled face) in one side of the screen.

3.2.5 EYETRACKING DATA REDUCTION

Analyses were run in SMI BeGaze 3.1 (SensoMotoric Instruments inc., Teltow, Germany). Saccades and fixations were computed according to the following parameters: peak velocity threshold= 40º/s; minimum fixation duration= 50 ms. We computed the proportion of looks to any of the boxes during the anticipatory period for the shifting task. Anticipatory looks that occurred in the first 200 milliseconds after the onset of peripheral target were excluded, as they do not represent a real expectation (Canfield & Haith, 1991). Two 21º x 19º areas of interest (AOI) were defined, covering both the left and right box. Only trials with direct looks to one of the two boxes were included in subsequent analyses. Children without enough quality data were excluded (n=11). Mean number of valid trials was

8.56 and 8.61 for block 1 and 2 respectively. There was no differences between blocks in the number of valid trials (*t*(58)<1).

In the case of the emotional disengagement task, cumulative looking time to face and distractor was computed. Two AOI were defined, covering both the central face (17º x 13º) and right and left distractor (17º x 8º). Only infants with enough quality data (minimum 4 trials per condition) were included in the analyses (n=55). Mean number of valid trials per condition were 7.09, 7.02, 7.09 and 6.75 for fear, happy, neutral and control conditions respectively (*F*(3,162)<1).

3.3 RESULTS

3.3.1 ATTENTION FLEXIBILITY: SHIFTING TASK

Proportion of correct anticipatory looks was calculated for each block. The proportion of correct anticipations significantly decreased in block 2 compared to block 1 (*t*(58)=7.35; *p*< .001; see figure 3.3). Anticipatory looks in the post-switch block to the box in which the animated cartoon appeared during block 1 were considered as perseverations. The percentage of perseverations per participant was calculated as an index of attention flexibility. The average percentage of perseverations was 52.37 (*SD*: 32; See Table 3.1).

Table 3.1. Descriptive statistics of all measures included in the T1 session.

		Valid n	Min	Max	Mean	*SD*
Experimental tasks	Shifting task (% Perseverations)	59	0	100	52.37	32
	Disengagement from fearful faces (ms)	55	252	2631	1446	615
SES	SES index (z-scores)	65	-1.32	1.30	.12	.67
	Parents Occupation (1–9)	65	1	7.5	5.04	1.23
	Parents Education (1–7)	65	1	7	5.54	1.12
	Family Income-to-need-ratio	65	.21	3.77	2.04	.99
Temperament (raw scores)	Negative affectivity	65	2.96	5.26	3.98	.48
	Surgency	65	4.05	6.58	5.32	.59
	Orienting/Regulation	65	3.62	6.28	5.01	.56

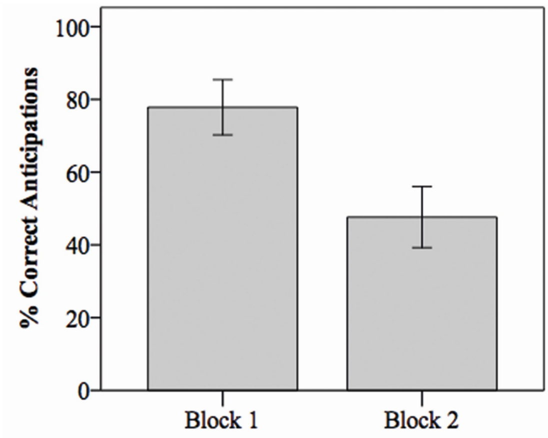


Figure 3.3. Difference between block 1 (preswitch) and block 2 (postswitch) in the proportion of correct anticipations. Bars represent standard errors.

3.3.2 Emotional disengagement task

Two different AOIs were defined: an AOI of visual angle of 17.3º x 6.1º covering either the left or right peripheral target and another one of visual angle of 17.5º x 13.2º covering the central face. As a measure of disengagement, we subtracted the total fixation time to the peripheral target from fixation time to the face for every condition. Shorter times indicated greater ability to disengage. Thus, larger scores mean greater difficulty to disengage from faces. We ran repeated-measures ANOVA to test the effect of Emotion of the face in disengagement (see figure 3.4). We found a significant effect of Emotion ($F(3,162)=29.59$; $p<.001$; $\eta_p^2=.35$). Planned comparisons showed that disengagement was easier for non-face stimuli than for fearful ($F(1,54)= 65.96$; $p<.001$), happy ($F(1,54)= 27.74$; $p<.001$) or neutral faces ($F(1,54)= 32.77$; $p<.001$). There was no differences in disengagement between happy and neutral faces ($F(1,54)=.22$; $p>.05$), whereas disengagement was more difficult for fearful faces compared to neutral (F(1,54)=18.48; p<.001), and happy faces (F(1,54)= 9.43; p<.01). Therefore, for further analyses we used disengagement from fearful faces as a measure of regulation of attention to emotional stimuli.

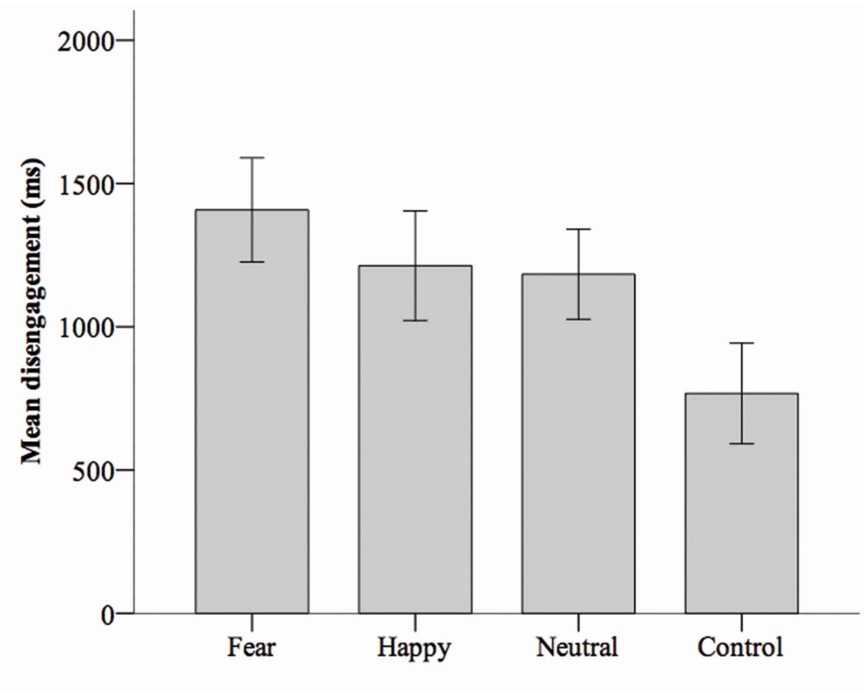


Figure 3.4. Disengagement time in every condition (fearful, happy, and neutral faces, and non-face control stimuli). Bars represent standard errors.

3.3.3 Correlation analysis

Pearson's correlations were performed to test inter-correlations among different measures of attention regulation, temperament and SES. Table 3.2 summarize correlation analysis. We found that perseverations in the shifting task and disengagement from fearful faces were positively correlated (r=.28; p<.05).

Regarding temperament, only NA was associated with performance in both experimental tasks. NA was positively related to proportion of perseverations in the shifting task (r=.40; p<.01), and disengagement from fearful faces (r=.26; p<.05).

Finally, SES was negatively correlated to perseverations in the shifting task (r=-.26, p<.05) indicating that infants from low SES families were more likely to perseverate in the shifting task. SES was also related to NA, in a way that higher SES was associated with lower levels of NA (r=-.25, p<.05). No relationship was found between SES and disengagement from fearful faces (r=-.00, p>.05).

3.3.4 CONTRIBUTION OF SES AND TEMPERAMENT TO INDIVIDUAL DIFFERENCES IN ATTENTION FLEXIBILITY

Given that both NA and SES correlated with percentage of perseveration in the shifting task, we conducted a mediation analysis in order to test whether NA was mediating the SES association with attention flexibility. The mediation analysis was conducted with PROCESS macro for SPSS (Hayes, 2013) using model 4 (which correspond to simple mediation models). The mediation analysis revealed that SES significantly predicted NA (F(1,57)=4.52, p<.05, R^2=.07; b = -.21, t(57)=-2.13, p < .05), as well as percentage of perseverations in the shifting task (F(1,57)=3.66, p=.06, R^2=.06; b = -12.56, t(57)=-1.91, p = .06). Also, introducing together NA and SES in the model significantly predicted percentage of perseverations F(2,56)=5.76, p<.01,$R^{2=}$.17). However, SES did not longer predict perseverations in the shifting task after controlling for NA (b= -7.78, t(56)=-1.20, p > .05), whereas NA remained significant (b= 23.25, t(56)=2.73, p < .01) . This indicates that SES shows an indirect contribution to attention flexibility (i.e. rate of perseverations in the shifting task), being mediated by NA (see Figure 3.5). We estimated the coefficient for this indirect effect at a confidence interval level of 99% (p<.01) using bias corrected bootstrapping approach with 5000 samples, resulting in a value of *b*=-4.78; *CI* [-13.87, -.09].

Table 3.2. Correlations among attention regulation, temperament and SES measures.

*=p<.05 **p<.01		Experimental tasks: **Shifting task (% perseverations)**	Experimental tasks: **Disengagement fearful faces (ms)**
SES	SES index	**-.26***	.00
	Parents Occupation	**-.31***	.09
	Parents Education	.01	.11
	Family Income-to-need-ratio	**-.24***	-.19
Temperament (raw scores)	Negative affectivity	**.40****	**.26***
	Surgency/extraversion	.04	-.02
	Regulation/orienting	-.17	-.08

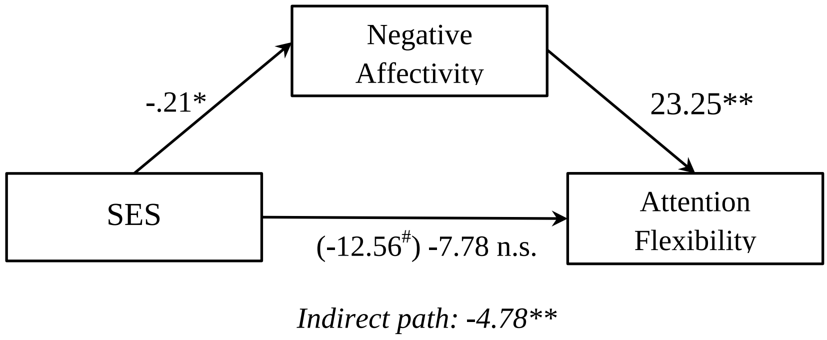


Figure 3.5. Role of NA as a mediator of SES effect on attention flexibility. Values represent unstandardized regression coefficients. Value inside parentheses indicate coefficient for the direct path from SES to attention flexibility before controlling for NA. * p<.05, ** p<.01, # p=.06.

3.3.5 Role of attention flexibility on predicting disengagement from fearful faces

Provided the relationship between attention flexibility, NA and disengagement from fearful faces, we conducted a moderation analysis to test the hypothesis that attention flexibility was modulating the effect of NA on disengagement. The moderation analysis was performed with the macro PROCESS for SPSS (Hayes, 2013). NA scores were used as the independent variable, percentage of perseverations in the shifting task as the moderator and disengagement from fearful faces as the dependent variable (Model 1, corresponding to a simple moderation analysis). Confidence intervals were calculated for 5000 bias corrected bootstrap samples. Results are presented in Table 3.3. The overall model was significant (F(3,52)=4.87, p<.01, R^2=.22) with the interaction between SES and NA significantly predicting disengagement from fearful faces (b=17.58, t=2.83, p=.01). Adding the interaction term to the model significantly increased the proportion of explained variance (ΔR^2 = .12, *F*(1, 52) = 8.04, *p* =.01).

For an easier interpretation of the moderation effect, the relationship between variables is plotted in Figure 3.6. Difficulty to disengage attention does not change as a function of NA when infants present low (from 1 *SD* below the mean) and average percentage of perseverations (*b*=-214.87, *t*=-.56, *p*>.05 and *b*= 335.81, *t*=1.40, *p*>.05 respectively) whereas difficulty to disengage from fearful faces significantly increases as a function of NA in the case of infants that with high (from 1 *SD* above the mean) proportion of perseverations (*b*=265.25, *t*=3.34, *p*<.01).

3.4 Discussion

The purpose of the current study was to investigate attention regulation in infancy taxing two distinct mechanisms: flexibility and disengagement of attention. We found large individual differences in infants' percentage of perseveration in the switching task as well as in their ability to disengage from fearful faces. Results revealed that both SES and temperament were associated with early attention flexibility skills. We observed a negative correlation between perseverating behaviour in the switching task and familial SES, indicating that infants from lower SES families show larger percentage of perseverations. In addition, we found that temperament NA was also related to poorer attention flexibility (i.e. increased perseverations). The relationship between low SES and attention flexibility was also found in a prior study in which infants performed the A-not B task (Lipina et al., 2005). However, in this research the role of temperament was not examined. Given the literature showing increased vulnerability to environment for children with more reactive temperament,

Table 3.3. Moderation analysis testing the moderating role of Negative Affectivity in the relationship between Attention Flexibility and Disengagement from fearful faces. Significance levels: * p=.05, **p<.01

	DV: Disengagement from fearful faces	R^2	B	t	*95% CI*	ΔR^2
Step 1		.07*				-
	Negative Affectivity		412.67	2.13*	[23.73, 801.62]	
Step 2		.10*				.03
	Negative Affectivity		305.95	1.45	[-116.21,728.11]	
	Attention flexibility (% Perseverations)		4.04	1.27	[-2.35, 10.43]	
Step 3		.22*				.12**
	Attention flexibility (% Perseverations)		3.69	1.13	[-2.86, 10.25]	
	Negative Affectivity		335.81	1.61	[-82.42, 754.04]	
	Attention flexibility x Negative Affectivity		17.58	2.83**	[5.14, 30.03]	

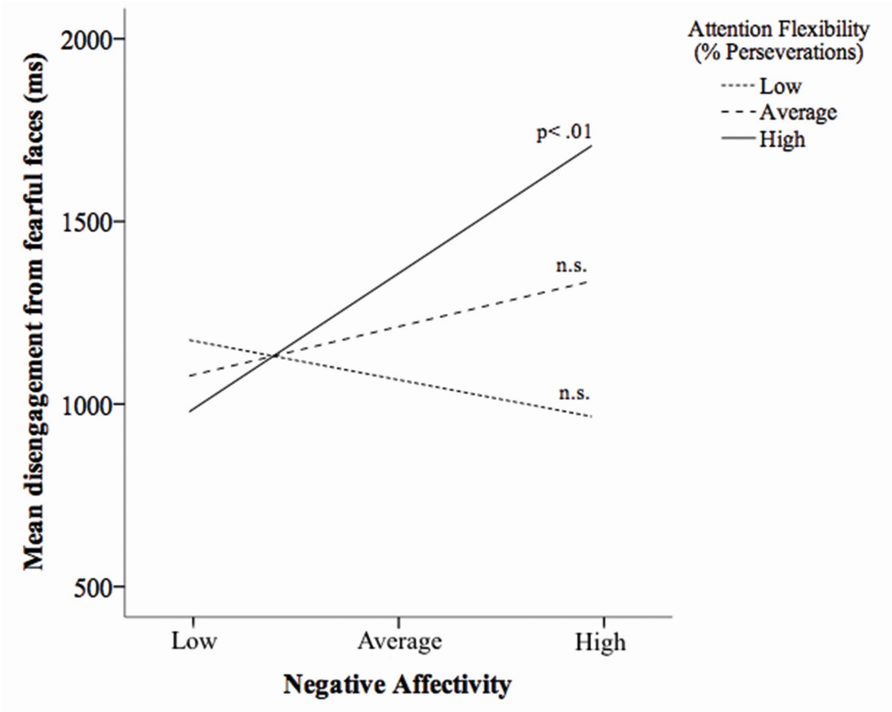


Figure 3.6. Moderation effect of attention flexibility on the relationship between disengagement from fearful stimuli and NA. Low and high levels of the variables refers to values from 1 SD either below or above the mean.

we expected that NA would mediate the effect of SES on the development of attention flexibility in the first year of life. Consistent with our hypothesis, results revealed that SES had an indirect effect on attention flexibility being mediated by infants' NA. Thus, infants raised in low SES families who also showed high NA were more likely to perseverate in the attention flexibility task. One possible explanation for this result is that infants characterized by high levels of NA may be more sensitive to negative life events, therefore being more vulnerable to the environmental stressors (Rothbart & Bates, 2006). This interpretation is supported by a recent study showing that both stress perceived by children and NA mediated the influence of environment and predicted cognitive flexibility in children living in impoverished environments (He & Yin, 2016). Together, these results indicate that individual differences in temperament should be taking into account in order to understand and estimate the effect of environment conditions on the development executive attention, which are observed from the first year of life.

An important question to this matter is related to what aspects of the environment are most responsible for shaping infants' cognitive development. Some authors propose that the effect of SES on attention regulation development can be explained in terms of differences in the number of educational resources available and exposition to stressors that may detriment the quality of parents-children interactions (Hackman, Farah, & Meaney, 2010). In our data, parents' occupation and family income (but not parents' education) where the aspects of SES associated with attention flexibility. These results suggest that during infancy, quality of home environment and family stress (related to income and labour situation) may be more relevant than other environmental factors more related to parents' education, such as parenting practices. However, further research including more specific information of the home environment, such as sleeping time and routines, nutrition, stressful events, or caregivers' availability and sensitivity is needed.

We also investigated the role of attention flexibility on regulation of attention to emotional salient stimuli. Consistent with previous research that identified biased attention of infants towards fearful expressions (Kotsoni, De Haan, & Johnson, 2001), we found that infants showed larger disengaging time for fearful faces compared to happy or neutral faces. This replicated results of previous research with infants in which an emotional version of the gap-overlap task was also used (Nakagawa & Sukigara, 2012; Peltola, Forssman, Puura, van Ijzendoorn, & Leppänen, 2015; Peltola et al., 2013). Prior studies using event-related potentials have observed enhanced neural response over mid-frontal areas when infants show larger latencies to disengage from fearful expressions (de Haan, Belsky, Reid, Volein, & Johnson, 2004; Leppänen, Moulson, Vogel-Farley, & Nelson, 2007), suggesting an increased attention capture of threat-related stimuli. Thus, greater difficulty to disengage from fearful faces may not be explained as a result of novelty (Peltola et al., 2008) or greater perceptual saliency of fearful faces (Peltola, Leppänen, Vogel-Farley, Hietanen, & Nelson, 2009), but to the higher attention engagement produced by fearful faces.

We hypothesized that infants' individual differences in attention flexibility would predict disengagement from fearful faces particularly in infants with high NA. In agreement with previous studies (Johnson et al., 1991; Nakagawa & Sukigara, 2012), our data revealed that those infants with higher NA tended to show larger latencies to disengage from fearful faces. However, as anticipated, not only differences in temperament reactivity but also in attention flexibility contributed to predict disengagement from fearful faces. This finding supports the idea that the development of the executive attention network may be key to voluntary engage and disengage attention toward and from emotional stimuli. This indicates that, by the end of the first year of life, the executive attention network is involved in regulating attention to emotional stimuli in infancy, as suggested by prior research (Posner et al., 2012; Posner & Rothbart, 2009; Rothbart et al., 2011). Moreover, our data confirmed that infants' individual differences in attention flexibility were moderating the relationship between NA and disengagement from threatening stimuli. As can be seen in Figure 3.6, infants with higher negative reactivity levels who also show poor attention flexibility (i.e. high percentage of perseverations) presented greater difficulty to disengage from fearful faces. However, babies showing good attention flexibility skills (i.e. low or average percentage of perseverations) show better rate of disengagement independently of NA. Therefore, as NA have been related to larger bias of attention toward emotionally negative stimuli (Compton, 2000), having better attention flexibility facilitates disengaging from threatening stimuli. Thus, our data suggest that attention flexibility is a protective factor for infants who are more vulnerable to threatening stimulation, such as those with high NA. In line with these data, Ursache et al., (2013) have shown that better distress regulation in infancy predict development of executive function in childhood particularly in babies with higher in NA.

Also, the interaction between temperament reactivity and attention flexibility may also explain differences in emotional regulation later in development. Disengagement from negative emotional stimuli is thought as an early indicator of emotion regulation (Posner & Rothbart, 2007; Rothbart, Posner, & Boylan, 1990). In fact, infants' distress can be reduced by switching their attention away from stimuli evoking negative emotionality (Crockenberg & Leerkes, 2004; Harman, Rothbart, & Posner, 1997; Rothbart et al., 1992). Studies like the present may help to identify early mechanisms that support the development of emotion regulation, thus informing initiatives taxing the prevention of social maladjustments and psychopathology starting from infancy. Difficulties for disengaging attention from negative emotional stimuli have been related to poor emotional regulation skills in children, also associated with externalizing and internalizing behavioural problems (Eisenberg et al., 2001; Graziano, Reavis, Keane, & Calkins, 2007; Lawson & Ruff, 2004; Spinrad et al., 2006). Anxiety has been also associated with a difficulty for emotional regulation that is linked to an attention bias to threat-related cues (Derakshan & Eysenck, 2009). People that suffer from higher levels of anxiety generally experiment a greater difficulty to disengage from negative emotional stimuli, being attributed to their hipervigilance and extra sensitivity towards possible threats in the environment (Fox et al., 2001; Georgiou et al., 2005; Leleu et al., 2014). Likewise, attention regulation (particularly attention flexibility) has demonstrated to play a fundamental role facilitating disengagement from threatening stimuli in individuals with high anxiety, moderating the effect of anxiety in the same way as we observed in infants with high NA (Derryberry & Reed, 2002; Taylor, Cross, & Amir, 2016). The interaction between temperament reactivity and regulation of attention during infancy may constitute a valuable model to predict future regulation of emotion and determine risk patterns for the development of externalizing and internalizing problems, such as anxiety-related psychopathologies.

All in all, these results may contribute to a better comprehension of early development of attention regulation. Our data highlight the importance of exploring the relationship between environmental factors and temperamental in order to better understand how to promote attention regulation from the earliest stages of development. Furthermore, establishing the mechanisms by which attention is regulated in response to emotional stimuli may help understanding why emotional regulation is more challenging for some infants. The disengagement task included in our study used faces as stimuli that did not evoke such a strong emotionality to cause any visible signs of distress to babies, in contrast to other experiments (Harman et al., 1997; Morasch & Bell, 2012; Rothbart et al., 1992; Sheese et al., 2008). Therefore, we did not obtain a direct measure of the effectiveness of disengagement in reducing distress levels. Further research including complementary measures addressing infants' emotional response would be needed in order to establish the relationship between disengagement and early development of emotional regulation. Additionally, more research is needed in order to identify other variables that could be modulating the early development of attention regulation to emotional stimuli such as parenting (Bernier et al., 2010; Mathis & Bierman, 2015), stress (He & Yin, 2016) or genes responsible to codify neurotransmitters related to attention regulation (Brocki et al., 2009; Leppänen et al., 2011). Studies addressing these questions from a longitudinal perspective may serve to trace trajectories conducing to different developmental outcomes. This knowledge would enhance prevention by both serving the early detection of infants at risk and enabling the adjustment of cognitive interventions to children's individual characteristics.

CHAPTER 4

EXECUTIVE ATTENTION BETWEEN 16–18 MONTHS OF AGE

The content of this chapter has been published in Conejero, A., Guerra, S., Abundis-Gutiérrez, A., & Rueda, M.R. (in press). Frontal theta activation associated with error detection in toddlers:Influence of familial socio-economic status. *Developmental Science*

CHAPTER 4: EXECUTIVE ATTENTION BETWEEN 16–18 MONTHS OF AGE

4.1 INTRODUCTION

Executive attention (EA) refers to the effortful and voluntary control of attention, a function that involves processes of conflict resolution, inhibitory control, and error detection (Rueda, Posner, & Rothbart, 2005). This function is related to a network of brain structures including the anterior cingulate (ACC) and lateral prefrontal cortices, and their connections with parietal regions (Petersen & Posner, 2012). EA underlies both perceptual and conceptual learning as well as the ability to self-regulate behaviour (Posner & Rothbart, 2007; Posner & Rothbart, 2014). Individual differences in EA and self-regulation are reliable predictors of schooling achievement and socio-emotional competence during childhood and early adolescence (Checa, Rodríguez-Bailón, & Rueda, 2008; Rueda, Checa, & Rothbart, 2010), as well as life outcomes including health and professional success (Moffitt et al., 2011).

