Early development of attention control:
impact of temperament and home environment factors

Doctoral dissertation

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DOCTORAL DISSERTATION

Early development of attention control: Impact of temperament and environment factors

Desarrollo temprano del control atencional: impacto de factores temperamentales y ambientales

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The images for the front and back cover of the thesis, as well as for the cover of each chapter, have been generated using Artificial Intelligence (Midjourney text-to-image generator).

Tell me Haku, what are the limits?

The limits are three, Chihiro: the sky, the imagination, and yourself.

Spirited Away

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“Psychology as a science has its limitations, and, as the logical consequence of theology is mysticism, so the ultimate consequence of psychology is love.”
Erich Fromm - The Art of Loving

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1.1. Getting to know attention

Throughout a day in children's lives, they are in constant interaction with their immediate environment, which could occur with inanimate objects (i.e. a puzzle that they are doing in the living room), or with another living being (i.e. a friend with whom they are playing in the schoolyard). During interactions, there is multiple information available in the environment, either coming from the agent that children are interacting with or from the context in which the interplay is taking place. Most of the time, children are willingly *paying attention* to part of the information available. Although *paying attention* seems like a simple process, several cognitive functions operate to support and regulate the different stages of information processing. In general terms, during an interaction, multiple sensory information will reach children's senses. However, only a portion of the sensory input will be selected and processed, that is the information judged as relevant for their current goals (i.e. to maintain a conversation with the friend they are playing with). The selection of the relevant input will also allow them to choose an appropriate course of action based on their goals. Attention is the supervisory mechanism that enables children to regulate the flow of information within the cognitive system but also grants them the ability to control thoughts and behavior based on internal goals. Although as stated by William James (1890) everyone knows what attention is, this seems to be restricted to a general knowledge of what attention involves on a daily basis. However, not everyone knows about the different functions that attention is responsible for during the *paying attention* act.

First, to effectively process incoming sensory information (i.e. visual, auditory, tactile, etc.), the cognitive system needs a certain level of optimal *activation*. We know that children will not be very good at paying attention to the speech of their friends under low levels of activation, which could cause drowsiness (i.e. if the child is sleepy because he/she went to bed late at night). Similarly, if children are under high activation (i.e. if they are excited about going to the leisure park after school), they will not be able to focus either, as the increased arousal would lead to distractibility and anxious emotional states. Consequently, one of the main functions of attention is to increase and sustain an optimal level of *activation* for different situations that a child could face on a daily basis. Once the adequate level of activation is achieved, the sensory organs will be able to efficiently grasp available information, allowing other attentional functions to be engaged in the next steps of the information processing chain.

As the cognitive system is known to have limited capacity, attention would engage in a required *selection* process from all the information that reaches a person’s senses. Consequently, attention will allocate space within the cognitive system only for relevant information based on the child’s goals. For instance, if the child is talking to his/her teacher in the schoolyard during playtime, they will need to filter out irrelevant information such as background noises of children screaming or the football ball rolling through the floor, to focus on the teacher’s speech. Information selection allows processing only task-relevant inputs, bringing them to consciousness to be aware of them.

So far, we know that attention allows us to keep an optimal level of *activation* and *select* the relevant inputs. Once the filtered information is processed, the person will be able to decide an appropriate course of action considering the inputs and his/her goals. In this sense, attention will implement *control* over thoughts, examining the current information but also recalling past experiences in similar contexts and their outcomes to determine the most appropriate response. Attentional *control* would not only be applied to thoughts but also to behaviour and emotion to control how these responses are implemented. Therefore, attention is an umbrella construct that serves as a dominion for these three attentional functions (*activation*, *selection*, and *control*) described in Posner's model (Posner & Petersen, 1990). From a developmental perspective, attention will progressively mature with age, following two developmental axes: 1. Within each attentional function attention will progress from being controlled by stimulation (stimulus-driven; bottom-up) to being self-regulated by the child's internal goals (goal-directed; top-down). 2. Across functions, attentional control will go through being dependent on activation (alerting), to selection (orienting), and supervised by executive attention (EA; executive control; see Figure 1.1).

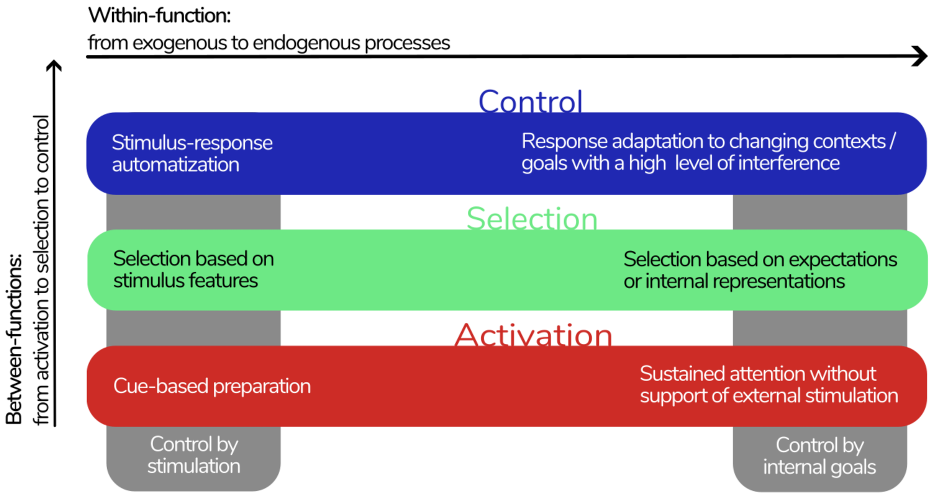


Figure 1.1. Two developmental axes of attention: 1. Within-function: from automatic/externally-driven to self-regulated attention. 2. Between-functions:

from attentional control being dependent on activation, to selection, and executive control.

Attentional functions are supported by three functionally and anatomically distinct brain networks, which together compose the attentional system. Posner's model describes a first *alerting network* committed to managing the attentional system alertness or activation. Important nodes of the alerting network are located in prefrontal and parietal areas (Coull et al., 2001), with norepinephrine (NE) as its main neuromodulator. The production of NE within the brain is located in the locus coeruleus (LC), a brainstem nucleus with several projections irradiating to different areas of the cerebral cortex including prefrontal and parietal cortices (Aston-Jones & Cohen, 2005). Attentional alertness is known to have two modes induced by the function of the LC: phasic and tonic (Aston-Jones et al., 1999). Phasic alertness is driven by task-relevant stimuli, leading to bursts of fast activation to maintain the attentional system focused during short periods to detect and respond to sudden changes in stimulation. On the contrary, tonic alertness is known to be intrinsically driven to voluntarily maintain a vigilant state during prolonged periods (Aston-Jones & Cohen, 2005). Under a tonic alerting mode, the attentional system is more susceptible to distractions as more fluctuations in the alertness level are introduced (Rueda et al., 2021). Keeping a balance between these two modes of alertness is essential, as too low or too high levels of activation led to inattentive (increased omissions) or distracted attentional states (increased false alarms), respectively (Aston-Jones & Cohen, 2005). Optimal performance is related to prominent levels of phasic but moderate levels of tonic activation, with fast but accurate responses (Rueda et al., 2021)

1.1.1. Willingness to control attention: endogenous and executive attention

When referring to attention control, two networks are committed to differentiated but interactive aspects of control: the *orienting* and *executive networks*. As its name states, the orienting network is responsible for orienting the person's senses toward the relevant sources of information, with acetylcholine being the main neuromodulator of the orienting network (Petersen & Posner, 2012; Posner & Petersen, 1990). Orienting prioritizes the attended information for in a depth processing, which is closely related to a more likely access to consciousness (Petersen & Posner, 2012; Rueda, 2018). The idea of attention as a selection mechanism was first proposed by Donald Eric Broadbent (Broadbent, 1958) in his Attentional Filter Model. Broadbent established two systems: 1) A S system (storing) to which all inputs from the environment that reach the sensory organs arrive in parallel, being only stored for a limited amount of time; 2) A P system (perceptual) to which inputs arrive only after being filtered, that is selected based on their relevance. The P system is proposed to work serially, instead of in parallel as the S system, so each chunk of information is processed individually. Inputs should reach the P system to be processed, identified, and passed to long-term storage. In Broadbent's model, the filter is proposed to be located between both S and P systems, filtering the information processed in parallel by the former so only the selected inputs pass to the latter system, avoiding a cognitive overload due to a limited capacity. In sum, Broadbent highlighted the key role of attention as a mechanism for information selection, with only task-relevant inputs being processed and identified. The idea of attention as a filtering system was later integrated into Posner's model within the orienting network.

Two modes of attention orienting are distinguished. First, attention can be automatically captured and oriented (*bottom-up*) by novel and distinctive stimuli available in the environment, which is known as *exogenous* or *stimulus-driven* attention (Corbetta & Shulman, 2002). The distinctive characteristics of this type of stimulation grant them the ability to exogenously capture attention, leading to a fast orienting of a person's senses towards them to give them priority processing. For instance, if while listening to his/her teacher's speech, the child hears someone calling their name out loud, the information could imply that someone, probably a friend, wants to invite him/her to play. However, if instead of his/her name, the child hears a loud noise or feels something touching his/her ankle, the information could warn of a potential danger due to the football ball coming towards us or an insect climbing up his/her leg. Also, attention can be voluntarily oriented (*top-down*) based on the person's goals or expectations, which is commonly known as *endogenous* or *goal-oriented* attention (Corbetta & Shulman, 2002). Endogenous orienting enables the individual to voluntarily focus attention on processing the relevant inputs for the task at hand, even avoiding non-task relevant information to exogenously capture attention. For example, if understanding his/her teachers' speech constitutes the child's main goal, he/she will voluntarily filter out irrelevant stimuli that could potentially capture his/her attention (i.e. other children's conversations or even the sound of children's laughter) distracting him/her from the current goal.

In a neuroimaging study, Corbetta & Shulman (2002) identified two differentiated brain networks supporting these two types of attentional orienting. A *ventral frontoparietal network* (V-FPN) was found to be engaged during *exogenous reorientation of attention* towards unexpected stimulation in unattended locations. The temporoparietal junction (TPJ), ventral prefrontal cortex (vPFC), and thalamus were the main nodes recruited during the activation of the V-FPN. Moreover, the V-FPN network was found to be lateralized to the right hemisphere and to respond independently of the sensory modality of presentation or the location of the stimulus. Furthermore, a *dorsal frontoparietal network* (D-FPN) was found to be recruited during periods of *endogenous attention*, maintaining the person’s current goals and expectations to sustain voluntary control over the attentional selection of relevant stimuli. The main nodes of the D-FPN are located in the frontal eye fields (FEF), intraparietal sulcus (IPS), and superior parietal lobe (SPL; see Figure 1.2). Both networks seem to be in a continuous interplay implementing these two modes of attentional orienting for an efficient information selection (Vossel et al., 2013). For instance, Shulman et al. (2003) found that when the D-FPN is engaged to maintain a voluntarily focused attentional state, areas of the V-FPN, such as the TPJ, show functional deactivation. The temporal downregulation of the V-FPN avoids attention to be disengaged and reoriented by non-relevant stimuli during a visual search, even inducing inattentional blindness (Todd et al., 2005).

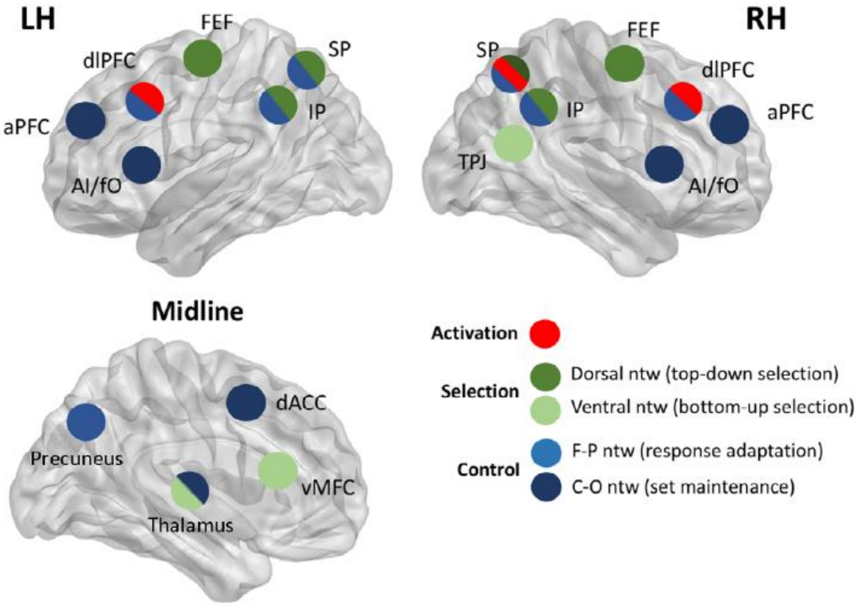


Figure 1.2. Representation of the brain networks involved in activation, selection (Corbetta et al., 2002), and attentional control (Dosenbach et al., 2008). Adapted from Rueda et al. (2021) with permission.

Once endogenous attention selects the information to be processed, the attentional system produces a response judged as the most appropriate for the current context and the person's goals. The function of response selection is assigned to the *executive attention network*, which most of the time implements a *top-down control* over attention with a central role in cognition, emotion, and behavior regulation (Rueda et al., 2021). For an efficient top-down control, the attentional system requires feedback on the changes induced by the issued responses. This is achieved by implementing a continuous evaluation between the expected and the actual outcomes, which allows EA to flexibly adjust subsequent responses when a mismatch between both is found. In essence, EA involves different mechanisms to select the most appropriate course of action: 1. *Target and error detection*; 2. *Cognitive flexibility* to switch and adjust responses after changes in the task set are encountered; 3. *Inhibiting* dominant or inadequate responses to solve conflict and 4. *Monitoring* the current context and outcomes (Posner & DiGirolamo, 1998). The dominion of EA over all these sophisticated mechanisms of control is what differentiates executive attention from endogenous attention.

EA can supervise response selection under a more automatic or controlled mode based on the context (D'Angelo et al., 2013). The former is engaged when the person has previous experience with similar scenarios, in which a certain response is known to have produced the desired outcomes in the past. The automatic mode of response selection is more adaptive for situations that require an on-the-fly response from the individual (i.e. covering the head when children see something coming fast towards them), or when certain responses are automatized after practicing a task several times (i.e. automatization of the set of behaviors to carried a bicycle). The convenience of an automatic response selection lies in a faster speed and lower demand for attentional resources that are kept available for other tasks (Rueda et al., 2015). Although the aforementioned advantages, the automatic mode drastically reduces flexibility, leading to an increase in errors when sudden changes are introduced in the task (i.e. hitting an unexpected obstacle on the bike lane while riding the bicycle under automatic control). When these errors are detected (*target and error detection*), EA will terminate the automatic control mode when a more conscious and deliberate response is required (*inhibition and cognitive flexibility* - i.e. turning the bike's wheel to avoid a collision after encountering an obstacle on the bike lane), due to contextual changes or because the person does not have enough experience with the task at hand (Posner & Rothbart, 2007).

The automatic and controlled modes of response selection have been previously considered in Kahneman's attention capacity model (Kahneman, 1973). Following Broadbent's idea that the attentional system is of limited capacity, Kahneman proposed an allocation policy system. The system determines the number of attentional resources that are supplied to one or more cognitive processes that will dictate the mode of response selection. The distribution of resources is decided by several factors: 1. Dispositions to automatic behavior (*enduring dispositions*); 2. Intentionality in the person's voluntary and conscious behavior based on goals (*momentary intentions*) 3. Evaluation of attentional demands by the task at hand in relation to capacity (*evaluation of attentional demands and available capacity*) and 3. Physiological activation (*arousal*). The weight of enduring dispositions and momentary intentions are the ones that will define the attentional resources that are assigned to information processing activities related to a more automatic or voluntarily controlled mode. Finally, these possible activities will produce responses related to the selected mode of processing.

Although the alerting and orienting networks were considered in Posner and Petersen's (1990) original attention model, the EA network was not introduced under this name in the model until a recent review (Petersen & Posner, 2012). However, it does not imply that EA control has not been previously considered as such (Posner & DiGirolamo, 1998). The architecture of the EA network derives from previous work by Dosenbach et al. (2008) who identified two main networks involved in a more executive mode of attentional control, with dopamine as the main neuromodulator. First, a cingulo-opercular network (CON) aimed to maintain a stable mental representation of the task set across trials, supported by the anterior prefrontal cortex (aPFC), anterior insula/frontal operculum (aI/fO), and dorsal anterior cingulate cortex (dACC). Second, a fronto-parietal network (FPN) is responsible for a top-down control to introduce adjustments in the response on a trial-by-trail basis. Brain structures such as the dorsolateral prefrontal cortex (dlPFC), precuneus, intraparietal sulcus (IP), superior parietal lobe (SP) and middle cingulate cortex (mCC; see Figure 1.2.) contribute to the network. An evaluative process underlies response adaptation, supplying the FPN with feedback obtained from the comparison between the expected and the current outcomes. An error network located in the cerebellum is proposed to perform such evaluation working in conjunction with structures from the FPN (Dosenbach et al., 2008). Within the EA, the anterior cingulate cortex (ACC) is considered the main node of the network (Posner et al., 2007). The ACC structure presents a dense anatomical and functional connectivity to other brain areas (Margulies et al., 2007; van den Heuvel et al., 2013), being crucial for processing and control processes such as conflict monitoring (Botvinick et al., 2001).

In the previous paragraphs, we have reviewed the implication of both orienting and EA networks on top-down control over attention following Posner's model. Moreover, the anatomical overlapping found between Corbetta's D-FPN and Dosenbach's FPN (i.e. IP, SP) also supports the engagement of both in processes of attention control. As we will see in the following sections, endogenous orienting is considered to be the building block of EA during development (Posner et al., 2014; Rothbart et al., 2011). Although to some degree endogenous and EA are related concepts, their functionality is in the end well-differentiated. While endogenous attention is related to an expectation or goal-based top-down regulation of information selection, EA incorporates more sophisticated mechanisms of control to allow for a voluntary regulation of cognition, behavior, and emotion (Rueda et al., 2021) that will flexibly and dynamically adjust performance.

Additionally, EA has been proposed to supervise not only elements of cognitive control but of activation and orienting based on the person's expectations and goals (Rueda et al., 2021). Hence, when goals are actively being pursued, EA will control the maintenance of an optimal level of activation (i.e. *sustained attention*) while endogenously selecting information (i.e. *focused attention*) and responses based on these goals. Recent studies have found evidence of this supervision, with the EA network supporting the maintenance of tonic alertness, and with D-FPN and FPN networks being engaged during conditions of higher attentional control demands (Coste & Kleinschmidt, 2016; Sadaghiani & D'Esposito, 2014). Consequently, once EA control is engaged, it will also supervise other attentional functions.

1.1.2. Relevance of attentional control during development

Attention is known to have a central role in cognition, being able to impact different dimensions of the person's functioning (Amso & Scerif, 2015). Especially during childhood, attentional abilities are related to several spheres of the child's development, with some of them being self-regulatory abilities (Rothbart et al., 2011), academic achievement, and socioemotional adjustment (Rueda et al., 2010). Attention gains special relevance for self-regulation, being proposed to be at the basis of self-regulatory abilities (Rueda et al., 2021; Rueda et al. 2005), and sharing common neural structures (Bell & Deater-Deckard, 2007; Posner & Rothbart, 2009). Self-regulation could be defined as the ability to voluntarily engage in processes aimed at regulating the individual's reactivity at the behavioral, cognitive, and emotional levels (Rueda et al., 2005; Vohs & Baumeister, 2004).

From infancy, increases in attention control enable infants to implement self-controlled strategies to down-regulate emotional states and behavioral reactions (Posner & Rothbart; 1998; Rueda et al., 2005). One of the first attentional mechanisms that infants employ for self-regulatory purposes is visual attention disengagement and reorienting (Harman et al., 1997). In this respect, infants of 3-to 6 months of age are already able to voluntarily disengage from a distressful stimulus, reorienting attention towards a novel and distracting object to reduce behavioral and emotional reactivity (Harman et al., 1997; Crockenberg & Leerkes, 2004). Similarly, Sheese et al. (2008) found that 6-to 7-month-old infants with more correct anticipatory looking, that is better endogenous attention control, displayed longer durations of self-soothing behaviour to down-regulate reactivity after being presented with a distressful mask. During middle childhood, an EA factor has been found to explain up to 30% of the variance of self-regulatory abilities in a sample of 11-to 12-year-old children (Tiego et al., 2020). These results support the close link between attention control and self-regulatory abilities, which seems to be maintained across development.

Although previous literature has considered the association between attention and self-regulation concurrently, it has also been reported to be longitudinally found. For instance, Perry et al. (2016) reported that the higher sustained attention infants displayed when looking at a glove puppet at 10 months, the greater their ability to self-regulate frustration when solving a challenging puzzle at 36 months. In the same direction, 9-month-old infants with higher focused attention during a free-play task predicted higher self-regulatory abilities at 22 months (Kochanska et al., 2000). Nevertheless, not all studies replicate these findings. In a recent study, Hendry et al. (2021) employed an impulse control task at 10 and 16-18 months of age, measuring infants' self-regulation through a self-restraint task. Moreover, they also included measures of attentional switching through the A-not-B task and the Early Childhood Inhibitory Touchscreen Task (ECITT). No association was found between infants' self-regulatory skills and switching scores neither concurrently nor longitudinally. Authors argue that the lack of correlation could be attributable to variability in infants' motor abilities, suggesting that eye-tracking measures can offer a less variable and more sensible measure during the first years of life.

Volitional control over the attentional system also plays a significant role in academic achievement during the schooling years (Rueda et al., 2010). Children's ability to select the relevant information to be attended constitutes an important asset for academic performance (Stevens & Bavelier, 2012), as well as the active inhibition of non-task relevant stimuli during learning that compete for attentional resources. However, when competing information is judged to be task-relevant, attentional control allows to flexibly switch the attentional focus toward the source of information, leading to subsequent gains in learning outcomes (Markant & Amso, 2021).

The relevance of attention to academic competence has been reported from early childhood until late adolescence. In preschoolers, higher sustained attention has been associated with better academic outcomes a year later (Rhoades et al., 2011) and at 10 and 15 years of age (Gardner-Neblett et al., 2014). Authors suggest that children with higher competence on sustained attention display traits as proactive behavior and better endogenous attention orienting towards task-relevant information in a learning context. Likewise, in a large longitudinal study, Stipek & Valentino (2015) found that the lower the attentional problems reported in children at age 5, the higher the academic performance was from 5 to 14 years of age. Concerning measures of EA, Pearson et al. (2015) found attentional inhibition and switching in 8-year-olds to be positively associated with academic achievement at 16 years of age. During adolescence, higher EA skills to solve conflict in the Attention Network Test (ANT; Fan et al., 2002) were a significant predictor of higher grades in mathematics in 12-year-old schoolers (Checa et al., 2008). Moreover, a lower neural response of interference suppression in a Go/No-Go task, which corresponds to a more mature functioning of the frontal lobe resembling the adult response, was predictive of higher mathematics grades in a sample of the same age (Checa & Rueda., 2011).

Checa et al. (2008) also found that higher EA skills during conflict-solving were related to a lower score of unsocial behavior, indicating that attention control plays a role in socioemotional adjustment. This is not surprising considering the association of attention control with self-regulation, which grants children the ability to flexibly adjust their behavior in social contexts (Rueda et al., 2010). In this line, Schultz et al. (2009) reported attention control in 7-year-old children to be related to a higher positive emotionality and social success, that is, being more liked by your peers. Interestingly, attentional control mediated the effects of negative emotionality on children’s social achievement. Questionnaire-based measures of EA control have also been found to predict fewer social difficulties in children between 8 and 13 years of age (Reinholdt-Dunne et al., 2022).

In general, literature corroborates important correlations of early attentional control with self-regulatory skills, academic achievement, and socio-emotional adjustment during development. The early associations with self-regulation are of special importance, as early differences in self-regulatory skills have long-term effects on the person's functioning during adolescence and adulthood. Longitudinal research has found lower self-control abilities at early ages to be predictive of negative outcomes later in life, such as school withdrawal, financial instability, criminal offenses (Moffitt et al., 2011), or unemployment (Daly et al., 2015).

1.2. Endogenous and executive attention during early development

During the first and second years of life, infants progressively gain control over fine-grained motor skills (Berthier & Keen, 2006). Between 6 and 12 months, correct motor reaching has been found to have intra-individual stability in straightness, velocity, and smoothness (Clearfield et al., 2006; Thelen et al., 1996). These changes are induced by gradual gains in control over postural control, visual contact, and manual responses (Rachwani et al., 2019). However, infants still show inter-individual differences in speed together with developmental variability (Thelen et al., 2019). As attentional paradigms usually require short time constraints for responses to take place, manual responses at these ages could jeopardize developmental effects. For instance, Hendry et al. (2021) recently reported a lack of stability in manual responses between the first and second year of life involving attentional tasks, advising for the use of alternative approaches. To sort out the limitation of motor responses in early development, researchers have relied on video-based gaze recordings and eye-tracking for the study of cognitive development from infancy to early childhood (Oakes, 2012).

1.2.1. Eye-tracking for the study of early attentional control

Eye-tracking and video-based gaze recordings offer valuable insights into what information is being selected and processed based on the spatial position of the infant's gaze. Eye-tracking offers certain advantages over video-based gaze recordings: 1. More accurate and reliable spatial precision of infant's gaze through the use of near-infrared light, using pupil and corneal reflection to keep track of eye movements; 2. Higher sampling rates than video recordings. Modern eye trackers can sample at a rate between 20 and 2000 Hz, which translates into 60 to 2000 samples per second or one sample every 50 or 0.5 milliseconds, respectively. Video recordings only register one frame each 33 ms (Nyström & Holmqvist, 2010); 3. Automatization of event detections such as blinks, fixations, saccades, or pupil dilatation, contributing to reduce differences in subjective parsing of events during manual coding of video-based recordings. Depending on the characteristics of the studied phenomenon and the level of precision required for gaze events, both methodologies could be equally acceptable.

Control over visual behavior matures early in the first year of life. Infants of around 2 to 3 months of age start to show an endogenous control of visual attention (Johnson, 1990; Johnson et al., 1991; Stechlar and Iatz, 1966). At 3 months of age, infants can use acquired expectations to guide visual attention to anticipate stimuli displayed on a screen (Canfield et al., 1991), or to voluntarily disengage from a foveated stimulus to reorient attention towards those that infants aimed at fixating (Atkinson et al., 1992). The early control over visual attention makes eye-tracking an appropriate technique to be employed for the study of early developmental changes in attention control. Also, the lack of verbal or written instructions represents an important advantage when studying preverbal infants and toddlers (Francois et al, 2018)

Although the advantages provided by eye-tracking, there are some drawbacks to be considered when conducting developmental research. One of the mains is the higher movement of infants during eye-tracking recordings. Wass et al. (2014) compared the quality of eye-tracking between 9-month-old infants and adults examining: 1) *Robustness* - eye detection during the recording to report gaze position; and 2) *Precision* - consistency in gaze coordinates between samples. Lower robustness and precision were found for infants compared to adults. Likewise, in a large cross-sectional study covering ages from 0 to 9 years, Hessels et al. (2019) reported that robustness and precision were lower for 5 and 10-month-old infants, as well as for 3 and 9-year-old children compared to adults. In general, higher quality of the recordings as well as reduced variability within-group was found for older cohorts.

Apart from age, other aspects of developmental research also impact data quality. In a sample of 9-month-old infants, Hessels et al. (2015) investigated whether infants positioning during the recording, eye color, and movement impacted data quality. For this, they considered: 1) *Spatial accuracy* on the comparison between the gaze coordinates reported by the eye-tracker and the actual position; and 2) *Precision*. Data quality was higher for dark (i.e. brown eyes) compared to blight-colores eyes (i.e. blue eyes), as well as for infants seated in baby seats in comparison to in parent’s lap. Similar results are also found during toddlerhood. In a cross-sectional study, Dalrymple et al. (2018) compared the quality of eye-tracking calibration for 18-month-old, 30-month-old toddlers, 8-to 11-year-old children, and 26-year-old adults on spatial accuracy and precision. Spatial accuracy and precision of calibration procedures were lower for toddlers in comparison to children and adults. No differences were found between 18 and 30-month-old toddlers. The lower calibration and recordings quality for infants and toddlers could lead to more noisy data, compromising fixation and saccade data (Hessels et al., 2015; Wass et al., 2014).

In order to get reliable data for developmental research, several tools have been developed in recent years to reduce noise and increase data quality. Saez de Urabain et al. (2015) created GraFIX, an application developed in C++ that involves two steps during fixation parsing of eye-tracking data: 1) Automatic parsing of fixations employing a velocity-based algorithm and 2) Manual evaluation and modification of the automatic parsing. GraFIX was developed to capture the best of automatic and hand-coding approaches, although it is still time-consuming and introduces subjectivity during the manual evaluation phase of parsed fixations. Hand-coding is especially significant for long experimental tasks, which will require evaluating an increased number of samples and trials. Concerning automatic approaches, Wass et al. (2013) developed an algorithm to automatically parse fixations for low-quality infant data. However, their algorithm included up to 6 conditions that need to be checked to reject false fixations and saccades, which could result in a higher probability of data exclusion. Recently, Hessels et al. (2017) proposed an automatic algorithm to parse fixations at different levels of noise and data loss, the Identification by Two-Means Clustering (I2MC). This algorithm employs a 2-clustering analysis within a moving window to detect fixations and saccades based on characteristics of transitions between clusters. Candidate fixations are detected by a high frequency of transitions between the clusters due to noise in the signal, resulting in a high cluster weight. On the other hand, saccades are characterized by low-frequency transitions and low cluster weight. The approach followed by the I2MC algorithm reduces the number of conditions that fixations need to meet in order not to be excluded, reducing also the probability of data exclusion in comparison to Wass et al. (2013).

Eye-tracking has been proven to be a suitable technique to study early attentional development, with multiple tools available to get reliable data. Manual responses in infants and toddlers could be affected by developmental differences in motor abilities, especially when time constraints for manual responses are introduced. The earlier maturation of visual control offers less variability in this respect. Also, the lack of verbal and written instructions in most of the paradigms used prevents individual differences in task comprehension that could lead to a reduction of usable sample size.

1.2.2. Early markers of endogenous and executive attention during infancy and toddlerhood

Attentional networks are found to be in place at birth (Doria et al., 2010). During the first years of life, they go through a refinement process of their functional connectivity (Gao et al., 2012; Xie et al., 2018), coupled with changes in attentional control (Hendry et al., 2019). Infants' alertness is the first attentional ability to be developed right after birth in the first two months of life (Laurie-Rose et al., 2015). Gaining control over attentional alertness (*activation*) is the first step on the way to achieving endogenous control over attention. Maintaining an alerting state allows infants to keep attention sustained over periods of time, enabling them to select and direct attention under voluntary control (Sturm et al., 1999; see Figure 1.1).

One of the main indicators of infants' voluntary control of attentional alert is tonic alertness. With age, infants regulate the sleep-wake cycle, increasing the awakening times during the day, which is translated into an improvement in their ability to maintain attentional activation over time. Specifically, from 2 weeks to 6 months of age, infants achieve a reduction from 6 to 4 hours of daytime sleep (Figueiredo et al., 2016), reaching just 2 hours of daytime sleep at 24 months (Paavonen et al., 2020). Volitional control over attentional alertness increases infants' occasions to interact with their environment, boosting early cognitive development (Colombo & Horowitz, 1987). In this respect, newborns' alertness is associated with better cognitive development and socio-emotional adjustment (Field & Diego, 2008).

Tonic alertness is closely related to the construct of sustained attention, offering the required arousal to voluntarily maintain an alerting state over time (Posner, 2008). During infancy, different markers have been employed to measure sustained attention. Using a habituation paradigm with 3.5-to 5-month-old infants, Richards (1985a, b) found that infants' sustained attention measured through visual fixation durations was related to respiratory sinus arrhythmia and heart rate deceleration variability from a baseline measure. From 3.5 to 6.5 months of age, Richards (1985b) reported that older infants with longer visual fixations also showed larger heart rate deceleration, as an indicative of higher sustained attention control. Duration of attention towards manipulated toys has also been used as a proxy for sustained attention (Ruff, 1986), revealing an increase in sustained attention from 12 to 24 and 36 months of age (Ruff & Lawson, 1990).

Endogenous orienting of attention is an important prerequisite for sustained attention to take place. If infants have not gained volitional control over attentional orienting (*selection*), sustained attention will be externally controlled. Before three months of age, visual orienting is mostly under exogenous control. Infants are found to be unable to voluntarily disengage from a foveated object. The attentional capture is broken if a new stimulus is presented in the visual space, leading to an exogenous reorienting of attention toward the novel object. This period in early infancy is often labeled as "*sticky* or *obligatory fixation*" (Stechler & Latz, 1966). Around the third month of life, infants start to implement endogenous control over attention disengagement and reorienting (see Figure 1.1). For this, the Gap-Overlap paradigm (Atkinson et al., 1992) has been widely employed to study these processes in young infants. An overlap condition introduces voluntary disengagement of attention under visual competition (overlap condition), as a peripheral target is presented while a central stimulus is being fixated. A gap condition also measures attentional disengagement in the absence of visual competition, with the central stimulus disappearing shortly before the target presentation. The gap condition is also proposed to measure infants' ability to benefit from attentional cues (i.e. the disappearance of the central stimulus) that signals the appearance of a novel stimulus in the visual field (Csibra et al., 2001). Employing the gap-overlap paradigm, Atkinson et al. (1992) found increases in attentional disengagement in the overlap condition between 1 to 3 months of age. The ability to disengage under visual competition keeps improving towards 6 months of age (Colombo & Cheatham, 2006) and even onwards (Csibra et al., 1998).

Although the gap-overlap task focuses on orienting processes, other aspects of control are required for disengagement to occur. In order to reorient attention towards the peripheral target in the overlap condition, infants need to actively inhibit the foveated central stimulus to disengage attention. This aspect of attention control has been studied through attentional flexibility paradigms. A classical one was developed by Piaget in 1954, the A-not-B task. In an initial pre-switch block, infants are presented with a toy that is hidden in location A for a fixed number of trials, with infants being encouraged to retrieve the toy from the hidden location after a short delay. After several correct reachings, a post-switch block is introduced with the toy's hidden location being switched to B. Perseverative errors of infants looking for the toy in the previously rewarded location A is measured as a proxy for attentional flexibility. Diamond (1985) observed that frontal areas are recruited for correct performance in the A-not-B task. She found that 6.5-to 8-month-old infants' execution was similar to rhesus monkeys with pre-frontal lesions. Nevertheless, monkeys with or without parietal lesions did not commit the expected perseverations. Thus, the prefrontal cortex is of special relevance during correct reaching after the switch on B trials, with its maturation with age-reducing perseverative reaching.

Due to its simplicity and infants' ability to reach objects without fine motor abilities, it has been widely used from 5 months of age onwards (Clearfield et al., 2006). Nevertheless, oculomotor adaptations of the A-not-B task have been also introduced to study early attentional flexibility. Based on the premise that during infancy behavioral responses are more complex due to the required planning and sequential execution of motor responses, Bell & Adams (1999) developed a looking version of the A-not-B task. The adaptation was intended to make possible the assessment at younger ages, as long as object permanence has been already acquired, and to detect earlier maturation of attentional flexibility replacing behavioral reaching.

Recently, Kovács & Mehler (2009) developed the Switching task, a pure eye-tracking procedure based on the A-not-B task logic. On a screen, infants are presented with two white empty boxes during the entire duration of a trial. In the first pre-switch block, a stimulus is systematically presented on the same white box (rewarded location) after a 1000 ms anticipatory interval during 9 trials. The pre-switch block is intended for infants to learn to anticipate the rewarded location before stimulus onset. Next, in a second post-switch block, a new stimulus is constantly presented on the non-rewarded location during the first block. Thus, correct anticipations reflect infants' ability to learn the contingency of stimulus appearance. Attentional flexibility is encoded through perseverative anticipations in the post-switch block. In general, these paradigms aim at quantifying infants' ability to endogenously switch attention when the current attentional strategy is no longer adaptive. Infants between 7 and 12 months of age (Conejero & Rueda, 2018; Kovács & Mehler, 2009; Shinya et al., 2022) have been evaluated with the switching paradigm, yet not analyzing developmental changes.

The use of infants' visual anticipations as a proxy for attention control, in protocols such as the Switching task, is possible as the ability to visually anticipate is developed around the third month of life. Haith and colleagues (Haith et al., 1988) used the Visual Expectation Paradigm (VExP) to measure 3.5-month-old infants' anticipatory attention, that is, their ability to create expectations to visually anticipate targets. An interstimulus interval of 1100 ms was introduced before the target presentation as an anticipatory period in a fixed symmetric sequence displaying stimuli on the left or right side of the screen (L-R sequence). During the anticipatory period, researchers measured infants' ability to visually anticipate the next stimulus location. Between 2 and 3 months of age, infants' visual anticipations for fixed symmetric L-R sequences were not found, but for asymmetric ones (L-L-R and L-L-L-R; Canfield & Haith, 1991). Results suggest that as soon as 2 months of age, infants are able to create visual expectations and voluntarily anticipate stimuli for fixed symmetric sequences based on learned contingencies, while asymmetric sequences take longer to be mastered.

Based on this contingency-learning paradigm, Clohessy et al. (2001) developed the Visual Sequence Learning (VSL) task. Intended to study different aspects of endogenous visual attention control in different contexts of monitoring demands, they established a sequence of three spatial locations to introduce easy and complex transitions. In easy transitions, the next location could be anticipated from the current one. However, for complex transitions, the next location can only be anticipated knowing the previous location to the current one. Complex transitions require engaging more sophisticated mechanisms for attentional control, such as context monitoring in order to maintain the locations in working memory to correctly anticipate the next one. Context monitoring is a necessary component for learning and memory creation (Nelson & Narens, 1990), being under the supervision of EA (Posner & DiGirolamo, 1998) and allowing for more efficient and flexible control of attention during event detection (Chevalier & Blaye, 2016). Clohessy et al. (2001) found no age differences in correct anticipations for easy transitions between 4 and 18 months of age, with their performance being similar to adults. Also, correct anticipations in complex transitions seem to emerge between 24 and 36 months (Rothbart et al., 2003).

The idea of infants being able to form accurate expectations of events has been successfully applied to violation of expectations (VoE) paradigms to assess infants' error detection abilities. Within the range of different experimental protocols, different dependent measures have been studied. For instance, Dunn & Bremner (2016) showed 6-month-old infants how a stimulus was being hidden behind a screen. Afterward, the screen was lowered to reveal the stimulus identity. Infants first completed a habituation phase of non-violation trials. In the test phase, infants were assigned to a novelty or violation condition. In the novelty condition, no violation of expectations occurred, although stimulus identity was novel compared to habituation trials. In the violation condition, the revealed stimulus identity was different from the toy that was initially hidden behind the screen. No differences between novelty and violation trials in total looking time were reported but on the number of social looks initiated by the infant toward the caregiver. Recently, Pätzold & Liszkowski (2020) employed a similar paradigm using pupillometry to measure infants' detection of unexpected outcomes, that is, the disappearance or appearance of a toy. During unexpected results, 18-month-old but not 10-month-old infants showed larger pupil sizes compared to expected outcomes.

Manipulative responses during expected and unexpected results were used by Stahl & Feigenson (2015). In their study, 11-month-old infants showed a higher manipulative/exploratory behavior of objects that were shown to violate physics laws of solidity and gravity compared to those that did follow the expected course of events. Finally, other protocols have measured brain responses using electroencephalography (EEG). For instance, Berger et al. (2006) found that 6-to 9-month-old infants displayed a longer looking time to unexpected incorrect arithmetic solutions, as well as a greater central negativity similar to the Error Related Negativity

(ERN) response in adults. A similar logic was applied by Conejero et al. (2018), employing a puzzle paradigm with 16-to 18-month-old infants. On a computer screen, toddlers were shown the formation of a three pieces animal puzzle in three steps, from the feet, the belly, and the head. Unexpected events occurred when the last piece of the puzzle (i.e. the head) was of a different animal (conceptual error) or when it was presented upside down (position error). They found toddlers to show higher fronto-central negativity for both types of errors, resembling adults' ERN response.

Although attention flexibility paradigms involve components of inhibitory control, other procedures have been developed to measure flexibility in a purer form during infancy and toddlerhood. One example is the Freeze-Fame task (Holmboe et al., 2008). In Holmboe and colleagues' procedure, infants are encouraged not to look to peripheral distractors while attending to a central stimulus, otherwise, the latter is frozen until the onset of the next trial. Higher inhibitory control was found to be engaged by 9-month-old infants for interesting (stimulus identity change every 2 seconds) compared to boring (geometric figure) trials. The same author also developed the ECITT (Holmboe et al., 2021), in which two blue buttons are displayed on the left and right side of the screen, with one of them showing a smiley face (target button). Once the infant touched the target's smiley face, a reward is triggered with an animated stimulus being displayed on the screen. Two trial types are denoted: 1. Prepotent trials - the target appears on the same side as in the previous trial; 2. Inhibitory trials – the target is presented on the opposite side. In the second infants should inhibit the tendency to touch the non-target blue button. The ECITT task allows to measure reaction times and accuracy at early ages, as the minimal verbal instructions make it suitable for pre-verbal infants and toddlers. Previous results showed no age differences in inhibitory control between 10 and 16 months of age (Hendry et al., 2021), but increases from 18 and 21 to 24 months (Holmboe et al., 2021).

Infant research has introduced a wide variety of experimental tasks to measure different attentional components during infancy and toddlerhood (see Table 1.1.). But, are these paradigms still suitable to be used with young children, or new research approaches are needed at these ages?

Table 1.1.

Paradigms to measure attention control during infancy.

Attentional construct	**Task**	**Youngest age of use**	**Dependent variable**
Sustained attention	Habituation task	Newborns	***Heart rate variability*** and ***respiratory sinus arrhythmia*** (Richards, 1985a, b)
	Free play task	7 months	***Looking /Intentional manipulation*** of toys (Ruff & Lawson, 1990)
Attention disengagement	Gap-overlap task	3 months	***Saccade latency*** to disengage from a fixated central stimulus (Hood & Atkinson, 1993)
Attention flexibility	Switching task	7 months	***Perseverative anticipatory looks*** to the previously rewarded location (Kovács & Mehler, 2009)
	A-not-B task	5 months	***Perseverative reaching*** (Diamond, 1985) ***Looking time*** to the previously rewarded location (Bell & Adams, 1999)

Anticipatory attention and context monitoring	VSL	4 months	***Reactive/anticipatory looks*** during easy and complex trials (Clohessy et al., 2001)
	VExP	2 months	***Reactive/anticipatory looks*** (Haith et al., 1988)
Error detection	Object permanence	10 months	***Pupil diameter*** to unexpected outcomes (Pätzold & Liszkowski, 2020)
	Stimulus identity switch	6 months	***Looking time*** to unexpected outcomes and ***social looking*** to the parent (Dunn & Bremner, 2016)
	Violation of physical laws	11 months	***Time of object manipulation*** of those that violated the expectations (Stahl & Feigenson, 2015)
	Arithmetic errors	6-to 9 months	***Greater negativity*** for incorrect solutions (Berger et al., 2006) ***Looking time*** to unexpected outcomes
	Puzzles errors	16-to 18 months	***Increased fronto-central negativity*** for incorrect configurations (Conejero et al., 2016)
Inhibitory control	Freeze-Frame task	9 months	***Inhibition of saccades*** towards distractors (Holmboe et al., 2008)
	ECITT	10 months	***Reaction time*** and ***accuracy*** (Hendry et al., 2021)
	Spatial Conflict task	24 months	***Reaction time*** and ***accuracy*** (Gerardi-Caulton, 2000)

Note. VSL = Visual-Sequence Learning task; VExP = Visual Expectation Paradigm; ECITT = Early Childhood Inhibitory Touchscreen Task

1.2.3. Measuring endogenous and executive attention in early childhood

In the previous section, we have seen that alerting develops early during the first year of life, while the maturation of orienting, and especially EA are protracted through toddlerhood and early childhood. Early signs of endogenous orienting are reported at 3 months of age (Hood & Atkinson, 1993). Although some functionality of EA control has been seen at 4 months of age (Holmboe et al., 2018), it is around the end of the first year when clear signs of EA control are found (Berger et al., 2006; Fiske et al., 2022). The early development of the orienting network is proposed to serve as a building block for more sophisticated mechanisms of attention control, being under the surveillance of the orienting network during infancy and toddlerhood. It is in early childhood when the maturation level of the EA network reaches a level that allows EA to overtake as the main supervisory system of attentional control (Posner et al., 2014). The orienting network remains to be involved in attentional control, being especially engaged in contexts where its recruitment is more adaptive (Rothbart et al., 2011).

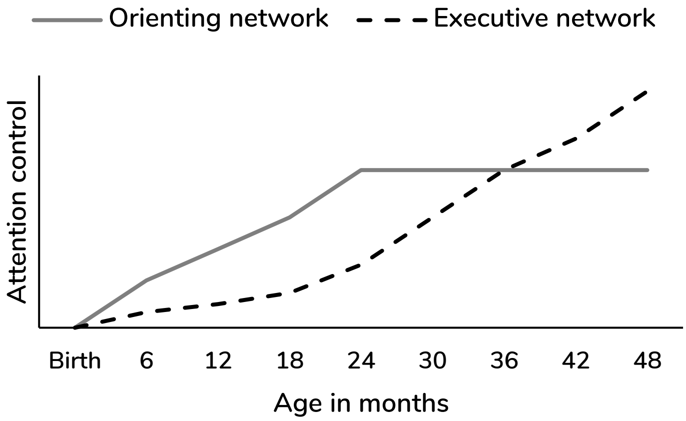


Figure 1.3. Developmental progression of attention control for the orienting and executive network. Adapted from Posner et al. (2014) with permission.

Some of the reviewed attentional paradigms used during infancy and toddlerhood are still suitable to be used with young children. For instance, the Free play task (Ruff & Lawson, 1990) has been used with children up to 42 months of age to study sustained attention, with measures showing stability from 24 to 42 months of age (Ruff & Lawson, 1990). Similarly, the development of attention disengagement has been widely covered by the Gap-overlap task from infancy (Atkinson et al., 1992; Holmboe et al., 2018; Hood & Atkinson, 1993; Johnson et al., 1991), toddlerhood (Nakaga & Sukigara, 2019; 2022) and early childhood (Nakaga & Sukigara, 2013). Likewise, the VSL has helped to extend research on anticipatory attention from infancy and toddlerhood (Clohessy et al., 2001, Sheese et al., 2008; Posner et al., 2012) to early childhood (Moyano et al., 2022; Rothbart et al., 2003).

At the same time, the increase in fine motor skills and linguistic abilities enables the use of behavioral approaches, based on simple binary responses, that require some sort of verbal instructions. To study components of attention flexibility during early childhood, the Dimensional Change Card Sort (DCCS; Frye et al., 1995; Zelazo et al., 1996) is among the most widely employed tasks between 30 and 72 months of age (Hongwanishkul et al., 2005; Zelazo et al, 2003). Similar to the Switching task (Kóvacs & Mehler, 2009), the DCCS introduces a switch in a preestablished rule at the beginning of the task, defining a pre- and post-switch period. In the first pre-switch phase of the task, children are given two cards and are required to sort a series of cards according to one dimension (i.e. color or shape). However, during the post-switch phase, children are no longer asked to sort the cards on this dimension, but on the one not used so far (i.e. if children were sorting the cards based on color during the pre-switch phase, they will have to do it based on shape in the post-switch). Previous studies have found children to improve in their switching ability between rules with age, leading to the development of more demanding versions of the DCCS increasing the load on working memory (Zelazo et al., 2003).

Recently, Holmboe et al. (2021) validated the ECITT task using two cohorts of 18 to 24-month-olds and 24 to 30-month-olds. Results showed that toddlers improved performance in inhibitory trials from 18 to 24 months of age and 30 months of age. The logic of the ECITT task is based on the Spatial Conflict task (Gerardi-Caulton, 2000), which follows a Stroop-like procedure to target children's ability to overcome cognitive conflict. On each block of the task, two animals with different identities are permanently displayed inside a house at the bottom left and bottom right side of the screen. On each trial, one of the animals is displayed above one of the two houses, with children being encouraged to touch the correct house of the animal. The cognitive conflict is generated using two types of trials: 1. Spatial compatible; 2. Spatial incompatible. In the former, the animal is displayed above the house that contains the animal identity, while in the latter the animal is displayed above the house of the other animal identity. Unlike the ECITT task, the need for more extended verbal instructions limits the age range at which the Spatial Conflict task can be applied, being mostly used from 24 months of age onwards (Gerardi-Caulton, 2000; Holmboe et al., 2008; Rothbart et al., 2003). Gerardi-Caulton (2000) found that 36-month-old children were faster and more accurate than 24-month-olds and 30-month-olds. Similar results are spotted at older ages, with Jones et al. (2003) finding that children's ability to inhibit responses increases from 22% to 90% between 36 and 48 months of age.

All the tasks reviewed so far are focused on measuring aspects of attentional control related to only one of the attentional networks. The Child-Attention Network Test (Child-ANT - Rueda et al., 2004) was developed to sort this problem, allowing us to measure aspects of the three attentional networks. The Child-ANT is a child-friendly adaptation of the original Attention Network Test (ANT; Fan et al., 2002) combining Eriksen & Eriksen's (1974) Flanker task (congruent vs. incongruent) with different alerting (cue vs. no cue) and orienting (valid vs. invalid) cues. Hence, the Child-ANT task is able to provide indices for the alerting, orienting, and EA networks, as well as their interactions. However, due to the complexity of the task and the need for verbal instructions, the Child-ANT has been mostly used with children above 48 months of age (Abundis-Gutiérrez et al., 2014; Pozuelos et al., 2014; Rueda et al., 2004; 2005). In the task, an array of fish is displayed on the screen. Children are encouraged throughout the task to feed only the fish in the central location of the array while ignoring the flanker fish surrounding it. Children should either press the left button if the fish mouth is oriented to the left or the right button otherwise. Rueda and colleagues (Rueda et al., 2005) found increases in children's ability to solve conflict, with 72-month-olds being more skilled than 48-month-olds. In a modified version of the Child-ANT to be used with younger samples, Casagrande et al. (2022) found 36-month-olds to show lower alerting, orienting, and EA scores in comparison to 48 and 60, and 72-month-olds.

In general, a certain continuity is observed in the paradigms used with infants, toddlers, and young children. Moreover, age increases in motor and verbal abilities allow to introduce a set of novel behavioral tasks and measures (see Table 1.2), with some of them even allowing to assess different attentional components with the same task.

Table 1.2.

Paradigms to measure attention control during early childhood.

Attentional construct	Task	Dependent variable
Sustained attention	Free play task	***Intentional manipulation*** of toys (Ruff & Lawson, 1990)
Attention disengagement	Gap-overlap task	***Saccade latency*** to disengage from a fixated central stimulus (Nakagawa & Atsuko, 2013, 2019; 2022)
Attention flexibility	DCCS	***Number of correct switches*** (Zelazo et al., 2003)
Anticipatory attention and context monitoring	VSL	***Reactive/anticipatory looks*** (Clohessy et al., 2001)
Inhibitory control	ECITT	***Reaction time*** and ***accuracy*** (Holmboe et al., 2021)
	Child ANT	***Reaction time*** and ***accuracy*** (Rueda et al., 2004)
	Spatial Conflict task	***Reaction time*** and ***accuracy*** (Gerardi-Caulton, 2000)

Note. DCCS = Dimension Card Sorting Test; VSL = Visual Sequence Learning task; ECITT = Early Childhood Inhibitory Touchscreen Task.

1.2.4. Summary of attentional development

In the previous sections, we have enumerated several paradigms for the study of early attentional control from infancy to early childhood. Additionally, we have provided developmental results reported with these paradigms. Figure 1.4 shows a summary of the main developmental stages of the three attentional functions from birth to toddlerhood.

From the first weeks after birth, infants gradually improve their ability to maintain an active attentional state (tonic alertness). Initially, the hours that infants are able to remain awake during the daytime shortly increase in the first months of life (i.e. a reduction from 6 to 4 hours of daytime sleep; Figueiredo et al., 2016). During early infancy, alertness is mostly exogenously controlled by stimulation provided by caregivers (Rothbart et al., 2011). External stimulation (e.g. shaking a rattle) is not only used to increase infants' arousal but also to exogenously orient them in the visual space (Harman et al., 1997). This is done due to infants' poor control over endogenous orienting during the first three months of life (Johnson, 1990; Stechler & Latz, 1966).

Progressively, the attentional scaffolding provided by caregivers would boost attentional development. Infants would gain more volitional control over attentional alertness and orienting, increasing their opportunities to engage in interactions with environmental stimuli (Colombo & Horowitz, 1987). These experiences would contribute to training infants' ability to voluntarily maintain an alerting state over time, that is, to sustain attention towards environmental agents. In this respect, from 3.5 to 6.5 months of age, infants are found to show increases in sustained attention (Richards, 1985a, b). Also, around 6 months of age infants gain control over endogenous orienting of attention. A significant reduction in the time required to voluntarily disengage and orient attention between stimuli in contexts of visual competition is found from 1 to 3 months of age (Atkinson et al., 1992). These initial changes in attention control would derive in a more efficient selection of information, which is allowed by infants' ability to maintain more prolonged periods of tonic alertness (Posner, 2008). For instance, infants between 2 and 18 months of age are found to be able to voluntarily orient attention based on expectations (Canfield & Haith, 1991; Clohessy et al., 2001), that is, to move attention to a specific location before the event onset.

With age, increases in infants’ endogenous attention would support the gradual growth of later executive control (Posner et al., 2014; Rothbart et al., 2011; see Figure 1.3). Between 6 and 11 months of age, infants start to show the ability to detect incongruencies in observed events that do not show the expected pattern of outcomes (Berger et al., 2006; Stahl & Feigenson, 2015). Additionally, inhibitory control seems to emerge in the middle of the first year of life, gradually increasing in individual stability towards the last quarter of the first year of life (Holmboe et al., 2018). Also, around 9 months of age, infants are found to successfully engage inhibitory control to avoid attention being exogenously oriented toward peripheral distractors (Holmboe et al., 2008). At the brain level, 10-month-old infants show an active engagement of prefrontal and parietal areas to inhibit dominant manual responses (Fiske et al., 2022).

During toddlerhood, all these attentional functions keep showing development increases. Tonic alertness displays a significant improvement towards 24 months of age, with daytime sleep being reduced to only 2 hours (Paavonen et al., 2020). Also, sustained attention keeps increasing towards 24 and 36 months (Ruff & Lawson, 1990), while endogenous attentional orienting shows increases from late infancy (Colombo & Cheatham, 2006; Csibra et al., 1998) towards early childhood (Moyano et al., 2022). Early EA functionality contributes to infants’ ability to engage in more sophisticated mechanisms of control. For example, although infants and toddlers are able to visually anticipate easy transitions within a sequence (Clohessy et al., 2011), only young children seem to employ an active monitoring of the sequence to correctly anticipate more during complex transitions (Rothbart et al., 2003; Moyano et al., 2022). Between the end of the first year of life and the beginning of the second, behavioural control seems to be immature, hindering the detection of developmental changes in inhibitory control measured through manual responses (Hendry et al., 2021). During early childhood, motor development is advanced enough to make manual responses a suitable option to detect developmental differences in attention control (Hendry et al., 2021; Gerardi-Caulton, 2000; Rothbart et al., 2003)

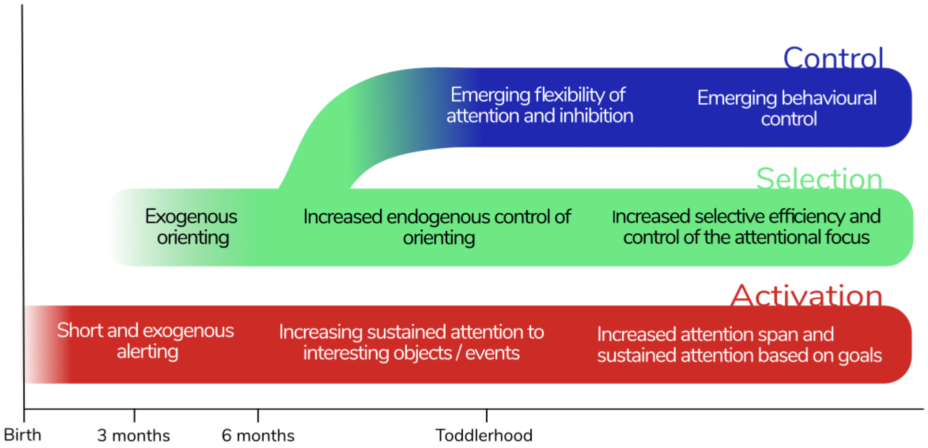


Figure 1.4. Developmental course of attentional processes of activation, selection, and control.

1.3. Contribution of constitutional and environmental factors to endogenous and executive attention control

As we have seen throughout the current chapter, children unveil new sets of behaviours as cognitive abilities improve with age. However, doubts arise regarding whether cognitive development could be considered a result of only genetic or environmental influences, or a product of both. In this respect, inner to the field of cognitive development is the nature-nurture debate. On one side, the nature perspective establishes that development is the process by which the information contained in children's genes is expressed. As genetic information is unique to each human being, genes will unfold the characteristics (i.e. phenotype; the set of observable traits in an individual from physical to cognitive and behavioural) that makes each person different from others. On the other side, the nurture framework defends that the individual's unique experiences with the environment are what determine the developmental process (Johnson et al., 2015). Although both perspectives are worthwhile for this debate, there is a recent consensus by which development can not be reduced to simple genes or experience intervention (Johnson et al., 2011). The growing support for complex and dynamic interactions between genes and environment has led research efforts to focus on how nature and nurture interact to shape development, resulting in the emergence of several theories (see Jonhson, 2020 for a detailed explanation):

1. *Maturational perspective*: the timing of the emergence of cognitive functions during development is set by the maturation of their physical substrate, that is, the brain regions involved in each cognitive function. Consequently, we could establish the maturational profile of cognitive functions characterizing the functional emergence of specific brain areas. The interpretation of the maturational perspective would entail that entire brain regions would remain inactive until reaching their maturational age. Nevertheless, we know that brain regions with protracted developmental courses are recruited at early ages after birth, such as prefrontal and parietal cortices (Ellis et al., 2021; Holmboe et al., 2018; Fiske et al., 2022).

2. *Interactive specialization*: exposes a more integrative approach compared to the maturational perspective. From the interactive specialization point of view, the development of new cognitive functions does not depend on the maturation of brain regions, but on the connectivity patterns between different brain areas. Thus, at early stages of development brain regions present a general role in cognition. Their growing interaction with other regions reduces their general functionality, leading to a more specialized role in cognition (Johnson et al., 2011).

3. *Skill learning*: the third and final perspective is not much different from the interactive specialization, being compatible in some cases (Johnson et al., 2020). The skill-learning perspective establishes that when learning a new skill, the recruited brain regions are similar, or even identical, in infants and adults. Hence, the amount of experience of the individual with the environmental causes that promote learning is the key factor that will determine the level of development of new abilities.

In general, the maturational perspective seems to minimize the role of environmental interactions, establishing that the main guide for cognitive development is set by the maturational timing of brain regions. On the contrary, both interactive specialization and skill learning perspectives set a main role for the individual's interaction with the environment on the emergence of new cognitive skills. Environmental factors interact with the individual to induce "*experience-expectant*" or "*experience-dependent*" changes. In the former case, changes are common to all members of the same species. Individuals are expectant of the interaction with the environmental factors that would induce such changes.

In the latter case, changes are not common to all members of the species, but only to those exposed to these interactions. As a result, individuals would develop new abilities depending on their interactions with different environmental factors (Johnson et al., 2015; Greenough et al., 2002)

To unveil the unique contribution of intrinsic (e.g. genes) and extrinsic factors (e.g. environment) to cognitive development, twin studies have emerged as an important asset. Twin studies allow us to disentangle the role of genetic heritability and environmental influence on a person's phenotype. The dissociation of the effects of genes and environmental factors is achieved by comparing monozygotic (i.e. 100% of shared genetic information) and dizygotic (i.e. 50% of shared genetic information) siblings. In a recent twin study, Finkel et al. (2021) investigated the effects of environmental (socioeconomic status) and constitutional factors (temperament) on children's general cognitive ability (GCA). Results revealed a moderation of SES on the effects fn temperament on GCA. The influence of temperament on GCA was not statistically significant for children from low-SES but for those of high-SES. In a recent review, Tistarelli et al. (2020) addressed the nature-nurture debate in the case of Attention Deficit and Hyperactive Disorder (ADHD). The authors conclude that besides its strong anatomical and functional brain basis, ADHD should not be studied excluding the effect of personality traits, and/or psychosocial factors.

In sum, early cognitive development is influenced by constitutional and environmental factors. Among other cognitive functions, emerging attentional control is of special relevance, being related to several outcomes during adulthood, such as socioeconomic success or emotional well-being (Moffitt et al., 2011; Daly et al., 2015). Developmental research has been long focused on studying the associations of attention with constitutional and environmental factors. In the following sections, we will review some of the evidence that supports the systematic and close relation between attention with children's temperament and environmental background. Additionally, we will revise recent literature exploring the interaction between intrinsic and extrinsic factors on the early emergence of attentional control.

1.3.1. Temperamental differences in relation to attention control development

Among individual predispositions, temperamental differences have been widely studied concerning attentional development. Temperament is a construct from the psychology of personality, defined as the person's emotional tendencies, individual differences in reactivity, and abilities for self-regulation at the behavioral, emotional, and attentional levels (Rothbart, 1981). Due to its intrinsic quality, parents can detect behavioral patterns in infants' reactivity and self-regulated behavior, resulting in constitutional individual differences. Studies using parent-reported measures have shown a strong attentional basis for temperament from very early in life (Rothbart, 2007). Temperament is usually measured considering a three factors structure: surgency (SUR), negative affect (NA), and effortful control (EC).

Individual differences in reactive behavior are captured by SUR and NA (Rothbart & Ahadi, 1994). Temperamental SUR targets behavioral personality traits of positive affect/approach, such as activity level, high-intensity pleasure, impulsivity, or smiling (Putnam et al., 2008). Although during toddlerhood and early childhood, a negative association is often found between SUR and attentional control, during infancy the association seems to be consistently reversed. In the first year of life, Putnam et al. (2008) found SUR to be positively correlated with EC. During toddlerhood, the relation between both factors was found to reverse. Similarly, in a sample of 6-month-old infants, McConnel & Bryson (2005) reported a positive correlation between SUR and visual attentional disengagement. However, later in development, Rothbart et al. (2003) found 18-month-old toddlers, scoring higher in SUR, to perform less easy correct anticipations in the VSL task. Likewise, 24-to 36-month-olds with higher SUR also performed less easy and complex anticipations.

A different set of reactive behaviors related to negative affect/avoidance is covered by NA, such as discomfort, fear, anger, or frustration (Putnam et al., 2008). Unlike SUR, NA shows a consistent negative association with attention during the lifespan. Higher attention control allows infants to down-regulate negative emotionality in a self-controlled manner, engaging volitional control over attention orienting (Harman et al., 1997). Also, infants with higher levels of NA show lower visual attentional control (Conejero & Rueda, 2018; Johnson et al., 1991; McConnell & Bryson, 2005). The negative association between NA and attention is consistently maintained during toddlerhood and early childhood, either for measures of visual (Rothbart et al., 2003) or behavioral control (Gerardi-Caulton, 2000).

In contrast, EC is the factor known to be associated with self-controlled attention and behavior (Rothbart & Ahadi, 1994). Specifically, EC targets behavioral traits related to perceptual sensitivity, attentional focusing, or inhibitory control, among others. Moreover, EC is found to show a consistent positive association with attention control. During infancy, a higher EC has been related to greater attentional abilities for visual disengagement (Johnson et al., 1991; McConnel & Bryson, 2005; Nakagawa & Sukigara, 2013), anticipatory attention (Sheese et al., 2008), as well as for longer fixation duration (Geeraerts et al., 2019; Papageorgiou et al., 2014). The same positive relation with EC is replicated during toddlerhood and early childhood (Rothbart et al., 2003; Gerardi-Caulton, 2000; Kochanska et al., 2000). Studies exploring the association between EC and visual attention are relatively scarce, and those conducted have reported null results (Moyano et al., 2022; Posner et al., 2012; Rothbart et al., 2003).

1.3.2. Effects of early environment on attention control development

We already know that attentional development is not only shaped by intrinsic forces to the individual but also by early experiences children have with the environmental context in which they grow up. For instance, the family SES background potentially defines the amount and quality of resources families can account for to invest in children's basic needs (Conger & Donnellan, 2007). Families' SES is a widely used measure to evaluate the impact of environmental factors on cognitive and brain development (Hackman & Farah, 2009). Material and immaterial aspects of the socioeconomic background can be often captured by parents' educational level, occupation, and income (Farah, 2017). These measures are often individually used as proxies for SES (e.g. Lipina et al., 2005; Tomalski et al., 2013). Recent studies have also adopted a more integrative approach, considering composite scores of these three aspects of SES (Conejero et al., 2016; Conejero & Rueda, 2018). Developmental research has consistently reported a positive association between SES and attention control. Infants from families of high-SES backgrounds show a higher ability for visual disengagement at 5 months of age (Siqueiros-Sanchez et al., 2021), or attentional flexibility between 6 and 12 months of age (Clearfield & Jedd, 2013; Conejero & Rueda, 2018; Lipina et al., 2005), which seems to highlight a developmental delay in the acquisition of cognitive abilities (Clearfield & Niman, 2012),

Although SES is a crucial factor during early development, other transversal factors also account for an important part of the variability. Some of these are CHAOS (Matheny et al., 1995) and maternal depression (Power et al., 2021), which can be present across different socioeconomic backgrounds. Previous research has shown that home chaos accounts for effects on cognition that are independent of those tapped by SES (Hart et al., 2007; Petrill et al., 2004). Formally, CHAOS could be defined as the level of disorganization, confusion, and noise in the home environment (Matheny et al., 1995). Most of the research concerning the effects of CHAOS on cognition is focused on EFs as the main outcome (Andrews et al., 2021). Although recent studies have reported the effects of CHAOS on infants' (Tomalski et al., 2017) and young children's (Moyano et al., 2022) visual attentional abilities, literature in this respect is still emergent and scarce. Children exposed to more chaotic households grow up under overstimulating conditions, tending to withdraw more often from their immediate context (Evans, 2006). During infancy, Tomalski et al. (2017) found a negative contribution of CHAOS over 5.5-month-olds' visual attention, with infants exposed to higher levels of CHAOS displaying slower processing speed times. However, Moyano et al. (2022) recently reported a positive contribution of CHAOS on young children's abilities to correctly anticipate complex visual sequences, which require monitoring abilities dependent on EA control.

Maternal mental health is also of special relevance during infancy and toddlerhood. The prevalence of maternal depression is significant during the perinatal period, with a recent meta-analysis suggesting a 12% of prevalence (Woody et al., 2017). As SES and CHAOS, maternal depressive symptomatology also contributes to characterizing the early environment to which infants are exposed. The effects of mothers' depressive symptomatology on children's development are mostly channeled through an impact on mother-child interactions (Coyl et al., 2002). In addition, children exposed to higher levels of maternal depression are more likely to be exposed to environmental stressors (Hackman et al., 2010). As for home chaos, much of the research studying the effects of maternal depression on early development has focused on the negative impact of higher exposure to maternal depressive symptomatology over EFs, with research on attention being relatively non-existent. In general, the available literature indicates that an early exposure to maternal depression harms cognitive development in the long run (Hughes et al., 2013; Hutchison et al., 2019; Leckman-Westin et al., 2009; Rigato et al., 2022; Oh et al., 2020).

1.3.3. Interactions between temperament and environment in relation to the development of attention control

As reviewed in the previous sections, attentional development is shaped by temperamental predispositions and characteristics of the rearing environment. In line with the interactionist proposal in the nature-nurture debate, intrinsic and extrinsic factors to the child would interact with each other to influence cognitive development, as shown by twin studies (Finkel et al., 2021; Tucker-Drob & Briley, 2014). As a result, developmental trajectories accounting for these interactive effects between individual predispositions and environmental factors would be different from those considering their individual effects.

In Conejero & Rueda’s (2018) study, the effects of families' SES and temperament on attentional flexibility were reported in a sample of 9- to 12-month-old infants. Based on these findings, they successfully tested a mediation model in which infants’ temperamental NA mediated the direct effect of SES on infants’ attentional flexibility. Nevertheless, the model was only tested based on concurrent measures. Further studies by Rigato evaluating the effects of maternal depression on temperament and cognition follow the same line. Specifically, they found that early exposure to maternal depressive symptomatology negatively impacted children’s later temperament (Rigato et al., 2020) and behaviour (Rigato et al., 2022). However, no longitudinal interactions had been reported so far. In the current thesis, we aim to fill this gap, considering longitudinal measures of temperament and environmental factors, as well as their interaction for the study of its effects on the development of attention.

2

Chapter 2: Research aims.

2.1. Research goals.

The purpose of the present doctoral dissertation is to characterize the development of endogenous and executive components of early attentional control from infancy to toddlerhood and early childhood. We aim to do this by employing visual attention as a proxy of the ability to endogenously control attention. The eye-tracking technique is used to collect spatially and temporally reliable gaze data in different attentional tasks that address core attentional abilities: 1. Attention disengagement; 2. Attention flexibility; and 3. Anticipatory attention and context monitoring.

To accomplish research goals, two studies were conducted:

1. A longitudinal study with three waves of data collection at 6, 9, and 16-18 months.
2. An accelerated longitudinal study with five cohorts of toddlers and young children evaluated at 24, 30, 36, 42, and 48 months of age. Each cohort was re-evaluated in a follow-up session placed 6 months after the first one.

In the first longitudinal study, we intend to analyze endogenous and executive attention development during the first and second years of life, as well as its stability across age. Moreover, we also aim at testing the correlation between different components of endogenous and executive attention. We intend to find support for the estimation of an attention control index during this developmental period. Finally, the contribution of temperament and environmental factors to predict attention control abilities is also tested.

In the second accelerated longitudinal study, we aim to investigate the development of anticipatory attention and context monitoring for 24 to

48 months of age. Also, we intend to analyze the stability of attentional measures over 6 months, as well as the contribution of temperamental and environmental factors to attentional control.

2.1.1. Development of endogenous and executive attention control in the first two years of life.

How does attention control unfold during infancy and toddlerhood? Does temperament and environment have an impact on its early development? We aim to address these questions, and some others, evaluating endogenous and executive aspects of attention control in a longitudinal sample of 160 infants that were evaluated at 6, 9, and 16-18 months of age. A gap-overlap, switching, and visual sequence learning (VSL) task were employed to measure different components of attention disengagement, flexibility, anticipatory attention, and context monitoring. Temperamental (i.e. effortful control, surgency, and negative affect) and environmental factors (i.e. socioeconomic status, home chaos, and maternal depression) were collected through parent-reported questionnaires.

The following specific research questions were considered:

1. Are there developmental differences between 6, 9, and 16-18 months of age in endogenous attention control and the growth rate across these ages?
2. Do different attention control abilities show stability between infancy and toddlerhood?
3. Are these attentional abilities correlated during infancy and toddlerhood? Is it feasible to combine them into an attention control index during this developmental period?

4. How do infants’ temperament and early environment contribute to predict future attentional abilities?
5. Does infants’ temperament longitudinally mediate the effect of early environment on attention control?

Chapter 3 will address the first three questions related to attention control development, stability, and inter-correlation between attentional components. Chapter 4 will consider the contribution of temperament and environmental factors in the prediction of attention control, as well as the longitudinal mediation of temperament on the effects of environmental factors on attention control.

For the ease of the reader, the structure of Chapters 3 and 4 is organized by research questions. That is, after the introduction and method sections, the hypothesis and results are described for each research question due to the amount of information. A discussion section sums up the main results and closes the chapter.

2.1.2. Development of endogenous and executive attention control during toddlerhood and early childhood.

How does anticipatory attention and context monitoring develop during early childhood? Do individual differences in temperament and environmental factors impact these abilities? We intend to answer these questions in an accelerated longitudinal study with a sample of 150 children aged between 24 and 48 months of age. According to their age, they were assigned to one of five cohorts: 24, 30, 36, 42, and 48 months. All age groups, except the 48-month-old cohort, were evaluated in a second follow-up session identical to the first session. A VSL task was employed to measure different components of endogenous and executive attention control. Parent-reported questionnaires were used to collect measures of children's temperament (i.e. effortful control, surgency, and negative affect) and families' environmental factors (i.e. socioeconomic status and home chaos). The following research questions are aimed to be answered:

1. Does age contribute to predict endogenous and executive attention control?
2. Does age contribute to predict the change in attentional measures between the first and follow-up sessions?
3. Do attentional measures show stability in 6 months?
4. Do temperamental and environmental factors contribute to predict attentional abilities once controlled by age?

Chapter 5 contains the responses to these research questions. As the content of this chapter has been already published, its structure follows a conventional one (i.e. introduction, method, results, and discussion sections).

Chapter 3: Endogenous and executive attention development from infancy to toddlerhood.

Part of the content of this chapter has been published as
Moyano, S., Rico-Picó, J., Conejero, Á., Hoyo, Á., Ballesteros-Duperón, M. A. & Rueda, M. R. (2023). Influence of the environment on the early development of attentional control. *Infant Behavior and Development*, *71*, 101842. doi: 10.1016/j.infbeh.2023.101842

3.1. Introduction

Attention control is subject to significant changes during infancy (Hendry et al., 2019; Johnson et al., 1991). During this developmental period, orienting skills play a main role in infants' capacity to focus on the relevant aspects of the environment (Posner et al., 2014). According to Posner's model of attention (Posner & Petersen, 1990), three brain networks are responsible for three main attentional functions: 1) Maintaining the alerting state (*alerting network*), 2) Orienting attention and selecting the relevant information to be processed (*orienting network*) and 3) Voluntarily controlling responses according to internal goals or instructions (*executive network*). Following Posner's model, the orienting network is considered to exert much of the control over attention in infancy and toddlerhood given the immaturity of the executive network (Posner et al., 2012). Functions of the orienting network emerge earlier in the first months after birth, compared to the executive attention network (Posner et al., 2014) which becomes functionally active at the end of the first year of life (Hendry et al., 2016). This is the main reason the orienting network is deemed a precursor of later executive control development (Posner et al., 2014; Rothbart et al., 2011), as both also share common neural substrates (Rueda et al. 2015).

The orienting network is responsible for key attentional abilities that enable infants to gain control over information selection (Posner & Petersen, 1990), an essential ability considering the abundance of visual stimuli in a constantly changing environment. Most of the evidence on infants' attentional development comes from tasks involving orientation of visual attention using experimental protocols suitable for infants (i.e. the gap-overlap task). These are combined with gaze video recordings or more precise techniques such as eye tracking. Automatic processes of exogenous orienting are present since birth, although endogenous attention would experience a significant development throughout the first months of life. In this sense, various important aspects related to the endogenous control of attentional orientation are to develop during the first year of life: 1) The capacity to disengage attention from a focused source of stimulation and reorient to a different one; 2) Voluntarily orient attention in anticipation of an event based on a learned expectation; and 3) Flexibly overcome previously learned visual responses when these are no longer adaptive (Hendry et al., 2019; Hendry et al., 2016). These abilities, related to the volitional control of attention, grant infants the capacity to freely move attention to explore and learn from the environment. In the current chapter, we aim to analyze the development of visual attention control from 6 to 16-18 months of age, targeting three core endogenous attention abilities: 1) Attention disengagement; 2) Anticipatory attention and context monitoring; and 3) Attention flexibility. In addition, we want to examine individual differences in these abilities and their stability over this developmental period. Finally, we also intend to analyze whether these three attentional abilities are inter-correlated and tap into different aspects of a common executive attention factor. In such a case, a general attention control index could be derived based on infants' performance in all three tasks.

3.1.1. Measuring visual attention control in infancy

3.1.1.1. Attention disengagement

Visual disengagement is one of the first manifestations of endogenous attention control in infancy. Being able to voluntarily disengage and reorient attention allows infants to explore and attend to the most relevant aspects of the environment. This ability has been mostly studied through the gap-overlap paradigm (Atkinson et al., 1992). In this task, researchers measure infants' ability to disengage and reorient attention from a foveated central stimulus towards a newly appearing peripheral target. For this, two experimental conditions are considered: 1) The central stimulus persists after the onset of the peripheral target (overlap trials) vs. 2) The central stimulus offset is followed by a short temporal gap before the onset of the peripheral target (gap trials; Hood & Atkinson, 1993). The overlap condition requires infants to disengage the attentional focus on the central stimulus in order to reorient attention towards the novel peripheral target, while both remain visible in the visual space. From the gap-overlap task, measures of disengagement latency per condition are extracted. These dependent variables are used to compute a *disengagement cost score*, that is, how much longer latencies to disengage are obtained for the overlap compared to the gap condition (Holmboe et al., 2018). Sometimes a so-called baseline condition is introduced and a *facilitatory effect score* can be calculated. This index reflects how much orienting is facilitated after being cued by the gap compared to the baseline condition in which the peripheral target is presented right after the offset of the central stimulus, without a temporal delay (Elsabbagh et al, 2009).

Frontal and parietal areas are recruited to disengage and reorient visual attention in a context of visual competition, being involved in the inhibition and reorienting of visual attention in contexts of visual competition (Özyurt & Greenlee, 2011). Nevertheless, the gap condition considerably reduces the cognitive effort to visually disengage. The removal of the central stimulus eases attentional disengagement and reorienting of attention to the new events. Moreover, the disappearance of the central stimulus is proposed to act as an alerting cue, which could promote saccade planning (Csibra et al., 1997; Kingstone & Klein, 1993). To this matter, Ross-Sheehy et al. (2015) reported that infants between 5 and 10 months were able to benefit from visual and auditive cues to ease attentional orienting. Also, in a recent fMRI study, Ellis et al. (2021) found that infants from 3-to 12 months of age can benefit from non-directive visual attentional cues to reorient attention, recruiting brain areas known to be involved in attentional control during adulthood (e.g. right anterior cingulate and lateral occipital cortex).