First signs of EA development can be observed as early as around 6 months of postnatal life, when babies begin to show rudimentary forms of attention control (Holmboe, Pasco Fearon, Csibra, Tucker, & Johnson, 2008; Johnson, 1995). Later, during the second half of the first year of life, infants show increased control of attention and display increased behavioural flexibility. During this period, infants become able to overcome the tendency to look for interesting objects in locations previously reinforced but that are not correct anymore (A not B task) or the tendency to reach for an object in the line of sight when inappropriate, both being conflict tasks that demand the activation of prefrontal structures (Diamond, 1990b). Then, by the end of the second year of age, toddlers are able to perform a somewhat more difficult version of the reaching task that requires an arbitrary means-action (e.g. pressing a level) in order to reach a toy (McGuigan & Núñez, 2006). Likewise, they can resolve a more complex version of the A not B task that requires searching for a hidden toy in one of five possible locations (Miller & Marcovitch, 2015). Developmental changes in the prefrontal cortex are thought to underlie increases in EA skills (Diamond, 1990a). During the first years of life, there are substantial structural changes in prefrontal regions, including myelination of white matter fibbers (Dean et al., 2014; Deoni, Dean, Remer, Dirks, & O'Muircheartaigh, 2015), large increases in grey matter volume and cortical thickness (Gilmore et al., 2012; Li, Lin, Gilmore, & Shen, 2015) and growth of thalamo-cortical connections (Alcauter et al., 2014).

One important function related to EA is error detection. In adults, a negative ERP component arises at about 100 milliseconds following the commission of an error (Gehring, Goss, Coles, Meyer, & Donchin, 1993). The so-called error-related negativity (ERN) can be observed after self-committing errors or in response to perceived errors (Bates, Patel, & Liddle, 2005; Mesika, Tzur, & Berger, 2014). Also, source localization of the ERN shows that this potential is originated in the ACC (Luu, Tucker, Derryberry, Reed, & Poulsen, 2003; Perry, Swingler, Calkins, & Bell, 2016) and is related to neural activation in the theta frequency range.

Berger, Tzur & Posner (2006) studied error-related brain activity in infants and found that, similarly to adults, 7 to 9 month-olds show a fronto-central negative component around 330 – 560 milliseconds following the presentation of an incorrect arithmetic operation performed with puppets. Also, Reid and colleagues (2009) observed that 9 month-olds (but not 7 month-olds) show a similar burst of activation over fronto-central leads at about 350 - 650 ms after seeing simple action sequences completed in an unexpected way (for example, the action of eating finished in the ear instead of in the mouth).

Increased frontal midline theta power following an error has been observed in different studies with adults (Luu, Tucker, & Makeig, 2004; Trujillo & Allen, 2007; Tzur & Berger, 2009). Changes in theta-band oscillations generated in the ACC and medial prefrontal cortex are thought to reflect EA processes (Tsujimoto, Shimizu, & Isómera, 2006). During infancy, age-related increases in theta rhythm have been reported and associated with the development of the cortical pathways supporting EA (Orekhova, Stroganova, & Posikera, 1999; Stroganova, Orekhova, & Posikera, 1998). However, in the previously mentioned error-related studies with infants results regarding theta power were not conclusive. In Berger et al. study, the difference in theta power between correct and incorrect conditions was not statistically significant, and no differences in theta power were obtained for expected and unexpected movements in the Reid et al. study.

On the one hand, research has linked EA to emotion regulation. There is evidence that attentional control plays a crucial role in regulation of emotion. Existing research has related poor EA skills in general population (Gyurak, Goodkind, Kramer, Miller, & Levenson, 2012; Tang & Schmeichel, 2014) to a low competence in regulating emotions. Neuroimaging studies further support that idea. There is some evidence that EA network is on the basis of emotion regulation as ACC is implicated in emotion regulation by reducing amygdala response towards emotional stimuli (Bush, Luu, & Posner, 2000; Gross, 2002). It has been suggested that emotion regulation is built from emotion discrimination skills (Tottenham, Hare, & Casey, 2011).

On the other hand, a growing body of literature shows the impact of familial socio-economic status (SES) on the development of cognitive skills, including EA. Studies indicate that low SES is related to poorer academic outcomes and lower performance in cognitive tasks, particularly when executive control is required (Duncan, Yeung, Brooks-Gunn, & Smith, 1998; Noble, McCandliss, & Farah, 2007). Moreover, parental education is associated with differences in cortical thickness of frontal structures within the EA network (Lawson, Duda, Avants, Wu, & Farah, 2013). However, most research examining the effect of SES on cognitive development has been conduced with children and adolescents, and only a few studies have focused in infancy and early childhood. Some studies have shown that home environment and experience impact the development of executive skills from very early on (Clearfield & Jedd, 2013; Lipina, Martelli, Vuelta, & Colombo, 2005; Noble et al., 2015), and very few have examined the extent to which SES influences the development of brain function in early age. In a longitudinal study including 5 months old infants who were followed until the age of 3 years, Hanson et al. (2013) found that familial income is associated with the rate of grey matter growth in frontal and parietal lobes. Also, Tomalski and colleagues (2013) found that 6-9 months old infants raised in low SES families show lower EEG activity in the gamma range frequency, a measure thought to support sustained attention processes. All this literature suggests that functions of the frontal lobe are susceptible to the influence of environmental factors from very early on. Given the central role of frontal regions in EA in general, and error detection in particular, it can be expected to find significant individual differences in this function in different SES groups. Yet, no prior studies have examined changes occurring at the brain functional level during early development associated with EA skills, and no other studies have tested SES-related variability in error detection skills in early childhood.

In the present study, we aimed at investigating toddlers' brain mechanisms involved in error-detection. For that purpose, we registered brain activity during an error-detection paradigm. We designed an experimental paradigm in which toddlers first played with three-pieces puzzles of cartoon animals, which were subsequently presented in a computer monitor being either correctly (as learned previously) or incorrectly completed while EEG was recorded. Based on the previous work, we expected to find an ERN-like potential associated with the perception of the erroneous completion of the puzzles over mid frontal channels. Also, we anticipated that increased theta-band power would be found in incorrect compared to correct completions of the puzzles.

We explored whether electrophysiological brain activity related to error perception at this age serves as a neural marker of EA function. With that purpose, we examined the relationship between brain activity associated with errors and the performance in an EA task. One simple behavioural measure of EA in infancy and toddlerhood is the ability of children to anticipate the location where the stimuli will appear (Canfield & Haith, 1991). In those experimental paradigms, stimuli appeared repeatedly in different locations following a certain order so that children learn that stimuli appeared in a predictable sequence. Infant eye movements are recorded during the task in order to observe whether children looked to the different locations before stimuli appeared. Anticipations reflect endogenous control as anticipations are guided by the knowledge about the sequence to which stimuli will appear in contrast to reactive looks (that is, looking after the appearance of the stimuli) that is thought to reflect exogenous control. Whereas, reactive looks are thought to involve subcortical structures, such as superior colliculus, anticipatory looks may require the maturation of the fronto-parietal network (Csibra, Tucker, &

Johnson, 2001; Johnson et al., 1988). It has been suggested that prefrontal cortex may inhibit superior colliculus in order to allow the voluntary control of attention. We hypothesised that neural markers of error processing would be associated with the proportion of anticipations in the visual sequence-learning task.

We also examined whether individual differences in EA at this age are related to emotion processing. We registered electrophysiological brain activity of toddlers to sad, happy and neutral faces. A negative deflection over right temporal-parietal electrodes arising between 100 and 200 milliseconds after face onset is consistently described in literature (Nelson & Moulson, 2006). This negative component is named N170 and is modulated by the emotional valence of stimuli. Larger latencies of N170 have been observed for emotional faces compared to neutral, being especially pronounced for faces expressing negative emotion (Batty & Taylor, 2003). Infants as early as 3 months of age, although delayed in time, already show this negative component in response to faces (Halit, Csibra, Volein, & Johnson, 2004). We explored whether N170 can be modulated by emotion in toddlers and examined whether N170 modulation by emotion was related to EA. People with higher levels of anxiety and poor regulation skills usually show enhanced N170 amplitude to negative emotional faces (Dennis & Chen, 2007; Kolassa & Miltner, 2006). We expected that both behavioural and electrophysiological measures of EA would be negatively related to the increase on N170 amplitude to sad faces.

Finally, parents were asked to report on a number of different aspects of home environment including parental education, parental occupation and familiar income, with which to calculate an index of familial socio-economic status. Based on previous work showing the impact of environmental factors on the structural growth of frontal regions of the brain, we hypothesized that toddlers from lower SES families would show decreased efficacy of EA skills revealed by reduced brain responses to errors compared to toddlers being raised in high-SES families, as well as by a decreased proportion of anticipations in the visual sequence-learning tasks.

4.2 METHOD

4.2.1 PARTICIPANTS

A total of 88 toddlers aged 16 to 18 months participated in this phase of the study. Toddlers born prematurely (n=3), did not have quality data because of fussiness before or during the experiment (n=9), or did not reach the minimum of computable trials per condition (see procedure section below for exclusion criteria and final sample per task) were excluded from data processing. Children received a 10 € gift card to a local educative toys store in appreciation for their participation in that session, and parents received a report of the general results and data of their child at completion of the study.

In addition, 14 adults (13 females) between 18 and 25 years of age (mean= 21.93; SD=2.34), recruited through the website of the Experimental Psychology Dept. of the University, who gave signed consent to be involved in the study, participated in exchange of course credits.

4.2.2 PROCEDURE

First, a visual sequence task (registered with an eyetracking system) was presented to toddlers. Experiment was conducted in a semi-dark room. After that, babies performed an error detection paradigm and emotional processing task (both registering EEG). Experimental tasks where EEG recording system was required took place in a different testing room, next to the eyetracking room. Infants were always seated on their parents' lap in front of the display screen approximately 60 cm from the monitor. Experimenter monitored babies' behaviour in a contiguous room in both cases: eye movements through the eyetracking system in the first case, motor behaviour during EEG acquisition through a web cam in the second case. A measure of SES was obtained when children were 9–12 months of age in session one (see Chapter 3, section 3.1.2 instruments and aparatus for a detailed description).

4.2.3 INSTRUMENTS AND APARATUS

4.2.3.1 EEG recording

In order to record toddlers' electrical brain activity, we used a pediatric high-density 128 sensors net (EGI's Geodesic Sensor Net, Eugene, Oregon) suited for 1 to 2 years old children with head circumference between 47–51 cm, which was the case for all participants in our study. EEG data was acquired with the following parameters: Signal digitized at 250Hz; 100 to 0.01 Hz band pass acquisition filter; Impedances below 50 KΩ during acquisition; Acquisition referenced to the vertex channel.

4.2.3.2 Eyetracking recording

SensoMotorics Instruments (SMI) corneal-reflection eyetracker RED 250 with iView X Hi-Speed (SensoMotorics Instruments, Teltow, Germany) system was used to record infants' looking behaviour. The system has temporal resolution of 250 Hz and a spatial resolution of .03°according to manufacturers. Stimuli were displayed in a 1024 × 768 pixels, 19-inch monitor (60 Hz). Experiment Centre software (SensoMotoric Instruments, Teltow, Germany) was used to control presentation of the stimuli. A 5-point child-friendly calibration (consistent in colourful looming points with sound located in the corners and centre of the screen) was performed before starting of the task.

4.2.4 EXPERIMENTAL TASKS

4.2.4.1 Visual sequence learning task

The task used was a modification of visual sequence learning task developed by Sheese et al. (2008). Stimuli were presented in SMI Experiment Centre 3.2 software whereas infants' looking behaviour was recorder with RED 250 eyetracker with iView X Hi-Speed (SensoMotorics Instruments inc., Teltow, Germany; see session 1 method section for a detailed description). Children were seated in parents lap, looking to the monitor screen at a distance of approximately 60 cm. Stimuli consisted in a number of attractive cartoon pictures. Stimuli could appear in 3 different positions on the screen (see Figure 4.1): left upper corner (position 1), right upper corner (position 2), and bottom central position (position 3). Stimuli appearance followed a fixed sequence: 1, 2, 1, 3. A total of 8 complete sequences (32 trials) were presented. Each trial started with the picture looming from 5x5 cms (150 ms), 7x7 cms (150 ms) to finally 10x10 cms (150 ms), accompanied with a sound of 330 Hz, 392Hz y 262 Hz respectively. Picture remained for 3500 ms. A 1 second blank screen (anticipatory period) appeared just before the next trial started.

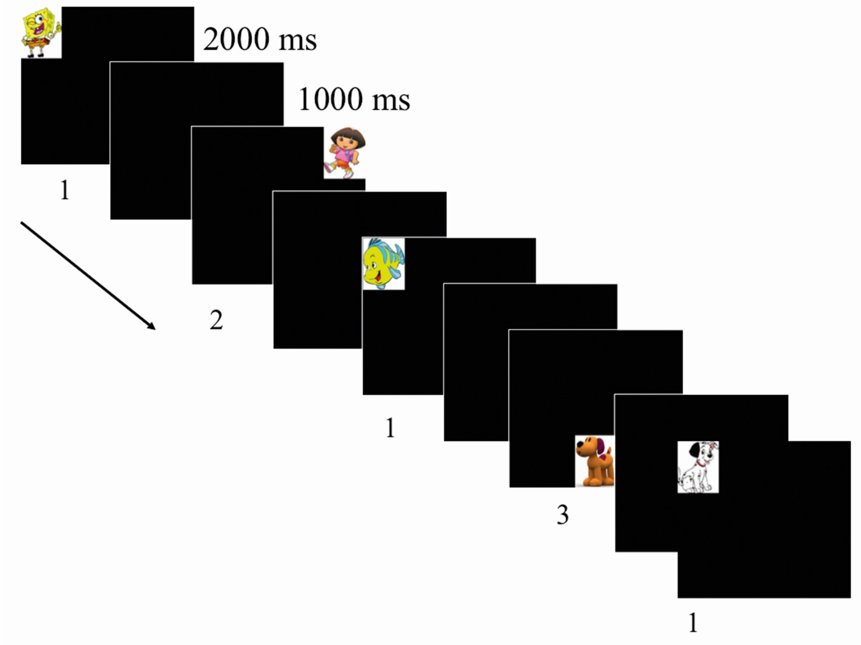


Figure 4.1. Visual sequence learning task. Stimuli always appeared following the sequence 1213.

4.2.4.2 Error detection paradigm

4.2.4.2.1 Experimental procedure

First, we carried out a familiarization phase in order to acquaint them with the correct configuration of three-pieces puzzles of different animal cartoons (sheep, monkey and chicken), similar to the stimuli to be used in the experimental phase (see Figures 4.2 and 4.3). The familiarization phase consisted of two parts. During part I, toddlers were encouraged to handle the pieces and complete the puzzles with the help of the experimenter. The experimenter guided the child to always start by placing the feet, then the body, and finally the head of each puzzle. After correctly completing each puzzle, the experimenter indicated the name of the represented animal, a process that was repeated three times with each puzzle. This procedure was run with all participants and intended to help the child to create a representation of the process of building each puzzle correctly. This part of familiarization phase took less than 5 minutes altogether. During part II, toddlers were seated on the caregiver lap facing a computer screen at 60 cm approximately. Parents were instructed to remain silent and not interact with their children during the entire experiment. The experimenter moved to a contiguous room and monitored children's behaviour with a web cam facing the child. Real photos of each puzzle in colour were presented on the screen next to schematic black and white line drawings of the same puzzles. This intended to familiarize children with line drawing pictures of the previously hand-handled objects. Line drawings of the puzzles were to be used as stimuli in the subsequent experimental phase in order to avoid the effect of colour mismatch in the EEG signal in conditions in which pieces corresponding to different animals will be mixed. Toddlers were shown the completion of each puzzle in the computer screen three times. Pieces of the puzzles were presented sequentially from feet to head, as in the previous familiarization phase. Presentation of the first two pieces of the puzzle was accompanied with a characteristic sound of the represented animal (e.g. the tweet sound for the chicken), whereas at the time of the presentation of the third piece toddlers heard the name of the animal (see Figure 4.2). The experimenter ensured the child was looking at the computer screen before initiating the presentation of stimuli.

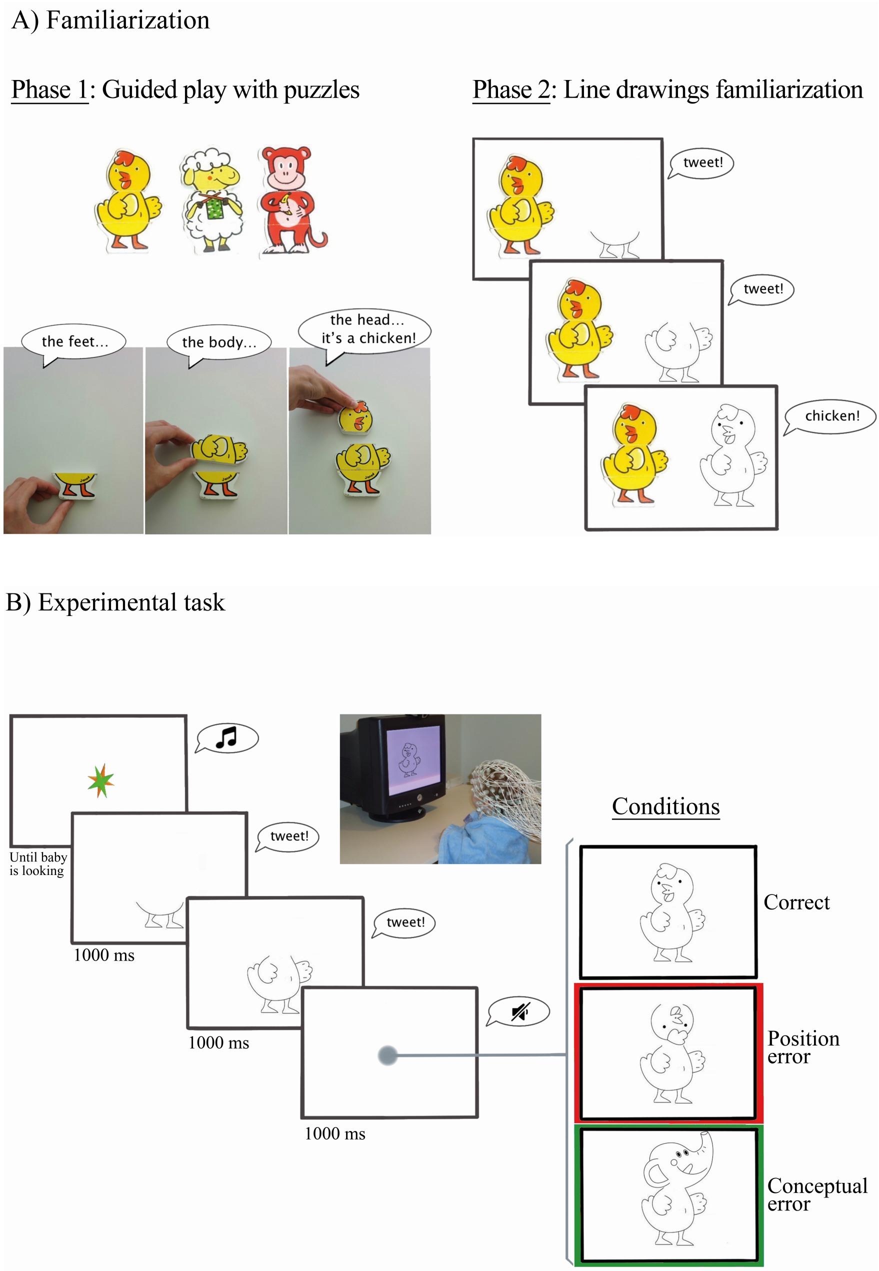


Figure 4.2. Experimental procedure. (A) Familiarization was divided in two phases: 1) toddlers manipulated puzzles with the help of experimenter; 2) toddlers

observed real pictures of the puzzles associated with its correspondent line drawing in black and white. (B) Experimental procedure: toddlers sat in the caregivers lap while observing the progressive completion of puzzles in the computer screen. Three conditions were presented: correct completion, incorrect completion related to the last piece position (upside-down), incorrect completion related to a conceptual mistake (head of a different animal).

The experimental phase began following the familiarization procedure. This net was fitted on the head of the child just before part II of the familiarization procedure. However, brain activity was only recorded during the experimental phase. Toddlers remained in front of the computer monitor sitting on the caregiver lap while the experimenter controlled stimuli presentation from the adjacent room. Stimuli were presented in E-Prime 2.0 software (Psychology Software Tools, Inc.) and synchronized with NetStation software for EEG recording (EGI, Eugene, Oregon) with E-Prime extension. Each trial started with a centrally located colorful rotating star presented with music, intended to attract toddlers' attention. Once the child looked at the screen, the experimenter initialized the trial. In each trial, the puzzle of an animal formed progressively from feet to head. All puzzles were matched in size, subtending a visual angle of 12.5 º x 5 º. Each piece was presented for 1 second. Presentation of the first two pieces was accompanied with the sound of the corresponding animal, whereas no sound was played when displaying the third piece. Twelve trials of a particular animal puzzle (sheep, monkey or chicken) were presented in each block of trials. In one third of trials the puzzle was formed correctly (correct condition), while in the remaining trials it was formed incorrectly by either presenting the head of the corresponding animal upside down (position error condition) or presenting the head of a different animal (conceptual error condition; see Figure 4.2). Block presentation order was randomized and the type of trial was randomly selected within each block. There were a total of 36 trials, with 12 trials per condition (correct, position error or conceptual error).

4.2.4.2.2 Stimuli selection

To build stimuli of the conceptual error condition, sheep, monkey and chicken bodies were mixed with the heads of different animals (crocodile, dog, cow, elephant, horse, lion, zebra, pig and giraffe) to form a total of 27 different combinations (see Figure 4.3). In order to determine which of the resulting animals' combinations are more clearly perceived as erroneous, we presented the different combinations to a group of 32 voluntary participants, all second-year students of psychology that were blind to the purpose of the study. Participants had to identify whether animals' drawings represented a real animal (head and body corresponded to the same animal) or to an unreal animal (incorrect combination of head and body). All newly created animals' head-body combinations as well as the correct combination for all the used animals were randomly presented to all participants. They had 1 second to observe each combination and to decide whether it was either correct or incorrect by pressing the corresponding key. The proportion of participants that judged a combination as incorrect was calculated for all the combinations presented (see Table 4.1). Only combinations perceived as erroneous by over 90% of participants were considered. Combinations with clear differences in the perceptual pattern of head and body (e.g. those having heads with black shapes) were also excluded. All included and excluded combinations are displayed in Figure 4.3.

Figure 4.3. Puzzle combinations included and excluded to build the conceptual error condition in the experimental phase of the study.

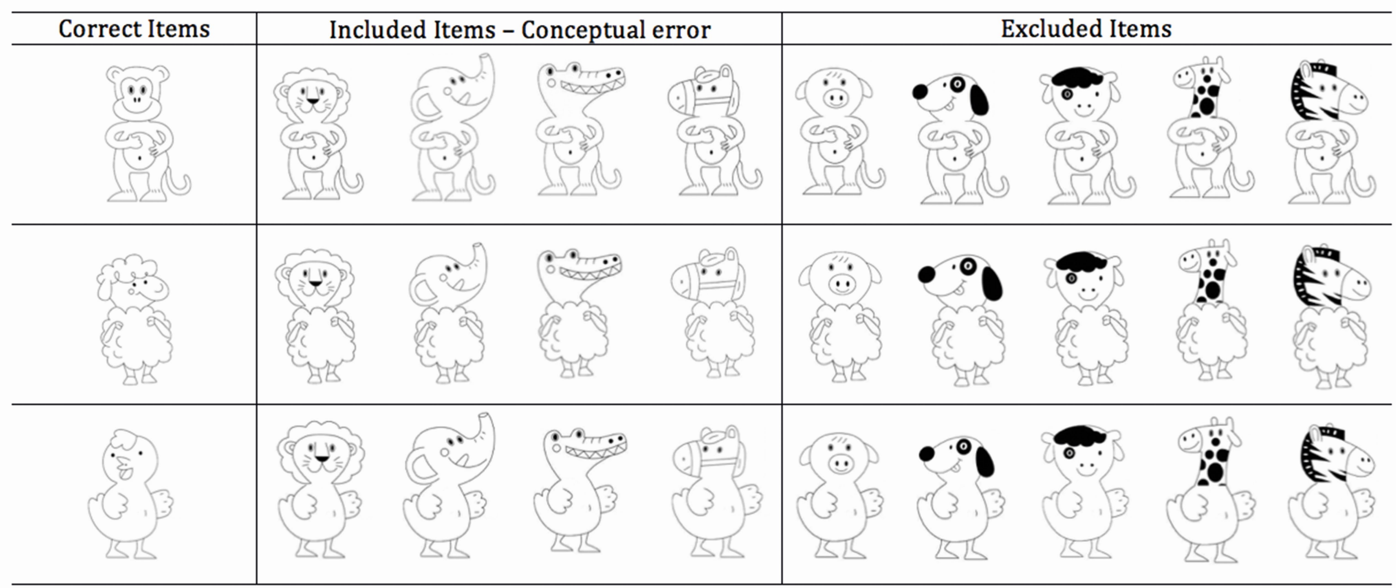
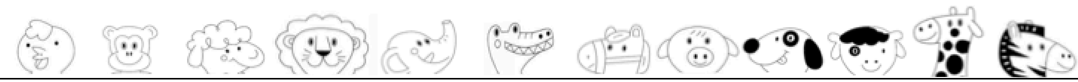
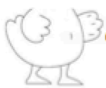
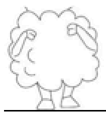


Table 4.1. Percentage of "incorrect combinations" responses given by adults judging the rightness of body-heads combinations

	Heads												
Bodies		Chicken	Monkey	Sheep	Lion	Elephant	Crocodile	Horse	Pig	Dog	Cow	Giraffe	Zebra
	Chicken	0	-	-	100	100	100	100	93.75	100	84.75	100	100
	Monkey	-	3.12	-	81.25	93.75	96.88	93.75	78.12	81.25	81.25	96.88	93.75
	Sheep	-	-	0	100	100	100	100	96.88	81.25	81.25	87.5	100
	MEAN	**0**	**3.12**	**0**	**93.75**	**97.92**	**98.96**	**97.92**	**89.58**	**87.50**	**82.41**	**94.79**	**97.92**

4.2.4.3 Emotion processing task

We presented toddlers male and female faces showing different emotions (happy, sad or neutral faces). Images from the NimStim stimuli set were used as stimuli (Tottenham et al., 2009). Stimuli were presented in E-Prime 2.0 software (Psychology Software Tools, Inc.) and synchronized with NetStation software for EEG recording (EGI, Eugene, Oregon) with E-Prime extension. Each trial started with a colourful attractor displayed centrally on the screen. Experimenter initialized each trial manually once baby was looking to the screen. Then, stimuli appeared in the centre of the screen at visual angel of approximately 11º x 8º. Faces remained at screen for 1 second, followed by a 1 second blank screen (see Figure 4.4). Stimuli were randomly presented. Task consisted of a total of 72 trials in 3 blocks of 24 trials with short breaks between blocks.

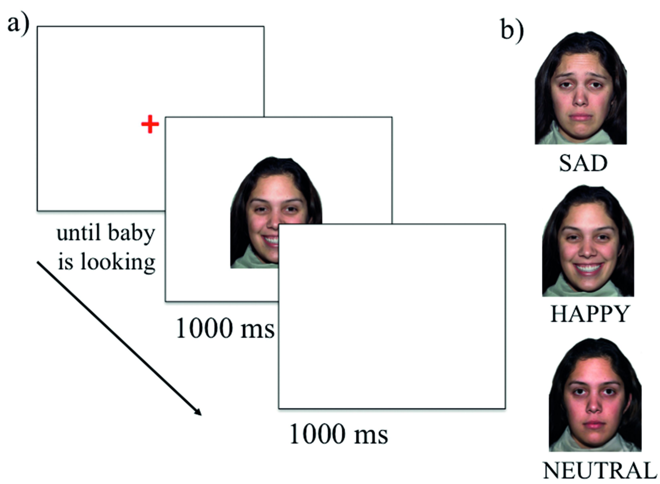


Figure 4.4. Emotional processing task procedure (a) and stimuli per condition (b).

4.2.5 ANALYSES

4.2.5.1 Visual sequence learning task data reduction

We computed the proportion of looks to each location during the anticipatory period. Analyses were run in SMI BeGaze 3.1 (Sensor Motoric Instruments inc., Teltow, Germany). Saccades and fixations were computed according to the following parameters: peak velocity threshold= 40º/s; minimum fixation duration= 50 ms. Three 16º x 16º AOIs were defined, covering the three possible locations for the target stimuli. Anticipatory looks that occurred in the first 200 milliseconds after the onset of peripheral target were excluded, as they may not reflect a endogenous control of attention (Canfield & Haith, 1991). A total of 56 children performed this task. Toddlers who attended for less than 20 trials (n=6) or had poor quality data (n=4) were excluded from the analyses (final sample n=46, 20 female; mean age=16.66 months, *SD*=.67).

4.2.5.2 ERPs analysis

We used EEGlab software (Delorme & Makeig, 2004) for preprocessing the continuous EEG recording. A 0.2 Hz high pass and 30 Hz low pass filter was applied. Bad channels were replaced by spherical interpolation provided that no more than 10 channels were identified as bad channels and were distributed over the scalp. Average re-reference was computed. Artefacts in the continuous EEG were identified by visual inspection and manually removed before running Independent Component Analysis (ICA) to detect and correct eye blinks artefacts. Next, continuous EEG was segmented into 800 milliseconds long epochs time-locked to the onset of the target stimuli (third piece of the puzzle, head presentation, for the error detection paradigm; faces in the emotional processing task). Only trials where toddlers were looking at the screen during the entire trial (according to the examination of the webcam recordings) were included in the analysis. Mean of trials excluded due to inattention were .76, .75, and .69 respectively for correct, position error and conceptual error conditions in the error detection paradigm and 2.41, 3.02 and 2.78 respectively for happy, sad and neutral faces in the emotional processing task.

The subsequent analysis of the ERPs was made using ERPlab software (Lopez-Calderon & Luck, 2014). The average ERPs were calculated per condition and corrected by a 200 milliseconds pre-stimuli baseline. In the case of error detection paradigm, only children with a minimum of 7 computable trials per condition were included in the final analysis. The final sample consisted of 52 toddlers (26 males, 26 females, mean age=16.75 months; SD=.67). Mean of valid trials were 8.15, 8.69 and 8.57 for correct, position error and conceptual error conditions respectively. No statistical differences were found between experimental conditions in the amount of valid trials (F (2,102)=1.69, p>.05). In the case of the emotional processing task, only children with a minimum of 10 computable trials per condition were included in the final analysis. The final sample for this task consisted of 61 toddlers (32 males, 30 females, mean age=16.77 months; SD=.61). The mean of valid trials per condition was 18.23, 19.45, and 17.80 for happy, sad and neutral faces respectively (F (2,120)<1).

As expected, the errors vs. correct contrast yielded a negative component with a mid frontal topographic distribution in the case of error detection paradigm (Figure 4.6 c). To analyse this Error-related Negativity (ERN) component, we selected a group of frontal midline electrodes around Fcz (electrodes 6, 7, 12, 13, 21, 24, 25, 30 and 31, and electrodes 4, 5, 11, 12, 20, 25 and 124 in the corresponding GSN lead locations respectively for toddlers and adults; see Figure 4.5). We calculated mean amplitude of the evoked signal per condition in a time window from 450 to 750 post-target milliseconds for toddlers and peak amplitude between 120 to 160 milliseconds for adults' potentials.

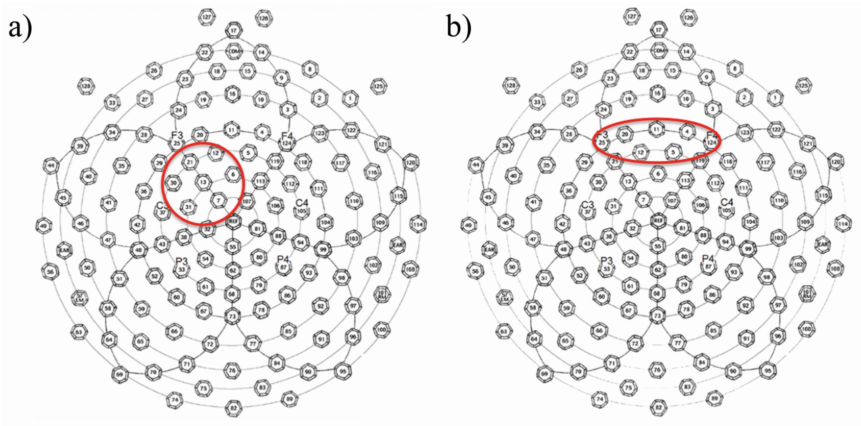


Figure 4.5. Topographical location of electrodes selected for the statistical analyses in toddlers (a) and adults (b).

In the case of emotion processing task, visual inspection of the ERPs revealed a negative deflection within a time window of 200–300 milliseconds after the onset of the presentation of faces. This negative component was identified as N170 according to previous literature (Csibra, Kushnerenko, & Grossmann, 2008; de Haan, Humphreys, & Johnson, 2002). We selected a set of electrodes for the analysis over temporal-parietal areas on right (electrodes 90 and 96) and left (electrodes 70 and 64) sites. Peak amplitude of the N170 in the three conditions was used as dependent variable.

4.2.5.3 Time-Frequency Analysis

A Time-Frequency Analysis was conducted in error detection paradigm using Brainstorm software (Tadel, Baillet, Mosher, Pantazis, & Leahy, 2011). We applied a Morlet wavelet transformed on the pre-processed and segmented EEG data. Wavelets family varied from 1 to 30 Hz, using 0,5 Hz steps. f_0/σ_f ratio was established in 7. The normalized change in power relative to a 200 milliseconds pre-stimulus baseline was computed for each participant and condition for all the electrodes.

4.3 RESULTS

4.3.1.1 Visual sequence learning task

Percentage of reactive and anticipatory looks was calculated for attended trials. Descriptive statistics of the different measures are presented in Table 4.2.

4.3.1.2 Error Detection Results

4.3.1.2.1 ERPs results

A fronto-central negativity that was larger for incorrect compared to correct trials was observed in toddlers as well as in adults (see Figure 4.6). Mean amplitude data per condition (correct, position error, conceptual error) were submitted to repeated-measures ANOVA separately for toddlers and adults (see Table 4.2 for descriptive statistics). A significant effect of condition was found for both toddlers (F(2,102)=12.18, p<.001, η^2_p=.19) and adults (F(2,26)=4.74, p<.05, η^2_p=.27). Planned comparisons revealed that the difference between error conditions (both position and conceptual) and the correct condition was significant for both toddlers (position error vs. correct condition: $F(1,51)=15.04$, $p<.001$; conceptual error vs. correct condition: $F(1,51)=17.18$, $p<.001$) and adults (position error vs. correct condition: $F(1,13)=6.64$, $p<.05$; conceptual error vs. correct condition: $F(1,13)=8.41$, $p<.05$), whereas there were no significant differences between error conditions in any group (toddlers: $F(1,51)<1$; adults: $F(1,13)<1$). Therefore, data from the two types of errors were merged for subsequent analyses. The difference wave was calculated by subtracting correct from error conditions. No relationship with age ($r=-.01$, $p>.05$) or gender differences were found in the ERN amplitude for toddlers group ($t(51)<1$).

4.3.1.2.2 Time Frequency Analysis Results

Both toddlers and adults showed an increase in relative theta power at Fcz (electrode 12) for the error compared to the correct condition (see Figure 4.7). This difference in theta power between conditions was statistically significant in theta frequency range between 6 and 7 Hz in both cases, matching the ERN time window. Theta power differences between error and correct conditions were significant between 300 and 600 milliseconds after stimuli presentation in toddlers ($t(51)=2.37$, $p<.05$, $d=.64$). No relationship with age ($r=-.07$, $p>.05$) or gender differences were found ($t(51)<1$). Adults showed a significant correct vs. error difference in theta power in the time window between 240 and 450 milliseconds ($t(14)=2.91$, $p<.05$, $d=.77$).

Table 4.2. Descriptive statistics of all measures included in the study. Means and standard deviations are provided for toddlers' and adults' data.

	Measure	Condition	Mean	*SD*
Toddlers	Visual Sequence Learning task	Nº attended trials	29.87	2.77
		% Anticipations	72.00	13.21
		% Correct anticipations	21.27	14.31
	ERN amplitude (µV)	correct	-2.32	4.84
		position error	-5.38	5.49
		conceptual error	-5.86	6.08
	Theta power (standardized change)	correct	8.19	7.34
		error	11.90	9.79
	N170	sad	-3.26	8.70
		happy	-2.04	7.71
		neutral	-1.60	7.49
	SES	Occupation (1-9)	5.05	1.25
		Education (1-7)	5.5	1.01
		Income-to-need	2.01	1.01
		SES general index	.02	.78
Adults	ERN amplitude (µV)	correct	-2.03	1.48
		position error	-3.42	3.07
		conceptual error	-3.55	2.44
	Theta power (standardized change)	correct	6.27	3.37
		error	12.03	7.36

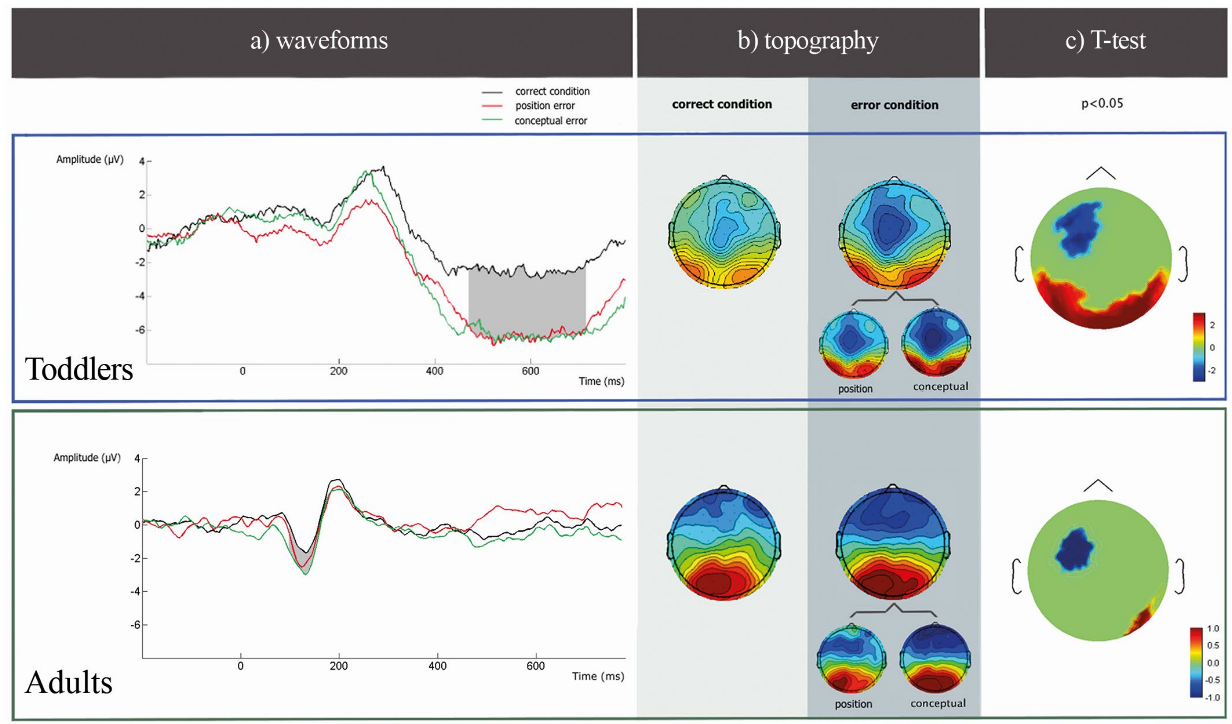


Figure 4.6. ERPs waveforms (a) and topographic maps (b) for correct and error conditions. ERPs were locked to the presentation of the third piece of the puzzle. c) T-test comparing amplitude differences between correct and incorrect (merged for position and conceptual error.

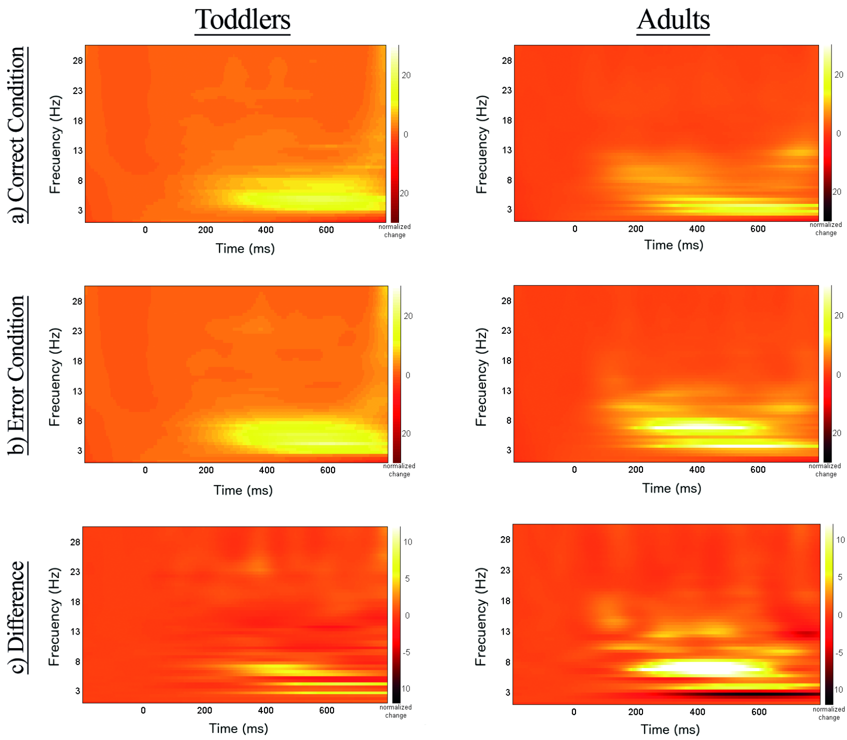


Figure 4.7. Time-frequency maps for adults and toddlers in the correct (a) and error condition (b). Maps at the bottom show the subtraction (incorrect-correct) of the signal (c).

4.3.1.3 Emotional processing results

We used repeated measured ANOVA to compare N170 peak amplitude between neutral, happy and sad faces on left and right areas. There was a main effect of emotion ($F(2,120)=3.67$, $p<.05$, $\eta^2_p=.07$). Planned comparisons revealed that N170 was larger for sad faces compared neutral faces ($F(1,60)=6.49$ $p<.05$) and also tended to be larger for sad compared to happy faces ($F(1,60)=2.88$ $p<.1$). There was no differences between happy and neutral faces in N170 amplitude ($F(1,60)=1.61$ $p<.1$).

There was a significant main effect of lateralization of N170 (F(1,60)=32.83, p<.001, η^2_p=.35) being more prominent on right electrodes. We run repeated measures ANOVA to test gender differences. Including gender as a factor revealed that interaction between toddlers' gender (male, female) and emotion was not significant (F(2,60)<1). Difference in peak amplitude between neutral and sad conditions were used for subsequent analyses as an indicator of emotional processing. Difference in amplitude between neutral and sad conditions was significantly correlated with age (r=.25, p<.05).

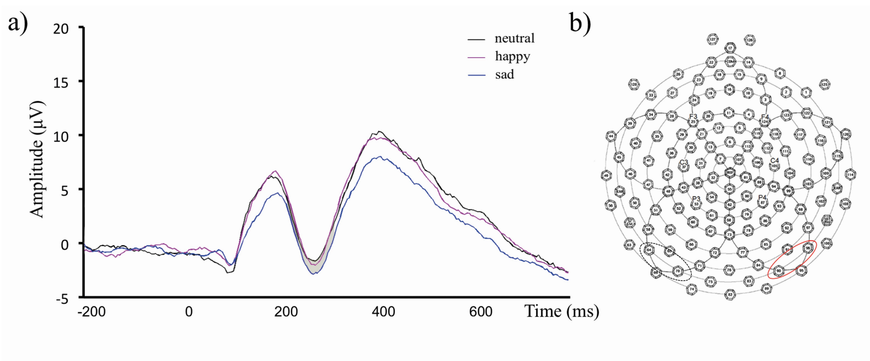


Figure 4.8. a) N170 ERP in right temporal-parietal areas (average of electrodes 90 and 96 corresponding to PO8 and T6-P8). b) electrodes selection for ANOVA on the right (90, 96; dashed red line) and on the left (70, 64; dashed black line).

4.3.1.4 CORRELATION ANALYSES

We run Pearson's correlations to examine the relationship among the different variables. We performed partial correlations controlling for age in the case of N170 and the percentage of correct anticipations in the visual sequence-learning task as both measures were related to age. Results of correlation analyses are presented in Table 4.4. ERN difference wave was positively correlated to theta power increase. ERN difference wave was also positively related to performance in the visual sequence-learning task (% of anticipations) but correlation was marginally significant. However, correlation between ERN amplitude and percentage of anticipations in the visual sequence-learning task was significant (r=-.40, p=.01).

Both ERN difference wave and percentage of anticipations in the visual sequence were significantly associated with parental education, parental occupation and family income, as well as to general index of SES. Higher family SES was related to larger difference between error and correct condition in the amplitude of ERN and a greater proportion of anticipations in the visual sequence-learning task. ERN amplitude was also associated with general SES (r=-.25, p=<.05). Additionally, children of highly educated parents experimented a significantly greater increment in theta power in error condition relative to correct condition. No further significant correlations were found among the studied variables.

4.3.1.5 Linear Regression Analyses of SES on Electrophysiological Brain measures of EA.

Simple linear regression was performed to examine the association between SES and amplitude of the ERN in toddlers. The analysis revealed that SES significantly contributed to the amplitude of the ERN (β= .355, F(1,51)=7.10, p<.05). ERN could be predicted from SES by the following model: ERN amplitude = 6.25 + 3.29 x SES general index (R^2=.13). We also run additional simple linear regression analyses to test whether parental education was a predictor for both ERN and increase in theta power in response to errors. Parental education significantly contributed to the amplitude of the ERN (β= .31, $F(1,51)=5.03$, $p<.05$; $R^2=.10$; see Figure 4.9) but only marginally associated with theta power, (β= .25, F(1,51)=3.47, p<.07; $R^2=.07$; see Figure 4.10).

Table 4.2. Intercorrelations between electrophysiological measures, visual sequence measures and SES. † partial correlations controlling by age. Significance levels: ***p*<.01;* *p*<.05; #*p*<.1.