But how does attentional disengagement develop during infancy? Right after birth, Atkinson et al. (1992) found that the disengagement cost is higher at 1 month of age in comparison to older infants. A key structure for visual attention is the superior colliculus (SC), which plays a main role in visual fixations and saccadic responses (Johnson, 1990). The underlying proposed mechanism of this particular disengagement difficulty at young ages lies in an immature and highly active inhibitory pathway from the substantia nigra (SN) and basal ganglia (BG) to the SC, which down-regulates its activity (Johnson, 1990). It is the high level of activation in this subcortical pathway that impedes voluntary disengagement when focused on a stimulus. The attentional effect related to visual disengagement restriction that takes place in young infancy is referred to as “*obligatory fixation*” or “*sticky fixation*” (Stechler & Latz, 1966), with infants only being exogenously disengaged when another novel stimulus is presented. Inhibitory activity over the SC is known to reach an equilibrium around the second to the third month after birth. At this moment, maturation of the upper layers of the visual cortex (e.g. upper layers from V1, as well as layers from V2 and V3), leads to emerging activity in two excitatory pathways towards the SC that balance the inhibitory signals. First, a middle temporal pathway (MT), followed by a second frontal eye fields (FEF) pathway (Johnson, 1990). These early changes in the subcortical anatomy of visual control are followed by increases in attention disengagement from that age onward (Johnson et al., 1991). In this sense, while in the gap condition (non-competition) 1 and 3-month-old infants show similar disengagement latencies, 3-month-olds display a significant reduction in disengagement latency in the overlap (competition) compared to 1-month-olds. This result is expected, as visual facilitation effects have been found to develop earlier in infancy than interference effects, which would require the engagement of cognitive control processes (Ross-Sheehy et al., 2015). Visual disengagement is generally harder in the overlap than in the gap condition at all ages. However, in younger children, when the cortical systems of endogenous attention control are still immature, the disengagement cost is much higher due to a greater difficulty to disengage in the overlap condition.

Latencies to disengage in a context of visual competition keep showing decreases at 6 months of age (Colombo & Cheatham, 2006), although successful disengagement is not yet fully achieved (Csibra et al., 1998). Interestingly, inhibitory control, which is also required to terminate a fixation on the foveated central stimulus and disengage attention, has been found to show only certain stability at 6 months, increasing towards the end of the first year of life (Holmboe et al., 2018). Furthermore, from 6 to 36 months of age, longitudinal and cohort studies also found infants' and toddlers' disengagement latencies in the overlap condition to be higher compared to the gap (Nakagawa & Sukigara, 2013; 2019).

Visual attentional disengagement is an important predictor of developmental disorders during toddlerhood and early childhood. Disengagement ability in infants from 9 to 10 months of age with siblings diagnosed with autism spectrum disorders (ASD; high-risk infants) differ in comparison to a control low-risk group. Specifically, employing the gap-overlap task, Elsabbagh et al. (2009) found infants at risk to show longer disengagement latencies and less facilitatory effect. Likewise, Zwaigenbaum et al. (2005) found that impairment in disengagement at 12 months of age was predictive of a higher likelihood of 6 and 12-month-old infants at high-risk of

ASD, to be later classified inside the autistic spectrum at 24 months of age. Other studies have replicated this result, supporting the notion that differences in visual disengagement between high and low-risk groups of ASD arise at 12 to 14 rather than at 6 to 7 months of age (Bryson et al., 2017; Elsabbagh et al., 2013). Authors argue that these differences in visual disengagement could be related to a different style of processing information. In this respect, high-risk infants would focus attention on local features of the environment, instead of adopting a more flexible and exploratory style as would low-risk infants (Elsabbagh et al., 2013).

Overall, the evidence presented above supports the idea of visual disengagement being a core function of endogenous attention control. As discussed, detecting early differences in the ability to disengage attention during infancy might have clinical implications. Moreover, the age at which these differences emerge seems to play a key role in the later diagnosis of neurodevelopmental disorders involving attentional difficulties. Consequently, characterizing the typical development of visual attentional disengagement, through infancy and toddlerhood, would oil the wheels to identify key differences in attention control of infants at risk of developmental disorders.

3.1.1.2. Anticipatory attention and context monitoring

Infants' ability to visually anticipate the location of an upcoming event has been proven to be another important marker of endogenous attention control (Posner et al., 2012; Posner et al., 2014). It involves a voluntary movement of attention in the visual space, before the onset of a stimulus, based on a learned expectation. Moreover, anticipatory attention has been found to relate to other spheres of infants' early development, such as self-control

(Rothbart et al., 2003; Sheese et al., 2008) or language acquisition (Shafto et al., 2011).

The Visual Expectation Paradigm (VExP; Haith et al., 1988) is a classical method that has been used to measure infants' anticipatory looks. This experimental protocol allows us to measure both exogenous and endogenous shifts of attention within the same task. The VExP involves the presentation of a set of stimuli in different spatial locations in a fixed sequence, while infants' gaze is being recorded. Anticipatory looks to a particular location before the stimulus onset indicate the occurrence of expectancy-driven or endogenous movements of attention (*visual anticipation*). However, if the visual attentional shift towards the stimulus location takes place after its onset, it reflects stimulus-driven or exogenous orienting of attention (*reactive look*, Canfield & Haith, 1991). Sequence learning intrinsically requires attention control. Adult research has found that participants struggle to learn a sequence when the maintenance of the attentional focus is compromised due to the presence of distractors (Curran & Keele, 1993). Infants below one year of age are sensitive to statistical patterns on speech (Aslin et al., 1998; Saffran et al., 1996) or sequences of visual temporal events (Fiser & Aslin, 2002; Kirkham et al., 2002; Kirkham et al., 2007), making sequence-based protocols suitable to study anticipatory attention in infancy and toddlerhood.

As stated before, right after birth infants' attention is known to be exogenously driven until around 2 to 3 months of age (Johnson, 1990). From this age onwards, endogenous attention is recognizable through infants' behavioral patterns (Colombo & Cheatham, 2006; Johnson et al., 1990). Employing the VExP, Canfield et al. (1991) found that infants as young as 2-month-olds can generate expectations about symmetric visual sequences of stimuli (i.e. left-right alternating sequence) to correctly anticipate the upcoming location. Moreover, in the same study, the authors found that 3.5-month-old infants can show more correct anticipatory looks compared to 2-month-olds for asymmetric sequences (i.e.: left-left-right sequence). This increase in early attention control is coupled with increases in sustained attention, which is defined as the ability to maintain the attentional focus over a period of time on a stimulus, an event, or throughout a task (Ruff & Lawson, 1990). Sustained attention is closely related to executive function and self-regulatory abilities (Choudhury & Gorman, 2000; Johansson et al., 2015a; Johansson et al., 2015b), but also to anticipatory attention. Jacobson et al. (1992) found that infants' percentage of anticipations in the VExP at 6.5 months of age was positively associated with sustained attention during play at 12 months. Developmental studies suggest that it is from 3.5 to 6.5 months of age when infants show increases in sustained attention (Richards, 1985). After that, performance seems to remain more stable between 6 months and the second birthday, with significant increases in sustained attention being found after 42 months of age (Ruff & Capozzoli, 2003; Xie et al., 2019).

Most sequences utilized in the VExP are about anticipations during context-free trials, that is, sequences in which the next stimulus location can be anticipated from the current one. However, 8-month-old infants can consider contextual information during learning of visual sequences, and reallocate attentional resources based on the probabilities of the events (Tummeltshammer & Kirkham, 2013). Based on this idea, Clohessy et al. (2001) developed the Visual Sequence Learning (VSL) task to measure visual anticipatory attention from infancy to adulthood, while trying to disentangle developmental differences during sequence learning based on contextual information. Unlike the VExP, stimuli are displayed in three different locations on a screen (top-left, top-right, and centered-bottom) corresponding to positions 1, 2, and 3, respectively. The configuration of the sequence (1-2-

1-3-1-2-1-3- and so on) allows to define *easy transitions* (unambiguous or deterministic) in which position 2 or 3 are always followed by position 1, as well as *complex transitions* (ambiguous), in which position 1 could be followed by position 2 or 3 (50% of probability), depending on the previous location to the current one. Easy transitions require a more basic form of endogenous attention control, similar to the VExP, due to the deterministic nature of these trials. On the other hand, complex transitions require taking into account the previous stimulus location to be able to predict the upcoming location (e.g. from location 1 I must go to location 2 only if coming from location 3). This is a more sophisticated mechanism of attention control, which we will refer to as *context monitoring*.

Monitoring is defined as the ability to keep track of the course of events, is related to executive attention (Posner & DiGirolamo, 1998; Botvinick et al., 2001) and the flexibility with which attentional control is engaged (Chevalier & Blaye, 2016). It is a supervisory process required during learning and memory creation (Nelson & Narens, 1990). Monitoring the context has a significant relevance during infancy. It enables infants to learn and adapt to environments in constant change, making the reallocation of attentional resources more flexible and efficient. In this respect, Haaf et al. (1996) found 6-month-old infants to flexibly engage context monitoring to select and encode relevant information for the task at hand. Moreover, they ignored contextual information when it was irrelevant to the current goal. During complex transitions in the VSL task, this higher-order cognitive ability allows infants to actively keep track of previous positions to correctly anticipate the location of an upcoming stimulus.

Employing the VSL task in a cross-sectional study, Clohessy et al. (2001) found that 4 and 18-month-old infants showed a similar percentage of anticipations in easy transitions as adults. However, contrary to adults, the two age groups of infants did not show differences between easy and complex transitions. Correct anticipations in complex transitions have been found to increase between 24 and 36 months of age in comparison to easy (Rothbart et al., 2003). These results suggest that the ability to learn deterministic sequences is acquired early in infancy, as indicated by previous data (Clearfield et al., 1991). Moreover, functional commonalities have been recently reported between infants' and adults' brains during simple endogenous orienting of attention. In a recent fMRI study, Ellis et al. (2021) found that 3 to 12-month-old infants were able to recruit frontal and parietal areas during endogenous orienting of attention, the same areas that are engaged in adults. The protracted developmental course of correct anticipations in complex transitions suggests that it could be related to the development of the executive attention network, which develops at a slower pace compared to the orienting network (Posner et al., 2014). In their cross-sectional study, Rothbart et al. (2003) found that the percentage of correct anticipations during complex transitions in 30-month-olds was associated with a lower interference effect in a spatial conflict task. This could state that endogenous orienting of attention under monitoring demands is also tapping executive attention processes. However, no evidence has been reported concerning the longitudinal development of anticipatory attention under different conditions of ambiguity, as well as the growth rate of these abilities.

3.1.1.3. Attention flexibility

Attentional control is also characterized by the flexibility it provides to infants' and toddlers' behaviour. A flexible behaviour enables infants to overcome dominant responses that were established by certain learned rules in a previously experienced context, but that could not be no longer adaptive in the current situation (Stahl & Pry, 2005). Similarly, a flexible attentional control allows to dynamically switch attentional strategies engaging a goal-directed selection of the most appropriate one, following changes in the stimulation context (Conejero & Rueda, 2018)

Attentional flexibility during infancy and toddlerhood has been mostly studied relying on motor response-based tasks. For instance, through the A-not-B task (Diamond, 1990). In this paradigm, infants are shown an object that is hidden in an initial location (A trials). After a short temporal delay, infants are encouraged to retrieve the toy from this location during several trials to establish a solid rule. Following several successful retrievals, the hiding location is switched (B trials), with infants being required to inhibit the tendency to look for the object in the previously rewarded location (A) and switch to the new one. Attentional abilities have been found to influence performance in the A-not-B task. Recent studies have reported that infants' focused attention (Marcovitch et al., 2015), as well as toddlers' attentional switching (Mulder et al., 2020), were predictors of performance in the A-not-B task.

Previous research employing the A-not-B paradigm has found that from 5.5 to 12 months of age, infants increase the ability to flexibly switch attention. This translates into a reduced tendency to search for the toy in the previously rewarded location, decreasing the number of perseverative errors (Cuevas & Bell, 2010). In a longitudinal study covering ages between 5 and 8 months, Clearfield et al. (2006) reported that it is not until 7 to 8 months when infants show a perseverative behavioural pattern in the A-not-B task, that is being correct on A trials but perseverating on B trials. Surprisingly, 5-month-olds reached correctly on both A and B trials more often than any other age. According to the authors, this behavioral pattern is linked to infants' ability to form stable representations in memory that could influence performance in B trials. In comparison with older ages, 5-month-olds are not able yet to create such stable representations due to an unstable motor reaching. Consequently, performance on B trials would be only influenced by information available in the current moment, without previous memories that could drive infants to look for the toy in the previously rewarded location. However, as reaching behaviour stabilizes around 7 to 8 months, infants form more stable representations of previous reachings, influencing performance in B trials. From 7.5 to 12-month-olds, there is a developmental reduction in perseverative behavior in the A-not-B task (Diamond, 1985). In this regard, perseverations could be considered as a preliminary step to achieve a correct attentional switch, reflecting infants' ability to bring previous knowledge to the present and use it to adapt performance (Clearfield et al., 2012; Diedrich et al., 2001).

Although the A-not-B paradigm has been widely used to study attention flexibility during infancy, switching abilities could be influenced at some ages by motor development (Clearfield et al., 2006). A simplified form to study attention flexibility is through visual anticipations. We have already seen that anticipatory attention develops early in infancy (Johnson et al., 1991). Anticipations can be classified either as correct if the infant fixates the location in which a stimulus is going to be presented next, or incorrect if the fixation occurs on a different location. Kovács & Mehler (2009) designed a switching paradigm that uses incorrect anticipations (perseverations) as a proxy for attention flexibility.

In a similar way to the A-not-B task but on a screen, infants are presented with two possible locations in which a stimulus could be presented. During a first block (pre-switch), an animated cartoon (reward) is always displayed in one of the two possible locations on a screen after an anticipatory period. The contingency of the event leads infants to learn to anticipate the rewarded location throughout the block, similar to A trials in the A-not-B task. After several trials, a second block is presented (post-switch), switching the stimulus displaying location to the previously non-rewarded position during the pre-switch block. At this point, infants should inhibit the tendency to anticipate to the previously rewarded location, to correctly anticipate during the post-switch block trials. Kóvacs & Mehler (2009) originally employed this task to compare attentional switching between mono and bilingual infants. They found that only a subset of 7-month-old bilingual infants showed fewer perseverative errors compared to monolingual. In a training study, Wass et al. (2011) employed the switching task to measure the effects of a 15-day attentional control training program in a sample of 11-month-olds. In the post-training phase, they found that infants in the trained group reduced perseverations compared to the control group. No changes in correct anticipations were found in the pre-switch block between groups. More recently, Shinya et al. (2022) used the switching task to account for attentional differences between a sample of preterm and term infants at 12 months. They used looking times to the incorrect location in the post-switch block as a proxy for attentional flexibility. Term and moderate-to-late preterm infants showed a decrease in looking times during perseverations, in comparison to very-late preterm infants. This suggests a higher ability of these infants to actively inhibit looking toward the incorrect location.

In general, data supports the use of perseverative behavior as a measure of attentional flexibility. However, no longitudinal changes in attention flexibility have been reported employing the switching task. The use of this task could reduce the impact that reaching behavior could have on young infants' performance (Bell & Adams, 1999; Clearfield et al., 2006), as oculomotor development is found to take place earlier. Thus, we intend to use this task during infancy and toddlerhood to measure: 1) Correct anticipations during the pre-switch block, as a measure of endogenous attention control during learning; and 2) Perseverative anticipations in the post-switch block as a measure of attention flexibility.

3.1.2. Are attention disengagement, anticipatory attention and attention flexibility tapping different aspects of a common attention control construct?

These three aspects of early attentional control gain relevance across the first year of life, supporting key abilities that would allow infants and toddlers to gain voluntary control over their cognition, behaviour, and emotion. The early engagement of these attentional abilities during infancy is supposed to lie in the early functional activity on a common neural ground, the executive attention network (Gartstein et al., 2013). But, are these aspects of attention control measuring different attentional mechanisms of a common supervisory system? We intend to answer this question by testing the inter-correlation between attention disengagement, anticipatory attention, and attention flexibility to measure the degree to which they settle on a common neural circuit.

Previous literature has found certain overlapping in the way attentional abilities engage the same mechanism of control. For instance, inhibitory control is known to be involved in attention disengagement and switching (Hendry et al., 2019). In the former case, infants are required to inhibit a foveated stimulus in order to ease disengagement and reorienting of attention. In the latter, inhibitory control allows inhibiting a dominant learned response that is no longer adaptive in the current context, granting infants a more flexible behaviour. The close relation between attentional disengagement and switching has also been reported in a recent infant study. In a sample of 9 to 12-month-olds, Conejero & Rueda (2018) found that longer latencies to disengage from emotional faces correlate with reduced attentional flexibility measured with the switching task. These results highlight a potential positive correlation between attention disengagement and switching. Both attentional abilities could be tapping a common circuit of brain regions involved in the endogenous voluntary control of attention (i.e. the dorsal fronto-parietal network), a circuit that is thought to be part of the executive attention network (Fiske et al., 2022).

Similarly, when learning a visual sequence, infants with a higher ability to maintain attention focused on the task while inhibiting potential distractors would learn relevant aspects of the same, which would lead to an overall better representation of the sequence. Supporting this idea, Holmboe et al. (2018) found a negative correlation between correct anticipations in a VExP and the cost to disengage in a gap-overlap task in 4-month-old infants. This implies that a higher ability to form accurate expectations to anticipate events is associated with a higher ability to engage inhibitory control to reduce the cost of visual disengagement. If this association is mostly driven by a common inhibitory control mechanism, it would be feasible to find a similar association between correct anticipations in the VSL and attentional flexibility measured by the switching task.

The ability to correctly anticipate hinges upon the predictive knowledge that has been extracted from contextual regularities (Rothbart et al., 2003). A higher ability to learn from stimulus contingencies should be related to more accurate anticipations. As both, the VSL task and the pre-switch block of the switching task rely on infants' contingent learning, we expect a positive correlation between these two measures. Sustained attention is also likely to be associated with attentional flexibility. For instance, Johansson et al. (2015a) found that higher sustained attention during a free-play in 12 months-old babies predicted higher attentional switching in the A-not-B task in toddlerhood.

All in all, there is evidence to support potential correlations between these three attentional abilities (i.e. attention disengagement, anticipatory attention, and attention flexibility). However, no previous study has tested this assumption. For this reason, we aim to study whether these attentional functions related to executive attention control are inter-correlated during the early stages of development. A positive correlation between tasks would support the estimation of an attention control index derived from the combination of these attentional functions during infancy and toddlerhood.

3.1.3. Aims

In the current research, we aim to study the longitudinal development of three aspects of early attentional control from 6 to 16-18 months of age: 1) Attention disengagement; 2) Anticipatory attention and context monitoring; and 3) Attention flexibility. Moreover, we intend to test the inter-correlation between these abilities in order to find support to compute an executive attention composite score.

Previous studies employing the gap-overlap task during the first and second year of life have not found changes in disengagement ability for the gap or overlap conditions (Nakagawa & Sukigara, 2013; 2019). However, we intend to solve some issues that could have negatively impacted this outcome. First, only Nakagawa & Sukigara (2013) have employed a longitudinal methodology to study attention disengagement from 12 to 36 months of age, without covering the first year of life. Also, they used a small sample size of

26 infants to be longitudinally evaluated. Second, Nakaga & Sukigara (2019) employed a cross-sectional design from 6 to 24 months of age, yet again with a small sample size of between 20 and 30 infants in each cohort. Also, they included alerting cues in the gap-overlap paradigm to test the effects of phasic alertness.

Thus, we aim at analyzing longitudinal differences in disengagement ability from infancy to toddlerhood using a larger sample size. We would consider disengagement in a context of visual competition (overlap) or facilitated disengagement (gap). Similarly, we intend to test longitudinal changes in infants' sustained and exogenous attention, as well as their ability to endogenously anticipate attention in context-free or context-dependent visual sequences. Finally, we aim at analyzing infants' longitudinal development of attentional flexibility in the same longitudinal sample using a switching task.

To the best of our knowledge, no previous study has addressed the longitudinal development of attention disengagement, anticipatory attention, and attention flexibility between infancy and toddlerhood within the same study. In the first part of this chapter, we aim to analyze these changes in the gap-overlap, VSL, and switching tasks. In the second part, we attempt to analyze the stability of the attentional measures across testing sessions. In the third and final part of this chapter, we aim at exploring the associations between these three aspects of attention control. For ease of reading, the research aims and hypotheses will be presented at the beginning of each part of this chapter.

3.2. Method

3.2.1. Participants

Families were recruited through advertisements in public health centers and recruitment visits in the Maternity Hospital of Granada. Researchers provided information about the general purpose of the study and a detailed leaflet to interested parents, either in hand during the recruitment visits, or through email for those parents that contacted the lab via phone call. A total of 160 families agreed to come to the Developmental Cognitive Neuroscience Lab when infants were 6 months of age from a pool of 216 families that gave their initial consent to participate. Infants were included in the final analyzed sample if: 1) Weight at birth was higher than 2500 grams, 2) They were born at term (37 weeks at least) and 3) They did not present any medical condition at birth. From the initial sample n = 18 did not meet inclusion criteria (n = 6 criteria 1; n = 10 criteria 2; n = 2 criteria 3). The final sample was composed of 142 infants at 6 months, 122 at 9 months, and 91 at 16-18 months with no family history of mental or neurological disorders (see Table 3.1 for descriptive statistics). The third session of the study took part during the COVID-19 pandemic. Due to a national lockdown, lab activity ceased for 4 months. The age of the third session was extended from 16 to 18 months to ease the participation of families in the study. Families were given a 10€ voucher for an educational toy store in appreciation for their participation in each session of the study.

Table 3.1.

Sample descriptive statistics.

		Mean (*SD*)	Min (*Max*)
6 months (*n* = 142; 73 female)	Gestational weeks	39.65 (*1.38*)	37 (*42.71*)
	Weight at birth	3354.87 (*472.43*)	2500 (*5000*)
	Age (*days*)	193.80 (*8.49*)	181 (*223*)
9 months (*n* = 122; 60 female)	Age (*days*)	284.75 (*9.21*)	259 (314)
16-18 months (*n* = 91; 50 female)	Age (*days*)	518.37 (*24.16*)	483 (582)

3.2.2. Procedure

Families were received in the Developmental Cognitive Neuroscience Lab located in the Mind, Brain, and Behaviour Research Center (CIMCYC) of the University of Granada. Parents/legal guardians were given details of the session and were required to sign an informed consent while giving the infant time to feel comfortable with researchers. Once parents/legal guardians and infants were ready, they were guided to the eye-tracking room to initiate the first half of the session. At 6 and 9 months sessions, infants were placed in a high chair with a head support pillow at approximately 60 cm from the monitor. Parents were seated behind the highchair to avoid infants to be distracted. If infants showed inattention or fussiness, the baby was seated on her/his caregiver’s lap. For the 16-18 months sessions, infants remained seated in the parent's lap during task administration due to increased infant mobility at this age. Parents were asked to remain silent and avoid any interaction with the infant during the procedure. Researchers controlled the administration of experimental tasks in an adjacent room, monitoring infants' behavior through a webcam camouflaged next to the eye-tracker lens. If needed, a short break was introduced between tasks, initiating a new calibration procedure if the task was interrupted. At the end of the session, parents were informed about and sent questionnaires to be fulfilled online at home. The present research was approved by the Ethics Board of the University of Granada (Ref. 488/SEIH/2018) following the Declaration of Helsinki. Participation in the current research was voluntary and legal guardians gave written consent before participating.

3.2.3. Eye-tracker

Gaze was recorded using the remote mode of an EyeLink 1000 Plus (SR Research, 2013) corneal-reflection eye-tracker with a sampling rate of 500Hz and 0.01º of spatial resolution. A 16mm lens attachment and an 890 nm illuminator were used for this purpose. At a distance of 60 cm, the remote mode has a tolerance of 35 x 35 cm head movements. Stimuli were presented with Experiment Builder software (SR Research, 2017b) in a LG 24M37H-B 24-inch LED monitor with a native resolution of 1920 x 1080 pixels (52 x 30 cm). A five-calibration points child-friendly procedure was initiated previously for stimulus presentation, using animated colorful shapes (1.97º x 1.97º of visual angle) accompanied with melodic sounds. Calibration points were manually presented in the corners and center of the screen and were repeated until a satisfactory calibration result was determined by the experimenter. Raw gaze data through sample reports for each participant was extracted using Data Viewer (SR Research, 2017a).

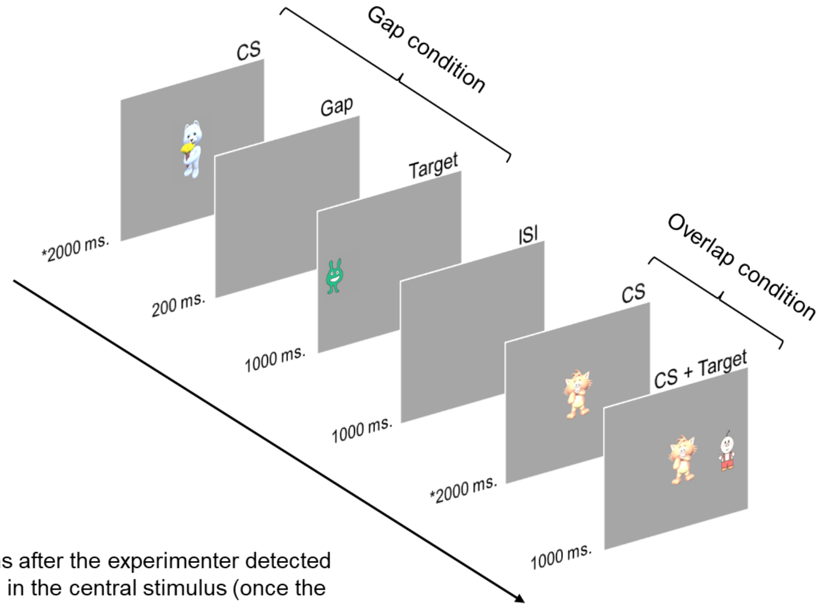
Fixations were parsed using the Python implementation of the identification by two-means clustering (I2MC) algorithm (Hessels et al., 2017), establishing a minimum fixation duration of 100 ms. This automatic algorithm was developed to deal offline with noisy data when periods of data loss could occur. Also, it is less affected by precision differences between 0-2° of RMS-s2s deviations, which is rarely over 3° in infant research (Hessels et al., 2017). Once pre-processed, data reduction was performed using custom-written Python 3 code.

3.3. Experimental tasks

3.3.1. Gap-overlap task.

We used a similar procedure to the gap-overlap task previously developed (Holmboe et al., 2018) at 6-, 9- and 16-18 months of age, considering only gap and overlap conditions. Differences between overlap and gap conditions have been recently proposed to be a good measure to study the development of disengagement ability during infancy (Cousijn et al., 2017), even recommending the exclusion of a baseline condition. Trials started with the presentation of an animated stimulus on the center of the screen (10.31° x 10.31°). Once the experimenter observed a fixation on the stimulus, a key was pressed to continue with the trial. In overlap conditions, the central stimulus remained on screen during the presentation of an animated peripheral target (6.76° x 6.76°). On the contrary, in gap conditions, the central stimulus disappeared from the screen, and a 200 ms gap interval was introduced before the onset of the peripheral target to induce the gap-overlap effect (Csibra et al., 1998). Peripheral targets were presented on the left or right side (13.11° of eccentricity to the nearest edge of the stimulus) of the screen for 1000 ms (see Figure 3.1). Forty-eight trials were presented in a pseudo-randomized order, avoiding more than two consecutive trials of the same condition to be sequentially repeated. Central and peripheral stimuli were randomly chosen from a pool of 74 and 6 stimuli for central and peripheral stimuli, respectively. Infants needed to look at the central stimulus during the last 200 ms before the peripheral target presentation to validate the trial, otherwise it was considered invalid and removed from analysis.

Two 16.34º x 20.47º areas of interest (AOIs) were created for the peripheral targets, while a 15.4º x 20.47º AOI was generated for the central stimulus. Saccade latencies (SL) were computed on valid trials subtracting the onset of the first fixation on the peripheral target from the target onset. SLs below the threshold of 120 ms were considered anticipatory and removed from the analysis (Csibra et al., 2001). As disengagement is still under development at this age, not only SLs but also failures to disengage from the central stimulus provide information about disengagement ability. Disengagement failure involves a fixation only in the central stimulus in overlap trials, or in the central area of the screen in gap trials, until the peripheral target offset. This measure was coded previously by Nakagawa & Sukigara (2013) for descriptive purposes but was not analyzed. Infants were removed from subsequent analyses if: 1) Did not achieve a minimum of 4 valid trials in each experimental condition and 2) Experienced family interference during task administration or 3) Did not have enough data for pre-processing steps. Criteria 1 was not met by 25 infants at 6 months, 11 at 9 months, and 6 at 16-18 months. Criteria 2 and 3 were met by 3 and 14 infants at 6 months.



* 2000 ms after the experimenter detected a fixation in the central stimulus (once the spacebar was pressed)

Figure 3.1. Procedure of the gap-overlap task illustrating both gap and overlap conditions.

3.3.2. Visual Sequence Learning (VSL) task.

The VSL task consists of the presentation of looming stimuli in a fixed sequence (Clohessy et al., 2001). Stimuli were presented during 1800 ms and consisted of a dynamic presentation of a picture varying in size (small-medium-small-medium-large stimulus size), to create a zoom looming effect. The small and medium stimuli sizes were presented for 150 ms each to induce the looming effect, while the large size remained for 1200 ms. The stimulus presentation was followed by a blank screen for a total of 800 ms that served as the anticipatory period between stimuli following. We adapted the original task to 6 and 9 months of age, while the original version was employed at the 16-18 months session. The details of the different versions of the task are described in the following sections.

We considered the total number of stimuli fixations as a measure of sustained attention, as it provides information about the active engagement of the infant during the duration of the task. We defined a reactive (e.g. stimulus presentation) and anticipatory period (e.g. blank screen) to identify reactive and anticipatory looks. Reactive looks are defined as fixations on the stimulus that occurred during the reactive period, as long as the infant did not perform correct anticipation in the previous anticipatory period (in such cases the observed fixation on the stimulus would be anticipatory instead of reactive). On the other hand, fixations that occurred during the anticipatory period and were preceded by a stimulus fixation in the previous trial were considered anticipatory looks. This ensures that before performing anticipation, the infant was engaged in the task, attending to the location of the previous stimulus before anticipating. This coding avoids computing artifactual anticipations (i.e. infants directing their gaze outside the screen).

Anticipatory looks that occurred in the first 200 ms of the anticipatory period were removed, as fixations occurring during this lapse of time might not reflect a real expectation. Instead, we considered the first 200 ms of the reactive period, as a saccade would have been prepared before the onset of the stimulus (Canfield & Haith, 1991; Figure 3.2).

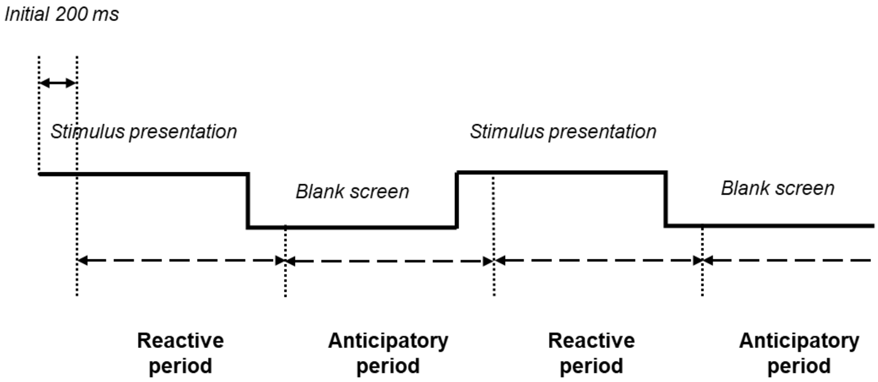
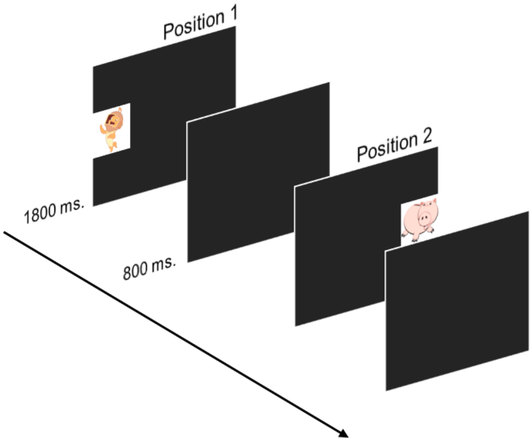


Figure 3.2. Timings considered for the reactive and anticipatory periods. The initial 200 ms of each period were discarded, considering instead the first 200 ms of the next period.

3.3.2.1. VSL task: 6-month-old version

An adapted version of the original VSL task was developed for this age. Similarly to the expectation paradigm employed by Haith et al. (1988), we presented stimuli in the centered-left (position 1; 14.93º x 9.46º of eccentricity to the nearest edge of the box) and centered-right side (position 2; 14.93º x 9.46º of eccentricity) of the screen in a fixed sequence (1-2; see Figure 3.3). Infants were presented a total of 24 trials. The first 4 trials were considered practice trials (16.6% of total trials), while the remaining 20 trials were considered experimental. Two 19.02º x 26.56º areas of interest (AOI) were defined around each of the possible stimulus locations in order to compute stimuli fixations, reactive and anticipatory looks.

We computed the percentage of stimulus fixation over the total number of experimental trials, as well as the proportion of reactive looks and correct anticipations based on total stimulus fixations. As this version of the VSL task does not allow incorrect anticipations to be performed, correct anticipations are also considered as the total anticipations performed in the task. In order to be considered for statistical analysis, infants must have more than 50% of trials with stimulus fixations in both practice and experimental trials (Rothbart et al., 2003). A total of 42 infants were excluded due to not meeting the experimental criteria of trials with stimulus fixations (*n* = 33), due to parent interference (*n* = 3) or not having enough gaze data (*n* = 6).



Sequence of positions: 1 – 2 – 1 – 2 – 1 – 2

Figure 3.3. Procedure for the VSL task for 6-month-old infants.

3.3.2.2. VSL task: 9-month-old version.

A modification of the sequence was introduced in the 9 months version of the task (1-1-2; Canfield et al., 1991; see Figure 3.4), to introduce a distinction between easy and complex trials (Clohessy et al., 2001). For easy trials (unambiguous; context-free), the anticipation of the next stimulus position could be unambiguously predicted (i.e. position 2 is always followed by position 1). On the other hand, for complex trials (ambiguous; context-dependent), infants must monitor the sequence keeping track of previous positions in order to be able to correctly anticipate the following location, as the correct anticipation of the next would depend on the previous location to the current one (i.e. position 1 could be followed by position 1 if it is the first occurrence, or by position 2 if it is the second occurrence in the sequence). Again, stimuli were presented in the centered-left (position 1) and centered-right side (position 2) of the screen. Infants completed a total of 48 trials, from which the first 9 trials were considered practice trials (18.75% of total trials), leaving a remaining of 39 experimental trials. Two 19.02º x 26.56º areas of interest (AOI) were defined around each stimulus position to compute stimuli fixations, reactive looks, and anticipatory looks.

As in the previous version, we computed the percentage of stimulus fixations over the total number of experimental trials and the proportion of reactive looks, total and correct anticipations based on the infant's total stimulus fixations. Total anticipations included both correct and incorrect anticipations, which reflect a voluntary intention to perform an anticipatory look to a location in which something is expected to occur, independently of its accuracy. In addition, we computed the proportion of correct anticipations based on total anticipations for each trial type (easy vs. complex; Rothbart et al., 2003). It should be noted that in trials in which position 1 is presented twice, infants are not likely to move attention from that position, coding a stimulus fixation but not a reactive or anticipatory look. This would lead to a lower number of reactive and anticipatory looks compared to the other versions of the task. To compute metrics for the 9 months version of the task, we only considered those trials with an overt orienting of visual attention, that is in trials from position 1 to position 2 (complex), and from position 2 to position 1 (easy). A total of 34 infants were excluded due to not meeting the trials requirements criterion (*n* = 28), experiencing parent interference (*n* = 2), or infant crying (*n* = 4).

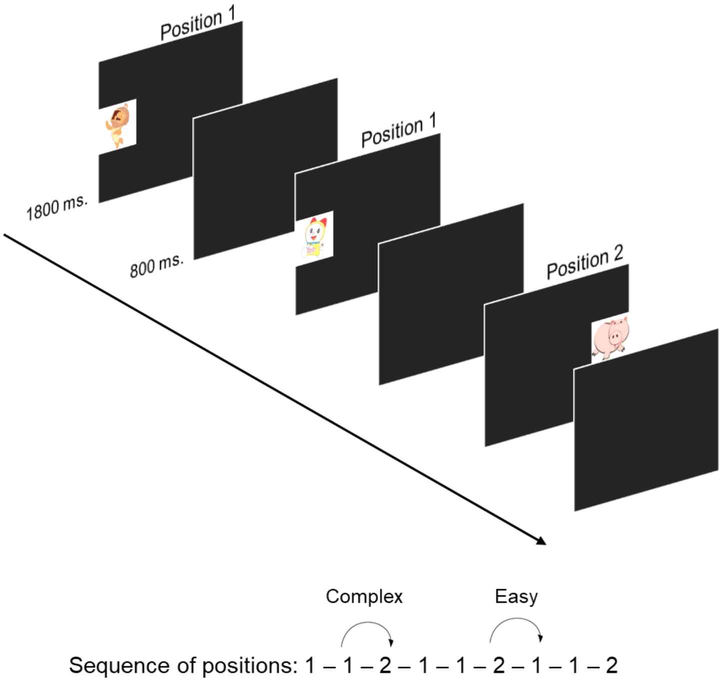


Figure 3.4. Procedure for the VSL task for 9-month-old infants.

3.3.2.3. VSL task: 16-18 month-olds version

Following Clohessy et al. (2001) stimuli were displayed in three locations on the screen: upper right corner (position 1, 14.93º x 4.76º of eccentricity to the nearest edge of the box), upper left corner (position 2, 17.58º x 7.59º eccentricity) and centered- bottom (position 3, 19.28º x 9.46º eccentricity) in a 1-2-1-3-… sequence. Infants were shown a total of 64 trials. The first 12 trials were considered practice (18.75% of total trials), with a remaining of 52 experimental trials. Three 19.02º x 14.03º areas of interest (AOI) were defined around each stimulus position to compute stimuli fixations, reactive looks, and anticipatory looks. Similar to the 9-month-old version, we were able to differentiate between easy and complex trials. For easy trials, the anticipation of the next stimulus position could be unambiguously predicted (context-free; i.e. position 2 and 3 are always followed by position 1). On the other hand, for complex trials the next stimulus position is ambiguous, being only correctly predicted if keeping track of the previous position to the current one (context-dependent; i.e. position 1 can be followed by position 2 or 3 depending on the previous position, see Figure 3.5).