	1.	2.	3.	4.	5.	6.	7.	8.
1.ERN (difference wave)	-							
2. Theta power	**.32***	-						
3.N170 amplitude (neutral-sad)†	.15	-.02	-					
4.Visual sequence % anticipations	**.25**#	-.06	.12	-				
5.Visual Sequence % correct anticipations†	.20	.11	.02	**.31***	-			
6. SES general index	**.35****	.11	.01	.26*	-.03	-		
7. SES Education	**.24***	**.23***	-.07	**.29***	-.21	**.76****	-	
8. SES Occupation	**.37****	-.07	.06	**.30***	.09	**.80****	**.35****	-
9. SES Income-to-need ratio	**.24***	.11	.04	.10	.06	**.84****	**.46****	**.56****

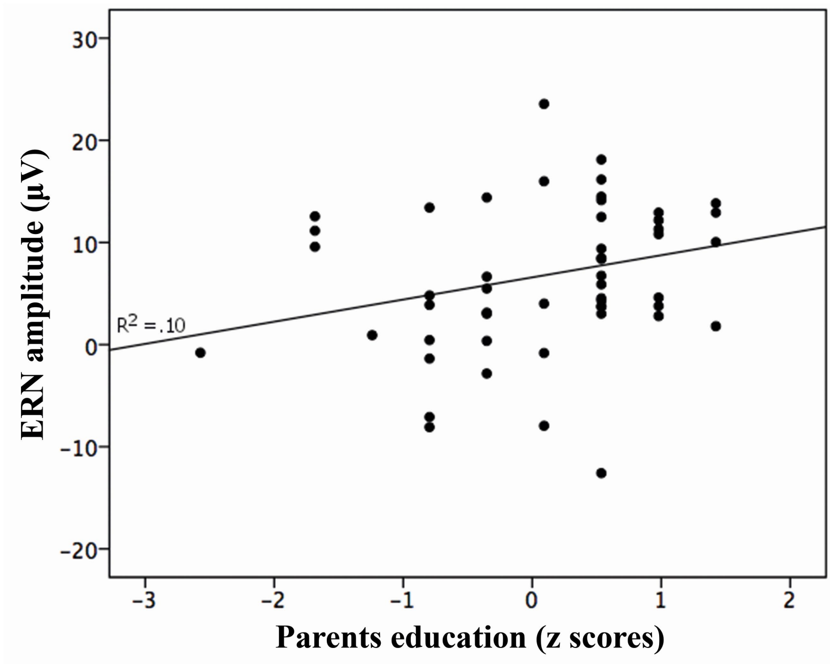


Figure 4.9. Linear regression model showing the association between amplitude of the ERN (error – correct difference in amplitude) and parental education. Parental education predicted toddlers' ERN.

4.3.1.6 Linear Regression Analyses of ERN and SES on behavioural measures of EA.

We also run multiple linear regression analysis to examine the contribution of both SES and ERN to individual differences in visual sequence-learning performance. We introduced together SES general index and ERN amplitude in the model with percentage of anticipations as the dependent variable. Results of the analyses are shown in table 4.3. The model significantly predicted performance in the visual sequence-learning task (F(2,31)=5.20, p=.01; R^2=.25). Both SES and ERN significantly predicted the percentage of anticipations, although the contribution of ERN was only marginally significant. Adding the interaction between ERN and SES to the model did not significantly increase the proportion of variance explained by the model (ΔR^2 = .04, F(1, 32) = 1.51, p =.23).

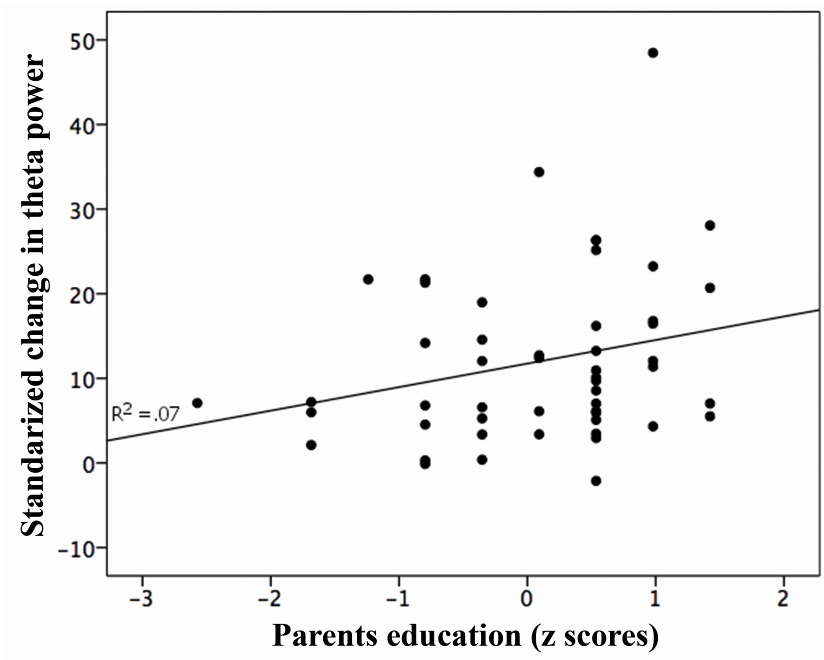


Figure 4.10. Linear regression model showing the association between theta power (error-correct difference in standardized change) and parental education. Parental education contribution to toddlers' theta power increase for errors.

Table 4.3. Multiple regression analysis of SES and ERN on visual sequence-learning task performance. Significance levels: $^{**}p$=.01;* p<.05; $^{\#}p$<.07

DV: % anticipations visual sequence-learning task	R^2	β	t
	.25**		
ERN amplitude		-.31	1.93$^{\#}$
SES general index		.32	2.01*

4.4 Discussion

The main aim of this study was to investigate the development of neural mechanisms underpinning executive control of attention during the second year of life and to explore the influence of SES on such mechanisms. To that purpose, we designed an experimental procedure in which toddlers' brain electrophysiological response to errors was registered. In adults, error-detection has been extensively related to neurophysiological mechanisms involved in action regulation and EA (Luu et al., 2004). In babies, brain reaction to errors is considered a measure of the functional emergence of the EA network (Rothbart, Sheese, Rueda, & Posner, 2011). A recent study has shown that when babies observe unexpected events (e.g. a toy car that passes through a solid wall) are more likely to engage in information-seeking behaviours, such as exploring objects that committed violations in a hypothesis-testing mode (Stahl & Feigenson, 2015). The authors of this study argue that babies use violation of expectations as a way to select information from the environment that is most useful for leaning.

Although the ability of babies to regulate action based on the feedback inherent to error detection (for example, slowing responses after committing an error) seems not to be present until 36 months of age (Jones, Rothbart, & Posner, 2003), our data indicates that the sight of an unexpected puzzle completion (e.g. a chicken body being completed with an elephant head) causes greater engagement of the EA network related to the detection of conflict between what was expected (toddlers' mental representation of the cartoon animals created during familiarization) and what happened.

Consistent with our predictions, toddlers exhibited an increased fronto-central negativity, similar to the adults' ERN, following the observation of configuration errors when adding the final piece of the puzzles. Our experimental protocol included two types of error. Error trials differed in the type of information manipulated to create the mismatch: one involved completing the puzzle with a new piece (conceptual error), and the other involved completing the puzzle with the old piece in an unexpected orientation (position error). It could be argued that conceptual errors involve a novelty component, as children were not familiarized with the head of other animals, besides the three correct configurations, during phases I and II of the protocol. Importantly, both types of errors produced a strikingly similar electrophysiological reaction over midfrontal channels, which was not statistically differentiable. This indicates that the observed brain response reflects a general cognitive mechanism dedicated to the processing of error and expectancy violations rather than to the processing of specific information or whether the final piece is novel or not. Nonetheless, novelty and surprise are inherent to errors when these consist on a mismatch between what was intended or expected and what finally occurred.

The topography of the error-related negativity in 16-18 months old toddlers in our study was comparable to that found in adults. Also, this component was delayed and more extended in time for toddlers compared to adults. Considering the common topography and functionality, this negative component can be seen as a precursor of the ERN as interpreted by other authors (Berger et al., 2006; Gullick et al., 2012). In support of this conclusion, we also found an increase in theta-band power in error trials compared to correct ones. As previously reported in infants (Berger et al., 2006), the theta power burst was concurrent with the ERN-like component and is thought to be the result of a phase alignment of theta-band activity (Luu et al., 2004; Trujillo & Allen, 2007). Indeed, the increase in theta power in response to the perception of errors or unexpected events has been consistently reported (Bates et al., 2005; Reid et al., 2009; Tzur & Berger, 2009).

Nevertheless, in contrast to previous research with infants where results regarding theta band did not reach the significance level, we found that the increment of theta power in the error condition was statistically significant for both toddlers and adults. Recent research suggests that frontal theta is an important mechanism supporting changes in white matter fibbers. Evidence from animal and human studies show increases in myelination and connectivity following bursts of frontal theta mediated by activation of the protease calpain (Posner, Tang, & Lynch, 2014). Frontal theta activation in young children may thus be an important mechanism promoting the development of optimal structural connections between regions within the EA network.

The fact that ERN amplitude is correlated to the performance in another concurrent EA task (the visual sequence-learning task) gives further support to the idea that this ERN-like component is reflecting the functioning of EA. Anticipations in a visual sequence-learning task has been previously associated with genes that control levels of dopamine in prefrontal areas of the brain, suggesting that anticipatory looks may engage EA network (Voelker et al., 2009). However, no relationship was found between electrophysiological brain reaction to emotional faces and measures of EA. We observed that N170 was modulated by the emotional expression of the face already in toddlers, being more prominent for sad faces compared to happy or neutral faces. Contrary to expected, individual differences in N170 were not related to EA. This may reflect a more basic emotional processing mechanism that, although at the core of emotion regulation, may be more related to emotional reactivity mechanisms. In fact, enhanced N170 to threatening facial expressions has been related to higher anxiety levels (Wieser, Pauli, Reicherts, & Mühlberger, 2010). Presumably, it would be related to more specific measures of emotion regulation rather than a general mechanism of EA control.

A second important piece of evidence provided by our study is that family SES was associated with both measures of EA: the magnitude of the brain response to errors and performance in the visual sequence-learning task. These results show that SES influences the functional development of the EA network from very early on. The influence of SES in early attention development is supported by prior behavioural studies, which demonstrated that infants coming from low-SES families show poorer performance in the A/not-B task (Lipina et al., 2005) and greater inattention (Clearfield & Jedd, 2013) compared to those raised in high-SES environments. We found that the impact of SES can also be observed at the level of brain function. This is consistent with recent evidence showing that children from low-SES backgrounds show diminished grey matter volume in frontal and parietal regions during the first years of life (Hanson et al., 2013). Reduced gray matter volume in structures within the EA network may contribute to the poorer functional efficiency of this network for error detection observed in our study. Likewise, infants raised in low-SES families show reduced power in frontal gamma oscillations while seeing video clips with familiar objects (Tomalski et al., 2013), an oscillatory activity thought to support processes related to object perception and attention (Engel, Fries, & Singer, 2001).

In our study, the reduced ERN shown by low SES toddlers could be due to either a weakened representation of the correct configuration of cartoons for which toddlers had only limited experience, a poorer activation of EA mechanisms of conflict detection, or both. The experimental protocol in our study included a standardized familiarization phase that intended to make the experience with the puzzles comparable for all children. In spite of that, children from high SES families might have formed richer and stronger representations of correct puzzle configurations compared to low SES children. Parents with higher education level speak far more to their children and use richer vocabulary compared to parents from low SES families, which has been shown to impact children's lexical development (Hoff, 2006). Restricted linguistic interactions together with the greater probability of suffering stress contribute to poorer-quality parent-child interactions in low-SES families (Farah, Hackman, & Meaney, 2010). These factors might have contributed to poorer learning capacities in toddlers from lower-SES backgrounds as well as diminished function of brain mechanisms of EA. Both effects can account for the more immature pattern of brain activation exhibited by lower-SES children for error detection in our study. It has been argued that SES disparities during infancy and toddlerhood explain individual differences in cognitive achievement even later in childhood (Hackman, Gallop, Evans, & Farah, 2015). Our study was limited by the lack of information about possible intervening variables that contribute to the association between SES and cognitive function, such as nutrition, stress, attachment, parent-child interactions, or language (Bradley & Corwyn, 2002; Farah et al., 2010). Consequently, more research is required to delimitate the factors that modulate the relationship between SES and early development of EA.

Electrophysiological ERN and related frontal theta oscillations related to error-detection has the potential to act as biomarkers of EA function in infancy and toddlerhood. Emerging evidence indicates that deficits in EA are central to a number of developmental disorders such as Autism Spectrum Disorder (ASD), Attention-Deficit Hyperactivity Disorder (ADHD), and language delay (Johnson, 2012), as well as conditions such as prematurity (van de Weijer-Bergsma, Wijnroks, & Jongmans, 2008). Atypical fronto-medial theta responses have been observed in ADHD (Groom et al., 2010), and abnormalities EEG connectivity in the theta range have been observed in children diagnosed with autism (García Domínguez, Stieben, Pérez Velázquez, & Shanker, 2013). The new ERN protocol utilized in this study can be used with toddlers in order to have an early neural measure of error-monitoring and associated theta power. This can be of use to identify individual differences that are not necessarily noticeable at behavioural level at this age, opening a window to early detection and prevention of risk for developmental psychopathology.

Likewise, poverty and low SES has been recognized as a risk factor for the later development of behavioural problems, attention deficits, psychopathology, learning disabilities and low academic achievement (Morgan, Farkas, Hillemeier, & Maczuga, 2009; Palardy, 2008; Shaw et al., 1998; Wadsworth & Achenbach, 2005). Our results show that the effect of disadvantageous environment can be observed from very early in development, making it clear that intervention to prevent SES negative impact on cognitive development should start as early as possible. However, future research aimed at identifying mediators of the effect of SES on attention development will be key to developing multifaceted prevention programs in early age.

CHAPTER 5

EXECUTIVE ATTENTION AT 2 YEARS OF AGE

The content of this chapter is being prepared for publication as Conejero, A. & Rueda, M.R. (in prep) *Influence of temperament and environmental factors on cool and hot aspects of executive attention by 2 years of age: differential effect.*

CHAPTER 5: EXECUTIVE ATTENTION AT 2 YEARS OF AGE

5.1 INTRODUCTION

Studies addressing early development of Executive Attention (EA) have primary focused on preschool ages and there is still little published data on EA comprising the period before the third year of life (see (see Hendry et al., 2016 for a recent review). Limited motor skills, poorer language comprehension and shorter attention spans of infants and toddlers suppose a methodological challenge when measuring EA at these ages. However, there has been reported a noticeable change in prefrontal structures associated with improvements in EA skills during the first years of life that make the study of EA during this developmental period of particular interest (Barkovich, 1988; Dean, 2014; Deoni, 2015; Lin, 2015). Even more if we take into account the involvement of EA in latter children's school competence (Blair, 2002; Blair, Granger, & Razza, 2005; Riggs, Blair, & Greenberg, 2004), social adjustment (Hughes, 1998; Hughes, Dunn, & White, 1998), and some developmental disorders such as autistic disorders or ADHD (e.g., Barkley, 1997; Diamond, Prevor, Callendar, & Druin, 1997; McLean & Hitch, 1999; Pennington & Ozonoff, 1996).

In literature is common to find the terms "cool" and "hot" to distinguish between two different components of EC. Traditionally, research on EA has focused in processes involved in merely cognitive tasks lacking any affective or motivational component. This type of EA in emotionally neutral settings received the name of cool EC whereas hot EC is applied to EC exerted in emotional arousing contexts or highly motivating situations (Zelazo & Carlson, 2012) Tasks measuring hot EC in children often include some rewards or appetitive stimuli in tasks, manipulating their value in order to elicit the desired level of excitement and motivation in children (Welsh & Peterson, 2014). Examples of tasks measuring hot EC in children are the so-called Delay of Gratification task (Mischel, Ebbesen, & Zeiss, 1972) or the Snack Delay task (Kochanska, 2000), in which children have to resist eating a tempting snack placed at a reaching distance. Research on early development of EA have confirmed the two-factor structure of EA corresponding to and hot aspects of EA, being observed as early as by 2 years of age (Mulder, 2014). Numerous studies also revealed that children's cool and hot EA skills contributed in predicting different developmental outcomes: cool EA skills has been mainly associated with academic performance, in contrast to hot EA skills that has been mostly associated with behavioural problems (Willoughby et al., 2011; Kim et al., 2013; Brock et al., 2009). Given that, it is possible to think that although related, hot and cool EC could have similar but separate developmental courses from very early on. In the present study, we investigated early development of both hot and cool EC during the second year of life, considering the differential impact of environmental factors and individual differences in temperament from infancy.

EA has been consistently observed to be quite sensitive to environmental features. Developmental studies have mainly centred their interest in the effects of socioeconomic status (SES) and parenting on EA. Children raised in families from lower-SES contexts generally show poorer performance in EA-related tasks (Duncan, Yeung, Brooks-Gunn, & Smith, 1998; Noble, McCandliss, & Farah, 2007), being linked to reduced cortical thickness and lower white matter density in prefrontal brain structures, like cingulate cortex, associated with EA skills (Lawson et al., 2013). This EA-SES relationship is also observed as early as from infancy (Lipina, Martelli, Vuelta, & Colombo, 2005). The influence of SES not only is observed in cool EA skills, but also in hot EA skills. Preschool children from low-SES families demonstrate less sensitivity to penalties in the child version of the Gambling task, taking more disadvantageous choices (Mata, Sallum, Miranda, Bechara, & Malloy-Diniz, 2013). Concerning to parenting, previous studies have already shown that low-quality parenting could also have a negative impact on children's EA from very early on. Inconsistent parenting strategies, low sensitivity to children's needs and a coercive patenting style have been related to poorer EA and externalizing behaviour problems (Bindman et al., 2013; Morrell & Murray, 2003; Rioux et al., 2015). Specifically, intrusive and directive style of parenting is particularly associated with poorer inhibitory control in delay tasks in children between 2 and 4 years of age (Merz et al., 2016; Russell, Londhe, & Britner, 2013). In contrast, high-quality parenting could act by benefitting EA. There is some evidence that indicates that certain parenting practices consisting in providing support and promote children's autonomy can function as a protective factor for the effect of environment on EA (Gutman & Feinstein, 2010; Mayo & Siraj, 2015).

In addition to that, individual differences in temperament seem to be related to differences in EA. Temperament refers to those observed differences in motor, emotional and attentional reactivity, as well as the mechanisms involved in regulating such reactivity (Rothbart & Bates, 2006). Temperament is contemplated as a constitutional-based characteristic of children, being stable throughout development even from early years (Casalin et al., 2012). Individual differences in behavioural, emotional and attention reactivity can be observed from very early on development, so that parents can distinguish if children are more or less irritable or active.

Different temperamental profiles have been related to differences in children's EA (Rothbart, Sheese, Rueda, & Posner, 2011). On the one hand, higher levels of temperamental reactivity, either surgency/extraversion (SUR) or negative affect (NA), have been associated with poorer EA skills (Davis, Bruce, & Gunnar, 2002; Gerardi-Caulton, 2000; Wolfe & Bell, 2004; Wolfe & Bell, 2007). Poorer ability to delay a gratification is associated with higher levels of activity level and distress in two-year-olds (Mittal, Russell, Britner, & Peake, 2013). Even from infancy, higher NA is associated with difficulties in disengaging attention (McConnell, 2005). High levels of NA has been also linked to hemispherical asymmetries in brain electrical activity, predicting children's difficulties in resolving conflict (Solomon, 2014). On the other hand, better EA has been found among children that showed greater effortful control (EC). In a recent study that longitudinally explored temperament influence in EA they found that interaction between both temperamental reactivity and regulation better predicted EA from infancy to early childhood in a way that higher levels of EA were observed among children who exhibited high levels of emotional reactivity together with high levels of regulation (Ursache, 2013).

The aim of this T3 session was to investigate the contribution of both environmental and temperament factors to the individual differences in EA skills by 2 years of age. We further aimed to explore whether different variables are explaining individual differences in cool and hot EA skills separately. For that purpose, we measured cool EA skills with a conflict task (the Shape Stroop task, Kochanska et al., 2000) and a cognitive flexibility task (the Reverse Categorization task, Carlson et al., 2004) while hot EA was measured with a delay task (the Snack Delay task, Kochanska et al., 2000). We also asked parents to provide information about children temperament, parenting strategies and SES. In a previous study with preschool children authors found that EC was related to cool EA skills, whereas no relationship was found between hot EA and EC (Hongwanishkul et al., 2005). In line with those results, we expect that EC will be specifically related to cool EA skills. In contrast, we expect that low SUR would be more associated with hot EA. With respect environmental factors, we expect that both cool and hot aspects of EA will be related to both SES and parenting in a way that higher SES as well as higher quality parenting will be related to greater EA skills. However, we hypothesized that the use of coercion and inconsistent parental practices will be more related to hot aspects of EA, translating in poorer performance in the Snack Delay task. As we mentioned earlier, the over control of parents over children behaviour may cause a decreased ability to delay. Additionally, we explore whether parenting will also moderate the relationship between SES and EA acting as a protective factor as suggested by previous research.

5.2 METHOD

5.2.1 PARTICIPANTS

A total of 61 children (26 male, 35 female) returned to continue with the study at this time (mean age=26.62, *SD*=.90). 3 children were excluded due to prematurity. All children had participated previously either at 9–12 months of age or ta 16–18 months of age. We contacted parents either by email or by phone once children reached the minimum age to participate in this phase of the study in order to arrange an appointment. Parents received a 10 € gift voucher for educative toys in appreciation for their participation and a report with information about the performance of their children at the end of the study.

5.2.2 *PROCEDURE*

Parents and children were received in the waiting room by experimenter. Parents were explained the principal aims of the study and were asked to sign the informed consent form. After a short warming-up period in which children familiarized with experimenter, toddlers were conduced together with one of the caregivers to the experimental room. Toddlers performed three experimental tasks measuring conflict resolution (the Shape-Stroop task; Kochanska et al., 2000), inhibitory control (Snack Delay task; Kochanska et al., 2000) and attention flexibility (the Reverse categorization task; Carlson, Mandell, & Williams, 2004). Tasks were administered always in the same order. Experimental session was video recorded for offline coding. The coding was realized by two experimenters who did not participate in administering the tasks and were blind to the main hypothesis of the study. Both experimenters coded the 30% of the children. The interrater reliability for the experimental tasks was r = .93, r = .91 and r=.98 respectively (p <.001). Parents completed a computerized web-based version of the temperament questionnaire and a parenting strategies scale at home within the week after their visit to the laboratory. SES information was obtained in a previous visit to the lab (see Chapter 3, section 3.1.2 instruments and apparatus for a detailed description).

5.2.3 *INSTRUMENTS AND APARATUS*

5.2.3.1 Temperament assessment

Temperament was assessed with the Spanish short version of the Early Childhood Behaviour Questionnaire (ECBQ; Putnam, Gartstein, & Rothbart, 2006). This questionnaire is conformed by 107 items and it is indicated for children between 18 and 36 moths of age. Parents had to rate in a seven-points Likert scale the frequency they observed certain behaviours in their children under different daily life situations over the last week or two weeks. Items could be grouped in 18 different scales. We averaged scales to obtain three main factors as follows: negative affectivity (discomfort, fear, frustration, sadness, shyness and soothability reversed score) surgency/extraversion (activity level/energy, high-intensity pleasure, impulsivity, motor activation, positive anticipation, sociability), effortful control (attentional focusing, attentional shifting, cuddliness, inhibitory control, perceptual sensitivity). Low intensity pleasure scale was not included due to low reliability (Cronbach's alpha <.6). Parents completed the questionnaire online at home. Data about temperament from 5 children whose parents did not send back their responses were lost.

5.2.3.2 Parenting assessment

We used the Inventory of Parenting (IPC) developed by Bauermeister et al. (1995). This instrument consists of 37 items asking parents about the parenting strategies they usually apply. Parents esteemed how many often they use each strategy by rating each item from 0 (never or almost never) to 3 (very often). The instrument provided scores for two different scales: acceptation and sensibility scale, referring to strategies based on motivation, affect, sensitivity to children's needs and reasoning (e.g. "When my son/daughter do something bad or I don't like, I explain him/her what was wrong."); and inconsistency and coercion scale, referring to strategies based on control, punishment or inconsistent (e.g. "I threaten my son/daughter if he/she didn't do what I asked for."). Cronbach's alphas for both scales were.78 and .76 respectively. Parents completed the questionnaire online at home. Parents of 6 children did not return their responses on this questionaire.