We computed the percentage of stimulus fixations over the total number of experimental trials, as well as the proportion of reactive looks, total anticipations, and correct anticipations based on the child's total stimulus fixations. We also computed the proportion of correct anticipations based on total anticipations for each trial type (easy vs. complex; Rothbart et al., 2003). A total of 15 infants were excluded due to not meeting the trials requirements criterion (*n* = 13), or experiencing parent interference (*n* = 2)

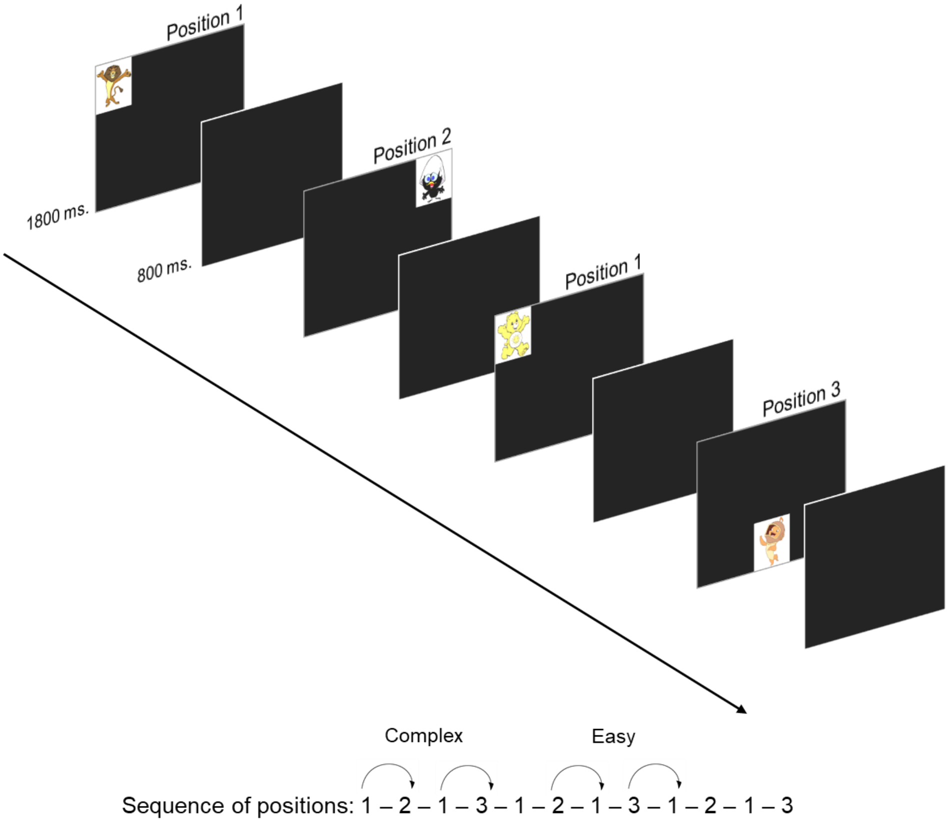


Figure 3.5. Procedure of the VSL task for 16-18 month-old infants.

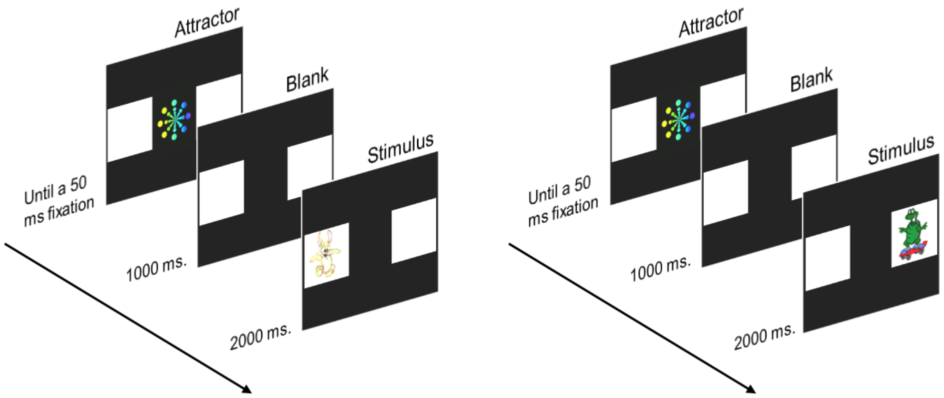
3.3.3. Switching task

To evaluate attention flexibility, we employed an adaptation of the-switching task (Conejero & Ruda, 2018; Kóvacs & Mehler, 2009). During the entire duration of a trial, two white boxes (15º x 15º) were displayed at either side of the screen (9.66º of eccentricity to the nearest edge of the box) over a black background. Each trial started with a colorful animated attention attractor in the center of the screen, that is between the white boxes, coupled with music. After a 50 ms fixation was detected on the attractor, an anticipatory period was introduced displaying only the white empty boxes during 1000 ms. Finally, an animated cartoon coupled with a funny sound was presented for 2000 ms in one of the boxes as a reward.

The task comprises two blocks. In the first block (*pre-switch*), the stimulus was always displayed in the same location on the same box during a maximum of 18 trials. The contingency of the events aims at infants to learn to anticipate the rewarded location. A minimum of 3 correct anticipations were required before trial 18 in order to move to the next block. Also, a minimum of 9 trials were administered if infants achieved the correct anticipations criterion early in the task. In the following block (*post-switch*) a different stimulus was presented on the remaining non-rewarded box for twelve trials (see Figure 3.6). The goal of this block is to measure infants' perseverative anticipations of the previously rewarded location during the pre-switch block. Both stimulus location and identity were counterbalanced between participants.

Two 19.57º x 27.4º AOIs were generated for the left and right sides of the screen (Conejero & Rueda, 2018). First, we coded all trials with a fixation on the stimulus in order to ensure that the infant was attending to the location in which the stimulus was being presented in each block. Regarding anticipatory fixations, we excluded those that occurred during the first 200 ms of the anticipatory period as they do not reflect a real expectation given that this is the time required to plan and perform a saccade (Canfield & Haith, 1991), considering instead the first 200 ms of the stimulus presentation. All anticipatory fixations were required to be followed by a fixation on the stimulus as a form to ensure that the infant was engaged in the trial when the anticipation was performed. This would help to avoid artifactual anticipations (i.e. detecting an anticipation when the infant was moving gaze outside the screen) which could not be followed by a fixation on the stimulus. If anticipations to the correct and incorrect side were recorded on the same trial, only the anticipatory look with the higher duration was considered (Kóvacs & Mehler, 2009). The proportion of correct anticipations in the pre-switch block and of perseveration in the post-switch block were computed over the number of total anticipations (Rothbart et al., 2003). The former was used as a proxy for endogenous attention control, while the latter targeted infants' attentional flexibility. Moreover, we also computed the trial at which infants achieved the criterion of 3 correct anticipations in the pre-switch block as a measure of rule learning.

Correct anticipations in the pre-switch block were analyzed for all infants, including those that performed less than 3 correct anticipations. This was decided to keep variability between waves. Consequently, infants were excluded from the analysis of correct anticipations if they: 1) Displayed a tendency to anticipate the non-rewarded location (6 months n = 16; 9 months n = 9; 16-18 months n = 7), 2) Experienced family interference during task administration (6 months n = 2; 16-18 months n = 1) or 3) Cried during task administration (6 months n = 1; 9 months n = 2; 16-18 months n = 1). There were 5 cases at 6 months and one case at 9 and another at 16-18 months that performed the task but there wasn't enough gaze data to parse fixations. However, only infants with 3 or more correct anticipations in the pre-switch block were considered for analysis of perseverative errors. In this sense, infants should show evidence of rule learning in the pre-switch block to fairly consider perseverative behaviour during the post-switch. Infants that did not achieve this criterion were excluded from perseverations analysis (6 months n = 39; 9 months n = 33; 16-18 months n = 16). Table 3.2 presents a summary of the main dependent variables derived from each attentional task and the attentional process that they target.



Pre-switch block

Post-switch block

Figure 3.6. Procedure for the switching task. Locations of stimulus presentation in the pre-switch block were counterbalanced between participants.

Table 3.2.

Comparison of scores computed by age.

Task	Dependent variable	Attentional process
Gap-overlap	Median saccade latency	Attentional latency to disengage
	Disengagement failure	Attentional failure to disengage
Visual-Sequence Learning	Stimulus fixations	Sustained attention
	Reactive looks	Exogenous attention orienting
	Total anticipations^1	Endogenous attention orienting
	Correct anticipations^2	Endogenous attention orienting
	Easy correct anticipations^3	Endogenous attention orienting-based learning
	Complex correct anticipations^3	Endogenous attention orienting + monitoring-based learning
Switching	Correct anticipations (pre-switch)	Endogenous attention orienting contingent-based learning
	Criterion achieved (pre-switch)	Task rule learning
	Perseverations (post-switch)	Endogenous attention flexibility

Note. 1) As the 6-month-old version of the VSL task does not allow for incorrect anticipations to be performed, correct anticipations are also the total number of anticipations performed in this version of the task. In this case, this measure was analyzed as both, correct and total anticipations. 2) As the 6-month-old version of the VSL task does not allow incorrect anticipations, the proportion of correct anticipations was computed over the number of stimulus fixations instead of total anticipations to make it comparable between waves. 3) Easy and complex correct anticipation were not computed at 6 months as the version of the VSL task does not consider this distinction between trials.

3.4. Attention control development from 6 to 16-18 months of age: Evidence from attention disengagement, anticipatory attention, and attention flexibility.

3.4.1. Hypothesis

Regarding the gap-overlap task, we expect a decrease in median saccade latencies (mdSL) and disengagement failure (DF) with age for the overlap condition. As a result of a higher attentional control, toddlers would be more skillful at disengaging the foveated central stimulus to reorient attention faster, compared to young infants. For the gap condition, we also expect infants to show a decrease in mdSL with age, that is, we anticipate toddlers to show a higher speed to orient attention faster from the central stimulus towards the peripheral target.. However, age differences are expected to be less steep in the gap than in the overlap condition. In the former, disengagement is externally eased by the disappearance of the central stimulus, while in the latter disengagement requires the maturation of brain structures related to endogenous attention control. We do not anticipate age differences in disengagement failure in the gap condition as it is facilitated with the removal of the central stimulus.

In the VSL task, we expect an increase in stimulus fixations with age, suggesting a higher ability to maintain attention across the task at older ages. On the contrary, we hypothesized a reduction in reactive looks but an increase in correct anticipations with age. Toddlers would be more likely to endogenously anticipate the location of the next stimulus, thus reducing the engagement of exogenous attention. In this respect, we also expect an increase in total anticipations from 9 to 16-18 months, with toddlers showing a higher ability to voluntarily attempt to anticipate the next stimulus location. Similarly, we hypothesize an increase in easy and complex correct anticipations from 9 to 16-18 months. This increase is expected to be higher for complex compared to easy correct anticipations, as a result of a higher gain in context monitoring abilities for complex trials with age.

For the switching task, we anticipate an increase in correct anticipations in the pre-switch block, but a decrease in the trial at which infants achieve three correct anticipations. This would indicate a higher ability to learn the underlying rule earlier in the block, leaving more room to correctly anticipate during the block. In consonance with the perseverative developmental pattern found in the A-not-B task, we expect an increase in perseverative errors from 6 to 9 months, but a reduction from 9 to 16-18 months.

3.4.2. Analysis strategy

Linear Mixed Models (LMM) were built to test the effects of Age, Condition, and their interaction while handling missing values implementing Maximum Likelihood (ML) estimation (Funatogawa & Funatogawa, 2019). LMMs are frequently implemented to analyze continuous variables for longitudinal data, involving the definition of fixed and random effects. The former is the main factor of interest in most experimental procedures (i.e. experimental conditions). An *F*-test is computed when multiple fixed effects are considered in the model, as well as their interactions. Random effects are unobserved random factors specific to the subject, allowing to introduce variability for a particular participant at each time point (West et al., 2015). This way we keep the independence between subjects while accounting for the dependence of the repeated measures for each participant over time (Long, 2012). In general, this allows to keep a higher variance in the data. In case a statistically significant effect of Age was found, we also computed the growth rate.

For model building we followed the top-down strategy proposed by Verbeke & Melenberghs (2000), removing predictors without a significant contribution to the model. For this, a first full model was fitted including all fixed and random effects, as well as the interactions of fixed effects. Then we first tested the deletion of interaction effects from the full model, followed by main effects (Long, 2012), to test if a more parsimonious model (reduced model) increased in model fit. A Likelihood Ratio Test (LRT) evaluated the contribution of the effects in terms of significant differences between the full and the reduced model in a χ^2 distribution (Long, 2012; West et al., 2015). A statistically significant result adds support for the full model, indicating that the removed effects significantly contributed to model fit and should be retained. If the test was found not statistically significant, the effects were removed and the reduced model was considered as the new full model for subsequent comparisons.

In the final step of model building, different covariance structures were tested as recommended by Shek & Ma (2011) for unequally spaced longitudinal data. Three different covariance structures employed with repeated measures data were tested: 1) Unstructured (UN), 2) Compound Symmetry (CS), and 3) First-Order Autoregressive (AR1). UN covariance is the more parsimonious with fewer restrictions, assuming that neither the variance nor the correlation between data points is homogeneous across waves. It leads to a large increase in the number of parameters as the number of time points increases further than three (Heck et al., 2014). CS covariance allows us to examine if the correlation and variance between data points are homogeneous across waves independently of the time interval between waves (Funatogawa & Funatogawa, 2019). Finally, AR1 covariance assumes the variance to be homogeneous, but the serial correlation between data points is reduced across waves, especially when the time interval between waves increases (Funatogawa & Funatogawa, 2019). Again, LRT between covariance structures was applied to find the one that offered the best model fit. For this, the covariance structure with the highest number of parameters (UN) was compared with the rest (Shek & Ma; 2011). In case the LRT did not reveal statistically significant differences, the covariance structure with the lowest -2 Log-Likelihood (-2LL) fit index was selected.

After fitting the LMM, the normality of the residuals was explored, especially for those variables that did not follow a normal distribution. Saterthwaite approximation was employed to compute degrees of freedom. Effect size was measured using Cohen's *w* for χ^2 distributions, with a threshold of .10, .30, and .50 indicating a small, medium, and large effect, respectively.

$$\text{Cohen's } w = \frac{\sqrt{\Delta\chi^2}}{n \text{ x } \Delta df}$$

3.4.3. Results

3.4.3.1. Descriptive statistics

Gender differences and the normality assumption were tested for each dependent variable for each task and in each wave. In the gap-overlap task, infants did not differ by gender in the number of trials completed (all *ps* > .52) or in the number of valid trials (all *ps* > .13) between conditions at any wave (see Table 3.3). Moreover, no gender differences were found neither for mdSL (all *ps* > .10) nor DF (all *ps* > .09) at any wave. Shapiro-Wilk test indicated that mdSL in the gap condition did not follow a normal distribution at 6 (*W* = .97, *p* = .03) and 16-18 months (*W* = .92, *p* < .01). Regarding DF, it did not follow a normal distribution at any wave (all *Ws* > .76, all *ps* < .01) for both overlap and gap conditions. Applying Tukey's Ladder of Power (Tukey, 1977), a normal distribution for mdSL was achieved after a logarithmic transformation in all waves, while for DF a square root transformation was applied.

Concerning the VSL task, gender differences were not found in the number of trials completed (all *ps* > .38) or in any of the VSL variables at any wave (all *ps* > .08; see Table 3.4). Shapiro-Wilk test and distribution plots suggested a non-normal distribution for most of the variables especially at 6 (all *Ws* > .88, all *ps* < .01) and 9 months (all *Ws* > .81, all *ps* < .01), with a negative skewness for stimulus fixations and reactive looks but positive for correct anticipations. None of the suggested transformations in Tukey's Ladder of Powers (Tukey, 1977) approximated a normal distribution for any of the variables.

Finally, for the switching task no gender differences were found in the number of trials completed (all *ps* > .64), correct anticipations, the pre-switch task criterion (all *ps* > .20), or perseverations at any wave (all *ps* > .20; see Table 3.5). Concerning the normality of the dependent variables, the Shapiro-Wilk test indicated a non-normal distribution for the proportion of correct anticipations, pre-switch block criterion, and proportion of perseverations at 6 (all *W* > .65, all *ps* < .001), 9 (all *W* > .57, all *ps* < .001) and 16-18 (all *W* > .68, all *ps* < .03) months of age. After applying several transformations considered in Tukey's Ladder of Powers (Tukey, 1977), we weren't able to approximate a normal distribution.

Table 3.3.

Descriptive statistics for dependent variables in the gap-overlap task at each wave.

	Mean (*SD*)			Min (*Max*)		
	6 months	9 months	16-18 months	6 months	9 months	16-18 months
mdSL gap (ms)	276 (*30.18*)	245 (*23.65*)	222 (*22.27*)	222 (*358*)	200 (*312*)	182 (*310*)
mdSL overlap (ms)	452 (*100.40*)	441 (*93.11*)	461 (*84.09*)	264 (*776*)	264 (*666*)	268 (*707*)
DF gap (%)	6.71 (*7.02*)	6.19 (*5.86*)	2.86 (*3.84*)	0 (*40*)	0 (*27.27*)	0 (*14.81*)
DF overlap (%)	13.92 (*9.16*)	13.04 (*9.01*)	13.46 (*9.73*)	0 (*36.66*)	0 (*38.46*)	0 (*37.04*)
Trials completed gap (trials *n*)	22.37 (*3.28*)	22.28 (*2.90*)	22.40 (*3.47*)	11 (*24*)	10 (*24*)	9 (*24*)
Trials completed overlap (trials *n*)	22.50 (*3.09*)	22.21 (*2.78*)	22.24 (*3.95*)	11 (*24*)	10 (*24*)	8 (*24*)
Valid trials gap (trials *n*)	11.85 (*4.01*)	12.17 (*4.11*)	13.74 (*4.32*)	4 (*21*)	4 (*20*)	4 (*22*)
Valid trials overlap (trials *n*)	11.88 (*3.94*)	11.44 (*4.11*)	13.45 (*4.40*)	4 (*22*)	4 (*20*)	4 (*22*)

N*ote*. mdSL = Median Saccade Latency; DF = Disengagement Failure.

Table 3.4.

Descriptive statistics for dependent variables in the VSL task at each wave.

	Mean (*SD*)			Min (*Max*)		
	6 months	9 months	16 months	6 months	9 months	16 months
Stimuli fixations (%)	84.70 (*14.21*)	82.33 (*14.98*)	82.72 (*13.63*)	55 (*100*)	51.28 (*100*)	51.92 (*100*)
Reactive looks (%)	88.31 (*11.19*)	87.44 (*10.69*)	89.09 (*6.47*)	57.14 (*100*)	58.82 (*100*)	70.58 (*100*)
Total antic. (%)	N/A	19.14 (*14.13*)	24.56 (*12.94*)	N/A	0 (*61.76*)	0 (*72.55*)
Correct antic. (%)	11.51 (*10.89*)	13.07 (*11.19*)	10.48 (*6.32*)	0 (*38.88*)	0 (*42.83*)	0 (*29.41*)
Easy correct antic. (%)	N/A	37.26 (*35.68*)	18.38 (*19.82*)	N/A	0 (*100*)	0 (*73.33*)
Complex correct antic. (%)	N/A	22.54 (*27.50*)	22.63 (*16.09*)	N/A	0 (*100*)	0 (*66.66*)
Trials completed (trials *n*)	23.78 (*.63*)	47.55 (*1.33*)	63.04 (*2.49*)	20 (*24*)	39 (*48*)	50 (*64*)

Note. Reactive, total, and correct anticipations are computed as a proportion of stimuli fixations. Easy and complex correct anticipations were computed as a proportion of total anticipations. N/A = Not Applicable.

Table 3.5.

Descriptive statistics for dependent variables in the switching task at each wave.

	Mean (*SD*)			Min (*Max*)		
	6 months	9 months	16 months	6 months	9 months	16 months
Total anticipations (pre-switch; %)	45.31 (*28.94*)	53.41 (*26.61*)	57.24 (*26.47*)	0 (*100*)	0 (*100*)	0 (*90.90*)
Total anticipations (post-switch; %)	69.84 (*25.05*)	82.49 (*19.43*)	85.38 (*12.39*)	0 (*100*)	12.50 (*100*)	0 (*100*)
Correct anticipations (%)	74.55 (*36.14*)	72.90 (*38.29*)	81.60 (*29.15*)	0 (*100*)	0 (*100*)	0 (*100*)
Criterion achieved (trial *n*)	8.23 (*4.01*)	7.32 (*3.21*)	6.60 (*2.80*)	4 (*18*)	4 (*18*)	4 (*13*)
Perseverative errors (%)	68.41 (*34.14*)	72.50 (*29.06*)	43.12 (*24.34*)	0 (*100*)	0 (*100*)	9.09 (*100*)
Trials completed (pre-switch; trial *n*)	10.30 (*2.50*)	9.68 (*1.79*)	9.50 (*1.14*)	9 (*18*)	9 (*18*)	9 (*13*)
Trials completed (post-switch; trial *n*)	11.96 (*.20*)	12 (*0*)	11.67 (*1.73*)	11 (*12*)	12 (*12*)	12 (*12*)

Note. Only infants with a minimum of 3 correct anticipations in the pre-switch block are considered for descriptive statistics of variables in the post-switch block.

3.4.3.2. Development of attention disengagement: gap-overlap task

Missing data

Infants with missing data due to follow-up nonattendance or protocol task omission at 9 or 16-18 months were included in the analysis and estimated implementing ML estimation. As the gap-overlap task was the last of the three eye-tracking tasks, some infants experienced fatigue at the end of the second task. In those cases, the task was omitted by protocol (i.e. not initiated), in order to guarantee data for other tasks applied later in the session. Data was not estimated if infants meet task exclusion criteria, or did not reach enough gaze data due to infant reasons (i.e. crying or being distracted, or distressed during the task), because of lack of confidence in fulfilling the *missing at random* assumption. It is worth noting that the sample at 6 months diminished from 100 to 90 cases, as n = 5, n = 3, and n = 2 at 16-18 months did not have data suitable for estimation, due to the reasons appointed before, at 9, 16-18 months or both, respectively (see Table 3.6)

As LMM assumes that data are missing completely at random (MCAR) or missing at random (MAR), we tested the randomness of the missing values for the dependent variables included in the model. We followed the next steps: 1) Little's test was performed to analyze if data was MCAR; 2) Explore whether gender influenced the pattern of data missingness; and 3) Explore whther differences in missing data are found concerning sociodemographic factors. Little's test was not found statistically significant for mdSL in the overlap (χ^2 = 2.57, df = 5, p = .76) or gap (χ^2 =2.92, df = 5, p = .71) conditions. In the same direction, the test was not found statistically significant for DF in the overlap (χ^2 =1.57, df = 5, p = .90) or gap (χ^2 =2.59, df = 5, p = .76) conditions.

Similarly, Little's test did not show differences in the pattern of missingness due to gender. Data missingness in mdSL was the same for boys in the overlap (χ^2 = 5.09, *df* = 5, *p* = .40) and gap (χ^2 = 1.98, *df* = 5, *p* = .85) condition, compared to girls in the overlap (χ^2 = 7.71, *df* = 5, *p* = .17) and gap (χ^2 = 4.87, *df* = 5, *p* = .43) conditions. Data missingness for DF was similar for boys in the overlap (χ^2 = .93, *df* = 5, *p* = .97) and gap (χ^2 = 4.13, *df* = 5, *p* = .53) conditions than for girls in overlap (χ^2 = 6.52, *df* = 5, *p* = .26) and gap (χ^2 = 2.61, *df* = 5, *p* = .76).

Finally, data missingness at 9 and 16-18 months was dummy coded, exploring differences (Holmboe et al., 2018) by SES and CHAOS. Independent t-tests did not show statistically significant differences in data missingness at 9 months (all *ps* > .12) or 16-18 months (all *ps* > .25) in SES or CHAOS. Although bias could not be completely excluded, test statistics did not show associations between the pattern of missing data and gender or sociodemographic variables.

Table 3.6.

Descriptive statistics of the sample at each wave for the gap-overlap task.

	6 months	9 months	16-18 months
n visit lab	160	131	103
n inclusion criteria	142	122	91
n valid data	100	76	56
n with estimable data[1]	90	62	42
n missing data from those with valid data at 6 months[2] (%)	0 (*0%*)	28 (*31.1%*)	48 (*53.33%*)

Note. 1. The number of infants diminished from 100 to 90 at 6 months as infants with data not suitable for estimation at 9 (*n* = 7), and 16-18 months (*n* = 3), were excluded from analyses. 2. *n* and percentage of participants with missing data over participants with data at 6 months (*n* = 90).

Median saccade latency (mdSL)

We build a full LMM introducing Age (3: 6 vs. 9 vs. 16-18 months) and Condition (2: overlap vs. gap) as fixed effects with random intercept. After fitting the full model, we built a reduced model removing the interaction term Age x Condition to test changes in model fit (see Appendix S.1.1.). LRT was statistically significant (Δ-*2LL* = 169.26, *df* = 2, *p* < .001), adding support for the full model and to retain the interaction term between fixed effects.

Next, we compared the three covariance structures to find the one that offered the best fit to the data. Differences between the UN and CS models were found statistically significant (Δ-*2LL* = 165.37, *df* = 19, *p* < .001). The same differences were found between UN and AR1 models in the LRT (Δ-*2LL* = 165.29, *df* = 19, *p* < .001; see Appendix S.1.2.). As UN offered the lower -2LL fit index as supported by the LRTs, this covariance structure was selected to be used in the final model.

The final model was fitted with fixed effects of Age (3: 6 vs. 9 vs. 16-18 months) and Condition (2: overlap vs. gap), and the interaction term Age x Condition, including a random intercept and with UN covariance structure. Regarding fixed effects, a statistically significant main effect of Age (*F*(2, 58.97) = 12.03, *p* < .001) was found, with infants at 6 months showing a higher disengagement latency compared to 9 months (*p* < .001) and 16-18 months (*p* < .001). No differences were found between 9 and 16-18 months. A statistically significant main effect of Condition was also found (*F*(1, 70.84) = 1467.55, *p* < .001), with infants taking longer to disengage from the overlap compared to the gap condition. Finally, an Age x Condition interaction was found to be statistically significant ($F(2, 56.30) = 35.76$, $p < .001$). Differences between sessions indicated that for the gap condition ($F(2, 63.37) = 151.84$, $p < .001$), infants were slower to disengage at 6 compared to 9 ($p < .001$) and 16-18 months ($p < .001$). Moreover, at 9 months were slower to disengage compared to 16 months ($p < .001$). No statistically significant differences were found in the overlap condition ($F(2, 62.55) = 1.94$, $p = .15$; see Figure 3.7). Fixed factors (marginal pseudo-R^2) explained 75% of the variance, while both fixed and random factors (conditional pseudo-R^2) explained 81% of the variance. Model residuals were normally distributed as suggested by histograms and Q-Q plots.

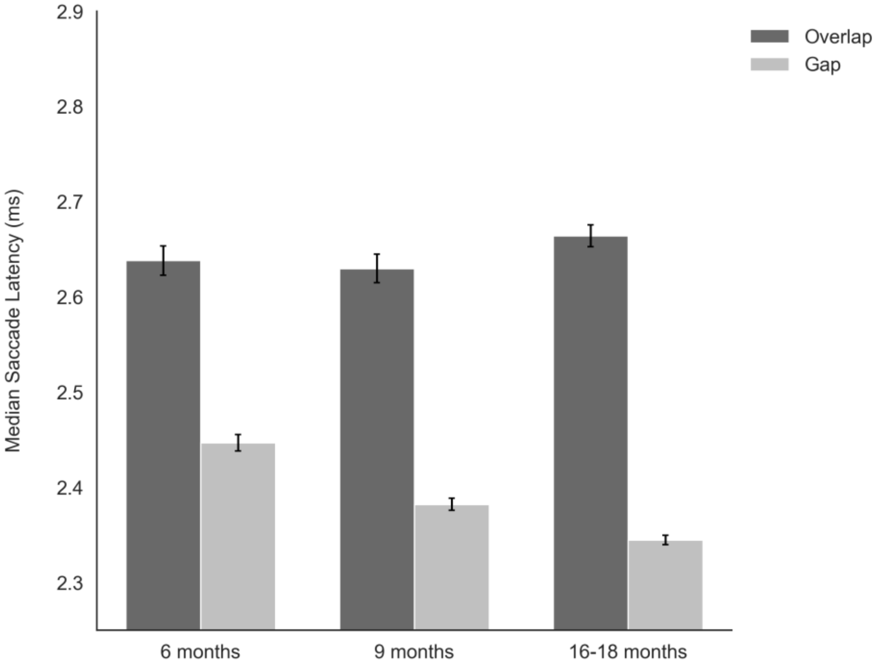


Figure 3.7. Bar plot showing the median saccade latency (log-transformed) for infants at each age of data collection for the overlap and gap conditions.

As the interaction Age x Condition was found statistically significant, we computed the growth rate by condition. We fitted an LMM introducing Age as a continuous variable. Age factor was centered as recommended by

(Shek & Ma, 2011) with 6 months = 0, 9 months = .25, and 16-18 months = .83, to keep the proportional distance between ages. Age and Condition were entered as a fixed effect to test growth rate differences between conditions, allowing the intercept to vary between subjects. Due to a data trend seen in plots between ages, we decided to include a quadratic Age factor (Age^2) in the model to test if it offered a better fit to the data.

In the first step, we built a full model including both, linear Age and quadratic Age^2 factors. Second, we fitted a reduced model removing the quadratic term, evaluating if the deletion of this factor led to an improvement in model fit. As the inclusion of the quadratic Age^2 term offered a better fit to the data (Δ-*2LL* = 66.75, *df* = 1, *p* < .001; see Appendix S.1.3.), it was retained.

We found a significant effect of the intercept (*β* = 2.65, *SE* = .01, *t*(327.20) = 322.33; *p* < .001). Centered Age slope was also statistically significant (*β* = −.19, *SE* =.03, *t*(2.74) = −5.23; *p* = .02), along with Age^2 slope (*β* = .29, SE =.03, *t*(2.74) = 5.90; *p* < .001). The negative linear slope of Age suggests that mdSL tends to linearly decrease over time. Nevertheless, this decrease in the slope shows a significant reduction in the change rate as indicated by the Age^2 factor. Finally, a statistically significant difference in the slope was found for infants in the gap condition compared to the overlap condition. Infants also showed a decrease over time in mdSL for the gap (*β* = −.15, *SE* =.02, *t*(19.54) = −8.63; *p* < .001) in comparison to the overlap condition, with the quadratic slope anticipating a plateau phase in the decrease of disengagement latencies for the gap condition.

Disengagement failure (DF)

The same steps specified in the previous model were followed. A full LMM model with Age (3: 6 vs. 9 vs. 16-18 months) and Condition (2: overlap vs. gap) as fixed effects with random intercept, as well as the interaction term between both, was built. As the LRT between the full and the reduced model was not found statistically significant (Δ-*2LL* = 4.74; *df* = 2; *p* = .09), the interaction term Age x Condition was removed (see Appendix S.1.2.). Comparing the covariance structures, we did not find statistically significant differences between UN and CS (Δ-*2LL* = 16.01; *df* = 19; *p* = .65) or AR1 (Δ-*2LL* = 15.61; *df* = 19; *p* = .68). In this case, AR1 covariance structure was selected as it offered the lowest –2LL fit index (see Appendix S.1.2.).

The final LMM was defined introducing fixed effects of Age (3: 6 vs. 9 vs. 16 months) and Condition (2: overlap vs. gap) as fixed effect with random intercept and AR1 covariance structure. A statistically significant main effect of Age was found (*F*(2, 189.14) = 3.44, *p* = .03). At 6 months of age, infants displayed a higher disengagement failure in comparison to 16-18 months (*p* = .04). Also, at 9 months infants displayed a tendency to fail to disengage more often than at 16-18 months of age (*p* = .08). Condition main effect was found statistically significant (*F*(1, 151.99) = 146.71, *p* < .001). Infants displayed a higher disengagement failure in overlap compared to the gap condition (*p* < .001). As the interaction Age x Condition was removed during model building, it was not computed in the final model (Figure 3.8). Marginal and conditional pseudo-R^2 was of 24% and 34%, respectively for DF.

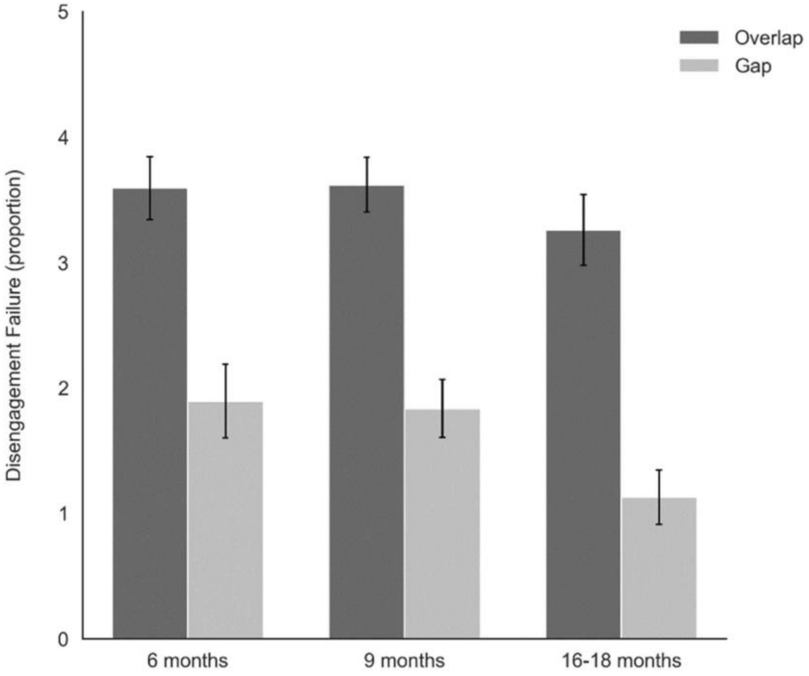


Figure 3.8. Bar plot showing the disengagement failure for infants at each age of data collection.

Although the interaction between Age x Condition was not found statistically significant, we computed the growth rate following the same steps as for mdSL analysis as the Age factor was found statistically significant. As previously, centered Age was introduced in the model as a continuous variable, with Condition as a fixed effect and with a random intercept. A significant effect of intercept was found (β = 3.47, *SE* = .14, *t*(316.91) = 24.85; *p* < .001). Only the linear Age term was retained in the model as the inclusion of the quadratic Age^2 factor was not supported by the LRT (see Appendix S.1.2.3.). The effect of the slope of Age was not found statistically significant (β = -.13, *SE* = .32, *t*(280.68) = -.42; *p* = .67). Results revealed a statistically significant difference in the slope of the gap condition in comparison to the overlap with age (β = -.96, *SE* = .42, *t*(224.28) = -2.26; *p* = 02), indicating that disengagement failure in the gap condition linearly decreases with age in comparison to the overlap condition.

3.4.3.3. Development of anticipatory attention and context monitoring: visual-sequence learning task

Missing data

Due to differences between versions of the VSL task, missing data analysis was completed in two steps: 1. Analysis of missing data for variables measured at 6, 9, and 16-18 months (i.e. stimulus fixations, reactive looks, total and correct anticipations); 2. Analysis of missing data for variables measures only at 9 and 16-18 months (i.e. easy and complex correct anticipations).

Missing data for variables measured at 6, 9, and 16-18 months

As for the previous task, infants with missing data as a result of follow-up nonattendance or protocol task omission were included in the analysis. Infants at 9 or 16-18 months that meet task exclusion criteria or did not have enough gaze data due to infant reasons (i.e. crying, distracted, or distressed during the task) were excluded from statistical estimation. The initial sample of 94 infants at 6 months decreased to 65, as n = 24 at 9 months and n = 5 at 16-18 months presented missing data not suitable for estimation based on the previous criteria (see Table 3.7).

In order to test the randomness of missing data points across sessions, we first explored if data were missing completely at random (MCAR) applying Little’s test. This assumption was also tested by splitting the database by gender to explore if gender affected incomplete data points. Finally, differences in the pattern of data missingness were also considered concerning the family’s sociodemographic factors.

Little’s test was not found statistically significant for stimulus fixations ($\chi^2 = 5.02$, $df = 5$, $p = .41$) but significant for reactive looks ($\chi^2 = 22.63$, $df = 5$, $p < .001$), total anticipations ($\chi^2 = 22.29$, $df = 5$, $p < .001$) and correct anticipations ($\chi^2 = 22.77$, $df = 5$, $p < .001$), indicating that the data was not MCAR, but MAR.

Next, we explored data missingness by gender. For boys, Little’s MCAR test was not found statistically significant for stimulus fixations ($\chi^2 = 3.64$, $df = 5$, $p = .60$), but for reactive looks ($\chi^2 = 16.91$, $df = 5$, $p < .01$), total anticipations ($\chi^2 = 16.41$, $df = 5$, $p < .001$) and correct anticipations ($\chi^2 = 16.55$, $df = 5$, $p < .01$). In the case of girls, Little’s MCAR test was not statistically significant for stimulus fixations ($\chi^2 = 4.82$, $df = 5$, $p = .44$), reactive looks ($\chi^2 = 9.28$, $df = 5$, $p = .10$) and total anticipations ($\chi^2 = 8.33$, $df = 5$, $p = .14$), but marginally significant for correct anticipations ($\chi^2 = 10.23$, $df = 5$, $p = .07$).

Finally, we explored the pattern of missing data in relation to sociodemographic factors. For this, the pattern of missing data was dummy coded, performing independent t-tests to explore differences by SES and CHAOS in these variables. Independent t-test did not reveal statistically significant differences in missing data at 9 (all *ps* > .10) or 16-18 months (all *ps* > .13). Consequently, as gender seems to influence missing data for variables measured at the three time points, it was controlled for when estimating missing values, assuming that data were missing at random (MAR). No other sources of a potential source of bias in data missingness were found.

Missing data for variables measured at 9 and 16-18 months

Little’s test was not statistically significant neither for easy correct anticipations ($\chi^2 = .33$, $df = 2$, $p = .85$) but marginally significant for complex correct anticipations ($\chi^2 = 5.71$, $df = 2$, $p = .06$). Exploring differences by gender, the pattern of data missingness did not differ between boys for easy correct anticipations (χ^2 = .30, *df* = 2, *p* = .86) and complex correct anticipations (χ^2 = 3.41, *df* = 2, *p* = .18), and girls for easy correct anticipations (χ^2 = .15, *df* = 2, *p* = .93) and complex correct anticipations (χ^2 = 1.88, *df* = 2, *p* = .39). In order to explore further sources of bias in the missingness of the dependent variables we explored whether the pattern of data at 16-18 months was related to environmental factors such as SES index or CHAOS. No differences were found in data missingness (all *ps* > .72). Although bias can not be completely discarded, data did not show any potential source of bias in the current variables in relation to gender or sociodemographic factors, and no need for variables to be controlled for when building models for each of these variables.

Table 3.7.

Descriptive statistics of the sample at each wave for the visual sequence learning task.

	6 months	9 months	16-18 months
n visit lab	160	131	103
n inclusion criteria	142	122	91
n valid data	100	83	67
n with estimable data[1]	72	59	40
n missing data from those with valid data at 6 months[2] (%)	0 (*0%*)	13 (*18.05%*)	32 (*44.44%*)

Note. 1) The number of infants diminished from 100 to 72 at 6 months, as infants with data not suitable for estimation at 9 (*n* = 21) or 16-18 (*n* = 7) months, were excluded from analyses. 2) *n* and percentage of participants with missing data over participants with valid data at 6 months (*n* = 68).

Stimulus fixations

We built an LMM with Age (3: 6 vs. 9 vs. 16) as a fixed effect with random intercept in order to test differences in stimulus fixation across testing sessions. The infant's gender was introduced in the model as a covariate as it was found to affect data missingness. No reduced model was computed as no other fixed effects were introduced along with Age. Although no statistically significant differences in the LRT were found between covariance structures (all *ps* > .09; see Appendix S.1.3.), we selected the UN covariance structure as it offered the lowest -2LL fit index. The age effect was not found statistically significant (*F*(2, 96.44) = 1.97, *p* = .14), with all infants displaying the same amount of stimulus fixations in the tasks across age (Figure 3.9). Fixed factors explained 2% of the variance, wile both fixed and random factors explained 22%, respectively.

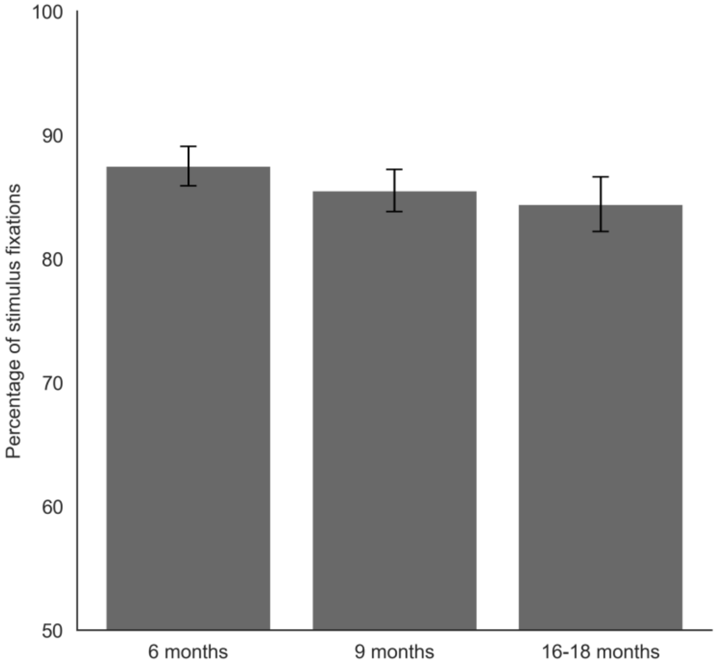


Figure 3.9. Percentage of stimulus fixation in the VSL task at 6, 9, and 16-18 months.

Reactive looks

A LMM was built introducing Age (3:6 vs. 9 vs. 16-18 months) as a fixed effect, random intercept, and gender as a covariate. UN covariance was employed as it offered the best fit to the data (see Appendix S.1.4.). Statistically significant differences were found in the LRT between UN with CS (Δ-*2LL* = 12.70; *df* = 4; *p* = .01) and AR1 (Δ-*2LL* = 11.97; *df* = 4; *p* = .02). No statistically significant main effect of Age was found (*F*(2, 48.41) = 1.64, *p* = .21), indicating an absence of differences in reactive look with age (Figure 3.10). Fixed factors explained 1% of the variance while including random factors increased it to 13%.

Correct anticipations

Correct anticipations were analyzed across the three ages evaluated, as easy and complex correct anticipations were only computed in the 9- and 16-18-month versions of the VSL task. Again, Age (3: 6 vs. 9 vs. 16-18 months) was introduced as a fixed effect, along with a random intercept and infant's gender as a covariate with UN covariance structure. Statistically significant differences were found in the LRT between UN with CS (Δ-*2LL* = 31.96; *df* = 4; *p* < .001) and AR1 (Δ-*2LL* = 31.50; *df* = 4; *p* < .001; see Appendix S.1.5.). Age effect was not found statistically significant (*F*(2, 22.76) = 2.11, *p* = .12; Figure 3.10), suggesting a lack of age differences in correct anticipations. Fixed factors explained 2% of the variance, while including random factors explained 12%.

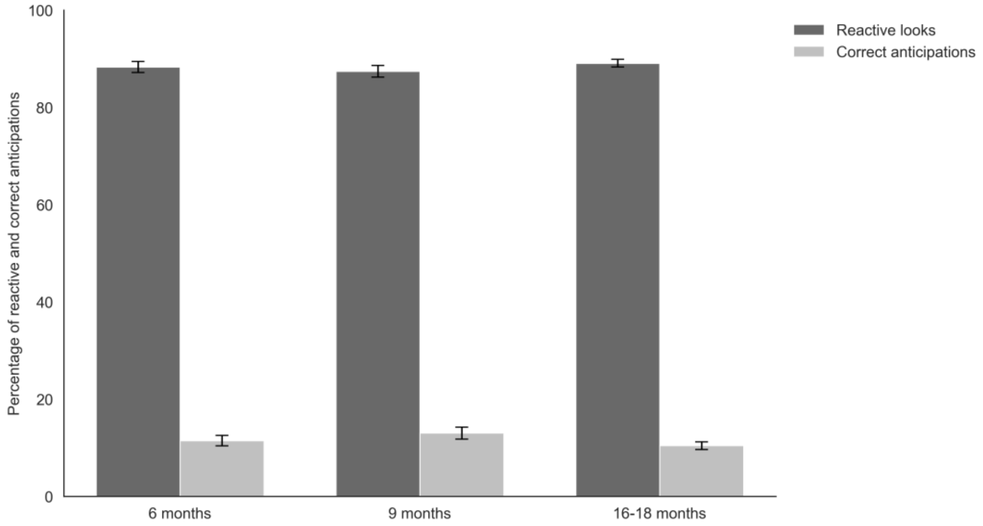


Figure 3.10. Percentage of reactive looks and correct anticipations in the VSL task at 6, 9, and 16-18 months of age.

Total anticipations

Next, we tested potential differences in total anticipations with age. We built a LMM introducing Age as a fixed factor (3: 6 vs. 9 vs. 16-18 months) with a random intercept. No significant differences were found between UN and CS or AR1 in a LRT (all *ps* = .27), although UN covariance was selected as it offered the lowest value for the -2LL index (see Appendix S.1.6.). Age effect was found statistically significant (*F*(1, 92.99) = 21.58, *p* < .001). Infants at 6 months performed fewer total anticipations compared to 9 (*p* < .001) and 16-18 months (*p* < .001). Likewise, at 9 months of age infants performed fewer total anticipations compared to 16 months (*p* = .04; Figure 3.11). A 19% of the variance was explained by fixed factors, while random factors increase it to 28%.

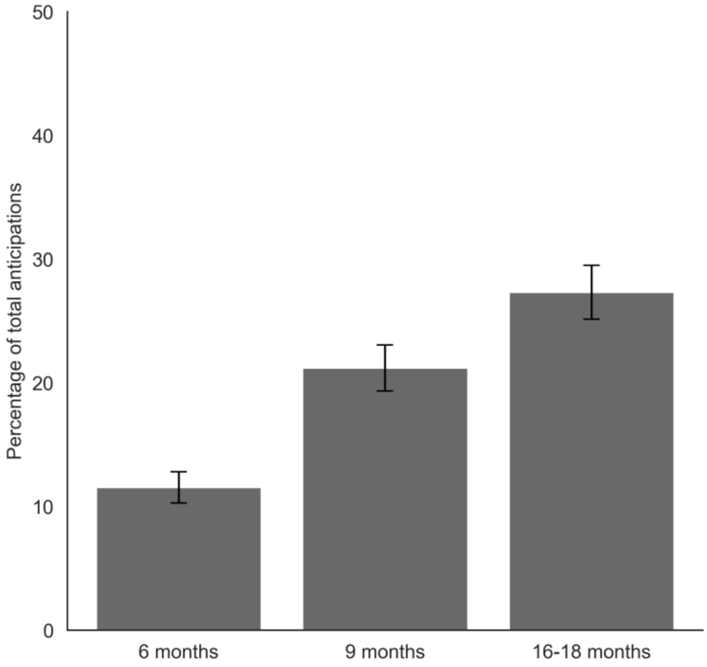


Figure 3.11. Percentage of total anticipations in the VSL task based on the number of trials with stimulus fixations.

As the age effect was found statistically significant, we computed the growth rate of total anticipations with age. Again, both linear Age and quadratic Age^2 factors were introduced in a full model. As the addition of the quadratic Age^2 factor did not improve model fit, it was removed from the final model (see Appendix S.1.6.). Intercept ($\beta = 14.18$, $SE = 1.12$, $t(96.06) = 12.68$; $p < .001$) and Age slope effect ($\beta = 20.43$, $SE = 3.45$, $t(9451.90) = 5.20$; $p < .001$) indicating an increase in total anticipations with age from 6 and 16-18 months.

Easy and complex correct anticipations

Fit indices for easy and complex correct anticipations were first computed for a full LMM with Age (2: 9 vs. 16-18 months) x Condition (2: easy vs. complex) as fixed effects, and a random intercept as a random effect. A reduced model was fitted removing the interaction Wave x Condition effect, although a statistically significant LRT (Δ-*2LL* = 11.02; *df* = 1; *p* < .001) supported the retention of the interaction effect (see Appendix S.1.7.)

Next, covariance structures were compared in the full model. As UN covariance offered the best fit indices for the model in comparison to CS (Δ-*2LL* = 50.17; *df* = 8; *p* < .001) and AR1 structures (Δ-*2LL* = 45.08; *df* = 8; *p* < .001; see Appendix S.1.7.), it was employed in the final model with Age x Condition fixed effects and random intercept. The age effect was statistically significant (*F*(1, 69.70) = 25.87, *p* < .001), indicating that at 9 months, infants performed less correct anticipations compared to 16-18-month-olds. Main effect of Condition was not found statistically significant (*F*(1, 69.99) = .59, *p* = .44). However, the interaction effect Age x Condition was found statistically significant (*F*(1, 68.25) = 11.87, *p* < .01), with infants at 9 months displaying a higher number of correct anticipations than 16-18-month-olds for easy transitions (*F*(1, 67.64) = 20.52, *p* < .001), while no differences between waves were found for complex transitions (*F*(1, 70.58) = .43, *p* = .51; see Figure 3.12).

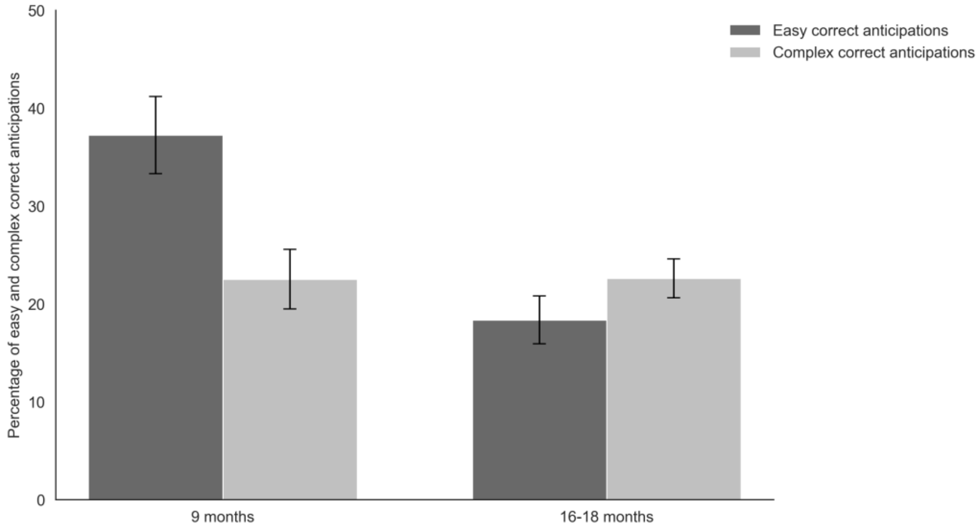


Figure 3.12. Percentage of easy and complex correct anticipations at 9 and 16-18 months in the VSL task based on the number of total anticipations.

Due to a statistically significant Age and Age x Condition interaction effect, we computed the growth rate for easy and complex correct anticipations. As only two time points are available to compute the growth rate for total anticipations, both linear Age and quadratic Age^2 factors would be redundant when introduced in the same model. Consequently, we built a LMM introducing only linear Age factor as a fixed effect with a random intercept. No reduced model was computed. Intercept (β = 38.19, *SE* = 4.07, *t*(75.01) = 9.39; *p* < .001) and linear Age slope effects (β = -38.21, *SE* = 8.43, *t*(67.64) = -4.53; *p* < .001) were found statistically significant. Infants showed an increase in complex correct anticipations with age (β = 42.56, *SE* = 12.35, *t*(68.24) = 3.44; *p* = .001) in comparison to easy correct anticipations.

3.4.3.4. Development of attention flexibility: switching task

Missing data

As for the previous task, only infants with missing data due to follow-up session nonattendance or protocol task omission at 9 or 16-18 months were estimated using Maximum Likelihood. Infants that meet task exclusion criteria or did not present enough gaze data due to infant reasons (i.e. crying, distracted or distressed during the task) were excluded from analyses ($n = 1$ at 9 months; $n = 1$ at 16-18 months; Table 3.8). Little’s MCAR test was not found statistically significant for correct anticipations ($\chi^2 = 7.90$, $df = 8$, $p = .44$), the pre-switch block criterion ($\chi^2 = 4.15$, $df = 8$, $p = .90$) or perseverations ($\chi^2 = 2.88$, $df = 5$, $p = .72$).

Similarly, Little’s MCAR test was not found statistically significant for correct anticipations either for boys ($\chi^2 = 4.89$, $df = 8$, $p = .77$) or girls ($\chi^2 = 3.66$, $df = 8$, $p = .89$). Regarding the pre-switch block criterion of 3 correct anticipations, Little’s MCAR test was not found statistically significant either for boys ($\chi^2 = 6.49$, $df = 8$, $p = .69$) or girls ($\chi^2 = 11.40$, $df = 8$, $p = .25$). Similarly, for perseverations the test was not found statistically significant for boys ($\chi^2 = 2.78$, $df = 5$, $p = .73$) or girls ($\chi^2 = 4.14$, $df = 3$, $p = .25$)

Next, we analyzed if differences in missing data at 9- and 16-18-months sessions were related to the family’s SES or CHAOS. Independent t-test showed statistically significant differences for SES based on the pattern of missing data at 9 months ($p < .01$) and at 16-18 months ($p < .01$) for correct anticipations. Differences in SES based on the pattern of missing data for perseverative errors were found to be statistically marginal at 9 months ($p = .08$) and at 16 months ($p = .06$). Consequently, as SES seems to be associated with the pattern of missing data in the switching task, we controlled for this variable in LMM.

¡Error! Marcador no definido.**Table 3.8.**
Descriptive statistics of the sample at each wave for the switching task for the pre- and post-switch blocks.

		Pre-switch		
		6 months	9 months	16 months
n visit lab		160	131	103
n inclusion criteria		142	122	91
Pre-switch	*n* valid data	118	102	71
	n with estimable data[1]	103	79	54
	n missing from those with valid data at 6 months[2] (%)	0 (*0%*)	24 (*23.30%*)	49 (*47.57%*)
Post-switch	*n* valid data	79	69	56
	n with estimable data[3]	64	54	42
	n missing data from those with valid data at 6 months[4] (%)	0 (*0%*)	10 (*15.62%*)	22 (*34.37%*)

Note. 1) The number of infants diminished from 118 to 103 at 6 months, as infants with data not suitable for estimation at 9 (*n* = 9) or 16-18 months (*n* = 6), were excluded from analyses. 2) *n* and percentage of participants with missing data over participants with valid data at 6 months (*n* = 103). 3) The number of infants diminished from 79 to 47 at 6 months, as infants with data not suitable for estimation at 9 (*n* = 9) or 16-18 months (*n* = 6), were excluded from analyses. 4) *n* and percentage of participants with missing data over participants with valid data at 6 months (*n* = 47).

Correct anticipations (pre-switch block)

A LMM was built introducing Age (3: 6 vs. 9 vs. 16-18 months) as a fixed effect with a random intercept and SES as a covariate. As only one fixed effect is considered in the current analysis, we did not test for differences between a full and reduced model. Regarding covariance structures, differences arise comparing UN covariance with CS (Δ-*2LL* = 10.63, *df* = 4, *p* = .03) and AR1 (Δ-*2LL* = 10.40, *df* = 4, *p* = .03; see Appendix S.1.8. 22). Consequently, UN covariance was employed in the final model. Main effect of Age was found statistically significant (*F*(2, 138.19) = 3.39, *p* = .04), with infants at 6 months performing less correct anticipations than at 16-18 months (*p* = .03). No differences were found between 6 and 9 months (*p* = 1), nor between 9 and 16-18 months (*p* = .22; see Figure 3.13). Fixed factors and both fixed and random factors explained 3% and 10% of the variance, respectively.

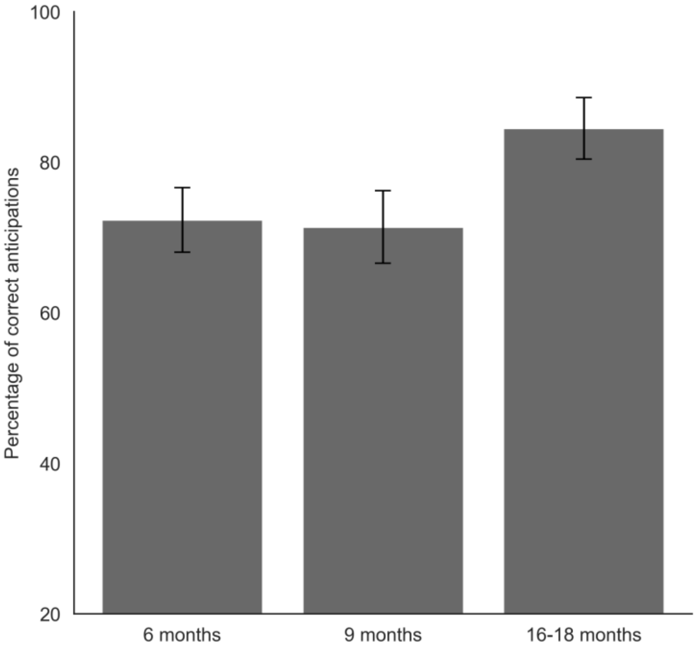


Figure 3.13. Bar plot showing the proportion of correct anticipations for infants at each wave in the pre-switch block of the switching task.

As the main effect of Age was found statistically significant, we computed the growth rate introducing both linear Age and quadratic Age^2. A reduced model retaining only the linear time change was fitted, in order to compare the model's fit between them. The quadratic Age^2 factor did not increase model fit (Δ-*2LL* < .01, *df* = 1, *p* = .92; see Appendix S.1.8.), so it was removed in the final model. A statistically significant effect of intercept was found (*β* = 66.94, *SE* = 3.79, *t*(84.04) = 17.64; *p* < .001). Moreover, the Age factor was also found statistically significant (*β* = 20.92, *SE* = 6.81, *t*(65.64) = 3.07; *p* < .01) indicating that correct anticipations show a linear increase with age.

Pre-switch task criterion: trial at which infants achieved 3 correct anticipations

The trial in which infants achieved three correct anticipations, the criterion to be considered for perseverations analysis (Figure 3.14), was also entered in a LMM with Age (3: 6 vs. 9 vs. 16-18 months) as a fixed effect and SES as a covariate. As the LRT was not show statistically significant between covariance structures (all *ps* > .10), UN was selected as it offered the lowest -2LL fit index (see Appendix S.1.9.). Main effect of Age was not found statistically significant (*F*(2, 88.54) = 1.92, *p* = .15). Fixed factors explained 2% of the variance, while fixed and conditional factors explained 25%.

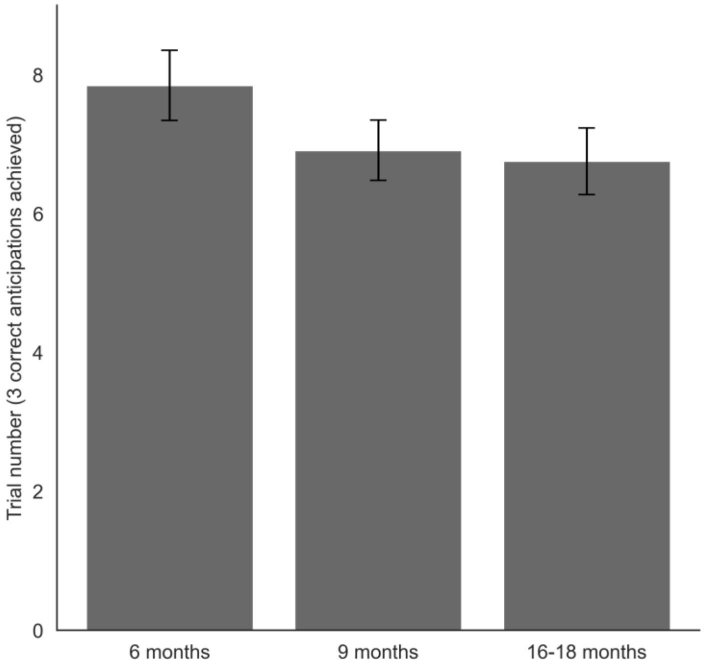


Figure 3.14. Bar plot showing the trial at which the pre-switch block criterion of three correct anticipations is achieved for infants at each wave of the switching task.

Perseverations (post-switch block)

We built a LMM considering Age (3:6 vs. 9 vs. 16-18) as the only fixed effect along with a random intercept and SES index as a covariate. Testing different covariance structures showed no statistically significant differences comparing UN with CS (Δ-*2LL* = 3.39, *df* = 4, *p* = .50) and AR1 (Δ-*2LL* = 3.11, *df* = 4, *p* = .54; see Appendix S.1.10.). However, as UN covariance structure offered lower fit index for -2LL, it was employed in the final model. Main effect of Age was found statistically significant (*F*(2, 140.18) = 4.94, *p* < .01), with infants at 9 months showing more perseverations compared to 16-18 months of age (*p* < .01). No differences were found between 6 and 9 months (*p* = .53), as well as between 6 and 16-18 months (*p* = .12; see Figure 3.15). A 5% of the variance was explained by fixed factors, while both fixed and random factors explained 6% of the variance.

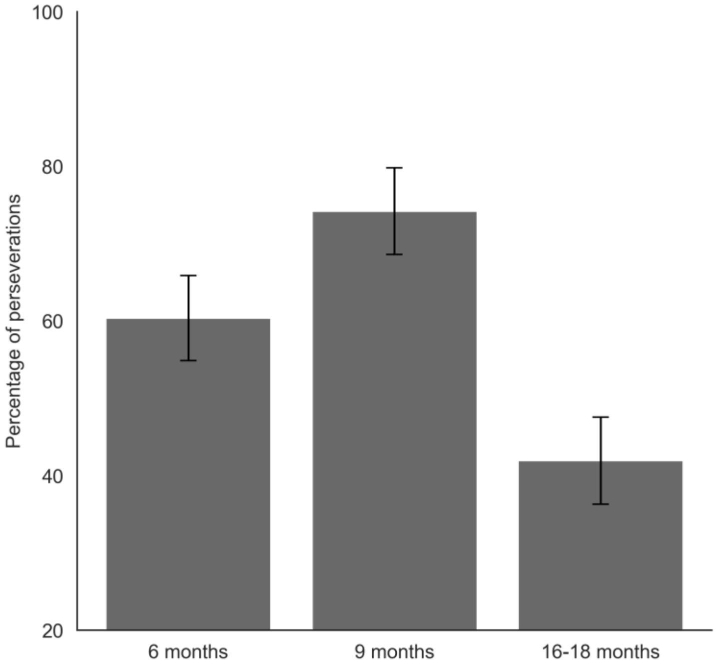


Figure 3.15. Bar plot showing the proportion of perseverations for infants at each wave in the post-switch block of the switching task.

We also computed the growth rate for perseverations. A comparison between a full model, including linear Age and quadratic Age^2 factors was performed. A statistically significant LRT supported the maintenance of the quadratic Age^2 factor as it increased model fit (Δ-*2LL* = 7.90; *df* = 1; *p* < .01; see Appendix S.1.10.). We found a statistically significant effect of intercept (β = 51.22, *SE* = 3.91, *t*(190) = 13.11; *p* < .001). While the linear Age effect was not statistically significant (β = 52.71, *SE* = 32.41, *t*(131.38) = 1.62; *p* = .10), quadratic Age^2 effect was found to be significant (β = -83.26, *SE* = 37.29, *t*(133.64) = -2.23; *p* = .03). The lack of a statistically significant linear effect makes the interpretation of the change rate more difficult. However, it suggests that the rate change in perseverations tends to decrease with age.

3.5. Do early attention control measures show stability from 6 to 16-18 months?

3.5.1. Hypothesis

In general, we anticipate higher stability between infancy and toddlerhood for attentional measures with no significant effects of development (e.g. disengagement in the gap condition, reactive looks in the VSL, or correct anticipations in the switching task, among others). We expect less stability in attentional measures with more protracted developmental courses (e.g. disengagement in the overlap condition, complex correct anticipations in the VSL or perseverations in the switching task).

3.5.2. Analysis strategy

Two-tail pairwise correlation coefficients with 95% confidence intervals (CI) were computed for each variable with itself across waves to test the stability between infancy and toddlerhood. We only considered cases with valid data in the two waves entered in the analysis (i.e. 6 and 9 months, 6 and 16-18 months; 9 and 16-18 months), to ensure that the association was computed for infants with valid data in both of the correlated waves.

3.5.3. Results

3.5.3.1. Stability of attention disengagement

For the overlap condition, only a statistically significant positive correlation between 6 and 9 months for mdSL ($r = .30$; $p < .05$, 95% CI [.06, .51]) was found. Regarding DF in this condition, a statistically marginal positive correlations were found between 6 and 9 months ($r = .22$; $p = .07$, 95% CI [-.04, .43]) condition, but not between 9 and 16-18 months, nor 6 and 16-18 months of age.

Regarding mdSL in the gap condition, statistically significant positive correlations were found between 6 and 9 months (*r* = .39; *p* < .01, 95% CI [.17, .58]), and 9 and 16-18 months (*r* = .54; p < .01, 95% CI [.29, .72]), but not between 6- and 16-18-months of age. No correlations were found for DF in the gap condition between any of the ages (see Table 3.9).

Table 3.9.

Two-tailed pairwise correlation coefficients of attention disengagement measures across testing ages.

		9 months	16-18 months
mdSL overlap	6 months	**.30***	.03
	9 months	**-**	.06
mdSL gap	6 months	**.39*****	.16
	9 months	**-**	**.54*****
DF overlap	6 months	*.22#*	-.16
	9 months	-	.07
DF gap	6 months	.20	.08
	9 months	-	.06

Note. Sample size for correlations between gap-overlap measures was variable depending on valid data at both ages considered: 6 and 9 months (*n* = 65), 6 and 16-18 months (*n* = 45), and 9 and 16-18 months (*n* = 45). mdSL = Median Saccade Latency; DF = Disengagement Failure

3.5.3.2. Stability of anticipatory attention and context monitoring

We first considered the stability of the measures collected at all ages (e.g. stimulus fixations, reactive looks, correct anticipations, and total anticipations). For stimulus fixations, we found a positive and statistically significant correlation between 9 and 16-18 months (*ρ* = .34, *p* = .01, 95% CI [.05, .58]). Reactive looks at 6 months show a tendency to positively correlated with itself at 9 (*ρ* = .17, *p* = .08, 95% CI [-.07, .40]), but not at 16-18 months. Also, correct anticipations at 6 months and 9 months displayed a tendency to be positively correlated (*ρ* = .16, *p* = .09, 95% CI [-.08, .39]), but not at 16-18 months. Finally, total anticipations did not show any correlation with itself across age (all *ps* > .16)

Secondly, we computed correlation coefficients for measures computed only between 9 and 16-18 months, (e.g. easy and complex correct anticipations). Results revealed no statistically significant correlations across age for these variables (all *ps* > .49; see Table 3.10)

Table 3.10.

Two-tailed pairwise correlation coefficients of anticipatory attention measures across testing ages.

		9 months	16-18 months
Stimulus fixations	6 months	.06	.04
	9 months	**-**	**.34***
Reactive looks	6 months	*.17#*	-.09
	9 months	-	-.08
Correct anticipations	6 months	*.16#*	-.08
	9 months	-	-.09
Total anticipations	6 months	.12	.07
	9 months	-	.01
Easy correct anticipations	6 months	N/A	N/A
	9 months	-	.01
Complex correct anticipations	6 months	N/A	N/A
	9 months	-	.01

Note. Sample size for correlations between gap-overlap measures was variable depending on valid data at both ages considered: 6 and 9 months (*n* = 63-66), 6 and 16-18 months (*n* = 50), and 9 and 16-18 months (*n* = 42).

3.5.3.3. Stability of attention flexibility

Regarding the stability of the switching variables between waves, we did not find statistically significant correlations for correct anticipations, pre-switch block criterion, or perseverations in the post-switch block between any of the waves (all *ps* > .11; see Table 3.11)

Table 3.11.

Two-tailed pairwise correlation coefficients of attention flexibility measures across testing ages.

		9 months	16-18 months
Correct anticipations (pre-switch)	6 months	.20	-.02
	9 months	-	.17
Pre-switch criterion	6 months	.07	.20
	9 months	-	.07
Perseverations (post-switch)	6 months	.07	.09
	9 months	-	.19

Note. Sample size for correlations between gap-overlap measures was variable depending on valid data at both ages considered: 6 and 9 months (*n* = 36), 6 and 16-18 months (*n* = 56), and 9 and 16-18 months (*n* = 51). Pre-switch criterion = trial at which infant reached 3 correct anticipations, that is, cumulative and not successive.

3.6. Are attention control measures inter-correlated? An attention control index.

3.6.1. Hypothesis

In order to look for support to calculate an attention control index, as a composite of the three attentional abilities measures in the current study (e.g. attention disengagement, anticipatory attention, and attention flexibility), we computed correlations between the three attentional tasks. For this, correlations were performed within age. We aimed at analyzing if support is found to derive an attention control index at any age from infancy to toddlerhood, or at certain ages otherwise. associations between these attentional abilities emerge later in development following a protracted functionality of the EA network.

We expect that the ability to disengage attention, which would require the engagement of mechanisms for inhibitory control and attention reorienting, will be related to a higher ability to: 1). Maintain attention; 2) Voluntarily direct attention to learn and anticipate predictable events; 3) A higher ability update previous knowledge to flexibly adapt performance engaging inhibitory control mechanisms to avoid perseverative errors. Specifically, we hypothesize that a higher disengagement ability in the gap-overlap task (i.e. lower mdLS and DF), would be associated with better sustained, anticipatory attention and attentional flexibility (i.e. higher stimulus fixations, total and correct anticipations, but lower perseverations) in the VSL and switching tasks, as well as with lower exogenous attention (i.e. lower reactive looks) in the former.

Likewise, we also hypothesize that a higher ability to maintain attention and learn predictable events within a sequence in the VSL task (i.e. higher stimulus fixations, total and correct anticipations) would be associated with a better ability to: 1) Learn and anticipate similar contingent events in the switching task (i.e. higher correct anticipations and lower pre-switch block criterion; 2) Update previous knowledge about the sequence when required to flexibility adapt performance (i.e. lower perseverative errors). On the other hand, we expect that a more reactive style of attention orienting in the VSL task (i.e. higher reactive looks) would be associated with a lower ability to learn and consequently to anticipate events in the switching task (i.e. lower correct anticipations and higher pre-switch block criterion), as well as with lower flexibility (i.e. higher number of perseverations). In general, we hypothesize more consistent associations between attentional abilities at 9 and

16-18 months compared to 6 months of age, due to the protracted functionality of the EA network (Posner et al., 2014).

3.6.2. Analysis strategy

The main variables of the VSL and switching task previously specified were used. For the gap-overlap task, we computed a Disengagement Cost and Disengagement Failure index as measures of general disengagement ability, instead of maintaining disengagement ability in each experimental condition individually. The Disengagement Cost index was calculated by dividing the mdSL in the overlap by the mdSL in the gap condition, to correct as much as possible for infants' baseline saccadic latency (Holmboe et al., 2018). For the Disengagement Failure index, as some infants did not have any failure to disengage in the gap condition, we subtracted DF in the gap from the overlap condition to avoid dividing by zero.

Two-tail pairwise correlation coefficients with 95% confidence intervals (CI) were computed between variables of the three tasks within each wave. Only considered cases with valid data in the two tasks were entered in the analysis, to ensure that the correlation was computed for infants with valid data in both of the correlated task variables.

3.6.3. Results

At 6 months, we found a statistically significant negative correlation between Disengagement Cost in the gap-overlap, with reactive looks (r = -.24, p =.03, 95% CI [-.44, -.02]) and correct anticipations (r = .24, p =.03, 95% CI [.02, .45]) in the VSL task. No statistically significant correlations were found between the gap-overlap and switching tasks (all *ps* > .14), as well as between the VSL and switching tasks at this age (all *ps* > .10; see Table 3.12).

Regarding correlations between tasks at 9 months, Disengagement Failure in the gap-overlap was found to be positively correlated with reactive looks (r = .24, p =.03, 95% CI [.02, .45]) in the VSL task. No statistically significant correlations were found neither between the gap-overlap with the switching task (all *ps* > .21) not between the VSL and switching tasks (all *ps* > .27; see Table 3.13).

At 16-18 months, no statistically significant correlations were found for the gap-overlap task with the VSL (all *ps* > .61) or switching tasks (all *ps* > .29). Similarly, variables of the VSL and switching tasks were not found to be significantly correlated (all *ps* > .13; see Table 3.14)

Table 3.12.

Two-tailed pairwise correlation coefficients between tasks at 6 months

		Switching			VSL		
		Correct antic.	Pre-switch criterion	Perseverations	Stimulus fix.	Reactive looks	Correct antic.
Gap-overlap	Disengagement Cost	-.01	-.0	-.18	-.11	**-.24***	**.24***
	Disengagement Failure	.05	.02	.03	.11	-.13	.14
Switching	Correct antic.	-	-	-	.01	-.03	.03
	Pre-switch criterion	-	-	-	-.02	.04	-.04
	Perseverations	-	-	-	.22	-.12	.11

Note. Sample size for correlations between tasks was variable depending on valid data at both tasks considered: gap-overlap and switching (*n* = 61); gap-overlap and VSL (*n* = 76); switching and VSL (*n* = 55).

Table 3.13.

Two-tailed pairwise correlation coefficients between tasks at 9 months.

		Switching			VSL					
		Correct antic.	Pre-switch criterion	Perseverations	Stimulus fix.	Reactive looks	Correct antic.	Total antic.	Easy correct antic.	Complex correct antic.
Gap-overlap	Disengagement Cost	-.03	.14	.01	-.08	.09	-.06	-.07	-.15	.17
	Disengagement Failure	-.01	.11	-.02	-.07	**.25***	*-.21#*	-.10	-.16	.01
Switching	Correct antic.	-	-	-	.04	-.02	.14	.13	.01	.11
	Pre-switch criterion	-	-	-	-.08	.17	-.11	-.16	.21	-.23
	Perseverations	-	-	-	.04	-.04	-.10	-.11	-.02	-.02

Note. Sample size for correlations between tasks was variable depending on valid data at both tasks considered: gap-overlap and switching (*n* = 55); gap-overlap and VSL (*n* = 67); switching and VSL (*n* = 51).

Table 3.14.

Two-tailed pairwise correlation coefficients between tasks at 16 months.

		Switching			VSL					
		Correct antic.	Pre-switch criterion	Perseverations	Stimulus fix.	Reactive looks	Correct antic.	Total antic.	Easy correct antic.	Complex correct antic.
Gap-overlap	Disengagement Cost	-.02	.16	.13	-.06	.01	-.03	-.05	-.01	.03
	Disengagement Failure	.01	.01	.16	-.13	-.05	.03	-.02	.07	.07
Switching	Correct antic.	-	-	-	-.06	-.04	.05	.08	-.15	.06
	Pre-switch criterion	-	-	-	-.12	.20	-.22	-.13	-.10	.17
	Perseverations	-	-	-	-.03	-.18	.18	.13	-.01	.05

Note. Sample size for correlations between tasks was variable depending on valid data at both tasks considered: gap-overlap and switching (*n* = 42); gap-overlap and VSL (*n* = 53); switching and VSL (*n* = 49).

3.7. Discussion

In the current study, we aimed to characterize the longitudinal development of endogenous and executive attention control abilities. (i.e. disengagement, anticipatory attention, context monitoring, and attention flexibility) from middle infancy (6 months) to late infancy (9 months) and toddlerhood (16-18 months). We also analyzed the stability of the measures across the testing ages. Finally, we also aim at testing the intercorrelations between tasks to explore the possibility of deriving an attention control index, as a composite score of infants' and toddlers' performance on each task.

Results support a longitudinal increase in infants' ability to benefit from attentional cues to reorient attention under facilitatory conditions (i.e. gap condition in the gap-overlap task). However, no changes in attentional disengagement under visual competition (i.e. overlap condition) were found. While no longitudinal changes were found in sustained and exogenous attention (i.e. stimulus fixations and reactive looks in the VSL task), infants increase their ability of attempting to anticipate with age (i.e. total anticipations). Interestingly, from late infancy to toddlerhood of age, infants decrease the number of anticipations in context-independent trials (i.e. easy trials), although no changes in context-dependent trials (i.e. complex trials) were found. Finally, infants gain control over attentional flexibility from late infancy to toddlerhood, reducing the number of perseverative errors at the latter age.

3.7.1. Longitudinal development of attention disengagement

Latency and failure to disengage were measured under two experimental conditions in a gap-overlap task: 1) An overlap condition (visual competition) in which the central stimulus remained on screen while the peripheral target was displayed; 2) A gap condition (non-competition) in which the central stimulus disappeared from the screen, with the peripheral target being presented after a 200 ms temporal gap. Previous studies have not found longitudinal or cross-sectional age differences by condition (Nakagawa & Sukigara, 2013; 2019), yet being limited by a small sample size (< 27 infants). Due to this, we longitudinally tested a larger sample of infants covering ages from infancy to toddlerhood in order to characterize the development of attention disengagement and its stability across these periods.