5.2.4 *EXPERIMENTAL TASKS*

5.2.4.1 Shape-stroop task

A set of cards (13 x 7 cm) depicting three different fruits (apple, banana and orange) in two different sizes (big, small) was shown to children to test their knowledge about fruits and size. Experimental task was not administered to children who did not identify any of the fruits or did not differentiate big ones from small ones (n=4). Next, experimenter presented three new cards each showing a small fruit embedded in a large different fruit (e.g. a small banana inside a big apple). Children were asked to point to one of the small fruits (e.g. “show me the small banana”). Experimental task consisted on three trials. Each trial was scored as correct (children pointed to the small fruit) or incorrect (children pointed to the fruit we asked for, but in large size, that was located next to target).

5.2.4.2 Reverse categorization

In this task, children were asked to classify 12 toy building blocks according to size (big blocks in a big box and small blocks in a small box). Before starting with experimental procedure, experimenter ensured that children could identify both the big and the small box and differentiate between big and small pieces. Experimenter while verbalizing the instructions classified the first 6 pieces. Children alone classified the last 6 pieces. Children had to correctly classify 4 pieces in a run to continue with the task. Next, children were asked to reverse the classifying rule: big blocks in the small box, small blocks in the big one. At the start of each trial, experimenter gave children the corresponding instruction (e.g. “the small piece goes to the big box”) showing children the next piece to be classified. A score were obtained by considering the number of correct trials after the change of rule. Toddlers who did not pass the pre-switch phase of the task were excluded from analyses (n=5). We did not obtain data from two additional children who refused to collaborate in this task.

5.2.4.3 Snack Delay task

Toddlers sat in front of a snack covered by a transparent plastic cup. Experimenter asked children not to eat the snack until the experimenter rang a bell. Several runs with different waiting times (5, 10, 15 and 20 seconds) were conducted. Each trial started with children hands on a hands-shape mat 15 cm away from the snack. Children behaviour during the waiting time was coded from 1 (ate the snack at the beginning of the trial) to 7 (waited the entire trial). Children who waited without moving their hands from the mat were given 2 extra points. Children who did not show any preference for the snack were excluded from the analyses (n=3).

5.3 RESULTS

5.3.1 DESCRIPTIVE STATISTICS

Descriptive statistics are provided in Table 5.1. Mean, *SD* and valid sample is provided.

5.3.2 CORRELATION ANALYSIS

Pearson's correlation analysis revealed that Snack Delay performance was unrelated to the performance in the Shape Stroop task (r=.05, p>.05), although marginally associated with the performance in the Reverse Categorization task (r=.23, p>.1). In contrast, Shape Stroop and Reverse Categorization performance were positively correlated (r=.43, p=.001). Thus, we averaged z-transformed scores of the Shape Stroop task and the Reverse Categorization task into a general index of Executive Attention for subsequent analyses.

Table 5.1. Descriptive statistics of all variables included in T3 session.

	Measures	Valid n	Mean	S.D.
Age (months)		61	26.76	1.06
Experimental tasks	Shape Stroop (raw score)	57	1.45	1.03
	Reverse Categorization (raw score)	54	7.13	3.44
	Executive Attention index (z-score)	53	0	1
	Delay of Gratification (z-score)	58	0	1
Temperament (raw scores)	ECBQ Surgency/Extraversion	57	5.19	1.03
	ECBQ Negative Affectivity	57	2.20	.61
	ECBQ Effortful Control	57	4.97	1.07
Parenting (raw scores)	Inconsistency/coercive parenting scale	57	.63	.30
	Acceptation/sensitivity parenting scale	57	2.11	.30
SES	SES index (z score)	59	.02	.75
	Parents Occupation (1–9)	59	5.17	1.20
	Parents Education (1–7)	59	5.40	1.90
	Income-to-need ratio	59	1.99	.93

Correlation analyses were also performed to test the relationship between temperament and environment factors (parenting and SES) with executive control. Results of the analyses are presented in table 5.2. Lower levels of positive and negative reactivity were associated with better executive control, whereas the better inhibitory control showed in the delay task was associated with better effortful control. Environmental factors were only associated with ability to delay, but not with executive control. Lower SES and higher coercive and inconsistent parenting style were related to a poorer inhibitory control in the Snack Delay task.

Table 5.2. Pearson's correlations between executive attention experimental tasks and temperament and environment factors.

$^{\#}$ *p* < .1 * *p* < .05 ** *p* < .01		Experimental tasks	
		Delay	**Executive Control index**
Temperament	ECBQ Surgency/Extraversion	-.07	**-.24***
	ECBQ Negative Affectivity	-.06	**-.34***
	ECBQ Effortful Control	**.33***	.10
Parenting	Coercion/inconsistency	**-.25***	-.06
	Acceptation/sensibility	.13	-.11
SES	SES general index	**.37****	.07
	Parents Occupation	**.28****	.13
	Parents Education	**.37****	.10
	Income-to-need ratio	**.20**$^{\#}$	-.07

5.3.3 INTERACTION BETWEEN TEMPERAMENT AND ENVIRONMENT FACTORS

As EC, parenting style and SES were the three related to performance in the Snack Delay task, we run moderation analysis to test whether there was a three-way interaction between SES, EC and parenting style that explained individual differences in the Snack Delay task. Analysis was performed with the macro PROCESS for SPSS macro for SPSS (Hayes, 2013) using model 3 (see figure 5.2). We estimated the coefficients at a confidence interval level of 95% using bias corrected bootstrapping approach with 5000 samples. Overall model results are summarized in table 11. The general model was significant ($F(7,38)=4.11$, $p<.01$, $R^2=.43$). Interaction between SES, EC and inconsistent/coercive parenting significantly predicted the performance in the Snack Delay task. Adding the interaction term to the model significantly increased the proportion of explained variance ($\Delta R^2 = .08$, $F(1, 38) = 5.20$, $p < .05$). As can be seen in Figure 5.3, performance in the Snack Delay task significantly decreased as a function of inconsistent/coercive parenting in the case of low-SES children that present low (from 1 *SD* below the mean) EC ($t(38)=-3.11$, $p<.01$). However, performance in Snack Delay task was unrelated to parenting in the rest of the cases ($t(38)<1$).

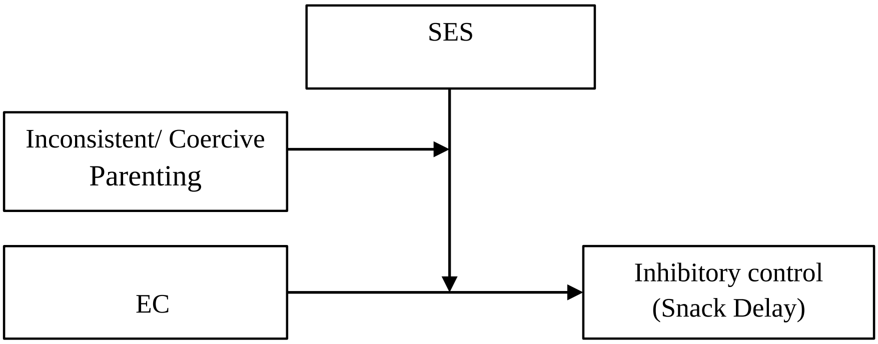


Figure 5.1. Theoretical model of the relationship between the variables included in the moderation analyses.

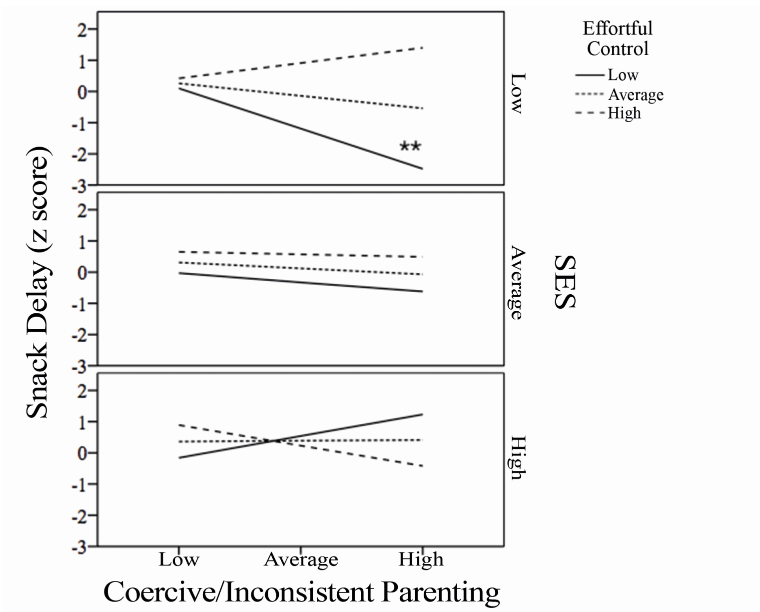


Figure 5.2. Moderation analysis: relationship between Parenting, SES and EC and individual differences in the performance Snack Delay task. Low and High variable levels refer to values from 1 *SD* below and 1 *SD* above the mean respectively. $^{**}p<.01$.

Table 5.3. Regression analysis testing the moderation of EC and SES in the relationship between parenting style and inhibitory control in the Snack Delay task. Significance levels: # p<.1, *p<.05, **p<.01.

	DV: Snack Delay performance	R^2	*B*	*t*	*95% CI*	ΔR^2
Step 1		$.06^{\#}$				-
	SES		0.37	$1.67^{\#}$	[-.08, .81]	
Step 2		.16*				.10*
	SES		0.43	2.03*	[0, .86]	
	Inconsistent/Coercive Parenting		-1.12	-2.27*	[-2.11, -.13]	
Step 3		.20*				.03
	SES		0.48	2.24*	[.05, .91]	
	Inconsistent/Coercive Parenting		-1.22	-2.48*	[-2.22, -.23]	
	EC		-0.20	-1.36	[-.51, .1]	

DV: Snack Delay performance		R^2	B	t	95% CI	ΔR^2
Step 4		.29**				.09*
	SES		-0.70	-1.32	[-1.77, .37]	
	Inconsistent/Coercive Parenting		-1.74	-3.38**	[-2.77, -.7]	
	EC		-0.28	-1.90#	[-.57, .02]	
	SES x Parenting		2.24	2.40*	[.36, 4.13]	
Step 5		.35**				.06#
	SES		2.27	1.37	[-1.09, 5.63]	
	Inconsistent/Coercive Parenting		-1.41	-2.66**	[-2.48, -.34]	
	EC		0.03	0.16	[-.41, .47]	
	SES x Parenting		1.81	1.93#	[-.08, 3.7]	
	SESxEC		-0.58	-1.88#	[-1.19, .05]	
Step 6		.35**				.00
	SES		2.05	1.02	[-2.03, 6.13]	
	Inconsistent/Coercive Parenting		-0.38	-0.07	[-10.81, 10.06]	
	EC		0.18	0.24	[-1.35, 1.7]	
	SES x Parenting		1.87	1.88#	[-0.15, 3.89]	
	SESxEC		-0.54	-1.45	[-1.28, .21]	
	Parenting x EC		-0.22	-0.20	[-2.41, 1.98]	

Step 7		.43**				.08*
	SES		-8.32	-1.69	[-18,31, 1.67]	
	Inconsistent/Coercive Parenting		-4.32	-0.83	[-14.84, 6.2]	
	EC		0.09	0.12	[-1.37, 1.54]	
	SES x Parenting		21.00	2.49*	[3.92, 38.08]	
	SESxEC		1.64	1.61	[-.42, 3.69]	
	Parenting x EC		0.73	0.66	[-1.52, 2.98]	
	SES x Parenting x EC		-4.06	-2.28*	[-7.66, -.46]	

5.4 DISCUSSION

The goal of this T3 session was to examine the development of EA by two years of age distinguishing between cool and hot aspects of EA. We aimed to examine the differential contribution of temperament and environmental factors to hot and cool EA skills. As we anticipated, hot and cool aspects of EA related to temperament and environmental variables following different patterns. Contrary to expectations, temperamental reactivity (both NA and SUR) were associated with cool aspects EA whereas hot aspects of EA were related to EC. Regarding cool EA, reactivity levels have been previously related to the performance in typical cool EA tasks. On the one hand, high levels of NA has been associated with poorer executive functioning and the use of a more reactive control in conflict and flexibility tasks (Bridgett, Oddi, Laake, Murdock, & Bachmann, 2013b; Shields, Moons, Tewell, & Yonelinas, 2016; West, Choi, & Travers, 2010). On the other hand, higher impulsivity (which characterize children with high SUR) is related to a decreased performance in tasks requiring of cognitive flexibility (Leshem, 2016). Higher SUR levels have been also associated with greater N2 amplitudes for the incongruent condition in 4–8 years old children while performing the Child-ANT. This has been suggested to reflect a greater deployment of mental resources and thus, less efficiency in resolving cognitive conflict (Buss, Dennis, Brooker, & Sippel, 2011).

The fact that low temperamental reactivity levels associate with cool EA is not surprisingly given its involvement in the regulation of affect (Bridgett, Oddi, Laake, Murdock, & Bachmann, 2013a). However, contrary to our expectations, cool aspects of EA were unrelated to EC, being uniquely associated with hot EA. A possible explanation for these results might be that measures of hot EA such as the Snack Delay task may elicits a greater awareness of the need for implementing control than cool EA tasks in two-year olds. Therefore, this kind of hot situations might be more sensitive for capturing self-regulation and voluntary control, and thus, EC at this early stage of development. In addition to EC, performance in the Snack Delay was also related to SES and parenting in our data. As we hypothesized, higher inconsistent parenting and lower SES were related to a poorer inhibitory control in the delay task. On the one hand, it has been widely reported children from low SES backgrounds generally perform below high-SES children in tasks that imply cognitive processes dependent on prefrontal structures (Noble et al., 2006). This is the case of inhibitory control. In fact, there is evidence that inhibitory control is altered at behavioural and neural level in 7–12 years children with low SES (Kishiyama, Boyce, Jimenez, Perry, & Knight, 2009). On the other hand, inconsistent and coercive parenting strategies may impairs the development of the necessary self-regulatory skills that facilitate toddlers to inhibit the approach tendency to the tempting snack. Previous research on delay of gratification indicate that exerting an over-control upon children behaviour may cause impairment on children to develop regulation skills, n. in contrast to high quality parenting and supportive parenting practices that tend to promote a greater ability of toddlers to delay (Spinrad et al., 2007). It has been suggested that those positive parenting strategies may foster the development of self-regulatory skills by promoting self-reflection and the active control of impulsive responses (Fay-Stammbach et al., 2014), whereas a coercive style might not allow children to develop self-regulation given that parents exert the control and children do not have the chance of applying regulation strategies by their own.

Interestingly, we found that interaction between parenting, SES and EC in predicting performance of toddlers in the Snack Delay task. Those toddlers raised in low-SES families that also had low EC were more affected by inconsistent/coercive parenting practices, showing a decreased inhibitory control in the delay task. In contrast, high and average EC protected low-SES children against the possible detrimental influence of inconsistent/coercive parenting on the development of inhibitory control. Poor inhibitory control is related to the development of externalizing problems in childhood and adolescence. A hostile and rejecting parental style has been associated with a higher probability of developing externalizing behaviour problems by 3 years of age in a sample of low-income children (Shaw et al., 1998). The role of EC as a protective factor has been also signalled by previous research. For instance, EC has been observe to prevent the development of externalizing behaviour on behalf of higher levels of reactivity in three-year-olds (Moran et al., 2013). Our results indicate that individual differences in EC may serve as a protective factor in the case of children at high risk for later behaviour problems, such as in the case of children raised in low SES contexts and whose caregivers tend to use more coercive parenting practices or/and inconsistently.

Overall, data from this session at T3 differentiate between the influence of temperament and environmental factors on two different aspects of EA (cool EA and hot EA) as early as by two years of age. This corroborates the idea that these two aspects of EA might have different developmental trajectories. It would be interesting to compare the developmental trajectories of both aspects of EA from infancy in order to better understand how these two mechanisms differentiate and interact. A further study could explore development from infancy to childhood longitudinally, assessing academic and psychosocial outcomes related to different developmental patterns. Results from this wave of the study also revealed the importance of EC as a potential protective factor for children raised in disadvantageous environments even from two years of age. An implication of this is the possibility of implementing intervention programs based on promoting children’s EC as a way to prevent later problems associated with poor self-regulation skills.

CHAPTER 6

EXECUTIVE ATTENTION AT 3 YEARS OF AGE

CHAPTER 6: EXECUTIVE ATTENTION AT 3 YEARS OF AGE

6.1 INTRODUCTION

One of the main functions of executive attention (EA) is the resolution of cognitive conflict (Petersen & Posner, 2012). Dealing with conflict requires ignoring irrelevant stimulation or information that is interfering with the main goal of the task. A classic experimental paradigm measuring cognitive conflict is the so called Flanker Task (Eriksen & Eriksen, 1974). In this task, a central target (e.g. an arrow) is presented flanked by a number of non-target stimuli at both sides. In the incongruent condition, non-target stimuli interfere with target stimuli. For instance, being an arrow the central target, flankers would be arrows too but pointing to the opposite direction. Participants are required to respond to the direction of the central arrow. What is generally found is a diminution of accuracy and increase in reaction time for incongruent condition compare to congruent. The difference in performance in the incongruent and congruent conditions (conflict effect) in considered an index of the efficiency in resolving conflict and thus, of EA. The Simon task (Simon, 1990) is another example of a task measuring cognitive conflict. In this task, the conflict is provoked by the incompatibility between the location of the target stimuli and the hand to which the response is made (e.g. responding to a stimuli appearing on the left side of the screen by pressing a button on the right).

Children start to be able to resolve cognitive conflict in tasks very similar to those used by adults by the second year of life. Two-year-olds show the conflict effect typically observed in adults while performing a child-friendly version of the Simon task (Gerardi-Caulton, 2000). In this version of the task, children have to press the button that matches with the picture displayed on the screen. Picture could appear either in the same side (spatial compatible condition) or in the contralateral side (spatial incompatible condition). Author found that between the two and the three years of age ability of children in resolving conflict improved, diminishing conflict scores.

Another task suitable for measuring conflict resolution in children is the child version of the Attention Network Test (Child-ANT; Rueda et al., 2004). The original ANT was thought to measure the three attention networks by combining the flanker task with cueing paradigms (Fan et al., 2002). In the child version, fishes substituted the arrows used as stimuli in the adult version in order to motivate children (Rueda et al., 2004). As for adults, 6–9 years old children were slower and committed more errors in the incongruent condition, improving performance across age.

Apart from improvements in conflict resolution, improvements in self-regulation have been also observed during this developmental period (Kochanska et al., 2000). Self-regulation refers to the control of thoughts and behaviour according to goals and is implicated in modulating affect, inhibiting impulses, or behaving according to rules (Baumeister & Vohs, 2004). Self-regulation is considered to reflect the hot aspect of EA. One of the most used tasks to measure self-regulation in children is the delay of gratification task (DoG; Walter Mischel, 1974). In this kind of tasks, children have to resist the temptation of an immediate reward in order to get later a bigger reward. The greater inhibitory control, the more probability that children delayed the reward.

The development of EA and self-regulation might be affected by both temperament and environmental factors. On the one hand, different temperamental profiles have been related to differences in children's executive attention. Temperament refers to those observed differences in motor, emotional and attentional reactivity, as well as the mechanisms involved in regulating such reactivity (Rothbart & Bates, 2006). Higher levels of temperamental reactivity, either surgency/extraversion or negative affect, have been associated with poorer executive attention skills. (Davis, Bruce, & Gunnar, 2002; Gerardi-Caulton, 2000; Wolfe & Bell, 2004; Wolfe & Bell, 2007). More specifically, ability to resolve conflict, as well as self-regulation has been associated with higher EC (Aksan & Kochanska, 2004; Gerardi-Caulton, 2000). On the other hand, children raised in families from lower-SES contexts generally show poorer performance in executive attention-related tasks (Duncan et al., 1998; Mezzacappa, 2004; Noble, McCandliss, & Farah, 2007). In addition to SES, inconsistent parenting strategies, low sensitivity to children's needs and a coercive patenting style have been related to poorer executive attention and later behavioural problems (Bindman et al., 2013; Morrell & Murray, 2003; Rioux et al., 2015).

The aim of the T4 session was to investigate the development of EA and self-regulation at three years of age. For that purpose, we measured EA in two different conflict tasks. We used a Spatial Conflict task similar to the one designed bay Gerardi-Caulton (2000). We developed a new version of the Child-ANT by simplifying stimuli in order to make this task apt for children as young as by 3 years of age. We expected that performance in both task would be related. We further anticipated that children at that age would show a similar pattern than adults and older children in our version of the ANT for young children. We also measured self-regulation with a DoG task. We explored whether performance in DoG task and performance in conflict tasks were related. Since both processes seem to depend on EA, we hypothesized that they would be related.

Finally, we further investigated the association of temperament and environmental factors (SES and parenting practices) with performance in conflict tasks and DoG. There is some evidence that the two processes, conflict resolution and self-regulation, although related seem to present different patterns of association with temperament (Hongwanishkul et al., 2005). We explored whether variables also associated in a different way for conflict task and DoG task in our data.

6.2 METHOD

6.2.1 PARTICIPANTS

From the initial sample, 57 children (28 male, 29 female) returned to participate in the study by 3 years of age (mean age 37.74 months, *SD*=2.44). One child was excluded from the analyses due to prematurity. Parents were contacted to arrange an appointment once children reached the minimum age to participate in this phase of the study, either by email or by phone. Parents received a 10 € gift voucher for educative toys in appreciation for their participation and a report with the results of their children.

6.2.2 PROCEDURE

After a short warming-up, experimenter conduced children to the experimental room. Parents remained in a contiguous room completing a temperament questionnaire about their child during experimental session. Children performed a spatial conflict task (Gerardi-Caulton, 2000), a simplified version of the Child-ANT (Rueda et al., 2004) for younger children and a delay of gratification task (Walter Mischel, 1974). Tasks were administered always in the same order. Additionally, children performed a child-friendly alert task and orienting task at the beginning of the experimental session. Results of these two tasks are not presented in this paper. A measure of SES was obtained in previous experimental sessions (see Chapter 3, section 3.1.2). Parenting practices, as measured by a questionnaire at T3 (see Chapter 5, section 5.2.3) was also considered.

6.2.3 Instruments

6.2.3.1 Temperament assessment

Temperament was assessed with the Spanish version of the short form of the Child Behaviour Questionnaire (CBQ; Putnam & Rothbart, 2006). This questionnaire is conformed by 94 items and it is indicated for children between 3 and 7 years of age. Parents rated in a six-points Likert scale the frequency to what their children behaved in a certain way under different common daily life situations in the last weeks (1 = extremely untrue of my child, 2 = quite untrue of my child, 3 = slightly untrue of my child, 4 = neither true nor false of my child, 5 = slightly true of my child, 6 = extremely true of my child). Items could be grouped in 14 different scales. We averaged scales to obtain three main factors as follows: negative affectivity (fear, frustration, sadness, distress and soothability reversed score) surgency/extraversion (activity level, high-intensity pleasure, impulsivity and shyness reversed score), effortful control (attentional focusing, low intensity pleasure, inhibitory control, perceptual sensitivity). All scales had an acceptable internal consistency (Cronbach's alpha >.7).

6.2.3.2 Touch screen

Stimuli of the Spatial conflict task and the Young-Child-ANT were presented using an ELO touch screen (Elo Touch Soultions inc., www.elotouch.com) connected to a computer running E-Prime 2.0. This device permits to register children response by touching right on the stimuli displayed on the screen. Monitor dimensions were 228.10mm x 304.13mm with a 1024x768 pixels resolution and 60 hz refresh rate.