As hypothesized, a general decrease in disengagement latency occurred from infancy to toddlerhood. Reductions in disengagement latencies have been previously reported between 1 and 3-month-old infants (Atkinson et al., 1992) as well as when comparing 1.5- with 3- and 6-month-olds (Hood & Atkinson, 1993). However, in the latter case differences were not significant between 3 and 6-month-olds. During the second half of the first year of life, Nakagawa & Sukigara (2019) reported age differences in general disengagement latency. In their study, 6-month-olds were surprisingly faster to disengage compared to a cohort of 12-month-old infants. Our results indicate a longitudinal decrease in disengagement latencies between middle and late infancy, as well as between middle infancy and toddlerhood. This result suggests an increase in the maturation of parietal structures at the base of attention orienting, as well as higher integrity of fasciculus fibers that connect parietal (posterior) and frontal areas (anterior). The higher connection could improve orienting speed through the dorsal (endogenous) and ventral (exogenous) networks. However, 36-month-old children display shorter disengagement latencies in comparison to younger cohorts (Nakagawa & Sukigara, 2013), suggesting a protracted developmental course. In line with our hypothesis, longitudinal differences in disengagement failure were found, with infants in middle infancy displaying a higher failure to disengage compared to toddlerhood. We found an age-related decrease in disengagement failure, but only between middle infancy and toddlerhood. This discrepancy in the pattern of age differences between disengagement latency and failure could be related to methodological aspects of the metrics. Disengagement latency could be a more sensitive metric to account for variability in visual disengagement, as it captures the speed of the disengagement process per se. This more meticulous encoding could allow it to capture more fine-grained differences with age even in a short temporal gap of 3 months (i.e. 6 vs. 9 months). Disengagement failure could account for more rough changes compared to latencies, as it encodes the *decision* of not disengaging from the central stimuli. Although its characteristics, disengagement failure also offers interesting insights in relation to infants' ability to decide not to disengage during overlap trials.

As expected, infants displayed higher disengagement latencies and failure to disengage in the overlap compared to the gap condition. Although both require shifting attention towards a novel peripheral target, conditions differ in the cognitive effort to visually disengage. During overlap trials, infants must decide to disengage, that is, to voluntarily terminate a fixation on the foveated stimulus to allow attention to be shifted towards the peripheral target. The disengagement decision process is eased in gap trials, as the disappearance of the central stimulus exogenously imposes the termination of the fixation. Indeed, the removal of the central stimulus is known to act as an alerting cue for individuals to plan and initiate a saccadic response, which is additionally eased by the 200 ms temporal gap after central stimulus' offset (Csibra et al., 1997;

Kingstone & Klein, 1993). Consequently, the overlap condition involves a higher demand of control over attention, increasing the cognitive effort to engage in visual disengagement.

Although we hypothesized longitudinal changes in visual disengagement for the overlap condition (disengagement latencies and failure), analyses revealed no age-related differences. This informs of a similar ability of infants in this age range to voluntarily disengage attention when stimuli compete for attentional resources. Moreover, toddlers could be engaging inhibitory control processes to remain exploring the fixated stimuli. During the first year of life, inhibitory control measured with the gap-overlap task presents modest stability at 6 months of age, which increases towards 9 months (Holmboe et al., 2018). Recent data from neuroimage studies show that, at 10 months of age, infants are able to engage prefrontal and parietal areas when required to inhibit a dominant manual response to shift attention (Fiske et al., 2022). This suggests that inhibitory control is under development from early infancy, with brain areas involved in this cognitive function being already active at 10 months. Hence, disengagement displays a steady development from 6 to 16-18 months of age. Likely, differences could emerge from toddlerhood onward. It is at this developmental stage when a shift in attention control, from the orienting towards the executive attention network, will take place, setting executive attention as the main attentional supervisory system (Posner et al., 2014). This shift in attention control would ease the engagement of more sophisticated mechanisms of control (i.e. inhibitory control), perhaps leading to more noticeable differences in disengagement ability compared to younger infants. Although the prevalent reading of the overlap effect in infants is that they would voluntarily decide to terminate a fixation on the central stimulus to explore the novel peripheral one, other interpretations might also explain these results. Nakagawa & Sukigara (2013) found toddlers with a higher temperamental effortful control to display longer disengagement latencies in the overlap condition. This opens the possibility that toddlers could engage inhibitory control to precisely avoid exploring the peripheral target, voluntarily remaining on the central stimulus. Additionally, it could even lead to an increase in latencies to disengage during toddlerhood, based on the salience and attractiveness of the central stimulus.

In line with our hypothesis, infants displayed a continuous linear decrease across testing sessions in the gap condition, suggesting an underlying longitudinal improvement to benefit from non-directive attentional cues. This eases the engagement of orienting mechanisms to shift visual attention faster with age. Similar results have been reported in samples of younger infants. In their cross-sectional study, Hood & Atkinson (1993) did not find age differences in saccade latencies for the overlap but for the gap condition, with 6-month-olds being significantly faster than 3-month-olds. Similarly, Johnson & Tucker (1996) found that infants become faster to shift attention between spatial locations from 2 to 6 months of age, when a temporal gap of 200 ms was introduced after the onset of a visual cue. These findings suggest that the ability to benefit from this type of non-directive attentional cues is already under development between 3 and 6 months of age, which could be also captured in the gap condition. A recent study employing Posner's cueing paradigm in a magnetic resonance protocol with infants between 3 to 12 months of age, suggests that infants are able to benefit from non-directive attentional cues to shift visual attention (Ellis et al., 2021). Moreover, in this study a higher activation in the right anterior cingular cortex was found for invalid (cues appearing at the opposite location of the subsequent target) or neutral cues compared to valid ones (those appearing at the same location as the subsequent target). Although the anterior cingular cortex is considered a central hub of the executive attention network, it is also known to be part of the salience network, controlling oculomotor and response selection processes (Menon, 2015). Moreover, it has been found to relate to orienting processes during development (Konrad et al., 2005). Therefore, improvements in visual orienting during the gap condition are likely to be associated with maturation of prefrontal and parietal areas. Adult data show that in the gap effect, the prefrontal cortex displays a positivity before the peripheral target presentation, which is related to preparatory processes (Csibra et al., 1997). On the other hand, parietal activity would be associated with the reorienting of attention once the peripheral target is displayed.

3.7.2. Development of anticipatory attention and context monitoring

Anticipatory attention was measured using the VSL task. Aspects of context monitoring were introduced from 9 months onwards with a distinction between easy and complex trials. As a reminder to the reader, easy trials are deterministic, as the upcoming stimulus location can be predicted from the current one. However, in complex trials the next stimulus location would depend on the previous location to the current one, requiring infants to monitor the sequence in order to correctly anticipate. Different markers of attention control were computed with this paradigm: 1) Sustained attention (stimulus fixations); 2) Exogenous orienting (reactive looks); 3) Endogenous orienting (total anticipations); 4) Endogenous orienting-based learning (total anticipations and easy correct anticipations); 5) Endogenous orienting + monitoring-based learning (complex correct anticipations).

Contrary to our hypothesis, no differences were found for sustained attention between the considered ages. From middle infancy to toddlerhood, infants displayed a similar ability to maintain attention throughout the task. Research on sustained attention reported increases towards middle infancy using heart rate measures (Richards, 1986), as well as from late infancy to early childhood in a free-play task (Ruff & Capozzoli, 2003). However, Xie et al. (2018) did not report differences in sustained attention from 6 to 12 months of age using changes in heart rate, but only on the brain's functional connectivity during periods of sustained attention. Although different methodologies are used to study sustained attention in infants (i.e. looking time, heart-rate deceleration, or interbeat interval), they tend to show an increase in this attentional ability with age in relation to infants' active engagement on an ongoing task (i.e. free-play settings or watching media material; Laurie-Rose et al., 2015).

Regarding the unexpected current results, one aspect that could have impacted is the different versions of the task employed at different ages. Specifically, at 6 months infants were presented with 24 trials, while these increased to 48 and 64 at 9 and 16-18 months, respectively. The increased length of the task with age also demands higher sustained attention engagement. The 6 and 9-month-old versions could be too short for these ages, making it easier for infants to maintain attention throughout the task. In this respect, descriptive statistics show that infants in the 6 and 9-month-olds version of the VSL display higher percentages of stimulus fixations compared to the 16-18-month-old version. Using the same version of the task across ages could have eased the detection of age differences in sustained attention. The 3 positions version of the VSL task (1-2-1-3) is known to be suitable for infants, toddlers, and young children, as it has been previously employed in samples from 4 (Clohessy et al.,

2001) until 48 months of age (Moyano et al., 2022). However, at 4 months infants were administered only 32 trials instead of 64 in the current version.

Similar to sustained attention, no differences were found in exogenous attention control from middle infancy to toddlerhood. This is surprising as previous research has found an age-related reduction in exogenous attention in young infants from 1.5 months of life until 3.5 months (Krieber-Tomantschger et al., 2022). A recent cross-sectional study conducted between 24 and 48 months of age (Moyano et al., 2022) found a decrease in reactive looks with age using the three positions VSL task, suggesting that this ability is still under-tuning in this age range. Consequently, is could be expected that these differences could be also found between middle infancy and toddlerhood. Again, the different versions of the VSL employed could have impacted in this result.

Regarding endogenous attention control, total anticipations offer a first insight into this ability. Specifically, it taps an attempt to visually anticipate independently of the accuracy of the acquired expectation, thus entailing a voluntary shift of attention. As total anticipations couldn’t be computed in the 6-month-old version, as the sequence does not allow to perform incorrect anticipations, differences were explored from late infancy to toddlerhood. In line with our hypothesis, results show a linear increase in total anticipations from late infancy to toddlerhood. Although Clohessy et al. (2001) have previously employed this metric in the VSL task with 4-month-old infants, they do not compare with older ages. During young childhood, Rothbart et al. (2003) did not find age differences in total anticipation between 24, 30, and 36-month-old children. However, Moyano et al. (2022) reported an age increase in total anticipations in young children from 24 to 48 months of age. Altogether, their results highlight an increase in endogenous anticipatory attention control from middle infancy to toddlerhood, which keeps improving during childhood.

Although the supported a longitudinal change in endogenous attention control measured through total anticipations, no differences were found in general correct anticipations with age, contrary to our hypothesis. It should be noted that in this case, correct anticipations were computed over stimulus fixations, and not over total anticipations as in previous studies (Rothbart et al., 2003; Moyano et al., 2022). As the 6-month-old version of the task does not allow to perform incorrect anticipations, preventing computing total anticipations for this age, this methodological change was adopted to ensure a comparison in correct anticipations between the three ages considered. Although this result, developmental changes in anticipatory attention have been reported at younger and older ages. The ability to visually anticipate events in a voluntarily controlled form is found to be in place in the first months of life (Haith et al., 1988; Canfield et al., 1991). However, little change has been found in the percentage of anticipations during the first year of life between 2 and 8 months, yet infants become faster at anticipating (Canfield et al., 1997). This could suggest that although infants increase their attempts to anticipate (i.e. total anticipations), their ability to accurately do it does not change significantly during the first year of life. Therefore, introducing further distinctions in the context or cognitive demands that different types of correct anticipations require, could shed some light on developmental differences.

Due to this, we computed the percentage of easy and complex trials at 9 and 16-18 months of age, in order to analyze the endogenous control of attention in context-free and context-dependent trials. In the latter type of trials, infants are required to engage attentional mechanisms of context monitoring to monitor the sequence, to correctly anticipate the upcoming stimulus. Moreover, as the 9 and 16-18-month-old version of the VSL allows to account for incorrect anticipations, correct anticipations for each trial type were computed over the number of total anticipations. We believe that these metrics provide a more precise measure of infants' ability to form accurate expectations considering their baseline ability to anticipate (Moyano et al., 2022; Rothbart et al., 2003; Tummerltshammer & Kirkham, 2013).

In this respect, toddlers perform less easy correct anticipations compared to infants, indicating an age-related reduction from late infancy to toddlerhood. Also, infants displayed a linear increase in complex compared to easy trials from late infancy to toddlerhood, as indicated by the growth curve analysis. The ability to anticipate deterministic sequences have been found to develop during early infancy (Hood et al., 1988; Clohessy et al., 2001; Tummeltshammer & Kirkham, 2013). However, it is not until 18 months of age when toddlers display an equal performance on easy and complex trials (Clohessy et al., 2001). The reduction in correct anticipations for easy trials with age, but an increase in complex ones could be explained by a trade-off in attentional resources devoted to correctly ancipitate between both trial types, a tendency previously found during early childhood (Moyano et al., 2022). Higher attentional demands are required during complex trials, although it is not until toddlerhood, with early functionality of the EA network (Berger et al., 2006; Ellis et al., 2021; Fiske et al., 2022), when toddlers can meet these demands.

Moreover, infants also show an increase in total anticipations from infancy to toddlerhood. This could suggest that apart from improving their ability to correctly anticipate during context-dependent trials, they also attempt to anticipate more. In this respect, toddlers could be more focused on trying to learn and anticipate during complex trials, leading to lower attentional resources being allocated for easy transitions. It is long known that infants show a general preference for novel events (Fantz, 1964). Considering this, Rothbart et al. (2003) argued that easy trials offer less novelty in the sequence compared to complex, as it requires moving attention back to a previously visited location. Therefore, this could negatively impact the number of anticipations in easy trials. In the end, this could lead to a decrease in correct anticipations for easy trials, once toddlers find more attractive events to which they can meet the attentional demands to learn and anticipate. Alternatively, the result could be also related to an inhibition of return effect. As infants start focusing on complex transitions (i.e. from position 1 to 2 or 1 to 3), they would avoid anticipating to the previously visited location (i.e. from position 2 to 1 or 3 to 1), leading to a reduction in correct anticipations for easy trials.

Our results highlight that it is during toddlerhood when the ability to learn and monitor complex sequences seems to start emerging, in line with Clohessy et al. (2001). Moreover, we go a step beyond and find a longitudinal increase in this ability from 9 to 16-18 months of age. The early functionality of the EA network around this age could be supporting the increase in infants' ability to monitor and learn context-dependent sequences during toddlerhood, as this ability is known to be related to executive attention control (Posner & DiGirolamo, 1998; Botvinick et al., 2001). Further improvements in monitoring ability are reported at older ages. For instance, Rothbart et al. (2003) found correct anticipations in complex trials to increase from 24 to 36 months of age. Similarly, age has been found to predict increases in complex correct anticipations from 24 to 48 months of age (Moyano et al., 2022). In conclusion, this could suggest that it is during toddlerhood when monitoring ability emerges to support the learning of complex sequences, with early EA control being at the basis of this developmental increase.

3.7.3. Development of attention flexibility

The switching task was used as a proxy for endogenous attention control and attentional flexibility. This task provides measures of infants' ability to anticipate a visual stimulus, based on learning of a task rule sustained on stimulus contingency, but also to overcome an acquired dominant response established by this rule once the response is no longer adaptive, due to a task rule switch. In this regard, during the first pre-switch block of the task, infants learn to anticipate a stimulus on a specific location on the screen, out of two possible locations. During the following post-switch block, stimulus presentation is switched to the remaining location. Thus, infants should inhibit the dominant response to anticipate the previous location, flexibly adapting the performance to avoid perseverative errors. The switching task provides three measures of infant's attention control: 1) Correct anticipations, capturing their ability to endogenously direct attention towards a location in which a reward will be presented in an anticipatory form; 2) Pre-switch criterion, that is, how many trials infants need to achieve three correct anticipations. A faster pre-switch rule learning will translate into a lower trial; 3) Perseverations, reflecting infants' ability to inhibit a dominant response and update previously learned rules to flexibly switch the anticipation location.

Longitudinal differences were found in correct anticipations in the pre-switch block. Supporting our hypothesis, infants performed more correct anticipations during toddlerhood compared to middle infancy. Although no differences were found from middle to late infancy, or from late infancy to toddlerhood, we found a linear increase in correct anticipations with age. However, no differences with age were found for learning the pre-switch criterion, that is, how fast infants were able to acquire the stimulus contingency to reach three correct anticipations. Hence, results suggest that although infants from middle infancy to toddlerhood are equally able to learn stimulus contingencies, toddlers show a higher ability to endogenously anticipate than at 6 months of age. It should be noted that although differences in pre-switch block rule learning were not found statistically significant, infants at 6 months tend to show a more delayed learning of this rule compared to toddlers, which aligns with age differences in correct anticipations. However, this difference in correct anticipations could be also attributable to toddlers' higher engagement with the task. As all ages seem to be able to learn equally fast the pre-switch block rule, then the higher number of anticipations for toddlers could be related to a higher engagement with the task, leading to more opportunities to anticipate.

Infants' ability to correctly anticipate is already in place by middle infancy (Canfield & Haith, 1991; Clohessy et al., 2001; Jacobson et al., 1992; Johnson et al., 1991). Using the switching task in a 2 weeks attentional training program in 11-month-old infants, Wass et al. (2011) did not find differences in correct anticipations for the pre-switch block between pre and posttest phases. This could suggest that the attentional skills to correctly anticipate in a block that only entails contingent learning could be mastered by the end of the first year. This agrees with the lack of age differences between middle and late infancy. Unlike in the switching task, we did not find age differences in correct anticipations for the VSL task. This could be explained by an increase in task difficulty with age, as the VSL progresses from 6 to 16-18 months with increasing demands in attention control. Thus, age differences in the VSL could have been obscured by increased task difficulty. However, in the switching task, these differences emerge, probably due to using the same version of the task, as well as involving easier contingent learning than in the VSL, which during toddlerhood also involves sequence monitoring.

Regarding perseverative errors in the post-switch block as the main measure of attentional flexibility, results partially supported our hypothesis, with a decrease in perseverations from late infancy towards toddlerhood. No increase in perseverations was found from middle to late infancy, although descriptive statistics suggest a tendency for perseverations to decrease in the expected direction. This pattern in perseverative behavior has been previously found during the first year of life. For instance, an increase in perseverative errors during B trials in the A-not-B task, that is after the switch, has been reported from 5 to 7-to 8 months (Clearfield et al., 2006), as well as from 6-to 9 months of age (Clearfield & Niman, 2012). According to previous proposals (Clearfield et al., 2006; Clearfield & Niman, 2012; Diedrich et al., 2001), this could imply that around 9 months of age, infants’ ability to bring previously acquired knowledge to the present is emerging, due to an increase in their ability to create steady traces of visual representations in memory. However, as the stability of memory traces increase, infants need to gain control to update and overcome these previously learned tendencies, that is to gain attentional flexibility. This allows them to update their previous knowledge and to flexibly switch and adapt behavior when required, and this is exactly what previous studies have found. Using the A-not-B task, Diamond (1985) found infants to show a developmental decrease in perseverations during B trials from 7.5 to 12 months of age. Similarly, Clearfield & Niman (2012) also reported a reduction in perseverations in high-SES infants from 9 to 12 months of age. These results are replicated in the current longitudinal sample, even extending this developmental gain in attentional flexibility until 16-18 months of age. Consequently, it is after the second half of the first year of life onwards when infants become more able to modulate the strength of these memory traces. This allows them to inhibit and overcome dominant responses established by the preservation of previously reinforced behaviors. Therefore, these increases in attention control between the end of the first year of life and the second to a more efficient attentional flexibility. Moreover, this increases in attention flexibility at the end of the first year of life also matches the timing of some early functionality of the EA network is found (Berger et al., 2006; Fiske et al., 2022).

The lack of statistically significant differences between middle and late infancy could be related to the response modality. Clearfield et al. (2006) proposed that the developmental course of any skill goes through a first period of instability, heavily dependent on present information, followed by increased stability that allows bringing memories to the present. Studies with the A-not-B task have mostly employed reaching behavior, which is known to develop and become more stable later than oculomotor control (Johnson et al, 1991). Cuevas & Bell (2010) compared infants’ longitudinal performance in the A-not-B task through looking and reaching behaviour from 5 to 10 months of age. They found that infants had a better performance on A trials using looking compared to reaching behaviour between 5 and 7 months of age. As visual control is acquired earlier, infants could have created more stable memory traces of previous anticipations compared to behavioural reaching, which is more unstable at this age. However, in Cuevas & Bell’s study, no differences were found for perseverative behaviour in B trials between looking and reaching responses. Nevertheless, we propose that these stronger memory traces for the visual modality could have contributed to increasing perseverative anticipations at 6 months, reducing the difference at 9 months. Perhaps, if studied before 6 months of age, we could have found differences in perseverative behaviour, a time when oculomotor control could be less stable and more reliant on present information.

Although we aimed at characterizing the developmental progression of attentional flexibility in a typical development sample, other studies have focused on differences in atypical development and how this ability could be trained. Shinya et al. (2022) used the switching task to measure perseverative behavior between infants born at-term, pre-term, and very preterm. They found a developmental lag between infants born at term and very preterm. Specifically, infants born at-term and moderate-to-late term show a decrease in looking time during perseverative errors across the post-switch block in comparison to very-preterm infants. Although this developmental lag, Wass et al. (2011) reported evidence that attentional flexibility could be trained during infancy. Likewise, they used the switching task as a measure of attentional control and flexibility. After a 15-day attentional control training program, 11-month-old infants reduced the number of perseverations during the post-switch block compared to a control group. These results highlight that although attentional flexibility could be impaired during infancy due to birth time, developmental lags could be reduced during infancy through attention training programs designed to impact attention control abilities.

3.7.4. Stability of attentional control

Stability between sessions was found for disengagement latency but not for disengagement failure. In particular, disengagement latency in the gap condition showed the highest stability between consecutive sessions. Positive correlations in this measure were found between middle and late infancy, as well as between late infancy and todlerhood, but not for the longest temporal interval between sessions (i.e. 6 to 16-18 months). The ability to shift visual attention in non-competitive and facilitatory contexts for visual disengagement (gap condition) is developed short after birth. This early development is based on the early functioning of brain areas known to be involved in orienting processes and to benefit from non-directive attentional cues (Ellis et al., 2021; Johnson & Tucker, 1996). Specifically, the superior colliculus, frontal eye fields and parietal cortex are involved in these processes, which show a significant development between 3 and 6 months of age (Johnson, 1990; Johnson et al., 1991), with even 3-month-olds being able to voluntarily orient attention in the visual space based on acquired expectancies (Atkinson et al., 1992; Hood & Atkinson, 1993). This early development would lead to more gradual and smooth changes during the first years of life, likely related to a fine-tuning process of this skill, resulting in less variability and more stability throughout these years.

In the overlap condition, stability in disengagement latency was only found from middle to late infancy. Attention disengagement in contexts of visual competition would require the engagement of dorsal fronto-parietal areas involved in the control of orienting (Corbetta & Shulman, 2002), allowing for the inhibition of a foveated stimulus to disengage and shift attention from one object or location to another. These brain regions are known to be active during the first years of life, supporting the development of early executive functioning (for a review see Hendry et al., 2016). Also, inhibitory control abilities already show certain stability from 6 months of age (Holmboe et al., 2018), with 10-month-olds even recruiting prefrontal and parietal areas during inhibition and orienting of attention (Fiske et al., 2022). The early functional activation of these brain areas in conjunction with a small temporal gap of 3 months would explain the stability of the disengagement latencies in the overlap condition between the middle and late infancy. However, the fronto-parietal network shows a protracted developmental course compared to sensorimotor and ventral parietal regions involved in exogenous/automatic attention (Casey et al., 2005). This prolonged development could make performance in the overlap condition to be more conditioned to individual differences in fronto-parietal activation during the first years of life, which could lead to a lower stability than the one observed for the gap condition. This could explain why disengagement latencies in the overlap condition only show stability in a short temporal interval of 3 months, but not in longer ones.

Regarding endogenous attention control in the VSL task, contrary to our hypothesis no stability for attentional measures between middle and late infancy were found, but for stimulus fixations between late infancy and toddlerhood. During the first year of life, Canfield et al. (1995) did not find stability for anticipations in the VExP between 4 and 6 months of age, but only certain stability in the second half of the first year (Canfield et al., 1997). Similarly, in toddlers and young children between 24 and 48 months, correct anticipations in easy and complex trials did not show stability between two sessions placed 6 months apart (Moyano et al., 2022). Stability in sustained attention from infancy to toddlerhood

(Gaertner et al., 2008; Lawson & Ruff, 2004) has been previously reported, as well as partial stability during early childhood (Moyano et al., 2022). Similar to the VSL task, no stability was found for any of the attentional control measures of the switching task (i.e. correct anticipations, pre-switch criterion, and perseverations). The first and second years of life are known to be periods with steep intra-individual attentional changes. Visual anticipations in the VSL and switching task could be more easily impacted by this individual variability, as they also rely on infants' differences in the ability to generate expectations. However, stimulus fixations in the VSL could be less affected by individual variability in infants' expectation creation, as it mainly encodes their ability to remain task engaged. Nevertheless, in this case, it is also surprising the lack of stability in exogenous attention (i.e. reactive looks in the VSL task).

An alternative theory could be related to the measures employed. We used fixations as our main metric in the VSL, switching task, and disengagement failure in the gap-overlap task, all of them showing little or no longitudinal stability. We also employed saccade latencies in the gap-overlap task, which in this case offered some stability across ages. This raises the question of using only fixations as the main dependent variable leads to a loss in infants' and toddlers' individual variability, which could be necessary to capture longitudinal stability in attentional measures. A recent longitudinal study measured different eye-tracking markers of attention control in infants at 6, 10, and 18 months of age (Tu, Lindskog & Gredebäck, 2022). A wide set of tasks tapping different attentional processes were employed, from the VSL to coherent motion or face perception tasks. A short fixation ratio and a look percentage were derived from the combination of all tasks, using infants' and toddlers' gaze duration as a basis to compute the scores. They found stability of these two composite scores, being positively correlated with themselves across these ages. In our case, the stability found for saccade latencies could support our theory, as it could be able to capture more individual variability that could contribute to detecting longitudinal stability.

3.7.5. Attention control index

Contrary to our hypothesis, no consistent associations were found between the attentional measures of the three tasks. Correlations were found between disengagement ability and anticipatory attention. Specifically, at 6 months higherdisengagement cost was found to be related to more exogenous attention (i.e. reactive looks) and less endogenous control (i.e. correct anticipations). This is an unexpected result, as in a sample of 4-month-old infants, Holmboe et al. (2018) found a positive association between anticipatory attention and disengagement ability. This result suggests that at 6 months of age, it is still too early for infants to decide not to disengage, but it could be a more voluntary decision later at 9 and 16-18 months of age.. At 9 months of age, we found a correlation that goes in this direction, with a higher disengagement failure being correlated with more exogenous attention (i.e. reactive looks). In this case, this association would indicate that a lower general maturation of the orienting system leads to a more reactive (exogenous) attentional control, with also a higher difficulty to disengage.

No correlations were found between attention flexibility and attention disengagement in any of the three ages. Conversely, Conejero & Rueda (2018) found higher disengagement latencies from emotional stimuli in 9-to 12-month-old infants to be associated with more perseverations in the post-switch block of the switching task. The current results do not replicate this finding. Also, it should be noted that the used disengagement task does not contain any emotional component in our study. This difference between tasks could have impacted the lack of correlation found in the current results.

Finally, anticipatory attention and attention flexibility were neither found to be correlated with attention flexibility measures in any of the ages considered. Surprisingly, not even correct anticipations between the VSL and switching tasks were associated, as they are both targeting an endogenous control of attention during learning of visual events. Associations between endogenous attention and attention flexibility have been found in previous literature, although not specifically with anticipatory attention. For instance, Johansson et al. (2015) found that higher sustained attention at 12 months during a free-play scenario was associated with higher attention flexibility during toddlerhood in the A-not-B task.

In general, the lack of consistent associations between the three attentional components measured by our set of tasks does not support the computation of an attention control index. This states that the different attentional mechanism measured in the current study, are independent of each other, although they are at the base of visual attention control. The lack of association between mesures could be also related to the lower stability found for each of the measures across waves, suggesting that the first and second years of life are periods of great individual changes in attention control. This would reduce the likelihood of finding consistent associations between the three attentional mechanisms considered.

3.7.6. Conclusion

The current study deepens the characterization of the longitudinal development of three core attentional abilities related to executive attention control between the first and second years of life. Specifically, we measured infants' ability for attentional disengagement, attentional flexibility, as well as anticipatory attention, and context monitoring. A secondary goal was to analyze the stability of these attentional measures from middle infancy to toddlerhood. The third and final aim of the study was to explore the associations between these three attentional abilities to consider the estimation of an attention control index, which could be employed as a general proxy for EA control during infancy and toddlerhood. Results revealed longitudinal increases in these abilities, although a lack of stability across waves in some of them. Moreover, no consistent correlations were found between these three attentional components at each wave, not supporting the idea of a general attention control index.

Results from the gap-overlap did not reveal changes in disengagement ability under visual competition (overlap condition). This suggests a slow progression from middle infancy to toddlerhood in infants' ability to control attention in contexts where stimuli compete for infants' attentional resources. Larger differences could likely emerge around the second birthday, once the first glances of inhibitory control ability found at the end of the first year are more established (Holmboe et al., 2018; Fiske et al., 2022), and attention control supervision starts to be under the EA network (Posner et al., 2014). On the other hand, infants increase their ability to reorient attention in contexts in which disengagement is facilitated with a non-directive attentional cue (gap condition). Previous research has found that infants decrease their latency to reorient attention when disengagement is eased during the first year of life. The current results would suggest a more protracted development of this ability until 16-18 months of age.

Infants also showed a linear increase in anticipatory attempts (i.e. total anticipations) with age, indicating a higher ability to endogenously control attention to try to anticipate upcoming stimuli in a sequence. However, easy correct anticipation shows a decrease from middle infancy to toddlerhood, while no differences were found for complex correct anticipations. Nevertheless, the growth curve suggests an increase in complex correct anticipations compared to easy. We argue that although infants display an equal ability to correctly anticipate complex trials across waves, they attempt to anticipate more during toddlerhood. This increase in total anticipations could likely be related to increased attempts to anticipate during complex trials, which are known to be more novel compared to easy trials. As infants are found to show a general preference for novel events, a higher preference for complex trials would harm performance on easy, which could explain the reduction observed for easy correct anticipations.

Longitudinal results from the switching task indicate a developmental linear increase in correct anticipations with age during the pre-switch block, with toddlers being more able to acquire the rule faster in comparison to 6 and 9 months. Moreover, older infants also displayed fewer perseverative errors during the post-switch block, suggesting a developmental increase in the ability to inhibit and overcome a dominant response previously learned. All in all, endogenous attention control seems to improve with age, leading to an increase in correct anticipations followed by a decrease in perseverative errors, suggesting improvements in attention flexibility during the first and second years of life.

Stability was partially found for fine-grained measures, that is saccade latencies in the gap and overlap conditions. Metrics using only general fixations occurrence to tap attentional processes showed little or no stability between infancy and toddlerhood. Finally, the lack of consistent correlations between attentional measures did not support the estimation of estimating an attention control index unifying different components of attention control.

3.7.7. Limitations

Although the current study offers interesting insights into attentional development studied on a large sample size, it is not free in limitations. Habituation effects in the gap-overlap task should be considered, as the pool of peripheral targets was lower than central stimuli, which were always novel and more attractive than peripheral targets. Infants could habituate to already-seen peripheral targets, affecting infants' attention disengagement in overlap trials. This is not expected to have an effect in gap trials as the peripheral target was the only stimulus displayed on the screen. Nevertheless, previous studies with infants have used the same stimuli for central and peripheral targets (Holmboe et al., 2018), finding the expected gap-overlap effect.

Another aspect to be improved in future research is to keep constant the same version of the VSL task across ages, as the use of different sequences could mask significant differences in anticipatory attention (Canfield et al., 1997). The 3 positions version of the task has been already used with infants and toddlers (Clohessy et al., 2001), with the only modification being the number of trials administered. This would allow having measures of total anticipations, as well as easy and complex correct anticipations at 6 months of age, easing the comparison and longitudinal change in these relevant measures. However, maintaining the same number of trials between versions would allow having more comparable measures of sustained attention across ages.

Future research should focus on producing more longitudinal data focused on understanding the development of these aspects of attention control. This would also contribute to replicate the current results, but also to strengthen the characterization of infants' attentional development. Considering earlier stages of infancy or beyond toddlerhood will also contribute to create a more complete picture of the early development of different domains of attention control.

Chapter 4: Predictive factors of attention control during infancy and toddlerhood.

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4.1. Introduction

4.1.1. Importance of attention control during infancy and toddlerhood

Developmental of endogenous attention is a key aspect in the emergence of a more self-controlled behaviour (Posner et al., 2014). As infants and toddlers progressively gain control over attention, significant behavioural changes could be observed (Hendry et al., 2019), transitioning from being exogenously to endogenously controlled (Johnson, 1990). Following Posner's model of attention (Posner & Petersen, 1990), voluntary control is implemented by the orienting attention network in the first two years of life (Posner et al., 2014), establishing the foundations for the executive attention network to take control over attentional control from the second year onwards (Rothbart et al., 2011; Rothbart & Posner, 2022). This developmental jump in the neural basis of attention control allows deploying more sophisticated and efficient mechanisms of control (Rueda et al., 2021), providing the attentional system with the flexibility and adaptability required for a more mature functioning. But how are these improvements in attention control translate into the daily functioning of infants and toddlers?

During infancy, increases in attention control allow infants to implement self-controlled strategies to down-regulate emotional states (Harman et al., 1997; Crockenberg & Leerkes, 2006; Sheese et al., 2008), allowing certain independence from external regulators (e.g. parents or caregivers; Jahromi et al., 2004; Kopp, 1982). This ability is known as self-regulation, involving top-down control over individuals' reactivity at the behavioural, cognitive, and emotional levels (Rueda et al., 2005). Higher self-regulatory ability during the preschool period is related to a higher self-control behaviour in adulthood (Casey et al., 2011), as well as to predict adults' well-being (e.g. educational, health, economic or socio-emotional factors; Daly et al., 2015; Mischel et al., 2010; Moffitt et al., 2011). Attention plays an important role in these outcomes, as it is proposed to be at the basis of self-regulation (Rothbart et al., 2011; Rueda et al., 2021), with which it shares common brain structures of attention control networks (e.g. executive attention; Bell & Deater-Deckard, 2007). In general, infants' and toddlers' attention contributes to predict self-regulation during early development, among other intrinsic and extrinsic factors (Fox & Calkins, 2003).

Attention disengagement and reorienting are some of the first attentional abilities that can be observed in infancy to down-regulate behavioral and emotional reactivity (Harman et al., 1997). Infants' anticipatory attention has also been found to be associated with a higher self-controlled behavior. Using the Visual Sequence Learning (VSL) task in a sample of 6-to7-month-olds, Sheese et al. (2008) found that the more correct anticipations infants performed, the longer the duration of self-soothing behaviour to down-regulate emotional reactivity. This positive association between attention control and self-regulation is also found at the longitudinal level. For instance, infants with higher sustained attention at 10 months when looking at a glove puppet, also displayed higher down-regulation of frustration at 36 months (Perry et al., 2016). In the same direction, 9-month-old infants with higher focused attention during a free-play task predicted higher self-regulation measured through an effortful control battery at 22 months (including self-restraint and response inhibition behavioural tasks; Kochanska et al., 2000).

Other aspects of attention control during infancy and toddlerhood had also been proven to be associated with better control over behaviour and cognition. Infants' ability to inhibit attentional reorienting from an attended interesting stimulus towards a peripheral distractor, was found to be associated with a higher ability to solve cognitive conflict at 24 months of age (Holmboe et al., 2008). Using the VSL task, distinguishing easy (unambiguous) and complex (ambiguous; involving context monitoring ability) trials, Rothbart et al. (2003) found the percentage of correct anticipations in complex trials to be associated with a higher ability to solve cognitive conflict at 30 months of age.

Finally, the developmental increase in attention control has also been found to be associated with other spheres of toddlers' and children's functioning, such as academic achievement or socioemotional adjustment (Rueda et al., 2010, Simonds et al., 2007). For example, Bornstein et al. (2012) found that 4-month-olds who habituate faster (i.e. faster information processing) also show better general cognitive development at 18 months, fewer behavioral problems at 36 months, and better academic achievement at 14 years of age. In a recent longitudinal study, Blakenship et al. (2019) reported that infants' attention at 5 months of age was found to be predictive of a composite score of executive functioning at 10 months, involving aspects of attention flexibility, working memory, and inhibitory control. This executive functioning during childhood also mediated the effect of infants' attention at 5 months and reading achievement at 6 years of age. Similarly, Kraybill et al. (2019) also reported infants' attention at 5 months is related to higher executive functions at 3 years of age. This suggests a contribution of attention not only to proximate cognitive functions but also to the unfolding of other significant abilities for the adequate functioning of children during early development.

In general, these results highlight the importance of attention control in infants' forthcoming self-controlled behaviour and cognition. These abilities are potential predictors of the individual functioning in the short (e.g.

academic achievement and socio-emotional adjustment during childhood) but also long run (e.g. educational level, well-being, and economic factors during adulthood). However, cognitive development does not take place in isolation. In contrast, infants are in constant interaction with their environment. How infants interact with it relates to individual differences (i.e. constitutional factors), but also to a cognitive system that is shaped based on the characteristics of the early environment that infants grow up in (i.e. environmental factors). There is evidence that the biological system that supports attention interacts with both constitutional (i.e. temperament; Posner & Rothbart; 2007; Rothbart & Posner, 2022) and environmental factors (i.e. socioeconomic status; home chaos; Conejero et al., 2016; Conejero & Rueda, 2018; Tomalski et al., 2013; 2017) from very early stages of development. In the following sections, we will focus on reviewing the impact of temperament, and the early environment (i.e. home chaos, socioeconomic status, and maternal depression) on early attentional control.

4.1.2. Impact of temperamental individual differences on attention control

Constitutional individual differences correspond to one of the nearest levels of interaction with attention, with temperament being one of the most studied factors concerning individual differences in attention control (Rothbart, 2007). This construct could be defined as constitutional individual differences in reactivity at the behavioral, emotional, and attentional levels, as well as the ability to self-regulate them (Rothbart, 1981). Temperament is composed of three main factors that can be identified from early moments after birth based on infants' behavioural correlates (e.g. smiling, laughter, avoidance movements, frustration, etc.). Two of these factors are related to the individual's reactivity, either positive/approach (Surgency; SUR: e.g.: smiling, impulsivity, positive anticipation, etc.) or negative/avoidance

(Negative Affect; NA: e.g. fear, anger, discomfort, etc.). The third factor is known to be related to self-regulatory abilities (Effortful Control; EC: e.g. attentional focusing, inhibitory control, perceptual sensitivity, etc.; Rothbart & Ahadi, 1994). This temperamental structure shows a strong attentional basis (Rothbart, 2007), with developmental research reporting a systematic association between temperament and attention control.

Out of the three main temperamental factors, Orienting/Regulatory Capacity (ORC) appears to be the one most related to emerging attention control (Rothbart et al., 2011), predicting the later emergence of EC in late infancy and toddlerhood (Putnam et al., 2008). Between 4 and 12 months of age, a positive correlation between infants' ORC (i.e. soothability and regulation of distress) and attention control, measured through visual attention disengagement, has been found in several studies (Johnson et al., 1991; McConnel & Bryson, 2005; Nakagawa & Sukigara, 2013). Similarly, infants with higher fixation durations between 7 and 11 months display a higher EC later in toddlerhood and early childhood (Geeraerts et al., 2019; Papageorgiou et al., 2014), suggesting a robust association between visual attention control and individual differences during early development. Nevertheless, the interrelation between ORC and visual disengagement ability seems to reverse from the first to the second year of life. At 12 months of age, Nakagawa & Sukigara (2013) found infants with a high ORC to display lower latencies to visually disengage attention (i.e. faster disengagement). Interestingly, this association was reversed at 18 and 24 months, with a higher ORC linked to higher latencies to visually disengage (i.e. slower disengagement). It is during toddlerhood when the function of inhibitory control could experience changes concerning attention disengagement based on toddlers' preferences. In this case, its purpose would be to inhibit not the currently attended stimulus, but potential distractors that could drive attention away from the current source of information.

Not only visual disengagement but other components of visual attention control have been found to relate to early ORC. Specifically, a negative association between soothability, as a measure of self-regulated behaviour, and correct anticipations in 4-month-olds employing a Visual Expectation Paradigm (VExP) was reported by Johnson et al. (1991). In contrast, Sheese et al. (2008) reported positive correlations between self-regulated behaviour, measured through a more cautious approach to novel toys and a longer self-soothing behaviour, with correct anticipations in the Visual Sequence Learning (VSL) task in 6-to 7-month-olds. The association between ORC and anticipatory attention seems to be quite mixed. For instance, Posner et al. (2012) did not find any correlation between correct anticipations in the VSL task and temperament in a longitudinal study from 6 to 48 months of age. Although Rothbart et al. (2003) reported a positive correlation between EC and complex correct anticipations in the VSL task in 30-month-olds, this was not consistently found for 24 and 36-month-olds.

Although during childhood SUR is related to reactivity and a lower attentional control (Rueda & Conejero, 2020), during infancy this temperamental factor seems to serve to contribute to self-controlled attention (Rothbart et al., 2011). In the same direction as ORC, components of Positive Affectivity/Surgency (PAS), such as smiling, are positively related to disengagement ability in 6-month-olds (McConnell & Bryson, 2005). On the other hand, SUR at 18 months is associated with less easy correct anticipations in the VSL task (Rothbart et al., 2003). But, why do these associations with attention control seem to change between the first and second year? Previous work by Putnam et al. (2008) found that a higher PAS at 3 to 12 months was correlated with a higher EC at 18 to 32 months of age. This correlation was mostly explained by associations of PAS with specific dimensions of EC, such as attention shifting and low-intensity pleasure. Interestingly, the correlation was reversed when PAS was measured from the second year onwards. In this case, a higher PAS at 18 to 32 months of age was associated with a lower EC at 37 to 59 months of age. This negative correlation was mostly due to a negative association between toddlers' activity level and the child's attention focusing and inhibitory control. This suggests that during infancy, PAS could be tapping temperamental aspects related to self-regulated behaviour and endogenous control of attention, which could serve as a foundation for future EC and attention control emergence. In this respect, Rothbart et al. (2011) proposed that the contribution of infants' PAS to attention control is due to a higher reliance on the orienting network as a supervisory system for attention control during the early stages of development. With the functional emergence of the executive attention network as the main supervisory system of attention control during the second year of life (Posner et al., 2014), is EC the temperamental factor that captures most aspects of control over attention.

A consistent negative relation between attention control and NA is found across different developmental stages. For instance, infants from 4 to 6 months of age with a higher NA, also show a lower ability to endogenously disengage visual attention (Johnson et al., 1991; McConnell & Bryson, 2005). In this respect, infants with a higher NA are less efficient at reducing discomfort by disengaging and reallocating attention away from a distressful stimulus (Harman et al., 1997; Stifter & Braungart, 1995). The same pattern of results had been found during the second half of the first year of life. Using perseverative errors as a proxy for attention flexibility, Conejero & Rueda (2018) reported a positive association between NA and perseverations in 9-to 12-month-old infants. In general, infants' temperament shows a consistent correlation with attention control in the first years of life (Rothbart & Posner, 2022) yet the stability of some of these associations seems to evolve with age.

4.1.3. Impact of early environment on attention control

Increasing literature shows that the rearing environment of infants and toddlers has an impact on their cognitive development (Conger & Donnellan, 2007). The socioeconomic status (SES) of the family is one of the most prevailing indexes used as a proxy to characterize the household environment (see Farah, 2017). Different individual aspects of the family unit are considered into the SES index, which is calculated using the average of normalized parental education level, parental occupation level, and the family’s income. Thus, the SES index provides an account for the interrelationship between social and economic aspects of the family unit. Measuring the income of families, Clearfield & Jedd (2013) reported that infants from low-income backgrounds appear to show a developmental delay in the active engagement of attention. In their study covering ages from 6 to 12 months of age, infants’ behavior was recorded in a free-play task. They found that infants from low-income homes displayed higher inattention and less attention engagement overall compared to infants from high-income households. Interestingly, only infants from high-income backgrounds were able to modulate attention according to the complexity of the context at 12 months of age, increasing attention engagement as the complexity of the setting increased (i.e. from one to six toys).

Concerning attentional disengagement, evidence shows mixed results in its association with SES. In a recent study, Siqueiros-Sanchez et al. (2021) investigated the association of maternal education (as a proxy for SES) and disengagement of attention using the gap-overlap task. Results showed that 5-month-old infants from low-income backgrounds displayed lower disengagement latencies in the overlap condition in comparison to infants from high-income homes. In an older sample of 9-to 12-month-old infants, Conejero & Rueda (2018) found families' income to be negatively associated with disengagement latencies to faces whether they showed emotional (negative or positive) or neutral expressions. In this study, higher disengagement latencies of infants from low-income households were interpreted as reduced ability to inhibit a fixated complex stimulus in order to shift attention. These developmental differences based on socioeconomic background could be explained by a developmental delay in attentional flexibility for low-income infants. Investigating this possibility, Clearfield & Niman (2012) used a perseverative reaching task to measure attention flexibility in a longitudinal sample followed from 6 to 12 months of age. They found low-income infants to show a developmental delay in correct manual reaching, leading to a higher number of perseverations. While infants from high-income families transitioned from random reaching at 6, perseverations at 9, and correct reaching at 12 months, infants from low-income households were lagged by one stage. That is, they correctly reached at 6 months, which is usually found at 5 months, performed random reaching at 9, and perseverated at 12 months. Similarly, Lipina et al. (2005) also found 6-to 14-month-old infants with uncovered basic needs to show less correct reaching and more perseverations in switch trials of a classic A-not-B task.

Other environmental factors that might have an impact on the development of infants' attention have been less investigated. For instance, over and above SES, families differ in their level of organization. To characterize these differences, Matheny et al. (1995) developed the Confusion, Hubbub and Order Scale (CHAOS). Households with high scores in this scale are characterized by unstructured spaces and messy environments combined with low levels of predictability and lack of routines, all together leading to greater environmental confusion (Matheny et al., 1995). Maternal depressive symptomatology is especially important during the perinatal period, with a prevalence of almost 12% (Woody et al., 2017), having its main impact canalize through mother-infant interactions.

The use of this CHAOS has recently provided with new insights for understanding the influence that physical characteristics of the environment have on cognitive development (Tomalski et al., 2017). Most of the research done with the CHAOS scale has found a negative impact of household organization on executive functions (Vernon-Feagans et al., 2016) and self-regulatory abilities (Lecheile et al., 2020) across development (Andrews et al., 2021). Although a chaotic home environment has been proposed to have a relevant impact on early attention control (Wass, 2022), research on this respect is scarce. Only Tomalski et al. (2017) have reported effects of CHAOS on early visual attentional control in a sample of 5.5-month-old infants. In their study, CHAOS was found to be positively associated with longer looking times, as a measure of processing speed, for complex visual stimuli compared to simpler ones. This suggests that the early effects of CHAOS could be traced back to early infancy, but further research on this matter is still needed.

Regarding the relationship between home chaos and SES, some authors have proposed that families from low-income backgrounds are more likely to have more unstructured environments at home, with increased levels of noise, crowding or turmoil (Evans, 2004; Evans & Kim, 2013). In this sense, Evans & Schamberg (2009) reported that the number of years that children are exposed to a low-income environment is positively associated with the physiological stressors related to more disorganized households. Conversely, Petrill et al. (2004) found the effects of CHAOS to be independent of those tapped by SES. In their study, CHAOS remained as a significant predictor of preschoolers' cognitive ability even after controlling for families' SES. Also, a recent study conducted with 24 to 48-month-olds found indices of SES and CHAOS to be uncorrelated, showing differential impact of children's visual attention skills (Moyano et al., 2022). Additional evidence supports this view, reporting a lack of correlation between SES and measures of household disorganization (Hart et al., 2007; Vernon-Feagans et al., 2012). The level of CHAOS at home appears to have a negative impact on social aspects of the home environment, such as parenting (Evans et al., 2009; Vernon-Feagans et al., 2016) or parent-child interactions (Tomalski et al., 2017), reducing parent's abilities to productively engage in interaction with their offspring (Vernon-Feagans et al., 2012). Additionally, home disorganization seems to reduce parent's contingent behavior, affecting over their abilities to positively scaffold children's cognitive and behavioral development (Vernon-Feagans et al., 2012). Finally, a higher exposure to household disorganization and instability increases children's tendency to withdraw from their immediate environment, reducing the amount of information that they can learn to promote cognitive development (Garrett-Peters et al., 2016). Overall, CHAOS seems to capture more proximal aspects of the home environment (i.e. predictability and organization of the house environment, and its effects over parenting) than SES, with families from low-income backgrounds not being necessarily exposed to higher levels of household disorganization. Instead, families' SES appears to capture the availability of resources to support children's development derived from the level of parental income and education. As such, SES might also constraint the options for household neighborhood, the hours spent by parents at home or their stress levels. All in all, there is evidence suggesting that both SES and CHAOS may impact on early cognitive development. Nevertheless, their effects over visual disengagement in the transition between infancy and toddlerhood remains unstudied. Measuring both environmental factors during these developmental periods will shed light onto their possible independent effects on the early development of attention.

The effects of maternal depression are mostly channeled through its effects on the quality of mother-infant interactions. Mothers with higher levels of depressive symptomatology display more negative interactions with their infants (Coyl et al., 2002; Jameson et al., 1997). Also, maternal depression is more likely to reduce the stimulation of the infants and increase their exposure to environmental stressors that could disturb early brain and cognitive development (Hackman et al., 2010). Negative effects of early exposure to maternal depressive symptomatology have been found on children's behaviour, temperament, and EF during toddlerhood and early childhood (Hughes et al., 2013; Hutchison et al., 2019; Leckman-Westin et al., 2009; Rigato et al., 2020). Recently, Rigato et al. (2022) reported that exposure to maternal depression during the first year of life, significantly predicts higher behavioural problems at 36 months of age. In another study, Oh et al. (2020) found in a sample of mother-child dyads, that mild to moderate maternal depressive symptoms from birth up to the second year, harm children's EF in late childhood. A recent meta-analysis supported results in this direction, with a small but significant association between higher perinatal maternal depression and lower EF in children (Power et al., 2021). Research on the effects of early maternal depression exposure supports negative effects on children's cognitive development. Both temperament and early environmental factors have been found to impact attention development. Most of the studies have addressed their individual effects, yet a potential interaction between both factors seems likely, as infants' environment can account for individual differences at the temperamental level (Belsky et al., 2009; Li-Grining, 2007).

4.1.4. Aims

In the current Chapter, we aim to study the predictive effects of early temperament and environment over different aspects of attention control in infancy described in Chapter 3 (i.e. attention disengagement, anticipatory attention, and attention flexibility). Moreover, we also intend to detect interaction effects between these factors when predicting attentional performance through longitudinal mediation models. Following Conejero & Rueda (2018), we intend to test the mediation role of temperament over the effect of the environment on infants' and toddlers’ attention. In their study, Conejero & Rueda (2018) found that infants’ NA mediates the relation between SES and attention flexibility in 9-to 12-month-old infants. Thus, we intend to replicate this mediation model from a longitudinal perspective, a goal that has not been addressed by any previous study, so far.

4.2. Method

4.2.1. Participants

As participants were the same of our longitudinal study, we refer the reader to a detailed description in section 2.1. of Chapter 3.

4.2.2. Procedure

A detailed description of the procedure used for the sessions of the longitudinal study can be found in section 2.2. of Chapter 3.

4.2.3. Parent-reported questionnaires

Temperament and environment data were considered in the current Chapter, along with attentional measures described in Chapter 3. Infants’ and toddlers’ temperament, as well as families’ environmental factors (i.e. socioeconomic background, home chaos, and maternal depression), were collected through parent-reported questionnaire data. In the next section, we will focus on describing only the new questionnaire measures considered.

4.2.3.1. Infants' and toddlers' temperament

Parents fulfilled the Spanish Very-Short version of the Infant's Behavior Questionnaire (IBQ-R VSF; Putnam et al., 2014) at 6 and 9 months of age. They reported how frequently infants displayed certain behaviors during the last week through 37 items using a 7-point Likert scale, ranging from 1 (Never) to 7 (Always). The IBQ-R VSF assesses three temperamental factors: Orienting/Regulatory Capacity (ORC), Positive Affectivity/Surgency (PAS), and Negative Affectivity (NA). The higher the score, the more the temperamental factor is distinctive in infants. At 6 months, Cronbach's alpha (α) for ORC, PAS, and NA was .83, .84, and .85, respectively. At 9 months, Cronbach's alpha of the subscales was: .72, .79, and .82 for ORC, PAS, and NA.

At 16-18 months of age, parents fulfilled the Spanish Very-Short version of the Early Childhood Behavior Questionnaire (ECBQ; VSF Putnam et al., 2006). Similar to the IBQ-R VSF, parents reported how frequently toddlers displayed certain behaviours in the last two weeks through 36 items using the same Likert scale as for the IBQ-R VSF (Putnam et al., 2014). The ECBQ VSF also allows measuring the 3 main temperamental factors: Effortful Control (EC), Surgency (SUR), and Negative Affect (NA). Cronbach's alpha for EC, SUR, and NA for the ECBQ scale was: .72, .83, and .70.

4.2.3.2. Socioeconomic status

Parents were asked about their educational level, professional occupation, and family incomes in the 6 and 16-18 months sessions. Following Conejero et al. (2016), education level was scored from 1 (no studies) to 7 (postgraduate studies). Professional occupation was rated following the National Classification of Occupations (CNO-11) of the National Institute of Statistics of Spain (INE) from 0 (unemployed) to 9 (manager). Finally, an income-to-needs ratio was computed by dividing the family's annual income by the official poverty threshold provided by the INE based on the number of members of the family unit. A general SES index was computed by averaging the z-scores of the three socioeconomic aspects assessed (parents' educational level, occupation, and family's income-to-need ratio).

At the 16-18 months session, parents were not asked about their educational level, in order to reduce the length of the questionnaires. This factor wasn't expected to change in a 10 months gap in comparison to the employment situation of the families, which would also affect family income-to-needs and the general SES index. Therefore, to compute the SES index at 16-18 months, we considered the education level reported by parents at 6 months. In the general SES index and subindexes, the higher the score, the higher the socioeconomic background.

4.2.3.3. Confusion, Hubbub, and Order Scale

A Spanish version of the CHAOS scale (Matheny et al.,1995) previously adapted to the Spanish language (Moyano et al., 2022), was applied to measure the level of confusion and household disorganization. Parents reported their level of agreement with different statements describing the organization, environment, and family routines at home through a six-point Likert scale (15 items, α = .87 at 6 months and α = .85 at 16-18 months) ranging from 1 (Completely agree) to 6 (Completely disagree). A total score of chaos was computed by adding all the items' scores. The higher the score, the higher the level of chaos at home.

4.2.3.4. Maternal depression

The Spanish version of the Beck's Depression Inventory (BDI-II; Beck et al., 1996) was employed to measure maternal depressive attitudes and symptoms. The BDI-II is a 21-item self-reported inventory fulfilled by mothers reporting how they felt in the last two weeks concerning different depressive symptoms. Answers were provided using a Likert scale from 0 to 3. The inventory showed an internal consistency of α = .88 at 6 months and α = .90 at 16-18 months. A total score was calculated by adding the scores in the 21 items, with a higher score indicating higher depressive symptomatology.

4.3. Results: Do temperamental and environmental factors show stability from 6 to 16-18 months? Evidence from questionnaire data.

4.3.1. Hypothesis

We expect to find stability of temperament and environmental factors across the analyzed ages. This stability is thought to be higher for environmental factors rather than for temperament, as the latter comprises individual differences that are tied to more changes over time, especially in the first years of life.

We anticipate a positive correlation of temperamental factors between-waves. We also expect that the strength of the correlation will be weaker as the temporal gap between sessions increases, as there is a bigger margin for individual changes. Specifically, correlations between 6 and 9 months, as well as between 9 and 16-18 months are hypothesized to be stronger compared to 6 and 16-18 months. Concerning environmental factors, we expect a positive correlation with themselves between 6 and 16-18 months. Note that environmental factors were not measured at 9 months.

4.3.2. Analysis strategy

Based on the hypotheses, pairwise two-tailed correlations with 95% CIs were employed to assess the stability of temperamental and environmental factors across sessions. Pearson correlation coefficient was computed when the distribution of the variables introduced in the analysis followed a normal distribution, otherwise, Spearman's rho coefficient was employed. Variables distribution was evaluated though the Shapiro-Wilk test, as well as histograms and Q-Q plots. Confidence intervals (95%) are reported along with p-values to denote statistical significance.

4.3.3. Results

4.3.3.1. Descriptive statistics

Most of the families completed the corresponding questionnaires at each wave, although some cases were missed (Table 4.1). In this regard, the number of cases with valid data for the general SES index (z-score) is lower than for the individual SES factors. As some families had missing data in one or more SES variables, the z-score in those cases could not be computed. In general, we can see that parent-reported data provides variability concerning temperamental and environmental factors, based on standard deviations from the mean and min and maximum values for each scale.

Concerning variables distribution, the Shapiro-Wilk test indicated that ORC at 6 months ($W = .89$, $p < .01$), as well as PAS at 6 ($W = .93$, $p < .01$), 9 ($W = .97$, $p = .04$) and 16-18 months ($W = .93$, $p < .01$), did not follow a normal distribution. Similarly, the Shapiro-Wilk test suggested a non-normal distribution for the majority of environmental factors, except for the SES index at 6 ($W = .98$, $p = .18$) and 16-18 months ($W = .97$, $p = .15$), as well as for CHAOS at 6 months ($W = .99$, $p = .34$). Histograms and Q-Q plots confirmed the non-normal distribution for these temperamental and environmental factors. In light of this, Spearman's rho (*ρ*) coefficient was used to compute pairwise correlations involving these factors.

Table 4.1.

Descriptive statistics for questionnaire measures of temperament and environment at 6, 9, and 16-18 months.

	n valid			Mean (*SD*)			Min (*Max*)		
	6 months	9 months	16-18 months	6 months	9 months	16-18 months	6 months	9 months	16-18 months
ORC/EC	132	106	72	5.346 (*.86*)	5.23 (*.74*)	4.32 (*.75*)	2.08 (*6.66*)	3.33 (*7*)	2 (*5.91*)
PAS/SUR	132	106	72	5.12 (*.95*)	5.51 (*.68*)	5.23 (*.79*)	2 (*7*)	3.31 (*7*)	2.50 (*6.91*)
NA	132	106	72	3.96 (*1.09*)	4.52 (*1.02*)	3.14 (*.72*)	1.5 (*6.09*)	2 (*6.66*)	1.83 (*5.10*)
SES index (z-scores)	112	N/A	66	.08 (*.82*)	N/A	.04 (*.76*)	-1.50 (*1.90*)	N/A	-1.19 (*1.90*)
Parental education	126	N/A	N/A	3.82 (*1.48*)	N/A	N/A	1 (*6*)	N/A	N/A
Parental occupation	127	N/A	68	4.25 (*2.45*)	N/A	4.92 (*2.08*)	0 (*8*)	N/A	0 (*8*)
Income-to-needs	120	N/A	68	1.32 (*.71*)	N/A	1.73 (*.80*)	0 (*3.13*)	N/A	.42 (*3.75*)
Maternal depression	131	N/A	70	10.74 (*7.43*)	N/A	11.29 (*7.79*)	0 (*40*)	N/A	4 (*39*)
CHAOS	130	N/A	69	41.09 (*13.07*)	N/A	40.48 (*12.46*)	15 (*81*)	N/A	20 (*76*)

Note. ORC = Orienting/Regulatory Capacity; EC = Effortful Control; PAS = Positive Affectivity/Surgency; SUR = Surgency; NA = Negative Affectivity.

4.3.3.2. Stability of temperament

Concerning the correlations of temperamental factors between waves, ORC at 6 months was positively correlated with ORC at 9 (*p* < 01; 95% CI [.14, .49]) but marginally with EC at 16-18 months (*p* < 10; 95% CI [-.01, .45]). Likewise, PAS at 6 months showed a positive correlation with itself at 9 months (*p* < .01, 95% CI [.18, .53]) and SUR at 16-18 months (*p* < .05, 95% CI [.05, .49]). Finally, NA at 6 months displayed a positive correlation only with NA at 9 months (*p* < .01, 95% CI [.36, .65]), but marginally with NA at 16-18 months (*p* < .10, 95% CI [-.01, .44]; Table 4.2).

Interestingly, ORC/EC and PAS/SUR were found to be positively correlated at 6 (*p* < .01, 95% CI [.63, .80]), 9 (*p* < .01, 95% CI [.27, .58]) and 16-18 months (*p* < .01, 95% CI [.17, .56]). Moreover, part of these correlations were also maintained between waves. For instance, ORC at 6 months was positively associated with PAS at 9 months (*p* < .01,95% CI [.27, .59]), but not PAS at 16-18 months. Also, PAS at 6 months showed a statistically significant positive correlation with EC at 16-18 months (*p* < .05, 95% CI [.01, .46]), but not with ORC at 9 months.

Table 4.2.

Two-tailed pairwise correlation coefficients for temperamental factors across testing sessions.

		1	2	3	4	5	6	7	8	9
6-months	1. ORC	-								
	2. PAS	**.73*****	-							
	3. NA	**.21***	**.33*****	-						
9-months	4. ORC	**.32****	.14	-.12	-					
	5. PAS	**.44*****	**.36*****	.11	**.44*****	-				
	6. NA	-.15	-.10	**.52*****	-.01	*.16#*	-			
16-18 months	7. EC	*.23#*	**.25***	-.01	**.31****	-.14	-.17	-		
	8. SUR	.11	**.29***	.19	.07	.02	.12	**.38*****	-	
	9. NA	-.05	.19	*.23#*	-.13	-.19	.13	.06	*.19#*	-

Note. Sample size for correlations across ages was variable depending on the collected data in both measures considered: Correlations within age: 6 months (n = 132), at 9 months (n = 106), and 16-18 months (n = 72). Correlations between ages: 6 vs. 9 months (n = 98); 6 vs. 16 months (n = 67); and 9 vs. 16-18 months (n = 63). ORC = Orienting Regulatory/Capacity; PAS = Positive Affectivity/Surgency; SUR = Surgency; NA = Negative Affectivity; EC = Effortful Control

*** $p < .001$; ** $p < .01$; *$p < .05$; #$p < .10$

4.3.3.3. Stability of environmental factors

Regarding correlations of environmental factors across ages, SES factors at 6 months were positively correlated with themselves at 16-18 months: income-to-needs ($p < .01$, 95% CI [.56, .82]), parental occupation ($p < .01$, 95% CI [.45, .76]) and SES index ($p < .01$, 95% CI [.77, .91]). As parental education was not measured at 16-18 months, we could not compute a correlation with itself between waves. The same high positive and high correlation coefficients were found for chaos ($p < .01$, 95% CI [.50, .79]) and maternal depression ($p < .01$, 95% CI [.67, .86]) between 6 and 16-18 months.

Concerning correlations within-wave between environmental measures, we found that socioeconomic factors (i.e.: income-to-needs, parental education, parental occupation, and SES index) were highly correlated between them, with a minimum of $\rho = .41$ at 6 and $\rho = .80$ at 16-18 months. These high correlations between SES factors within each wave also supported the estimation of the SES index as a general index of families' socioeconomic status. For correlations between factors, SES was not associated with CHAOS or maternal depression neither at 6 nor 16-18 months. On the other hand, chaos positively correlated with maternal depression at 6 ($p < .01$, 95% CI [.22, .52]), but marginally at 16-18 months ($p < .05$, 95% CI [-.02, .44]; Table 4.3)

Table 4.3.

Two-tailed pairwise correlation coefficients for environmental factors across testing sessions.

		1	2	3	4	5	6	7	8	9	10	11
6-months	1. Income-to-needs	-										
	2. Parental education	**.41*** **	-									
	3. Parental occupation	**.53*** **	**.54*** **	-								
	4. SES index	**.77*** **	**.79*** **	**.85*** **	-							
	5. CHAOS	-.08	-.03	.05	-.01	-						
	6. Maternal depression	-.01	-*.13#*	.07	-.03	**.38*** **	-					
16-18 months	7. Income-to-needs	**.71*** **	**.44*** **	**.43*** **	**.69*** **	-.10	-.09	-				
	8. Parental occupation	**.38*** **	**.45*** **	**.63*** **	**.62*** **	-.07	-.01	**.50*** **	-			
	9. SES index	**.55*** **	**.79*** **	**.63*** **	**.85*** **	-.01	-.08	**.79*** **	**.80*** **	-		
	10. CHAOS	.06	.10	-.03	.07	**.67*** **	*.21#*	-.03	-.14	-.04	-	
	11. Maternal depression	.02	.12	.06	.11	.09	**.78*** **	-.09	.07	-.01	*.22#*	-

Note. Sample size for correlations across ages was variable depending on the collected data in both measures considered: Correlations within age: 6 months (*n* = 112-125), and 16-18 months (n = 54-70). Correlations between 6 vs. 16 months (*n* = 59-69).

*** *p* < .001; ** *p* < .01; * *p* < .05; # *p* < .10

4.4. Do temperament and environment correlate during infancy and toddlerhood?

4.4.1. Hypothesis

We hypothesize a positive correlation between ORC/EC and SES within each wave, but negative with CHAOS and maternal depression. Additionally, negative correlations of PAS/SUR and NA with SES, but positive with CHAOS and maternal depression are hypothesized.

4.4.2. Analysis strategy

Two-tailed correlation coefficients with 95% CI were computed to test the hypotheses.

4.4.3. Results

For socioeconomic variables, parents' educational level at 6 months was found to be positively correlated with NA at 9 months (p = .01, 95% CI [.04, .42]). Also, a higher family's income-to-needs (p = .03, 95% CI [-.45, .02]) and SES index (p = .02, 95% CI [-.48, -.02]) at 6 months were associated with a lower SUR at 16-18 months. However, for these latter correlations, confidence intervals did not support a genuine correlation.

CHAOS at 6 months was found to be associated with a lower ORC (p < .01, 95% CI [-.39, -.06]) and PAS (p = .01, 95% CI [-.36, -.02]) at the same age, as well as with less NA (p < .01, 95% CI [-.54, -.11]) at 16-18 months. Finally, a higher level of maternal depression at 9 months correlated with a higher NA (p = .02, 95% CI [.01, .39]) at 16-18 months. However, confidence intervals did not support a significant correlation of maternal depression at 9 months with ORC at the same age (p = .03, 95%

CI [-.32, .01]) and at 16-18 months (*p* = .04, 95% CI [-.36, .02]). No statistically significant correlations were found between temperament and environmental factors in toddlerhood (all *ps* > .06)

Table 4.4.

Two-tailed pairwise correlation coefficients between temperamental and environmental factors.

		ORC/EC			PAS/SUR			NA		
		6-mo	9-mo	16-18-mo	6-mo	9-mo	16-18-mo	6-mo	9-mo	16-18-mo
6 months	Parental education	-.04	-.13	-.05	-.08	.04	*-.17#*	*.15#*	**.24***	-.15
	Parental occupation	-.06	*-.14#*	-.04	-.04	.02	-.13	.04	.07	-.08
	Income-to-needs	.09	-.04	-.13	-.02	.04	**-.23***	-.07	.11	-.10
	SES index	-.03	-.12	-.10	-.04	.04	**-.26***	.08	*.18#*	-.12
	Maternal depression	**-.16***	**-.18***	.06	-.09	-.11	.16	.11	**.21***	-.06
	CHAOS	**-.23****	-.09	-.14	**-.19***	-.12	-.13	.10	.08	**-.34****
16-18 months	Parental occupation	-	-	.10	-	-	-.04	-	-	*-.20#*
	Income-to-needs	-	-	-.02	-	-	-.13	-	-	-.07
	SES index	-	-	.03	-	-	-.12	-	-	*-.18#*
	Maternal depression	-	-	.03	-	-	.12	-	-	-.06
	CHAOS	-	-	*-.17#*	-	-	-.14	-	-	-.13

Note. Sample size for correlations between temperament and environmental factors within-wave was: 6 months (*n* = 112-131), and 16-18 months (*n* =56-66). Sample size for correlations between-waves: 6 and 16-18 months (*n* = 64-66), 9 and 6 months (n = 94-97), 16-18 and 6 months (n = 64-69), and 16-18 and 9 months (*n* = 60-62), with the first age denoting temperament and the second environmental factors. ORC/EC = Orienting/Regulatory Capacity/Effortful Control; PAS/SUR = Positive Affectivity/Surgency; NA = Negative Affectivity.

****p* < .001; ***p* < .01; **p* < .05; #*p* < .10

4.5. Do early temperament and environmental factors predict attention control? Evidence from correlation and regression analysis.

4.5.1. Hypothesis: correlations

In relation to the gap-overlap task, disengagement cost and failure are expected to be negatively correlated with infants' ORC and PAS, but positively with NA. Concerning environmental factors, these two attentional measures would display a negative correlation with SES, but positive with chaos and maternal depression.

For the VSL task, stimulus fixations (i.e. sustained attention), total and correct anticipations (i.e. endogenous attention) would show a positive correlation with ORC and PAS, but negative with NA. For complex correct anticipations, ORC is the temperamental factor that we expect to be associated with this trial type, entailing context monitoring. A negative association of reactive looks (i.e. exogenous attention) with ORC and PAS is expected, but positive with NA. Regarding environmental factors, sustained and endogenous attention are expected to be positively associated with SES but negatively with chaos and maternal depression. For exogenous attention, we hypothesize a negative correlation with SES, but positive with chaos and maternal depression.

Finally, for the switching task we expect correct anticipations in the pre-switch block to be positively correlated with ORC and PAS, indicating faster learning of event contingencies. This correlation is anticipated to be negative with NA. The pre-switch block criterion (i.e. trial in which infants reach 3 correct anticipations) would be associated in a positive direction with ORC and PAS, but negative with NA. Also, perseverative errors in the post-switch block would display a negative association with ORC, suggesting a higher ability to overcome previously acquired information flexibly. This correlation is expected to be positive with PAS and NA. For environmental factors, correct anticipations would be associated with a higher SES, but a lower chaos and maternal depression. The opposite associations are expected with the pre-switch block criterion and perseverative errors.

4.5.2. Analysis strategy: correlations

Two-tailed pairwise correlations of temperamental and environmental factors with attentional measures were performed considering infants with valid data in attentional measures.

4.5.3. Results: correlations.

4.5.3.1. Associations of attentional disengagement with early temperament and environmental factors.

Pairwise correlations were computed to test the association between temperamental factors measured at 6, 9, and 16-18 months with infants' performance in the gap-overlap task within and between ages. Within age, we found a statistically negative correlation between ORC (*p* = .02, 95% CI [-.43, -.04]) and PAS (*p* = .04, 95% CI [-.40, -.02]) with disengagement cost at 6 months. The sign of these correlations was reversed across age. Specifically, ORC (*p* = .02, 95% CI [.05, .53]) and PAS (*p* = .02, 95% CI [.05, .53]) at 6 months were positively correlated with disengagement cost at 16-18 months. Finally, PAS at 6 months was also found to be negatively correlated with disengagement failure at 9 months (*p* = .02, 95% CI [-.44, -.04]; see Table 4.5)

We also analyzed how early measures of the infant environment at 6 and 16-18 months were related to infants' attentional performance. Within age, only the SES index at 16-18 months (*p* = .03, 95% CI [-.58, -.04]) was negatively associated with disengagement failure at the same age. Across age, parents' occupational level (*p* = .05, 95% CI [-.49, -.01]) and CHAOS (*p* = .02, 95% CI [-.52, -.04]) at 6 months displayed a statistically significant negative correlation with disengagement failure at 16 months (see Table 4.6).

Table 4.5.

Two-tailed pairwise correlation coefficients between temperamental factors and gap-overlap variables at 6, 9, and 16-18 months

		Disengagement cost			Disengagement failure		
		6-mo	9-mo	16-18-mo	6-mo	9-mo	16-18-mo
6 months	ORC	**-.24***	-.05	**.31***	.09	-.16	*.25#*
	PAS	**-.21***	-.18	**.30***	-.11	**-.25***	.16
	NA	-.14	-.06	.09	.02	-.08	.21
9 months	ORC	-	-.06	-.09	-	-.07	-.10
	PAS	-	-.05	-.06	-	.07	.02
	NA	-	.03	-.10	-	.14	.08
16-18 months	EC	-	-	-.09	-	-	-.10
	SUR	-	-	-.05	-	-	.02
	NA	-	-	-.10	-	-	.08

Note. Sample size for correlations between temperament and gap-overlap measures was variable depending on the valid data in both measures considered. Temperament at 6 and: 1) Disengagement at 6 months (*n* = 93), 2) Disengagement at 9 months (*n* = 84); and 3) Disengagement at 16-18 months (*n* = 57). Temperament at 9 and: 1) Disengagement at 9 months (*n* = 78); and 2) Disengagement at 16-18 months (*n* = 53). Temperament and disengagement at 16-18 months (*n* = 47). ORC = Orienting/Regulatory Capacity; PAS = Positive Affectivity/Surgency; NA = Negative Affectivity; EC = Effortful Control; SUR = Surgency.

***p < .001; **p < .01; *p < .05; #p < .10

Table 4.6.

Two-tailed pairwise correlation coefficients between environmental measured at 6 and 16-18 months and gap-overlap variables at 6, 9, and 16-18 months

		Disengagement cost			Disengagement failure		
		6-mo	9-mo	16-18 mo	6-mo	9-mo	16-18 mo
6 months	Parental education	-.08	-.01	-.07	.04	.03	-.17
	Parental occupation	.01	.09	.01	.01	-.01	**-.26***
	Income-to-needs	.16	-.02	-.06	.14	-.09	-.04
	SES index	.01	.02	-.10	.10	-.03	*-.23#*
	Maternal depression	.15	.11	-.13	.03	.10	-.16
	CHAOS	.07	.08	-.15	.04	.05	**-.30***
16-18 months	Parental occupation	-	-	.04	-	-	*-.29#*
	Income-to-needs	-	-	-.05	-	-	-.19
	SES index	-	-	-.05	-	-	**-.34***
	Maternal depression	-	-	-.04	-	-	.05
	CHAOS	-	-	.10	-	-	-.02

Note. Sample size for correlations between environmental factors and gap-overlap measures was variable depending on the valid data in both measures considered: Environmental factors at 6 months and: 1. Disengagement at 6 months (n = 88-92); 2. Disengagement at 9 months (n = 71-84); and 3. Disengagement at 16-18 months (n = 51-57). Environmental factors at 16-18 months and disengagement at 16-18 months (n = 42-45).

***p < .001; **p < .01; *p < .05; #p < .10

4.5.3.2. Associations of anticipatory attention and context monitoring with early temperament and environmental factors.

Considering temperament, ORC at 6 months displayed a negative correlation with stimulus fixations at 9 months (p = .01, 95% CI [-.44, -.02]). Also, ORC at 6 months showed a negative correlation with reactive looks (p = .03, 95% CI [-.46, .01]), but positive with total anticipations at 16-18 months (p = .03, 95% CI [.04, .50]). Nevertheless, for the correlation with reactive looks, confidence intervals did not support a genuine association. Only PAS at 9 months was found to negatively correlate with reactive looks (p < .01, 95% CI [-.53, -.05]) but positively with total (p < .01, 95% CI [.06, .54]) and correct anticipations (p < .01, 95% CI [.07, .52]) at 16-18 months. Concerning NA at 6 months, it displayed a statistically significant negative correlation with reactive looks (p = .02, 95% CI [-.04, -.01]), but positive with correct anticipations at 6 months (p = .02, 95% CI [01, .04]). Also, NA at 9 months was positively correlated with easy correct anticipations at 16-18 months (p = .02, 95% CI [.01, .51]). Interestingly, this correlation was reversed for NA at 16-18 months, displaying a negative association with easy correct anticipations (p = .01, 95% CI [-.54, -.03]), but positive with complex correct anticipations (p < .01, 95% CI [.08, .57]; see Table 4.7) at the same age.

Regarding environmental factors at 6 months, parental education was positively correlated with easy (p < .01, 95% CI [.07, .53]) but negatively with complex correct anticipations (p < .01, 95% CI [-.52, -.06]) at 16-18 months. Also, the SES index at 6 months displayed a negative correlation with complex correct anticipations at 16-18 months (p = .02, 95% CI [-.49, .01]), although CI did not support a genuine association. Finally, the SES index at 16-18 months was found to positively correlate with easy correct anticipations at this age (*p* = .02, 95% CI [.03, .53]). Additionally, CHAOS was found to correlate with attentional measures at 16-18 months, specifically, it was positively correlated with reactive looks (*p* < .01, 95% CI [.13, .56]), but negatively with correct anticipations (*p* < .01, 95% CI [-.57, -.14]) and total anticipations (*p* = .01, 95% CI [-.49, -.03]; see Table 4.8) at 16-18 months. Maternal depression was not found to correlate with any attentional variables in the VSL task.

Table 4.7.

Two-tailed pairwise correlation coefficients between temperamental factors and visual-sequence learning variables at 6, 9, and 16-18 months

		Stimuli fixation			Reactive looks			Total antic.		Correct antic.			Easy correct antic.		Complex correct antic.	
		6	9	16-18	6	9	16-18	9	16-18	6-mo	9-mo	16-18	9	16-18	9	16-18
6-mo	ORC	-.06	**-.24***	-.06	-.05	-.09	*-.23#*	.05	**.28***	.06	.06	*.23#*	-.01	-.01	.03	*.19#*
	PAS	.06	-.10	-.06	-.09	.07	-.13	.05	.09	.09	-.01	.09	.04	-.16	-.10	.12
	NA	.07	-.03	-.01	**-.21***	-.04	.01	.10	-.07	**.21***	.10	-.07	.03	.05	-.07	.10
9-mo	ORC	-	-.02	-.01	-	.01	.02	.02	-.09	-	.01	-.01	.02	.08	.01	-.04
	PAS	-	-.16	.03	-	-.06	**-.31****	.03	**.32****	-	.03	**.32****	.07	.11	-.06	.16
	NA	-	-.04	.03	-	.14	.10	.14	-.10	-	-.02	.09	*-.18#*	**.28***	.09	.04
16-18 mo	EC	-	-	-.07	-	-	.04	-	-.09	-	-	-.10	-	.04	-	-.16
	SUR	-	-	-.11	-	-	-.04	-	.04	-	-	.01	-	.02	-	-.04
	NA	-	-	*.19#*	-	-	-.01	-	-.05	-	-	.05	-	**-.31***	-	**.35****

Note. Sample size for correlations between questionnaires at 6 months at Visual-sequence learning measures was variable at 6 months (n = 83-95), 9 months (n = 70-78), and 16-18 months (n = 50) depending on the valid data in both measures considered. ORC = Orienting/Regulatory Capacity; PAS = Positive Affectivity/Surgency; NA = Negative Affectivity.