6.2.4 *Experimental tasks*

6.2.4.1 Spatial conflict task

Children were instructed to hold their hands on the mat. A looming black circle was displayed as a fixation point before each trial. Experimenter initiated the trial pressing a key once the children were attending to the centre of the screen and their hands were on the mat. Two houses (7 cms) with a different animal inside each were displayed at both corners of the screen. One of these two animals (3x5 cms) also appeared at the same time above one of those houses, 2 cms away. Experimenter told children to find the house of the animal above. Children were instructed to touch the left house with the left hand and the right house with the right hand. Experimenter encouraged children to respond as fast as possible. Target was presented for 6 seconds. When children made a correct response, cartoons were animated accompanied with music. If children touched the wrong house or made no response, children heard a low beep sound and animals simply disappeared. Children performed three 8-trials blocks. The couple of animals to appear in each block were randomly selected from 6 different possible animals: frog, cat, pig, duck, monkey and hedgehog.

6.2.4.2 Young-Child-ANT

This task is a version of the Child-ANT developed by Rueda et al. (2004). In order to make the task simpler to younger children, target was flanked only by one flanker stimulus on each side and central target was augmented in size to respect flakers (see Figure 6.2). Thus, stimuli consisted in a big fish (5 x 3 cms) flanked by two small fishes (4 x 2 cms). Half of the times flanker fishes were pointing in the opposite direction that the central fish (incongruent condition). Two nets (5 x 7 cms) were displayed on the inferior corners of the screen. Children were instructed to catch the central big fish ignoring the smalls ones by touching the net in the side that the fish nose was pointing. Before starting with the experimental trials, we run a practice block of trials to ensure that children understood the instruction and performed the task accordingly. Children who did not collaborate (n=4), did not understand the task (n=3) or missed more than 30% of the trials (n=4) were excluded. Experimenter initialized each trial once children placed their hands on the mat. First, a central fixation point appeared for a random duration between 600 and 1200 ms. Then, a cue appeared for 150 ms. There were 4 different types of cue: spatial valid cue (signalling the location where target would appear), spatial invalid cue (signalling the opposite location where target would appear), double cue (up and down, signalling the two possible locations where target could appear), or no cue. Stimuli appeared 3 cms above or below the fixation cross. Stimuli remained for a maximum of 5000 ms or until children gave response by touching one of the two nets. Children were provided with a trial-by-trial feedback (fish was animated and trapped with the net together with a “wohoo!” sound in case of a correct response, whereas fish disappeared together with a low beep to indicate a wrong or late response) and a block feedback (the screen displayed as many fishes as they have caught). The task comprised two blocks of 32 trials: 2xcongruency (congruent/incongruent), 2xdirection left/right), 2xlocation (up/down), 4xcue (no cue/valid cue/invalid cue/double cue). In the second block, fishes were substituted by flying birds as stimuli in order to avoid that children got bored.

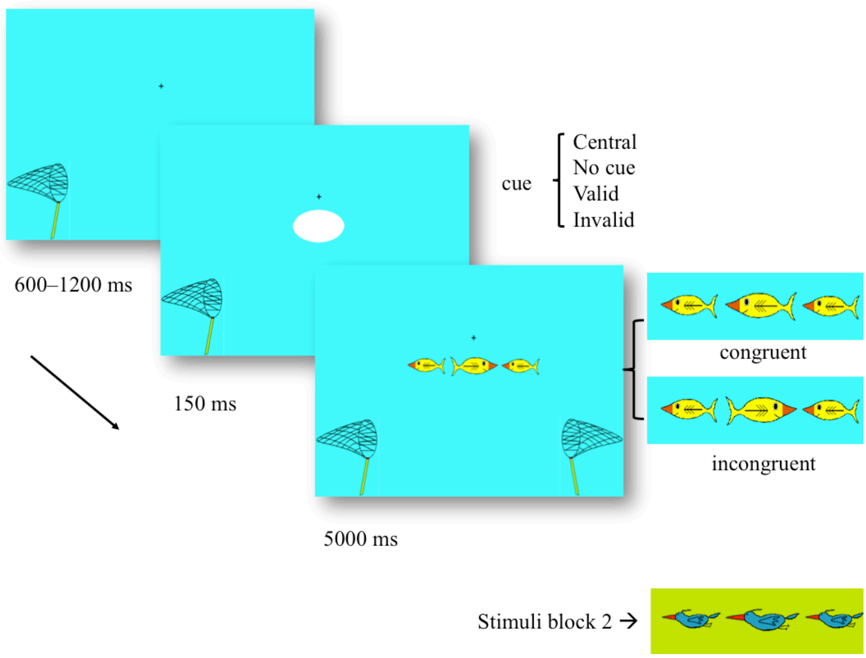


Figure 6.1. Schema of the procedure of the Young-Child-ANT.

6.2.4.3 Delay of gratification task

In this task we observed children's ability to delay an immediate gratification (a chocolate sweet or a colourful sticker) in order to get twice later. First, we asked children to point to their preferred prize (the chocolate sweet or the sticker). In each trial, experimenter asked children to choose between having one chocolate sweet/sticker immediately or keeping two in a bag that they will have at the end of experimental session. Children completed a total of 12 trials (6 with the chocolate sweet, 6 with the sticker).

6.3 RESULTS

6.3.1 SPATIAL CONFLICT TASK

We calculated mean accuracy and median reaction time to correct responses for spatial congruent and incongruent trials (see Table 6.1 for descriptive statistics). Children who did not understand the instruction (n=2), or that did not collaborate in the task (n=3) were excluded from the analyses. We compared the performance in spatial incongruent trials with performance in congruent trials. The proportion of correct response was higher for congruent than incongruent trials. Children were also slower in incongruent trials compared to congruent. However, differences in accuracy ($t(51)<1$) or reaction times ($t(51)=1.19$, $p>.05$) were not significant. We calculated a conflict score for accuracy (congruent minus incongruent trials) and reaction times (incongruent minus congruent trials) for further analyses.

6.3.2 YOUNG-CHILD-ANT

Mean accuracy (proportion of correct response) as well as median reaction times (RT) in correct trials were obtained for congruent and incongruent condition (see Table 13 for descriptive statistics). We run repeated measures ANOVA (2(Congruency: Congruent, Incongruent) x 4 (Cue: No cue, Center cue, Invalid cue, Valid cue)) to test the effect on accuracy and RT. In the case of accuracy, there was a main effect of congruency (F (1, 44) = 12.09, p = .001, η^2_p=.22; see Figure 6.3). Accuracy was greater in the congruent condition compared to the incongruent condition. Neither main effect of type of cue (F (3, 44)<1) or interaction between congruency and type of cue (F(3, 132) = 1.45, p = .23) were significant. Regarding RT, there was a significant main effect for congruency (F (1, 44) = 29.20, p < .001, η^2_p=.40; see Figure 6.4 a) and type of cue ($F(3, 132) = 4.38$, $p < .01$, η^2_p=.09; see Figure 6.4 b). Planned comparisons revealed that RT were larger when no cue was presented compared to central cue ($F(1, 44)$=6.68, p<.05), valid cue ($F(1,44)$=3.85, p=.05) or invalid cue ($F(1,44)$=6.96, p<.05). Interaction between congruency and type of cue was not significant ($F(3, 132)$ <1).

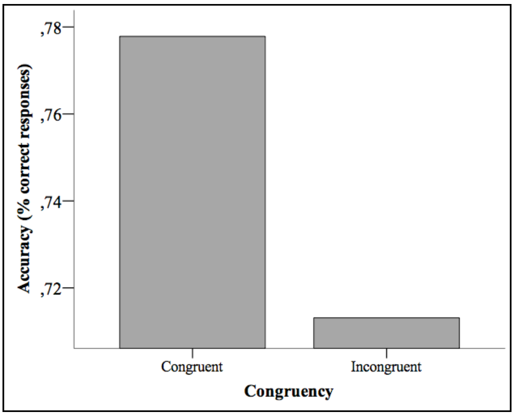


Figure 6.2. Difference in accuracy between congruent and incongruent conditions in the Young-Child ANT.

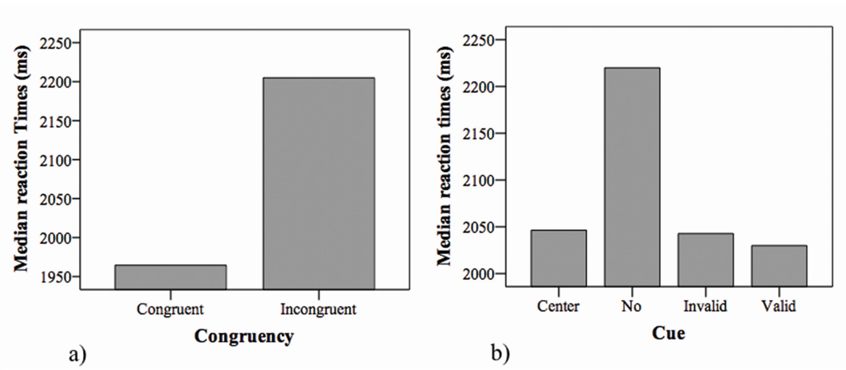


Figure 6.3. Difference in median RT between a) congruent and incongruent conditions and b) different types of cue in the Young-Child ANT.

Table 6.1. Descriptive statistics of all measures included in the study. RT=reaction time; ACC= accuracy.

Measure		**Valid n**	**Mean**	***SD***
	Age (months)	57	37.73	2.42
Spatial Conflict task	Congruent RT	54	2485.92	776.86
	Incongruent RT	54	2525.55	697.30
	Congruent ACC	54	78.28	13.88
	Incongruent ACC	54	77.98	14.70
Young-Child ANT	Congruent RT	45	1900.89	425.96
	Incongruent RT	45	2117.10	445.63
	Congruent ACC	45	79.51	12.89
	Incongruent ACC	45	72.97	15.31
CBQ	NEG	56	2.42	.68
	SUR	56	2.53	.77
	EC	56	5.14	.54
SES	Parents Education (1–7)	54	5.42	.89
	Parents Occupation (1–9)	54	5.25	1.06
	Income-to-need ratio	54	1.99	.89
	SES general index	54	.05	.63
Parenting	Acceptation/Sensitivity	39	.68	.28
	Inconsistency/Coercion	39	2.09	.67

6.3.3 *CORRELATION BETWEEN TASKS*

As can be seen in table 6.2, none of the measures from the different tasks were correlated.

Table 6.2. Correlations among executive attention tasks measures.

	1	2	3	4
1.Young-Child ANT Conflict Score (RT)	-			
2.Young-Child ANT Conflict Score (ACC)	.09	-		
3. Spatial Conflict Score (RT)	-.02	.21	-	
4. Spatial Conflict Score (ACC)	.06	-.01	-.10	-
5. Delay of Gratification	.00	. 12	-.06	.10

6.3.4 *INFLUENCE OF TEMPERAMENT AND ENVIRONMENTAL FACTORS*

First, we run Pearson's correlations to explore the relationship between temperament and parenting and SES. Results are shown in Table 6.3. We found that higher levels of SUR were associated with lower SES but was unrelated to parenting. In contrast, NA was significantly related to coercive/inconsistent parenting style, but not to SES. Only EC was associated with both SES and parenting in a way that high acceptation/sensitivity of parents and parental education were both positively correlated to EC.

Table 6.3. Intercorrelations between temperament and environmental factors. SUR= Surgency; NA= Negative Affectivity; EC= Effortful Control.

** $p < .01$ * $p < .05$ # $p < .1$		Temperament CBQ		
		SUR	**NA**	**EC**
Parenting	Coercion/inconsistency	.11	**.35***	-.19
	Acceptation/sensibility	-.18	-.07	**.30***
SES	Parental education	**-.21#**	.06	**.27***
	Parental occupation	**-.19#**	.16	.06
	Family income-to-need ratio	**-.18#**	**.22#**	-.08
	SES general index	**-.26***	.15	.09

Provided the relationship between parenting, parental education and EC, we conducted a moderation analysis to explore whether the interaction between parental education and acceptation/sensibility of parents predicted EC. The moderation analysis was performed with the macro PROCESS for SPSS (Hayes, 2013). Acceptation/sensitivity and Parental Education scores were introduced as independent variables and EC as the dependent variable

(Model 1, corresponding to a simple moderation analysis). Confidence intervals at 95% were calculated for 5000 bias corrected bootstrap samples. The overall model was significant ($F(3,32)=7.26$, $p<.01$, $R^2=.41$) with the interaction between Parental Education and Acceptation/sensitivity parenting style significantly predicting EC ($b=1.08$, $t=3.25$, $p<.01$). Adding the interaction term to the model significantly increased the proportion of explained variance ($\Delta R^2 = .20$, $F(1, 32) = 10.58$, $p <.01$). As can be seen in Figure 6.5, EC significantly increased with Acceptation/sensibility parenting in a context of high parental education ($b=1.28$, $t=3.39$, $p<.001$). This relationship was not significant in the case of average ($b=.35$, $t=1.33$, $p=.19$) or low ($b=-.57$, $t=-1.41$, $p=.17$) parental education.

Secondly, we performed correlation analyses to examine the relationship of both temperamental and environmental factors with EA. Results are provided in Table 6.4. None of the measures of EA were related to any of the temperamental factors. However, some of the measures were related either to parenting or SES. On the one hand, poorer performance in the delay task was related to coercive/inconsistent parenting practices. On the other hand, lower SES was associated with greater conflict scores in RT in the Young-Children ANT. Concretely, it was significantly correlated to family income, whereas the relationship was only marginally significant for parental occupation and general index of SES, being unrelated to parental education.

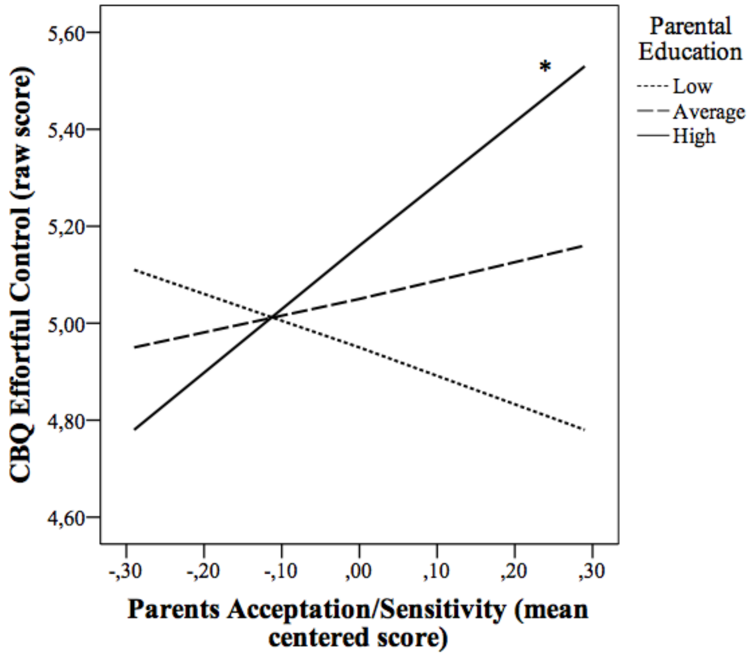


Figure 6.4. Interaction of parenting (acceptation/sensitivity) and parental education in predicting Effortful Control. Low= 1 *SD* below the mean; High=1 *SD* above the mean.

6.4 DISCUSSION

The aim of this T4 session was to observe the development of EA and self-regulation at 3 years of age, exploring the influence of temperament and environmental factors (parenting and SES) in EA skills at 3 years of age. Furthermore, we examined whether these variables had a differential effect on two different aspects of EA: conflict resolution and self-regulation. Consistent with the results obtained in prior research using

Table 6.4. Correlations between performance in Delay of gratification task and conflict tasks (conflict scores) with the measures of temperament, parenting and SES.

		DoG score	Spatial Conflict		Young-Child ANT Conflict	
			ACC	RT	ACC	RT
Temperament	CBQ Surgency	.04	.15	-.15	-.01	.16
	CBQ Negative Affectivity	-.01	-.17	-.04	.20	-.05
	CBQ Effortful Control	.15	-.09	.13	.21	.13
Parenting	Coercion/ inconsistency	**-.30***	.03	.05	.07	-.04
	Acceptation/ sensitivity	-.08	-.01	-.04	.18	-.09
SES	Parental education	.15	-.05	.09	.05	-.05
	Parental occupation	-.05	.04	-.13	-.03	**-.22#**
	Family income-to-need ratio	-.19	-.12	-.14	-.05	**-.26***
	SES general index	-.05	-.06	-.09	-.02	**-.25#**

** $p < .01$

* $p < .05$

\# $p < .1$

the Child-ANT with older children (Rueda et al., 2004), we found a main effect of congruency and type of cue in the Young-Child-ANT.Children were faster and more accurate for congruent trials than for incongruent trials. In the case of the Spatial Conflict task, there was no effect of conflict in RT or accuracy. Although children were generally faster and more accurate for spatial compatible trials compared to spatial incompatible trials, these differences did not reach the significant level. The absence of a significant difference may reflect a great variability among children. In our data, we find that standard deviations for conflict scores in the Spatial Conflict were 413.21 and 13.99% for RT and accuracy respectively.

Contrary to our expectations, performance in the Spatial Conflict task and Young-Child-ANT were unrelated. Although measuring highly related processes involving conflict detection and resolution, the Young-Child-ANT seemed to be more challenging for 3-year-olds than the Spatial Conflict. In fact, a lower proportion of children did reach the minimum performance criteria to be included in the analyses in the case of the Young-Child-ANT. Additionally, it is possible that children in the Spatial Conflict task presented greater performance variability. Looking at standard deviations of conflict scores, standard deviation was larger for Spatial Conflict than Young-Child-ANT (*SD*=12%) in accuracy conflict scores (*SD*= 13.99% and *SD*=12% respectively) and RT (*SD*=413.21 and *SD*=311.37 respectively). Similarly, performance in the DoG task did not correlate to any of the measures of conflict, suggesting that the two processes, conflict resolution and self-regulation, were independent. Whereas conflict resolution measured with the Spatial Conflict task and the Young-Child-ANT assess cool aspects of EA because both measure conflict resolution in an emotionally neutral context, the DoG task assesses self-regulation in a motivational and emotional context measuring hot aspects of

EA. This is in agreement to previous research that proposed that developmental course of cool and hot EA between the 3 and 5 years of age can be dissociated, as they found that each aspect of EA related to temperamental factors in a different way (Hongwanishkul, Happaney, Lee, & Zelazo, 2005).

Regarding temperament and environmental factors, we explored first the relationship between the three main temperamental factors (SUR, NA, EC), parenting style (acceptation/sensitivity and inconsistent/coercive parenting) and SES. We found that children from low-SES families were more prone to higher levels of SUR. This is consistent with a prior study that found greater levels of temperamental reactivity in low-SES infants (Jansen et al., 2009) as well as other studies that found an increased probability of suffering externalizing problems among low-SES children (Belsky & Pluess, 2009; Derauf et al., 2011). We also found that inconsistent/coercive parenting was associated with higher levels of NA. However, it is not clear whether inconsistent/coercive parenting leads to higher levels of distress and fear or alternatively parents whose children exhibit higher levels of NA tend to use inconsistent/coercive parenting strategies in a greater proportion. Our data also reveal that EC is related to greater parental education levels as well as to acceptation/sensitivity parenting style. This is in consonance to previous studies that related positive aspects of parenting, such as secure attachment and maternal sensitivity, to better EC (Bernier, Beauchamp, Carlson, & Lalonde, 2015; Bernier, Carlson, Desche, Deschênes, & Matte-Gagné, 2012). Parenting and parental education also interacted to predict EC, with higher levels of EC being associated with the use of parenting strategies of acceptation/sensitivity particularly in parents with high education levels. There is some evidence that positive parenting strategies may foster the development of self-regulation as they are based in encouraging children to self-reflection and implementing active control of behaviour (Spinrad, Eisenberg, & Gaertner, 2007).

Second, we found a relationship between temperament and environmental factors with the different measures of EA. As we anticipated, larger conflict effect in the Young-Child-ANT on RT was related to lower SES, in agreement with previous results that also found this association between SES and conflict resolution in the Child-ANT children between 5 and 7 years of age (Mezzacappa, 2004). There is some evidence that SES have an impact on EA not only at behavioural level (Duncan & Magnuson, 2012; Noble, Norman, & Farah, 2005) but also at neural level as some authors have linked low SES to reduced cortical thickness in prefrontal structures involved in executive attention network, such as anterior cingulate cortex (Lawson & Ruff, 2004). Our data confirm the association between SES and EA. Concerning parenting, inconsistent/coercive parenting related to a poorer inhibitory control in the delay of gratification task. This result is in line with other studies that relate low-quality parenting and coercion with excessive control over children behaviour (Conway & Stifter, 2012). The lack of consistency in the strategies used by parents may impair the development of children's self-regulation strategies. Over-control may limit children opportunities to implement self-regulation whereas inconsistency makes it difficult for children to generate and interiorize a general schema about social rules to guide behaviour. No relationship was found between temperament and any of the measures of EA, neither between the performance in the Spatial Conflict task and SES or parenting. Contrary to other studies that found a relationship between EC and self-regulation (Kochanska et al., 2000) or EA, we failed to find this relationship.

The current study presents a new version of the ANT suitable for children as young as 3 year of age. This task allows measuring the three attention networks described by Posner and Petersen (2002; 2012) from an earlier stage in development. Furthermore, we observed that different aspects of the family environment are relevant to conflict resolution and self-regulation, suggesting that, although both may depend on EA, they can be promoted and/or undermined by particular experiences. This information is particularly relevant to the design of interventions. Finally, analyses including more fine aspects of temperament in order to explore the relationship between conflict resolution and more concrete dimensions of temperament could serve to improve our understanding about the mechanisms that influence the development of EA.

CHAPTER 7

DEVELOPMENT OF EXECUTIVE ATTENTION: LONGITUDINAL ANALYSES

CHAPTER 7: DEVELOPMENT OF EXECUTIVE ATTENTION FROM INFANCY TO EARLY CHILDHOOD: LONGITUDINAL ANALYSES

7.1 INTRODUCTION

Over the previous chapters, we observed the relationship between different EA measures, as well as the influence of temperament and environmental factors at each age. In this chapter, we explore EA throughout development during the studied period. EA can be traced from early infancy, contrary to what it was though. EA network present an adult-like connectivity pattern already at birth. Furthermore, there is evidence that EA network is already functional by 7–9 months of age as babies of that age activated brain in response of perceived errors in a similar way that adults (Berger et al., 2006).

Few studies have attempted to measure EA during infancy and we only have available a few sensitive measures for that age. Even more, few studies have explored development of EA-related skills during infancy and toddlerhood from a longitudinal perspective. One example is the study of Holmboe and cols. (2008). In this task, the ability of infants to inhibit their attention to distractors is measured. Early differences in inhibitory control in this task predicted later EA at 2-year of age, and those children who showed a smaller conflict effect in a spatial conflict task where the ones that were more efficient in inhibiting attention to distractors at 9 months of age. Performance in the spatial conflict task at 30 months of age is also associated with the proportion of correct anticipations in a visual sequence task at 18 months. Anticipations in the visual sequence-learning task are thought to reflect EA (Rothbart, Ellis, Rueda, & Posner, 2003). Longitudinal research comprising the third year of life also observed improvements in the resolution of cognitive conflict (Gerardi-Caulton, 2000) as well as in self-regulation (Kochanska et al., 2000) between the two and three years of age.

In this chapter, we examine the relationship between all the different measures of EA, self-regulation and temperament obtained across the different stages of the research. In light of the reviewed literature, we expected that EA in infancy would be related to EA at 16–18 months, 2 and 3 years of age. At the same time, we expect self-regulation to be related over time. Finally, we anticipated that temperament would be stable over time and we hypothesized that temperamental reactivity and EC would be associated with EA and self-regulation across time.

7.2 Predictors of executive attention at 16–18 months of age

We performed Pearson's correlations to explore the relationship between measures at T1 and T2. Table 7.1 summarizes the results of the analysis. Temperamental reactivity was inversely related to the percentage of anticipations in the visual sequence-learning task, whereas more regulation/orienting was related to smaller difference in the amplitude of the N170 between sad and neutral conditions. Less difficulty to disengage from fearful faces was also related to smaller N170 difference wave. None of the measures at T1 was associated with ERN.

Given that both regulation/orienting and disengagement were associated with N170, we run multiple regression analyses to test the contribution of these two variables to N170 difference wave. After controlling for age, the overall model including both disengagement and regulation/orienting was marginally significant ($F(3, 31)=2.54$, $p=.07$,

R^2=.19) and the increase in the proportion of explained variance was significant ($F(2, 31)=3.35$, $p<.05$, $\Delta R^2=.17$; see Table 7.2). However, only disengagement from fearful faces resulted in a significant predictor (β=.32, t=2.01, $p<.05$).

Table 7.1. Correlation between measures at T1 and measures at T2. * p<.05. † partial correlations controlling by age.

Age		16 –18 months Measures	Visual Sequence % total anticipations	ERN correct-error	N170 † neutral-sad
9–12 mo.	Temperament	IBQR SUR	**-.29***	.09	-.16
		IBQR NA	**-.23#**	.02	.05
		IBQR REG	-.18	.01	**-.27***
	Experimental tasks	Shifting Task (% perseverations)	.02	.11	.04
		Disengagement from fearful faces	-.11	.14	**.32***

Table 7.2. Multiple regression analysis testing the role of regulation/orienting and disengagement from fearful faces (T1) in predicting N170 neutral-sad difference wave (T2) controlling by age at T2.*p<.1;#p<.1.

DV: N170 neutral-sad		R^2	β	t	ΔR^2
Step 1		.02			-
	Age T2		.15	.89	
Step 2		.19#			.17*
	Age T2		.09	<1	
	Disengagement fearful faces		.32	2.01*	
	Regulation/Orienting		-.25	-1.51	

7.3 PREDICTORS OF EXECUTIVE ATTENTION AT 2 YEARS OF AGE.

We run Pearson's correlation analysis to test the relationship between measures at T1 and T2 with measures at T3. Table 7.3 shows the results of the analysis. Regarding temperament, the three main factors SUR, NA and REG at T1 were positively correlated to SUR, NA and EC at T3 respectively. There was also a tendency of SUR at T1 to correlate with NA at T3, as well as NA at T1 to correlate with SUR at T3.

Correlation pattern was different for the delay task and the EA index. First, performance in the Snack Delay task was positively associated with NA and disengagement from fearful faces at T1 as well as to N170 difference wave between neutral and sad conditions at T2. We run multiple regression analysis to test the contribution of these measures at T1 and T2 to the individual differences in the performance in the delay task at T3. We introduced all variables as independent variables together in the model.

Table 7.3. Correlation analyses between T1, T2 and T3 measures. * p<.05, ** p<.01.

Age		25 - 27 months Measures	Snack Delay	Executive Control index	Temperament ECBQ SUR	NA	EC
9–12 mo.	Temperament	IBQR SUR	.13	**-.38****[**]	**.27***	**.25**[#]	.22
		IBQR NA	**.26**[*]	-.22	**.25**[#]	**.28***	-.08
		IBQR REG	.19	.08	-.01	.05	**.29***
	Experimental tasks	Shifting Task % perseverations	-.02	-.17	-.02	.10	-.17
		Disengagement from fearful faces	**.32**[*]	.24	-.25	-.11	-.08
16–18 mo.	Visual sequence learning task	% correct anticipations	-.03	**.39***	-.14	.25	.01
	ERN	Difference wave (correct-error)	.10	**.33***	-.23	-.03	-.07
	N170	Difference wave (neutral-sad)	**.47****	-.17	**-.44****	-.23	-.17

Overall model significantly predicted performance in the Snack Delay task (F(3, 36)=2.92, p<.05, R^2=.19). However, only disengagement from fearful faces predicted ability to delay, although relationship was marginally significant (see Table 7.4).

Table 7.4. Multiple regression analysis. Negative affect and disengagement from fearful faces (T1) and N170 neutral-sad difference wave (T2) were introduced in the model as predictors of Snack Delay at T3.*p<.05;#p<.06.

DV: Snack Delay	R^2	β	t
	.19*		
IBQR Negative affect		.08	<1
Disengagement fearful faces		.31	1.96#
N170 neutral-sad		.20	1.31

Second, EA index at T3 was associated with lower levels of SUR during infancy. Higher proportion of correct anticipations in the visual sequence-learning task at T2 was also related to better performance in EA tasks, but unrelated to Snack Delay at T3. We conducted subsequent regression analyses to test the contribution of those variables to the individual differences in EA by 2 years of age (Table 7.5). The model significantly predicted EA at T3 (F(3, 24)=3.49, p<.05, R^2=.22). It was found that SUR (T1) and performance in the visual sequence (T2) were significant predictors of EA (T3), but not ERN (T2).

Table 7.5. Multiple regression analysis. Measures at T1 and T2 predicting EA at T3. *p=.05.

DV: Executive Attention (T3)	R^2	β	t
	.22*		
IBQR Surgency		-.37	-2.16*
Visual Sequence (% correct anticipations)		.36	2.07*
ERN difference wave		.11	<1

7.4 PREDICTORS OF EXECUTIVE ATTENTION AT 3 YEARS OF AGE

We run Pearson's correlation analyses to explore the relationship of temperament and EA measures at T1, T2 and T3 with measures at T4. Results are presented in Table 7.6. Regarding temperament, scores in the three main factors at T1 and T4 were not significantly related, with the exception of the REG at T1 that was inversely related to SUR at T4. However, SUR, NA and EC at T3 and T4 were significantly related in a way that children with high levels of SUR, NA or EC at 2 years of age also showed higher levels by 3 years of age.

Additionally, temperamental reactivity at T1 and T3 was related to conflict scores for RT (not accuracy) in EA tasks. Higher conflict scores in the Spatial Conflict task were related to higher levels of NA (T1 and T3) and SUR (only marginally significant at T3). Likewise, higher conflict scores in the Young-Children ANT task were related to higher levels of NA and SUR, but only at T1. Conflict scores (for both RT and accuracy) in the Young-Children ANT were also associated with higher difficulty to disengage from fearful faces (T1) and lower proportion of correct anticipations in the visual sequence task (T2). Finally, the performance in the delay of gratification task was positively related to disengagement from fearful faces (T1), difference in amplitude of N170 neutral-sad (T2) and performance in the Snack Delay task (T3) whereas was negatively correlated to SUR (T3).

7.5 Discussion

7.5.1 Stability of temperament

As expected, the three temperamental factors demonstrated stability across age. Higher SUR, NA and REG at T1 were associated with higher SUR, NA and EC respectively at T3. At the same time, SUR, NA and EC at T3 and T4 were positively correlated. However, temperament at T1 did not relate to temperament at T4 with the exception of REG that was inversely related to SUR. This is consistent with previous longitudinal research (Putnam, Gartstein, & Rothbart, 2006) and is in line with the idea that temperament is a relatively stable constitutional characteristic. However, correlations were moderate, suggesting that other variables, such as environmental factors, may be also contributing to explain individual differences in temperament. Exploring other variables that may influence developmental trajectories of temperament factors may help to understand how these individual differences in temperament are built across infancy and toddlerhood.

Table 7.6. Correlations between T1, T2 and T3 measures. ** *p*<.01, * *p*<.05, $^{\#}$ *p*<.1; † partial correlations controlling for age.

Age		3 years	DoG	Conflict: Spatial Conflict		Conflict: Young-Child ANT		Temperament CBQ		
Age		**Measures**		**ACC**	**RT**	**ACC**	**RT**	**SUR**	**NA**	**EC**
9–12 mo.	Temperament	IBQR SUR	.14	-.09	-.02	-.04	**.30***	.10	-.07	.19
		IBQR NA	.06	.08	**.27***	-.15	**.29***	-.13	.16	-.01
		IBQR REG	-.24	-.10	-.16	.22	-.08	**-.35***	.19	.14
	Experimental tasks	Shifting Task (% perseverations)	.04	-.14	**.31***	-.11	-.11	-.12	-.18	.24
		Disengagement from fearful faces	**.34***	-.03	.04	**.32***	**.32***	-.06	.14	**.25**$^{\#}$
16–18 mo.	Visual sequence learning task†	% Correct anticipations	-.09	-.20	-.16	**-.40***	**-.53****	-.06	.24	**.27**$^{\#}$
	ERN	Difference wave (correct-error)	.10	-.09	-.01	.06	.09	**-.32***	.08	**.35***
	N170†	Difference wave (neutral-sad)	**.25**$^{\#}$	.02	-.24	-.05	-.04	-.13	.05	.14
2 years	Experimental tasks	Executive Control	.08	.19	-.04	.12	.03	-.04	-.07	.06
		Snack Delay	**.34***	-.19	-.08	.08	-.17	**-.25***	**-.23**$^{\#}$	.17
	Temperament ECBQ	SUR	**-.32***	.09	**.23**$^{\#}$	-.01	-.09	**.32***	.02	-.17
		NA	-.14	-.04	**.31***	.21	-.02	.07	**.36****	-.01
		EC	-.16	-.12	.20	.20	.03	-.15	-.08	**.47****

7.5.2 Association of temperament factors with latter Executive Attention skills.

We found that lower temperamental reactivity levels (SUR and NA) at T1 were consistently related to a more efficient EA at T2, T3 and T4. Overall, children that presented lower temperamental reactivity levels (SUR or NA) during infancy also showed better EA skills by 16–18 months of age (as measured with anticipations in the visual sequence task), at 2 years of age (as measured with the Reverse Categorization task and the Shape Stroop task), and at 3 years of age (as measured with the Spatial Conflict task and the Young-Child-ANT). Temperamental reactivity at 2 years of was also related to better EA by 3 years of age, showing smaller conflict effect on RT in the Spatial Conflict task. In agreement with our data, higher levels of temperamental reactivity have been associated with poorer EA skills in earlier studies (Davis, Bruce, & Gunnar, 2002; Wolfe & Bell, 2007). Given the important role of EA in regulation, infants that control attention in a more efficient way might be able to down-regulate affect more easily, translating into lower temperamental reactivity levels. In fact, in our data lower levels of SUR during infancy are also related to higher EC by 3 years of age. Despite of that, neither REG at T1 or EC at T3 were correlated to the performance in the EA tasks. A possible explanation for that might be that the regulatory system is developing at a slower rate than reactive systems. Thus, REG and EC at early stages of development would not translate into a more efficiency of EA until later. Conversely, the relationship between poor EA and higher temperamental reactivity seems to be observable relatively early in development. Some authors have suggested that these differences in the development rate between EC and temperamental reactivity systems could have its foundation in the different brain structures underlying each process (Eisenberg, Smith, Sadovsky, &

Spinrad, 2004). Authors argue that providing that EC is generally associated with the development of prefrontal structures, having a more protracted development than subcortical structures that seem to rely on temperamental reactivity systems. However, longitudinal studies assessing EA, temperamental reactivity and EC during these early years and including brain measures would be needed to confirm that hypotheses.

7.5.3 Relationship between Executive Attention tasks across time

7.5.3.1 Measures of EA at T1

At T1 we used two different tasks taxing EA-related mechanisms: an attention shifting task and an attention disengagement task. Correlation between measures over time revealed that the percentage of perseverations in the shifting task was only correlated to performance in the Spatial Conflict at 3 years of age. As expected, children who exhibited greater flexibility of attention during infancy resolved spatial conflict more efficiently by three years of age, presenting smaller differences in RT between spatial compatible and incompatible trials. This is in line a previous that found that the ability of infants to inhibit attention toeard distractors was associated with the performance in a Spatial Conflict task by 2 years of age (Holmboe, Pasco, Csibra, Tucker, & Johnson, 2008). In the case of the disengagement task, the more difficulty to disengage from fearful faces during infancy, the more difficulty to resolve conflict in the Young-Child-ANT by 3 years of age, having greater conflict scores in RT and accuracy. The fact that these early measures of EA did not relate to EA index at T3 but related to performance in EA tasks at T4 might be due to a difference in the characteristics of the tasks. At T1 and T4 experimental tasks where computerized and stimuli were presented to children throughout the computer monitor. In opposition, tasks used at T3 were not computerized and required children to manipulate stimuli and interact with researcher. There is some evidence that a same task presented under different conditions (that is, using a different methodology) produce different results in the same subjects. This phenomenon has been identified as the “task mode effect” and is consistently found in literature when comparing performance in paper-based and computerized tasks (see Leeson, 2006 for a review).

7.5.3.2 Measures of EA at T2

As a measure of endogenous control of attention at T2, we used the proportion of correct anticipations in a visual sequence learning-task. As we hypothesized, the performance in the visual sequence-learning task at T2 was associated with EA at T3 and T4. Children showing a greater endogenous control of attention by 16–18 months of age also performed better in EA tasks by two years of age and were more efficient resolving conflict (using both accuracy and RT) in the Young-Child-ANT by three years of age. These results are in line with those of Rothbart, Ellis, Rueda, & Posner (2003) that also found a correlation between anticipations in the visual sequence-learning task at 24 months and efficiency of cognitive conflict by 3 years of age. Our results give further support to the idea that anticipations reflect an important mechanism related to the early development of EA, the voluntary control of attention, serving as an early indicator of later EA. Our data reveal that anticipations can relate to three-year olds EA from even earlier than shown by Rothbart and colleagues, by 16–18 months of age. Interestingly, we failed to find any relationship between visual sequence-learning task and performance of the Spatial Conflict task, being correlations limited to the performance in the Young-Child-ANT. In contrast, the study mentioned earlier used a Spatial Conflict task to measure conflict resolution. In our study, the conflict effect was not statistically significant (see chapter 6). The lack of relationship with Spatial Conflict task might respond to a greater variability of children performing the task (conflict score RT *SD*= 413.21; conflict score accuracy *SD*= 13.99%).

7.5.3.3 Measures of EA at T3

Contrary to our expectations, EA at two years of age was unrelated to EA at three years of age. Scores in the two different tasks were combined in a general index of EA at two years of age: the Reverse Categorization task (measuring flexibility of attention) and the Shape Stroop task (measuring conflict resolution). These tasks involve the manipulation of objects and the interaction with experimenter, in contrast to the tasks used by three years of age that were computerized and administered by means of a touch-screen device. Properties of the task represent a source of variability that can reduce the proportion of shared variance between tasks and may explain the absence of correlation between the different measures of EA at T3 and T4.

7.5.4 Relationship between Neural indicators of Executive attention and measures at 2 and 3 yearso of age

As hypothesized, the size of the ERN effect at 16–18 months of age was related to EA at two years of age. A greater difference between error and correct condition in the ERN was associated with greater EA by two years of age. This was expected given that ERN is considered a neural marker of EA (Gehring, Liu, Orr, & Carp, 2011). However, it was unrelated to any of the EA tasks at T4. These results were unexpected as both error-detection and conflict resolution are thought to rely on EA network, sharing common mechanisms (Petersen & Posner, 2012). However, it is possible that the neural mechanisms undelaying both processes become more specific during this developmental period, explaining why the relationship between ERN and other measures of EA different from error detection weakens over time in our data. Interestingly, a larger ERN effect was related to greater EC and lower SUR levels at three years of age. EC is a more general construct built on EA skills that encompasses error monitoring (Rothbart & Rueda, 2005). Therefore, the EA network has been suggested to underpin observed individual differences in EC. Our results are consistent with this idea and may lead to consider ERN at 16–18 as an early indicator of EC at three years of age. The fact that ERN is also associated with lower SUR levels seems coherent, given that EC and SUR are generally inversely related (Putnam et al., 2006).

7.5.5 Emotion processing and self-regulation

At T2, we observed the modulation of the N170 ERP component by the emotion conveyed in the face. In line with our predictions, our results revealed that larger differences in amplitude of the N170 between neutral and sad faces were related to a greater difficulty to disengage from fearful faces and lower REG in infancy. The greater increase of the N170 amplitude for negative emotion stimuli has been associated with problems in regulating affect (Dennis & Chen, 2007; Kolassa & Miltner, 2006). Similarly, a difficulty to disengage from fearful faces is commonly observed among people with higher anxiety. These results indicate that as early as by 9–12 months of age we might observe early signs of emotion regulation, being associated with neural responses to emotion. However, it would be necessary to include the assessment of the effectiveness of emotion regulation mechanisms, such as disengagement of attention, in reducing emotional response in order to conclude whether this early measures of emotion processing and attention regulation can predict later emotion regulation.

We also measured self-regulation throughout two different delay tasks at T3 and T4. First, we found that self-regulation as measured with the delay tasks was stable between the second and the third year of life. Two-year olds that were able to refrain the impulse of eating the snack in the Snack Delay task were more likely to choose waiting longer time in order to get a bigger prize by three years of age.

Higher levels of NA and greater difficulty to disengage from fearful faces (T1), as well as N170 neutral-sad difference wave (T2) were related to self-regulation at 2 years. Together, these three variables significantly predicted inhibitory control in the snack delay, although only disengagement resulted in a significant predictor in the model. Disengagement of attention from fearful faces (T1) and the N170 neutral-sad difference wave (T2) were still associated with self-regulation in the delay task at 3 years of age, although the association was only marginally significant in the case of the N170. Additionally, low SUR at two years of age was also related to greater ability to delay at three years of age. These results are in agreement with the idea that self-regulation relies on fear-based mechanisms during the first years of life, as has been suggested by the work of Kochanska and colleagues (Aksan & Kochanska, 2004).

Contrary to our hypothesis, children's ability to delay gratification was not related to either EC or EA. It is therefore likely that the lack of relationship between EC and self-regulation in the delay task may indicate that mechanisms of EC are not mature enough by two years of age and fear-based mechanisms still have a predominant role in self-regulation, as suggested by previous research (Sheese, Rothbart, Posner, White, & Fraundorf, 2008). The fact that self-regulation in the delay of gratification task was also unrelated to EA might indicate that self-regulatory strategies are still predominantly based on orienting mechanisms. Altogether, Although improvements in EA are observed during this developmental period,

Studies such as the present one contribute to the understanding of the early development of EA, filling a current gap in developmental research. However, our study has two main limitations. First, we were not able to use a same task or sufficient equivalent measures of EA at each age, a common limitation identified in longitudinal studies addressing early development (Hendry, Jones, & Charman, 2016). Second, the sample size was reduced for some tasks and we lost some participants over the course of the study. These two aspects made not possible to perform analyses of changes in developmental trajectories due to temperament or different environmental factors or to employ other kind of statistical analyses such as structural equation modelling in order to test more complex models to predict later EA skills. Future studies should increase the sample size in order to deal with this problem. Developing measures of the different EA processes suitable to be used from infancy to toddlerhood that could be comparable may also improve the research on the development of EA during this developmental period. Furthermore, given the key role of EA in academic success and socio-emotional adjustment (Rueda, Checa, & Rothbart, 2010), this kind of studies can be particularly relevant for predicting later outcomes and prevent later developmental disorders. Further research is needed to explore not only developmental trajectories of EA but also how different developmental trajectories relate to different kind of outcomes along the childhood and adolescent periods.

CHAPTER 8
GENERAL DISCUSSION

CHAPTER 8: GENERAL DISCUSSION

The main goal of the present research was to investigate the development of executive attention during infancy and toddlerhood. Literature on the development of executive attention typically focuses on the study of executive attention from the preschool years onwards. However, prior findings indicate that the executive attention network is functional as early as form infancy, and first signs of executive attention are already observable by the end of the first year of life. So far, the work presented in this dissertation intends to address the existing gap in developmental research by exploring the development of executive attention during the first three years of life. For that purpose, we conducted a 4-waves longitudinal study in which executive attention was assessed at 9–12 months, 16–18 months, 2 years and 3 years of age.

Throughout this chapter, I will summarize and further discuss the main results of this study within the scope of the literature reviewed in the introduction. First, I will go into the longitudinal changes on executive attention during the studied period to continue exploring the neural markers of executive attention, and finally, the development of self-regulation to terminate with influence of temperament and environmental factors. I consider the significance of our findings in the field of developmental psychology with particular emphasis on the implications for the early prevention of developmental disorders and conclude by briefly noting the limitations of our study and proposing future directions for the research.

8.1 DEVELOPMENT OF EXECUTIVE ATTENTION

Earlier studies on development of executive attention created different measures of executive attention suitable for infants, which can be sensitive enough for capturing early individual differences at that age. That is the case of the A-not B task (Diamond, 1990b), gap-overlap task (Hood & Atkinson, 1993) or the more recently developed Freeze Frame task (Holmboe et al., 2008). Using these tasks, authors have shown that executive attention can be directly measured as early as by the end of the first year of life, opposing to a traditional perspective that considered that emergence of executive processes depending on prefrontal structures could not be observed until childhood. In our study, we observed individual differences in executive attention as early as by 9–12 months of age in attentional flexibility as measured with the attention shifting task (Kovács & Mehler, 2009) and in disengagement of attention (as measured with the emotional disengagement task; Peltola, Leppänen, Mäki, & Hietanen, 2009). The two measures were associated, corroborating the idea that both share common mechanisms related to the construct of executive attention. Our longitudinal analysis have shown that these early measures of executive attention predict to some extent individual differences in executive attention by 3 years of age. At 16–18 months we used an different measure of voluntary attention, namely the anticipation of attention to the appearance of stimuli following a particular sequence. This measure of executive attention was also related to later executive attention measures at 2 and 3 years of age.

All in all, our results give further support to the idea that executive attention can be assessed as early as by infancy. Furthermore, these findings suggest that measures of executive attention in infancy and early toddlerhood may serve as indicators of the later development of executive attention at least up to two and three years of age, in agreement with other studies (Holmboe et al., 2008; Rothbart, Ellis, Rueda, & Posner, 2003). However, none of the cited studies explored the complete period between the first and the third year of life, but covered either the first or the second year of life. Conversely, we failed to find any relationship between executive attention measures at two different time points: between 9–12 and 16–18 months of age and between 2 and 3 years of age. These results seem difficult to explain as continuity in the relationship was expected. Nevertheless, differences in the characteristics of stimuli and procedure (computerized tasks vs. manipulative) may account for these results (Leeson, 2006).

This developmental period is especially relevant for the detection of some developmental disorders. That is the case of autistic spectrum disorders. On average, the diagnosis of autistic disorders is received about the third year of age (Mandell, Novak, & Zubritsky, 2005). There is some evidence that the ability to disengage at 14 months of age is associated with the development of autistic disorders by three years of age in at-risk children (Elsabbagh et al., 2013). Results in our study suggest that not only disengagement of attention tasks but also attention shifting tasks can be considered as early indicators of executive attention functioning. Therefore, this may help to create more robust indexes of early executive attention. In this line of thought, combining different measures might increment the predictive value. Not only children at risk for autistic disorders can beneficiate from the early identification of alterations in executive attention functioning. This can be extended to the evaluation of possible executive attention deficits in children at risk for other developmental disorders characterized by alterations in executive attention (such as attention deficit disorders) or with any neurological condition (for instance, premature children). Our results indicate that patterns of perseverative behaviour or difficulties in disengaging attention from threatening stimulation may be considered as early markers of executive attention. Therefore, studies like the present one may help in the prevention of executive attention deficits as the early detection of risk may lead to earlier interventions.

8.2 NEURAL MARKERS OF EARLY EXECUTIVE ATTENTION

Apart from studying the development of executive attention at the behavioural level, we also examined the early development of neural mechanisms underlying executive attention. We observed that by 16–18 months children exhibit an ERN-like component in response to the perception of errors in the formation of simple animal puzzles. Our results are consistent with previous findings (Berger et al., 2006) and strengthen the idea that the executive attention network is functional from very early on. The ERN protocol used in our study provides a new paradigm for measuring executive attention, concretely error monitoring, in early development. We additionally found that toddlers also exhibit a significant increase in relative theta power for the error compared to the correct condition, matching the ERN time window and being correlated to the ERN difference wave amplitude. Interestingly, brain activation associated with error detection was related to the performance in another concurrent executive attention task requiring the ability to monitor a sequence of events and endogenously anticipate attention to particular locations. Moreover, brain activation associated with error detection was also related to EA at two years of age and temperament EC at three years of age. Therefore, our data suggest that the brain activity associated with error detection can be used as a neural marker for executive attention and might serve to predict executive attention and effortful control at two and three years of age.

8.3 DEVELOPMENT OF SELF-REGULATION

This research also aimed at investigating the involvement of executive attention in early self-regulation mechanisms. Our data revealed that attention flexibility and regulation of attention to emotionally salient stimuli were associated with each other in infancy. Disengagement from emotional stimuli is considered a self-regulatory mechanism in infants (Rothbart et al., 1992). In fact, difficulties in disengaging attention from emotional stimuli are related to impairments in self-regulate emotion (Georgiou et al., 2005; Leleu, Douilliez, & Rusinek, 2014). We found that infants with greater attention flexibility in the shifting task disengaged more easily from fearful faces. Moreover, executive attention, as measured with the shifting task, moderated the effect of NA in disengaging attention from fearful faces, indicating that good EA skills can be a protective factor and help in regulating attention away from those distressful stimuli. However, direct measures of the effect of disengagement on reducing distress were not obtained in our study. Notwithstanding these limitations, our results suggest that a relationship between executive attention and self-regulation can be observed as early as from infancy and that executive attention may act as a protective factor for the development of difficulties in self-regulation. It has been proposed that orienting mechanisms are at first prominent in self-regulation during infancy to progressively depend more on executive attention (Posner & Rothbart, 2009). Further longitudinal research including orienting, executive attention and self-regulation measures across the first year of life is needed in order to explore how and when the transition from orienting to executive attention in self-regulation might take place.

Despite the fact that we found a relationship between executive attention and self-regulation in infancy, we failed to find any association of performance in executive attention tasks with performance in tasks measuring self-regulation at two or three years of age. Together, these results may indicate that executive attention and self-regulation are two distinguishable processes. Executive attention and self-regulation may become more differentiable with age, probably by the increasing influence of other factors different from executive attention skills in the development of self-regulation. In fact, our results show that no influence of SES on disengagement from fearful faces is observed in infancy, whereas at two and three years of age self-regulation becomes associated with environmental factors such as parents education or parenting strategies. However other factors, such as language, have demonstrated to have also a key role in the development of self-regulation during toddlerhood (Vallotton & Ayoub, 2011). Thus, exploring other related factors, especially language development trajectories in conjunction to environmental factors and self-regulation development, would be of particular interest for future studies in order to better outline individual differences in the early development self-regulation.

Finally, our results give further support to the idea that self-regulation during infancy and toddlerhood may also rely on fear processes. Prior studies found that higher fearfulness in infants and toddlers is linked to the development of a greater ability to inhibit impulses later in childhood (Aksan & Kochanska, 2004). In line with that, we consistently observe a positive correlation between negative affectivity, disengagement from fearful faces and sadness effect on the N170 with self-regulation at two and three years of age. Extended longitudinal research is needed in order to understand how the transition from these fear-based mechanisms of self-regulation to other mechanisms of self-regulation based on the effortful control of the behaviour takes place.

8.4 INFLUENCE OF TEMPERAMENT AND ENVIRONMENTAL FACTORS

The present study was also designed to examine the influence of temperament and environmental factors on the development of executive attention during the first three years of life. Results revealed that both SES and temperament were associated with early executive attention development.

Regarding temperament, our results corroborate the stability of temperament across age. In general lines, lower temperamental reactivity levels were consistently related to a more efficient executive attention across the studied period. Contrary to our expectations, neither REG nor EC were correlated to the performance in EA tasks and only self-regulation at two years of age was related to EC. Given the role of executive attention in the regulation of affect, children with poorer executive attention skills would not be able to regulate reactivity as effectively as children with better executive attention skills. Alternatively, highly reactive children would probably struggle to develop more efficient regulation strategies, explaining why EA is related to NA or SUR but not with EC. However, further research is needed in order to confirm this idea.

Concerning environmental factors, our data suggest that SES and parenting practices are modulating the development of executive attention during this developmental period. Infants raised in low SES families already showed poorer attention flexibility, as well as poorer executive attention at 16–18 months. By this age, disparities in SES also affect executive attention at the neural level, as shown by the brain response to perceived errors. At 2 and 3 years of age, not only SES but also parenting style showed an association with self-regulation (as measured with Snack Delay and Delay of Gratification tasks respectively at each age), although not to EA measured with flexibility and conflict tasks. Higher inconsistent parenting and lower SES were related to a poorer self-regulation at age 2 years, but only inconsistent parenting at age 3 years. Moreover, our data indicate that environmental factors and temperament interact to predict self-regulation. EC seems to protect low-SES children against the detrimental effect of inconsistent/coercive parenting practices on inhibitory control by two years of age. All in all, the study highlights the importance of both constitutional aspects (temperament) and environmental factors (SES and parenting) when understanding cognitive development, particularly executive attention-related processes. Importantly, the interaction between temperament and environment has to be considered. More research is required to determine to what extent certain temperament factors constitute a risk in addition to the characteristics of environment or whether some temperamental profiles can be more susceptible to the influence of environmental factors as is proposed by some authors (Belsky & Pluess, 2009). Our results indicate that the more reactive children are at risk for potential alterations in EA, particularly when raised in low SES contexts. This finding suggests the importance of identifying those children at risk from early on so as to intervene in order to improve EA and self-regulation and prevent later negative outcomes, such as attention disorders or externalizing behaviour problems. Previous studies have proved that EA can be trained as early as from 11 months of age (Wass, Porayska-Pomsta & Johnson, 2011).

8.5 CONLCUSIONS AND FUTURE DIRECTIONS

This work contributes to existing knowledge on early executive attention development by providing further information about executive attention development during the first three years of life. Addressing this question longitudinally allows observing the origins during infancy of individual differences that are still observed later in childhood. The study has gone some way towards enhancing our understanding of early development of executive attention by exploring the influence of both temperament and environmental factors as well as its interaction. Moreover, this work also provides evidence about early neural markers of executive attention that may serve to predict executive attention and effortful control and complement behavioural measures.

The present study proves to be particularly valuable to the early detection of executive attention deficits. Future research including children at risk for diverse developmental disorders would provide insight for the identification or early signs of dysfunctions in executive attention. This would improve early prevention, permitting the early start of interventions and maximize its potential effects. Furthermore, this kind of research may help to identify not only individual profiles of children at risk but also characteristics of the context that represent a risk for children that belong to it. However, more research is needed in order to define more specific profiles and environmental variables, including the relationship among them. Increasing the sample number would help to test more complex models.

Finally, this research has several practical implications. Firstly, it points to the possibility of predicting children executive attention and self-regulation from infancy. Given the importance of those aspects to schooling skills and academic achievement, this knowledge may serve to evaluate school readiness and promote education programs that reinforce to these children at risk for academic problems. Furthermore, our research stresses the importance of educating caregivers on parenting practices that promote cognitive skills and self-regulation in children. Even more, studies like the present one may impulse changes in general policies driven to palliate the effects of poverty in our society, given the early impact of SES in children.

CHAPTER 9
RESUMEN EN ESPAÑOL

CHAPTER 9: RESUMEN EN ESPAÑOL

9.1 INTRODUCCIÓN

El trabajo presentado en esta tesis presenta como objetivo principal el estudio del desarrollo de la atención ejecutiva durante los tres primeros años de vida. La atención ejecutiva es el mecanismo encargado del control de la información sensorial, comportamiento, pensamientos y emociones. Representa una de las tres redes de la atención de acuerdo con el modelo propuesto por Posner y Petersen (2012; 1990), comprendiendo áreas de la corteza prefrontal, la corteza cingulada anterior (Fan et al., 2005) o la corteza prefrontal dorsolateral (Ravizza & Carter, 2008). La atención ejecutiva se halla involucrada en funciones tales como la resolución del conflicto cognitivo, la monitorización de errores, el control inhibitorio o la adaptación flexible a los cambios.

El estudio de la atención ejecutiva ha sido abordado por numerosos investigadores dentro del campo de la psicología del desarrollo dada su capacidad para predecir el grado de ajuste psicosocial (Lengua, 2003), así como por su relación con el desempeño académico (Rueda et al., 2010). Asimismo, juega un papel muy importante en el desarrollo de la autorregulación. La autorregulación se refiere a el control de pensamientos y conducta de acuerdo a objetivos, estando involucrada en la regulación de las emociones, en el control de impulsos o en la capacidad de adecuar la nuestro comportamiento de a cuerdo a las normas (Baumeister & Vohs, 2004). La atención ejecutiva y la autorregulación poseen substratos neurales comunes y de hecho la autorregulación parece cimentarse en el desarrollo de la atención ejecutiva (Rothbart et al., 2011).

A pesar del interés que despierta el desarrollo de la atención ejecutiva, son pocos los estudios que aún hoy abordan el desarrollo temprano de esta función cubriendo los primeros años de vida (ver Hendry et al., 2016 para una revisión reciente). No obstante, algunos estudios apuntan a que precisamente durante esta etapa hay un importante desarrollo de la atención ejecutiva y de las estructuras cerebrales asociadas. La red de atención ejecutiva en recién nacidos ya presenta un patrón de conectividad similar al encontrado en adultos (Doria et al., 2010) y hay pruebas de que la red de atención ejecutiva ya es funcional entre los 7 y 9 meses de edad (Berger et al., 2006). De hecho, ya desde bebés se puede medir el funcionamiento de la atención ejecutiva (Holmboe et al., 2008). Los niños demuestran una mayor flexibilidad cognitiva hacia el final del primer año de vida (Diamond, 1990b) y hacia el segundo año ya son capaces de superar algunas tareas que anteriormente eran incapaces de realizar, como… Paralelamente, durante estos primeros dos años de vida, el volumen cortical se incrementa sustancialmente, con un crecimiento más rápido en las estructuras frontales durante el segundo año (Gilmore et al., 2012). Más adelante, entre los dos y tres años de edad se observa una mejora de los niños para resolver el conflicto cognitivo (Gerardi-Caulton, 2000) a la vez que van demostrando una mayor capacidad para autorregularse (Kochanska et al., 2000).

Con este estudio, pretendíamos estudiar los cambios en el desarrollo de la atención ejecutiva durante los tres primeros años de vida. Con este propósito, diseñamos un estudio longitudinal en el que medimos la atención ejecutiva en cuatro momentos diferentes: a los 9-12 meses de edad (T1), a los 16–18 meses de edad (T2), a los 2 años de edad (T3) y a los 3 años de edad (T4). Seleccionamos una serie de tareas apropiadas para medir la atención ejecutiva en cada edad. Esperamos que las diferentes medidas de la atención ejecutiva se relacionen a lo largo del tiempo. De igual forma, examinamos la relación entre autorregulación y atención ejecutiva. No solo observamos cambios en la atención ejecutiva a nivel comportamental sino que también exploramos cómo esos cambios se relacionaban con la actividad neural asociada a la red de atención ejecutiva. Finalmente, investigamos la influencia tanto del temperamento como de factores ambientales (SES y estilo parental) en el desarrollo de la atención ejecutiva y la autorregulación.

Por un lado, el temperamento de los niños puede condicionar la forma en que la función ejecutiva se desarrolla. El temperamento se refiere a las diferencias observadas en reactividad a nivel motor, emocional y atencional (Rothbart & Bates, 2006). Podemos distinguir entre tres factores principales: afectividad negativa (disposición a experimentar emociones negativas), afectividad positiva (caracterizado por una tendencia a altos niveles de actividad e impulsividad) y control voluntario (fundamental en la regulación de los niveles de reactividad tanto positivos como negativos). Diferentes perfiles temperamentales se han asociado a diferencias individuales en atención ejecutiva. Altos niveles de afectividad tanto negativa como positiva se asocian con dificultades en tareas que requieren de la atención ejecutiva (Davis, Bruce, & Gunnar, 2002; Wolfe & Bell, 2004; Wolfe & Bell, 2007), mientras que poseer un alto grado control voluntario se relaciona con un mejor desempeño en este tipo de tareas (Gerardi-Caulton, 2000).

Por otro lado, el desarrollo de la atención ejecutiva no se ve exento de la influencia del entorno. Diversos estudios muestran que crecer en un ambiente con bajo nivel socioeconómico impacta negativamente al desarrollo de la función ejecutiva de los niños incluso desde que son bebés (Lipina et al., 2005; Noble et al., 2006), afectando al desarrollo cerebral desde muy temprano (Hanson et al., 2013; Lawson et al., 2013) y alterando su actividad funcional (Tomalski et al., 2013). Otro aspecto relevante del entorno a tener en cuenta es la influencia que las prácticas de crianza empleadas por los padres tiene sobre el desarrollo de esta función. Un estilo parental basado en la coerción o inconsistente se relaciona con un dificultades por parte de los niños en realizar tareas que implican la atención ejecutiva, así como para regular su comportamiento (Bernier et al., 2010; Merz et al., 2016).

En nuestro estudio, los padres proporcionaron información sobre el temperamento de sus hijos a través de cuestionarios en T1, T3 y T4. De igual forma, obtuvimos información acerca del SES en la primera sesión y acerca de las prácticas de crianza empleadas por los padres en T3. Dada la evidencia existente, esperamos que tanto temperamento como los factores ambientales se asocien con el desarrollo de la atención ejecutiva y la autorregulación y que incluso su interaccionen para predecir la atención ejecutiva. A continuación, resumimos los principales resultados encontrados en cada etapa y cómo las medidas se relacionan a lo largo del periodo estudiado, terminando con unas breves conclusiones.

9.2 Atención ejecutiva a los 9–12 meses de edad

A los 9–12 meses de edad utilizamos dos diferentes medidas asociadas con la atención ejecutiva: una tarea de flexibilidad atencional y una segunda tarea de desenganche de la atención. Esta última incorporaba un elemento emocional al utilizar caras con distintas emociones (felices, asustadas, neutras) como estímulo central, siendo considerado una medida antecedente de la autorregulación. La proporción de perseveraciones se utilizó como indicador de flexibilidad atencional, mientras que la facilidad o dificultad en desenganchar la atención de particularmente las caras que expresaban miedo fue la medida utilizada en el caso de la tarea de desenganche. A parte de la atención ejecutiva, se recogió información sobre el SES y temperamento de los bebés. Tal y como esperábamos, encontramos que ambas medidas, perseveraciones en la tarea de flexibilidad atencional y desenganche de las caras que expresaban miedo estaban positivamente relacionadas y aquellos bebés que mostraban una mayor dificultad de desengancharse eran también los que mostraron una menor flexibilidad atencional. Nuestros resultados también revelaron que tanto SES como temperamento estaban asociados con la flexibilidad de la atención. Encontramos que aquellos niños provenientes de un entorno de bajo nivel de SES que además presentaban una alta reactividad negativa fueron aquellos que mostraron una menor flexibilidad atencional. Por otro lado, una alta afectividad negativa se asociaba con una mayor dificultad en desenganchar la atención de caras que expresaban miedo. No obstante, encontramos que la flexibilidad atencional modulaba el efecto de la afectividad negativa y que aquellos niños con mayor flexibilidad cognitiva no se vieron afectados por una mayor dificultad en desenganchar a pesar del grado de afectividad negativa que presentasen.

9.3 ATENCIÓN EJECUTIVA A LOS 16–18 MESES DE EDAD

A esta edad medimos la atención ejecutiva tanto comportamentalmente (con una tarea de aprendizaje de secuencias visuales) como a nivel cerebral (midiendo la actividad neural asociada a la detección de errores). Además, medimos el procesamiento a nivel cerebral de emociones presentando caras neutras, tristes y alegres. Igualmente, utilizamos la información sobre SES proporcionada por los padres en la sesión anterior. Tal y como esperábamos, encontramos que los niños presentaron una negatividad asociada a la detección de errores en la formación de puzles simples de animales, similar a un ERN en adultos. De igual forma, también mostraron un incremento significativo en la banda de frecuencia theta. Por último, encontramos que la amplitud del componente N170 era mayor en el caso de caras tristes. En primer lugar, encontramos que la ejecución en la tarea de aprendizaje de secuencias visuales se asociaba con la amplitud del ERN. De igual forma, tanto la ejecución en la tarea de aprendizaje de secuencias visuales como la actividad cerebral asociada a la percepción de errores se asociaron con el nivel de SES. En concreto, los niños provenientes de familias con un mayor nivel de SES presentaron una mejor ejecución en la tarea de aprendizaje de secuencias visuales (esto es, una mayor proporción de anticipaciones). De igual forma, los niños cuyos padres presentaban un mayor nivel educativo exhibieron un mayor ERN y un incremento mayor de potencia para el ritmo theta. Ninguna medida se relacionó con la amplitud del componente N170 para caras tristes. En definitiva, estos resultados indican que el ERN puede ser considerado un indicador temprano del funcionamiento de la red de atención ejecutiva, estando asociado con medidas comportamentales de la atención ejecutiva. Además, nuestros datos corroboran la importancia que variables ambientales, como el SES, tienen sobre el desarrollo temprano de esta función ya no sólo observable a nivel comportamental sino también a nivel de actividad funcional del cerebro.

9.4 Atención ejecutiva a los 2 años de edad

En esta fase del estudio medimos diferentes aspectos de la atención ejecutiva. De un lado, observamos la habilidad de los niños para resolver el conflicto y comportarse de una manera flexible, agrupando estas medidas en un único componente de atención ejecutiva. De otro lado, observamos la capacidad de los niños para inhibir impulsos, más relacionado con su capacidad de autorregulación. De nuevo volvimos a preguntar a los padres acerca del temperamento de sus hijos a esta edad, además de acerca de las prácticas de crianza que ellos utilizaban normalmente. Igualmente, consideramos la información acerca del SES de la familia obtenida en sesiones anteriores. Encontramos que atención ejecutiva y autorregulación presentaban diferentes patrones de asociación con los distintos factores de temperamento y las distintas variables ambientales. Mientras que una mayor atención ejecutiva se asociaba con un temperamento menos reactivo (menor afectividad tanto negativa como positiva), la capacidad de autorregulación se asociaba a mayores niveles de control voluntario, menor uso de técnicas coercitivas y más consistencia en la aplicación de disciplina por parte de los padres y un mayor nivel de SES. La interacción entre SES, estilo parental y control voluntario explicaba las diferencias individuales en autorregulación. Nuestros datos indican que el control voluntario puede servir como factor protector especialmente en el caso de aquellos niños con bajo SES y cuyos padres tienen un estilo parental coercitivo e inconsistente.

9.5 ATENCIÓN EJECUTIVA A LOS 3 AÑOS DE EDAD

En esta última etapa, utilizamos dos tareas para medir la capacidad de los niños para resolver el conflicto: la tarea de conflicto espacial desarrollada por Gerardi-Caulton (2000) y una adaptación de la Child-ANT (Rueda et al. 2004) simplificada para poder ser utilizada con niños a partir de los 3 años de edad. Igualmente, medimos la capacidad de regulación a esta edad con una tarea de demora de la gratificación (Mischel, Shoda, & Rodriguez, 1989). Una vez más, pedimos a los padres información acerca del temperamento de sus hijos a través de un cuestionario. Finalmente, también se consideró la información acerca del SES obtenida con anterioridad, así como acerca de las prácticas de crianza utilizadas. La eficacia en la resolución del conflicto no estaba relacionada con la capacidad de los niños de autorregulación. En contra de lo esperado, el temperamento a esta edad no se asociaba con ninguna de las medidas de conflicto o con autorregulación. Con respecto al SES, los niños pertenecientes a familias con mayores ingresos mostraron un menor efecto de conflicto en tiempo de reacción en la versión simplificada de la Child-ANT . Las prácticas de crianza empleadas por los padres, sin embargo, sólo se asociaron con la capacidad de autorregulación de los niños de forma que el uso de un estilo parental coercitivo e inconsistente se relacionó con una mayor dificultad para autorregularse.

9.6 Desarrollo de la atención ejecutiva entre los 9–12 meses y los 3 años de edad: análisis longitudinales

Además de examinar las particularidades del desarrollo de la atención ejecutiva en cada una de las edades estudiadas, exploramos los cambios en la atención ejecutiva a lo largo de las diferentes edades. Para ello, realizamos análisis de correlaciones entre las distintas medidas obtenidas en cada fase del estudio. En primer lugar, observamos que las medidas de atención ejecutiva a los 9–12 meses y 3 años de edad correlacionaban positivamente. De igual forma, la atención ejecutiva medida a los 16–18 meses de edad estaba relacionada con la atención ejecutiva que los niños mostraban a los 2 y 3 años de edad. Además, la actividad cerebral asociada a los errores, considerada un marcador neural de la atención ejecutiva, se relaciona con la atención ejecutiva a los 2 años de edad, y el control voluntario a los 3 años de edad. Estos resultados indican que la atención ejecutiva puede ser medida tan pronto como a los 9–12 meses de edad y puede llegar a predecir la atención ejecutiva más adelante a los 3 años de edad y no sólo a través de medidas comportamentales sino que la propia actividad neural de la red de atención ejecutiva puede servir como marcador de dicha función más adelante en el desarrollo. En segundo lugar, nuestros datos revelaron que la atención ejecutiva medida con tareas de conflicto y flexibilidad de la atención y la autorregulación son dos funciones independientes con patrones distintos de relación con medidas de temperamento y variables ambientales. Además, encontramos que la medida de autorregulación a los dos años de edad predecían la capacidad de autorregulación a los 3 años de edad. Finalmente, encontramos que las distintas medidas de temperamento muestran estabilidad a lo lardo del tiempo. De forma general, bajos niveles de afectividad negativa o afectividad positiva se relacionaban con una mayor eficiencia de la atención ejecutiva durante el periodo estudiado.

9.7 Conclusiones

Este trabajo contribuye al conocimiento existente acerca del desarrollo de la atención ejecutiva aportando nuevos datos acerca del desarrollo de esta función en los tres primeros años de vida. El abordar esta cuestión en un estudio longitudinal nos permite observar los cambios en la atención ejecutiva a lo largo del tiempo. De acuerdo con otros estudios, nuestros datos indican que las medidas de atención ejecutiva en el primer y principio del segundo año de vida pueden servir como predictores de la atención ejecutiva a los tres años de edad (Holmboe et al., 2008; Rothbart, Ellis, Rosario Rueda, et al., 2003). Sin embargo, al contrario que los mencionados estudios que bien cubren un periodo de un año entre medidas, nuestro estudio abarca un periodo más extenso, entre los 9–12 meses y los 3 años de edad.

Además, este estudio va un poco más allá aportando nuevos datos acerca de la influencia del temperamento y los factores ambientales, así como su interacción, en el desarrollo temprano de la atención ejecutiva. El presente estudio puede ser de gran utilidad en la detección temprana de déficits en la atención ejecutiva. Estudios futuros que incluyan en su muestra niños con riesgo de sufrir trastornos del desarrollo puede ayudar a comprender mejor cómo identificar los signos tempranos de una alteración en la atención ejecutiva, siendo de gran utilidad para el diagnóstico precoz, la prevención e intervención temprana. Esto es especialmente relevante en el caso de trastornos del espectro autista, los cuáles son diagnosticados como promedio alrededor de los 3 años de edad (Mandell et al., 2005). De hecho, se ha podido observar que aquellos niños en riesgo de desarrollar trastornos del espectro autista que finalmente son diagnosticados a la edad de tres años ya presentan alteraciones en la atención a los 14 meses de edad (Elsabbagh et al., 2013). Nuestro estudio aporta nuevos posibles indicadores, incluyendo marcadores neurales de la atención ejecutiva.

De igual forma, este tipo de investigación puede ayudar a identificar no sólo determinados perfiles individuales que sirvan para identificar niños en riesgo de desarrollar cualquier alteración de la atención ejecutiva, sino que también para encontrar aquellas características del entorno que pueden representar de la misma manera un riesgo. No obstante, es necesaria más investigación para determina hasta qué punto los ciertos factores pueden actuar como agentes protectores o si ciertos perfiles pueden ser más susceptibles de la influencia del entorno, tal como proponen algunos autores (Belsky & Pluess, 2009). En cualquier caso, ampliar el tamaño de la muestra de cara a futuros estudios ayudaría a comprobar modelos más complejos que incluyan un mayor número de variables, así como examinar cómo determinados factores influyen en la propia trayectoria del desarrollo.

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