***p < .001; **p < .01; *p < .05; #p < .10

Table 4.8.

Two-tailed pairwise correlation coefficients between environmental factors measured at 6 and 16-18 months and VSL variables at 6, 9, and 16-18 months

		Stimuli fixation			Reactive looks			Total antic.		Correct antic.			Easy correct antic.		Complex correct antic.	
		6	9	16-18	6	9	16-18	9	16-18	6	9	16-18	9	16-18	9	16-18
6-mo	Parental education	-.09	.10	*.20#*	.12	-.14	-.07	.07	-.06	-.12	.10	.05	.02	**.31****	.11	**-.31****
	Parental occupation	-.05	.05	.01	-.01	.14	-.06	.08	.03	.01	.01	.03	-.12	.11	.12	-.14
	Income-to-needs	-.09	*-.18#*	.01	.04	-.05	-.16	-.04	-.01	-.04	-.03	.15	-.01	*.20#*	.15	-.16
	SES index	-.07	.03	.07	.12	-.02	-.08	.03	-.02	-.11	.01	.05	.02	*.20#*	.09	**-.26***
	Maternal depression	.12	.08	*-.21#*	-.01	.14	*.22#*	.04	*-.18#*	.02	.03	*-.23#*	-.09	-.07	.10	-.03
	CHAOS	*.14#*	.13	-.11	.02	.01	**.36****	.03	**-.27***	-.02	.04	**-.37****	-.10	.01	.01	*-.20#*
16-18 mo	Parental occupation	-	-	-.08	-	-	-.04	-	-.07	-	-	.05	-	*.21#*	-	-.01
	Income-to-needs	-	-	.02	-	-	-.06	-	-.08	-	-	.0	-	*.18#*	-	-.13
	SES index	-	-	-.04	-	-	-.07	-	-.08	-	-	.05	-	**.30***	-	*-.20#*
	Maternal depression	-	-	-.18	-	-	.16	-	-.05	-	-	-.11	-	-.04	-	-.08
	CHAOS	-	-	.02	-	-	.18	-	-.07	-	-	-.18	-	*-.23#*	-	-.10

Note. Sample size for correlations between questionnaires at 6 months and VSL measures was at 6 months (*n* = 83-95), 9 months (*n* = 83-95), and 16-18 months (*n* = 50) depending on the valid data in both measures considered. Sample size for correlations between questionnaires and VSL measures at 16-18 months was (*n* = 48-53).

***p < .001; **p < .01; *p < .05; #p < .10

4.5.3.3. Associations of attention flexibility with early temperament and environmental factors.

For temperament only PAS at 9 months was found to negatively correlate with correct anticipations at the same age (*p* = .02, 95% CI [-.52, -.05]; see Table 4.9). No other statistically significant correlations between temperamental factors as performance in the switching task were found. Concerning the association between environmental factors and attentional flexibility, the SES index (*p* = .03, 95% CI [.02, .48]), parental education (*p* < 01, 95% CI [.13, .55]) and parental occupation (*p* = .04, 95% CI [.01, .45] at 6 months were found to be positively correlated with correct anticipations at the same age. Moreover, the SES index (*p* = .03, 95% CI [-.55, -.02]), parental occupation (*p* = .01, 95% CI [-.56, -.07]), and income-to-needs (*p* < .01, 95% CI [-.59, -.11]) at 6 months were found to negatively correlate with the pre-switch block task criterion (i.e. the trial at which infants achieved three correct anticipations in the pre-switch block) at 16-18 month (see Table 4.10). No other statistically significant correlations were found between environmental factors and the switching task variables.

Table 4.9.

Two-tailed pairwise correlation coefficients between temperamental factors and switching variables at 6, 9, and 16-18 months

		Correct anticipations			Pre-switch block task criterion			Perseverations		
		6-mo	9-mo	16-18 mo	6-mo	9-mo	16-18 mo	6-mo	9-mo	16-18 mo
6 months	ORC	.18	.09	.16	.12	.04	.03	-.03	-.17	-.12
	PAS	.19	-.01	.15	.07	.05	-.01	.19	-.12	.13
	NA	.05	.04	.19	-.04	.06	-.10	.04	-.13	.16
9 months	ORC	-	-.19	.03	-	.01	-.14	-	.13	-.10
	PAS	-	**-.30***	.18	-	.01	-.08	-	.01	*.25#*
	NA	-	-.15	.20	-	-.05	.03	-	-.06	.11
16-18 months	EC	-	-	-.07	-	-	-.04	-	-	.04
	SUR	-	-	-.01	-	-	.09	-	-	.10
	NA	-	-	.18	-	-	-.11	-	-	.12

Note. ORC = Orienting/Regulatory Capacity; PAS = Positive Affectivity/Surgency; NA = Negative Affectivity; EC = Effortful Control; SUR = Surgency. Sample size for correlations between questionnaires at 6 months at Switching measures was variable at 6 months (*n* = 72-73), 9 months (*n* = 60-64), and 16-18 months (*n* = 42-53) depending on the valid data in both measures considered.

****p* < .001; ***p* < .01; **p* < .05; #*p* < .10

Table 4.10.

Two-tailed pairwise correlation coefficients between environmental measures at 6 and 16-18 months and switching variables at 6, 9, and 16-18 months

		Correct anticipations			Pre-switch block task criterion			Perseverations		
		6-mo	9-mo	16-18 mo	6-mo	9-mo	16-18 mo	6-mo	9-mo	16-18 mo
6 months	Parental education	**.36****	-.10	-.01	-.01	-.03	-.22	.02	-.20	.03
	Parental occupation	**.24***	*-.23#*	.18	-.04	.01	**-.34***	-.11	-.06	.13
	Income-to-needs	.03	-.13	.06	.03	.04	**-.38****	-.12	-.05	.05
	SES index	**.27***	-.20	.02	-.01	.10	**-.31***	-.10	-.11	.07
	Maternal depression	.09	-.05	.03	-.05	-.13	.21	.11	-.04	-.03
	CHAOS	-.08	-.13	-.07	.02	.08	.10	-.03	.07	.11
16-18 months	Parental occupation	-	-	.01	-	-	-.07	-	-	.07
	Income-to-needs	-	-	-.20	-	-	-.13	-	-	.05
	SES index	-	-	-.19	-	-	-.12	-	-	.09
	Maternal depression	-	-	-.15	-	-	-.01	-	-	-.19
	CHAOS	-	-	.03	-	-	-.06	-	-	.13

Note. Sample size for correlations between questionnaires at 6 months and Switching measures at 6 months was (n = 64-73), 9 months (n = 59-62), and 16-18 months (n = 40-47) depending on the valid data in both measures considered. Sample size for correlations between questionnaires and switching variables at 16-18 months was (n = 41-45). CHAOS = Household disorganization.

***p < .001; **p < .01; *p < .05; #p < .10

4.5.4. Hypothesis: regressions

In line with the correlation hypothesis, we expect a positive contribution of early ORC and PAS, but negative for NA, in the prediction of disengagement cost and failure. For environmental factors, we anticipate a positive contribution of SES, but a negative one of CHAOS and maternal depression over these two measures of attention disengagement.

We also hypothesize a positive contribution of early ORC and PAS to predict stimulus fixations (i.e. sustained attention), total and correct anticipations (i.e. endogenous attention). Moreover, NA is expected to negatively predict these attentional measures. Infants' ORC is the temperamental factor that is expected to predict a higher performance of toddlers on complex correct anticipations. We anticipate a negative contribution of ORC and PAS to predict reactive looks (i.e. exogenous attention), but a positive one for NA. Concerning environmental factors, SES would predict a higher later sustained and endogenous attention, while CHAOS and maternal depression are expected to predict a lower performance in these measures. For the case of exogenous attention, SES would negatively contribute to predict it, while CHAOS and maternal depression would have a positive predictive power.

A positive contribution of ORC and PAS to predict more correct anticipations and a lower pre-switch block criterion in the switching task is expected, but a negative contribution of NA. Also, ORC is hypothesized to predict a lower number of perseverative errors in the post-switch block, while PAS and NA would positively predict perseverations. For environmental factors, early SES would predict more correct anticipations and a lower pre-switch block task criterion later in development. CHAOS and maternal depression would have the opposite predictive power, with a lower number of correct anticipations and a higher task criterion. Concerning perseverative errors, SES would negatively contribute to predict them, while CHAOS and maternal depression are expected to have a positive contribution to the prediction of perseverations.

4.5.5. Analysis strategy: regressions

Regarding regression models, in order to predict attentional control at 9 and 16-18 months, we followed Bernier et al. (2016) approach. The next steps were followed for model building: 1. Infant's performance at the previous age; 2. Infant's temperament at the previous age; and 3. Early environmental factors. To predict attentional outcomes at 9 months, previous performance, as well as temperamental and environmental factors at 6 months, were considered in the model. Likewise, to predict attention at 16-18 months we considered performance and temperamental factors at 9 months, while environmental factors were only considered at 6 months as they were not measured at 9 months of age. Following Geeraerts et al. (2019), hierarchical regressions models were built using the lavaan package (Rosseel, 2012) for R (R Core Team, 2021), implementing Full Information Maximum Likelihood (FIML) to estimate missing values. Likelihood Ratio Test (LRT) was used to evaluate increases in model fit between the current and the previous step. A significant increase in model fit by the last predictors added to the model was found with a statistically significant LRT. Yuan-Bentler correction for the LRT and robust (Huber-White) standard errors were computed to account for non-normality when required. Effect sizes for LMM and regression models were evaluated based on Cohen's *w* for $\chi 2$ distributions.

Thresholds of .10, .30, and .50 defined small, medium, and large effect sizes for Cohen's w, respectively.

4.5.6. Results: regressions

4.5.6.1. Predicting disengagement cost

Hierarchical regression models were built to predict disengagement cost at 9 and 16-18 months. In the first step, only infants' disengagement cost in the previous wave was introduced, followed by temperamental factors at the previous age in step 2 and environmental factors at 6 months in step 3. None of the steps lead to a statistically significant increase in model fit neither at 9 months (all LRT *ps* > .61), nor at 16-18 months (all LRT *ps* > .30). The full models explained 8% of the variance for disengagement cost at 9 months, and a 29% at 16-18 months (see Table 4.11).

4.5.6.2. Predicting disengagement failure

Next, we regressed disengagement failure at 9 months and 16-18 months following the same steps used for disengagement cost. For the 9 months measure, the inclusion of temperamental factors at 6 months led to a statistically marginal increase in model fit ($\Delta R^2 = .11$, $\Delta\text{-}2LL = 7.12$, $p = .07$, $w = .16$), although none of the predictors was found statistically significant (all *ps* > .10). The introduction of environmental factors at 6 months in step 3 did not significantly increase model fit (LRT $p = .72$). The full model explained 17% of the variance for disengagement failure at 9 months. Concerning the prediction of this measure at 16-18 months, only the inclusion of environmental factors at 6 months led to an increase in model fit with a small effect size ($\Delta R^2 = .24$, $\Delta\text{-}2LL = 9.17$, $p = .03$, $w = .18$). Infant's previous performance at 9 months ($\beta = .39$, $p < .01$, 95%

CI [.11, .66]), as well as ORC (*β* = -31, *p* = .04, 95% CI [-8.43, -.18]) and CHAOS (*β* = -.43, *p* < .01, 95% CI [-.59, -.11]) were found to be statistically significant predictors, while SES was only found to be marginally significant (*β* = -24, *p* = .09, 95% CI [-6.25, .41]). The full model explained 39% of the variance for disengagement failure at 16-18 months (see Table 4.12).

Table 4.11.

Hierarchical regression models predicting disengagement cost at 9 and 16 months

	Disengagement cost (9 months)			Disengagement cost (16 months)		
	Step 1	Step 2	Step 3	Step 1	Step 2	Step 3
	β			β		
1. Previous wave performance						
Disengagement cost	*.23#*	*.21#*	*.21#*	.22	.23	**.31***
2. Previous wave temperament						
ORC	-	.18	.19	-	-.19	-*.27#*
PAS	-	-.22	-.19	-	-.15	-.18
NA	-	-.01	-.03	-	-.11	-.07
3. Environment (6 months)						
SES index	-	-	.02	-	-	-.12
CHAOS	-	-	.07	-	-	-*.27#*
Maternal depression	-	-	.01	-	-	-.05
ΔR^2	.05	.03	.01	.05	.10	.14
LRT (full vs. reduced model†)	-	Δ-*2LL* = 1.79 Δ*df* = 3 *p* = .61	Δ-*2LL* = .33 Δ*df* = 3 *p* = .95	-	Δ-*2LL* = 1.72 Δ*df* = 3 *p* = .63	Δ-*2LL* = 3.64 Δ*df* = 3 *p* = .30
Cohen's w	-	.08	.03	-	.08	.12

Note. †The comparison between steps is performed between the full model (model with more parameters: last step performed) and the reduced model (previous step). ORC = Orienting/Regulatory Capacity; PAS = Positive Affectivity/Surgency; NA = Negative Affectivity; LRT = Likelihood Ratio Test.

Table 4.12.

Hierarchical regression models predicting disengagement failure at 9 and 16 months

	Disengagement failure (9 months)			Disengagement failure (16 months)		
	Step 1	Step 2	Step 3	Step 1	Step 2	Step 3
		β			β	
1. Previous wave performance						
Disengagement failure	*.21#*	.18	.18	.26	*.27#*	**.39****
2. Previous wave temperament						
ORC	-	-.05	-.06	-	-.17	**.31***
PAS	-	-.28	-.28	-	-.17	-.19
NA	-	-.01	-.01	-	.01	.01
3. Environment (6 months)						
SES index	-	-	-.04	-	-	*-.24#*
CHAOS	-	-	-.05	-	-	**-.43****
Maternal depression	-	-	.13	-	-	-.01
ΔR^2	.04	.11	.02	.07	.08	**.24**
LRT (full vs. reduced model†)	-	$\Delta\text{-}2LL = 7.12$ $\Delta df = 3$ $p = .07$	$\Delta\text{-}2LL = .87$ $\Delta df = 3$ $p = .72$	-	$\Delta\text{-}2LL = 1.62$ $\Delta df = 3$ $p = .65$	**$\Delta\text{-}2LL = 9.17$** **$\Delta df = 3$** **$p = .03$**
Cohen's w	-	.16	.05	-	.08	**.18**

Note. †The comparison between steps is performed between the full model (model with more parameters: last step performed) and the reduced model (previous step). ORC = Orienting/Regulatory Capacity; PAS = Positive Affectivity/Surgency; NA = Negative Affectivity; LRT = Likelihood Ratio Test.

4.5.6.3. Predicting stimulus fixations

First, we built a series of hierarchical regression models to predict stimulus fixations at both 9 and 16-18 months (see Table 4.13). No statistically significant improvements in model fit were found in any of the regression steps for stimulus fixations at 9 months (all LRTs *ps* > .60), with the full model explaining 5% of the variance. Regarding stimulus fixations at 16-18 months, the inclusion of infants' previous performance was found as a statistically significant predictor in step 1 (β = .38, *p* < .01, 95% CI [.12, .72]). However, the addition of temperamental factors in step 2 did not increase model fit (ΔR^2 = .01, Δ-*2LL* = .84, *p* = .83, *w* = .06), but the inclusion of environmental factors in step 3 (ΔR^2 = .33, Δ-*2LL* = 19.31, *p* < .01, *w* = .30). Specifically, previous performance at 9 months remained as a statistically significant predictor (β = .55, *p* < .01, 95% CI [.37, .83]). Also, maternal depression was found to be a significant negative predictor (β = -.60, *p* < .01, 95% CI [-.001, -.0001]). The full model explained 53% of the variance for stimulus fixations at 16-18 months.

Table 4.13.

Hierarchical regression models predicting stimulus fixations in the visual sequence learning task at 9 and 16 months

	Stimulus fixations (9 months)			Stimulus fixations (16 months)		
	Step 1	Step 2	Step 3	Step 1	Step 2	Step 3
		β			β	
1. Previous wave performance						
Stimulus fixations	.05	.05	.02	**.43****	**.44*****	**.55*****
3. Previous wave temperament						
ORC	-	-.13	-.07	-	-.01	-.*21#*
PAS	-	-.01	-.08	-	.06	.12
NA	-	.01	.01	-	.11	.18
3. Environment (6 months)						
SES index	-	-	-.09	-	-	-.13
CHAOS	-	-	-.02	-	-	.04
Maternal depression	-	-	.15	-	-	**-.60*****
ΔR^2	.01	.02	.03	.19	.01	**.33**
LRT (full vs. reduced model†)	-	Δ-*2LL* = .98 Δ*df* = 3 *p* = .80	Δ-*2LL* = 1.73 Δ*df* = 3 *p* = .63	-	Δ-*2LL* = .85 Δ*df* = 3 *p* = .84	**Δ-*2LL* = 19.31** **Δ*df* = 3** ***p* < .01**
Cohen's w	-	.07	.09	-	.06	**.30**

Note. †The comparison between steps is performed between the full model (model with more parameters: last step performed) and the reduced model (previous step). ORC = Orienting/Regulatory Capacity; PAS = Positive Affectivity/Surgency; NA = Negative Affectivity; LRT = Likelihood Ratio Test.

4.5.6.4. Predictors of reactive looks

Considering reactive looks at 9 months, only infants' previous performance at 6 months was found to be a statistically significant predictor in step 1 (β = .23, p = .02, 95% CI [.04, .43]). Nevertheless, neither steps 2 nor 3 significantly increased the variance explained by the model (all LRT *ps* > .39). The full model explained 10% of the variance of reactive looks at 9 months. Regarding reactive looks at 16 months, the introduction of temperamental factors in the second step significantly increased model fit (ΔR^2 = .16, Δ-*2LL* = 8.75, p = .03, w = .20). Specifically, infant's PAS (β = -.37, p = .02, 95% CI [-7.05, -.47]) was found to significantly predict reactive looks. Moreover, the inclusion of environmental factors in step 3 also contributed to increase model fit (ΔR^2 = .29, Δ-*2LL* = 15.52, p = .01, w = .27). Infant's PAS (β = -.47, $p < .01$, 95% CI [-7.17, -2.21]) remained as a significant predictor, along with maternal depression (β = .31, p = .02 .01, 95% CI [.05, .51]; see Table 4.14). The full model explained 45% of reactive looks at 16-18 months.

Table 4.14.

Hierarchical regression models predicting reactive looks in the visual sequence learning task at 9 and 16 months

	Reactive looks (9 months)			Reactive looks (16 months)		
	Step 1	Step 2	Step 3	Step 1	Step 2	Step 3
	β			β		
1. Previous wave performance						
Reactive looks	**.23***	**.24***	**.24***	.01	.01	-.05
2. Previous wave temperament						
ORC	-	-.17	-.19	-	-.07	.09
PAS	-	.31	.33	-	**-.37***	**-.47*****
NA	-	-.09	-.07	-	-.07	-.09
3. Environment (6 months)						
SES index	-	-	-.05	-	-	-.07
CHAOS	-	-	.01	-	-	*.28#*
Maternal depression	-	-	-.07	-	-	**.31***
ΔR^2	.05	.05	.01	< .01	**.16**	**.29**
LRT (full vs. reduced model†)	-	$\Delta\text{-}2LL = 3.03$ $\Delta df = 3$ $p = .39$	$\Delta\text{-}2LL = .37$ $\Delta df = 3$ $p = .94$	-	**$\Delta\text{-}2LL = 8.75$** **$\Delta df = 3$** **$p = .03$**	**$\Delta\text{-}2LL = 15.52$** **$\Delta df = 3$** **$p = .01$**
Cohen's w	-	.12	.04	-	**.20**	**.27**

Note. †The comparison between steps is performed between the full model (model with more parameters: last step performed) and the reduced model (previous step). ORC = Orienting/Regulatory Capacity; PAS = Positive Affectivity/Surgency; NA = Negative Affectivity; LRT = Likelihood Ratio Test.

4.5.6.5. Predicting correct anticipations

Next, we regressed correct anticipations at 9 months introducing infants’ measures at 6 months as predictors. Infants’ previous performance was found to have predictive power ($\beta = .27$, $p = .01$, 95% CI [.06, .52]) in step 1. No statistically significant improvements in model fit were found in any other step (all LRTs *ps* > .25). The full model explained 13% of the variance for correct anticipations at 9 months. Regarding correct anticipations at 16-18 months, the introduction of infants’ previous temperament contributed to improve model fit ($\Delta R^2 = .17$, $\Delta\text{-}2LL = 8.07$, $p = .04$, $w = .17$). Infant’s PAS was found to be a statistically significant predictor ($\beta = .37$, $p = .03$, 95% CI [.37, 7.05]). Also, the inclusion of early environmental factors in the last step improved model fit ($\Delta R^2 = .32$, $\Delta\text{-}2LL = 17.19$, $p = .01$, $w = .23$). Infant’s PAS remained as a predictor ($\beta = .47$, $p < .01$, 95% CI [2.36, 7.16]). Also, infants’ chaos at home was found to significantly predict correct anticipations ($\beta = -.33$, $p = .02$, 95% CI [-.35, -.03]), along with early maternal depression ($\beta = -.29$, $p = .02$, 95% CI [-.48, -.04]). The full model explained 49% of the variance for correct anticipations at 16-18 months (see Table 4.15).

Table 4.15.

Hierarchical regression models predicting correct anticipations in the visual sequence learning task at 9 and 16-18 months

	Correct anticipations (9 months)			Correct anticipations (16-18 months)		
	Step 1	Step 2	Step 3	Step 1	Step 2	Step 3
		β			*β*	
1. Previous wave performance						
Correct anticipations	**.27***	**.27****	**.25***	-.09	-.07	-.12
2. Previous wave temperament						
ORC	-	.10	.11	-	.06	-.10
PAS	-	-.31	*-.35#*	-	**.37***	**.47*****
NA	-	.13	.15	-	.05	-.08
3. Environment (6 months)						
SES index	-	-	-.01	-	-	.03
CHAOS	-	-	-.06	-	-	**-.33***
Maternal depression	-	-	.08	-	-	**-.29***
ΔR^2	.07	.06	.01	.01	**.17**	**.32**
LRT (full vs. reduced model†)	-	Δ-*2LL* = 4.10 Δ*df* = 3 *p* = .25	Δ-*2LL* =.30 Δ*df* = 3 *p* = .96	-	**Δ-*2LL* = 8.07** **Δ*df* = 3** ***p* = .04**	**Δ-*2LL* = 17.19** **Δ*df* = 3** ***p* < .01**
Cohen's w	-	.14	.04	-	**.17**	**.23**

Note. †The comparison between steps is performed between the full model (model with more parameters: last step performed) and the reduced model (previous step). ORC = Orienting/Regulatory Capacity; PAS = Positive Affectivity/Surgency; NA = Negative Affectivity; LRT = Likelihood Ratio Test.

4.5.6.6. Predicting total anticipations

Next, we intended to predict total anticipations at both, 9 and 16-18 months. For the 9 months measure, none of the steps led to an increase in model fit (all LRTs *ps* > .30). However, for 16-18 months the inclusion of infants' temperament at 9 months significantly improved model fit ($\Delta R^2 = .21$, Δ-*2LL* = 8.87, $p = .03$, $w = .20$). Only infant's PAS ($\beta = .42$, $p = .02$, 95% CI [1.02, 15.66]) was found to be a statistically significant predictor. Also, the introduction of infants' early environment significantly improved the variance explained by the model ($\Delta R^2 = .26$, Δ-*2LL* = 8.69, $p = .03$, $w = .20$). In this case, infants' PAS remained as a statistically significant predictor ($\beta = .48$, $p < .01$, 95% CI [5.11, 15.31]). Moreover, environmental CHAOS ($\beta = -.33$, $p = .04$, 95% CI [-.78, -.01]) was also found to be a statistically significant predictor. The models explained 10% and 46% of total anticipations for the variance of total anticipations at 9 and 16-18 months, respectively (see Table 4.16).

Table 4.16.

Hierarchical regression models predicting total anticipations in the visual sequence learning task at 9 and 16-18 months

	Total anticipations (9 months)			Total anticipations (16-18 months)		
	Step 1	Step 2	Step 3	Step 1	Step 2	Step 3
	β			β		
1. Previous wave performance						
Total anticipations	*.19#*	*.19#*	.18	.02	-.01	-.08
2. Previous wave temperament						
ORC	-	.07	.07		-.01	-.12
PAS	-	-.27	-.31		**.42***	**.48*****
NA	-	-.13	.13		-.24	-.21
3. Environment (6 months)						
SES index	-	-	.08	-	-	-.05
CHAOS	-	-	-.08	-	-	**-.33***
Maternal depression	-	-	.12	-	-	-.19
ΔR^2	.04	.04	.02	< .01	**.21**	**.26**
LRT (full vs. reduced model†)	-	$\Delta\text{-}2LL = 3.63$ $\Delta df = 3$ $p = .30$	$\Delta\text{-}2LL = 1.23$ $\Delta df = 3$ $p = .74$	-	$\boldsymbol{\Delta\text{-}2LL = 8.87}$ $\boldsymbol{\Delta df = 3}$ $\boldsymbol{p = .03}$	$\boldsymbol{\Delta\text{-}2LL = 8.69}$ $\boldsymbol{\Delta df = 3}$ $\boldsymbol{p = .03}$
Cohen's w	-	.13	.07		**.20**	**.20**

Note. †The comparison between steps is performed between the full model (model with more parameters: last step performed) and the reduced model (previous step). ORC = Orienting/Regulatory Capacity; PAS = Positive Affectivity/Surgency; NA = Negative Affectivity; LRT = Likelihood Ratio Test.

4.5.6.7. Predicting easy and complex correct anticipations

For easy and complex correct anticipations, hierarchical regression models were built to predict both measures at 16-18 months. Note that for we do not have a measure of previous performance in easy and complex trials at 6 months to be introduced as a predictor for the 9 months attentional measure. Regarding easy correct anticipations at 16-18 months, the inclusion of infants' previous temperamental factors in step 2 led to a statistically marginal improvement in model fit ($\Delta R^2 = .14$, $\Delta\text{-}2LL = 7.67$, $p = .05$, $w = .18$). Infant's NA at 9 months ($\beta = .34$, $p = .02$, 95% CI [.96, 12.16]) was found to significantly predict easy correct anticipations. The inclusion of infants' early environment also led to a marginal improvement in model fit ($\Delta R^2 = .19$, $\Delta\text{-}2LL = 6.69$, $p = .08$, $w = .17$). Infant's NA remained as a significant predictor ($\beta = .37$, $p < .01$, 95% CI [2.46, 12.48]), along with the family SES index ($\beta = 2.71$, $p < .01$, 95% CI [2.15, 13.31]). The full model explained 33% of the variance for easy correct anticipations.

For complex correct anticipations only the introduction of environmental factors led to a marginally significant improvement in model fit ($\Delta R^2 = .28$, $\Delta\text{-}2LL = 7.31$, $p = .06$, $w = .18$). Infant's PAS ($\beta = .32$, $p = .02$, 95% CI [1.30, 13.95]), along with the SES index ($\beta = -.40$, $p < .01$, 95% CI [-13.98, -3.24] and CHAOS ($\beta = -.30$, $p = .03$, 95% CI [-.81, -.04]) were found to be statistically significant predictors. The full model explained 33% of the variance for complex correct anticipations (see Table 4.17).

Table 4.17.

Hierarchical regression models predicting easy and complex correct anticipations in the visual sequence learning task at 16-18 months

	Easy correct anticipations (16-18 months)			Complex correct anticipations (16-18 months)		
	Step 1	Step 2	Step 3	Step 1	Step 2	Step 3
		β			β	
1. Previous wave performance						
Easy/Complex correct anticipations	.06	.12	.10	.01	.06	.01
2. Previous wave temperament						
ORC		.15	.07	-	-.17	-.14
PAS		-.02	-.16	-	.22	**.32***
NA		**.34***	**.37****	-	-.14	-.14
3. Environment (6 months)						
SES index	-	-	**.31****	-	-	**-.40****
CHAOS	-	-	*.25#*	-	-	**-.30***
Maternal depression	-	-	*-.24#*	-	-	-.07
ΔR^2	.01	.14	.19	.01	.05	.28
LRT (full vs. reduced model†)	-	$\Delta\text{-}2LL = 7.67$ $\Delta df = 3$ $p = .05$	$\Delta\text{-}2LL = 6.69$ $\Delta df = 3$ $p = .08$	-	$\Delta\text{-}2LL = 2.70$ $\Delta df = 3$ $p = .44$	$\Delta\text{-}2LL = 7.34$ $\Delta df = 3$ $p = .06$
Cohen's w	-	.18	.17	-	.11	.18

Note. †The comparison between steps is performed between the full model (model with more parameters: last step performed) and the reduced model (previous step). ORC = Orienting/Regulatory Capacity; PAS = Positive Affectivity/Surgency; NA = Negative Affectivity; LRT = Likelihood Ratio Test.

4.5.6.8. Predicting correct anticipations

Correct anticipations during the pre-switch block were introduced in a hierarchical regression model following the same steps as for previous models. Regarding this outcome at 9 months, none of the considered steps significantly increased the variance explained by the model (all LRT *ps* > .71). Concerning correct anticipations at 16-18 months, again none of the steps improved model fit (all LRT *ps* > .15) The full models explained 5% and 23% of the variance of correct anticipations at 9 and 16-18 months, respectively (see Table 4.18).

Table 4.18.

Hierarchical regression models predicting correct anticipation in the pre-switch block in the switching task at 9 and 16 months

	Correct anticipations (9 months)			Correct anticipations (16-18 months)		
	Step 1	Step 2	Step 3	Step 1	Step 2	Step 3
		β			β	
1. Previous wave performance						
Correct anticipations	-.03	-.03	-.01	-.29	**.34***	**.34***
2. Previous wave temperament						
ORC	-	.04	.02	-	**.35****	**.35****
PAS	-	.11	.12	-	-.04	-.02
NA	-	.01	.05	-	-.13	-.16
3. Environment (6 months)						
SES index	-	-	-.15	-	-	.04
CHAOS	-	-	-.04	-	-	.08
Maternal depression	-	-	.03	-	-	.06
ΔR^2	.01	.02	.03	.08	.15	.01
LRT (full vs. reduced model†)	-	Δ-*2LL* = 1.24 Δdf = 3 *p* = .74	Δ-*2LL* = 1.38 Δdf = 3 *p* = .71	-	Δ-*2LL* = 5.34 Δdf = 3 *p* = .15	Δ-*2LL* = .66 Δdf = 3 *p* = .88
Cohen's w	-	.06	.07	-	.13	.05

Note. †The comparison between steps is performed between the full model (model with more parameters: last step performed) and the reduced model (previous step). ORC = Orienting/Regulatory Capacity; PAS = Positive Affectivity/Surgency; NA = Negative Affectivity; LRT = Likelihood Ratio Test.

4.5.6.9. Predicting the pre-switch block criterion

Next, we tried to predict when infants achieved the criterion of 3 correct anticipations in the pre-switch block. The first hierarchical regression model targeting this criterion at 9 months indicated that none of the steps significantly improved model fit (all LTR *ps* > .29). Regarding this criterion at 16-18 months, infants' previous performance at 9 months was found to be a statistically significant predictor in step 1 (β = .41, *p* < .01, 95% CI [.15, .58]). Including infants' temperamental factors at 9 months did not contribute to increase model fit (ΔR^2 = .02*,* Δ-*2LL* = .83, *p* = .84, *w* = .05), but including early environmental factors (ΔR^2 = .20*,* Δ-*2LL* = 8.78, *p* = .03, *w* = .17). Infant's previous performance was found to remain as a significant predictor (β = .33, *p* = .01, 95% CI [.06, .55]), along with the family SES index (β = -.52, *p* < .01, 95% CI [-2.58, -1.24]). The models explained 18% and 39% of the variance at 9 and 16-18 months, respectively (see Table 4.19).

Table 4.19.

Hierarchical regression models predicting the pre-switch block criterion of 3 correct anticipations in the switching task at 9 and 16 months

	Pre-switch block criterion (9 months)			Pre-switch block criterion (16-18 months)		
	Step 1	Step 2	Step 3	Step 1	Step 2	Step 3
		β			*β*	
1. Previous wave performance						
Pre-switch block criterion	.23	**.25***	*.24#*	**.41****	**.41****	**.33***
2. Previous wave temperament						
ORC	-	-.10	-.11	-	-.17	.01
PAS	-	-.10	-.06	-	-.09	.10
NA	-	-.07	-.09	-	-.01	.01
3. Environment (6 months)						
SES index	-	-	-.03	-	-	**-.52*****
CHAOS	-	-	.14	-	-	*-.20#*
Maternal depression	-	-	.18	-	-	-.07
ΔR^2	.05	.06	.07	.17	.02	**.20**
LRT (full vs. reduced model†)	-	Δ-*2LL* = 2.40 Δ*df* = 3 *p* = .49	Δ-*2LL* = 3.69 Δ*df* = 3 *p* = .29	-	Δ-*2LL* = .83 Δ*df* = 3 *p* = .84	**Δ-*2LL* = 8.78** **Δ*df* = 3** ***p* = .03**
Cohen's w	-	.09	.11	-	.05	**.17**

Note. †The comparison between steps is performed between the full model (model with more parameters: last step performed) and the reduced model (previous step). ORC = Orienting/Regulatory Capacity; PAS = Positive Affectivity/Surgency; NA = Negative Affectivity; LRT = Likelihood Ratio Test.

4.5.6.10. Predicting perseverations

The same approach was applied to predict perseverative errors in the post-switch block at 9 months. Nevertheless, none of the steps improved the variance explained by the model (all LRT *ps* > .17). In relation to perseverations at 16-18 months, the introduction of infants' previous performance was found to significantly predict perseverations at 16-18 months (β = .29, *p* = .02, 95% CI [.05, .50]). However, none of the subsequent steps increased model fit (all LRTs *ps* > .10). The models explained 39% and 36% of the variance of perseverations at 9 and 16-18 months, respectively (see Table 4.20)

Table 4.20.

Hierarchical regression models predicting perseverations in the post-switch block in the switching task at 9, and 16 months

	Perseverations (9 months)			Perseverations (16-18 months)		
	Step 1	Step 2	Step 3	Step 1	Step 2	Step 3
	β			β		
1. Previous wave performance						
Perseverations	.04	.15	.07	**.29***	**.36***	**.43****
2. Previous wave temperament						
ORC	-	-.31	*-.36#*	-	**-.27***	**-.36****
PAS	-	-.05	-.01	-	.26	.18
NA	-	-.15	-.07	-	.09	.01
3. Environment (6 months)						
SES index	-	-	**-.42***	-	-	.24
CHAOS	-	-	.06	-	-	*.25#*
Maternal depression	-	-	.06	-	-	-.12
ΔR^2	.01	.18	.20	.08	.09	.18
LRT (full vs. reduced model†)	-	$\Delta\text{-}2LL = 2.81$ $\Delta df = 3$ $p = .42$	$\Delta\text{-}2LL = 4.93$ $\Delta df = 3$ $p = .17$	-	$\Delta\text{-}2LL = 3.76$ $\Delta df = 3$ $p = .29$	$\Delta\text{-}2LL = 6.13$ $\Delta df = 3$ $p = .10$
Cohen's w	-	.14	.19	-	.06	.26

Note. †The comparison between steps is performed between the full model (model with more parameters: last step performed) and the reduced model (previous step). ORC = Orienting/Regulatory Capacity; PAS = Positive Affectivity/Surgency; NA = Negative Affectivity; LRT = Likelihood Ratio Test.

4.6. Does temperament mediate the effect of environmental factors on attention control? Evidence from longitudinal mediation models

4.6.1. Hypothesis

Longitudinally, we expect infants' temperament at 9 months to mediate the effect of early environmental factors measured at 6 months on attentional outcomes at 16-18 months. Specifically, we hypothesize ORC and PAS to have a protecting role against the negative impact of a lower SES or higher CHAOS and maternal depression on attentional measures. On the other hand, NA could boost this negative effect of early adverse environmental conditions.

4.6.2. Analysis strategy

To test longitudinal mediations, we build three-wave cross-lagged panel models (CLPM) following the proposal of Cole & Maxwell (2003). The CLMP models combined autoregressive models for each variable and cross-lagged paths between variables of different waves, allowing us to test the predictive directional effects of our constructs measured at previous waves over the most recent ones. We adapted the proposal of Conejero & Rueda (2018) to a longitudinal perspective, testing whether the effect of environmental factors at 6 months (X) on attentional performance at 16-18 months (Y) was mediated by temperament at 9 months of age (M; see Figure 4.1). Input for the model was guided by previous significant predictors identified in hierarchical regression models in order to limit the number of tested models. We did not use correlation analyses to guide inputs due to the listwise nature of this analysis.

Taking a look at the model, X_3 (i.e. X at the third wave of the study) is a function of X_{t-2}, as environmental factors were not collected at time

2. The mediator M_t is based on M_{t-1} and X_{t-1}. It is worth noting that M_3 in this model is only a function of M_2 due to the absence of predictor X_2. Finally, the outcome Y_t is based on Y_{t-1} and M_{t-1}. Among all the model associations, different paths can be observed. Path *a* represents the effect of X_1 on M_2 controlled by M_1, while path *b* indicates the effect of the mediator M_{t-1} on Y_t controlling for Y_{t-1}. The direct effect is represented in the model by path *c'* from a directional effect from X_1 to Y_3. Note that for the indirect effect of the model, predictor X_1 precedes the mediator M_2, and M_2 precedes the outcome Y_3, all with one wave lag.

As stated before, previous levels of M and Y were controlled for as suggested by Gollob & Reichardt (1991) in order to get unbiased estimates for M_t and Y_t. All models were fitted using lavaan package (Rosseel, 2012) for R language (R Core Team, 2021), implementing full information maximum likelihood estimation. Percentile bootstrap with 5000 samples was employed to test indirect effects (Taylor et al., 2008), with standardized indirect effect coefficients reported to account for effect size (Preacher & Kelley, 2011). As recommended to evaluate model fit, we considered test statistics along with incremental and absolute fit indices. Specifically, a χ^2 test, with Yuan-Bentler correction and robust (Huber-White) standard errors to account for the non-normality of the variables, was employed to test model fit, with a non-statistically significant test indicating good model fit (Kline, 2016). Among incremental fit indices, we considered the comparative fit index (*CFI*). The root mean square error of approximation (*RMSEA*) and root mean square residual (*SRMR*) absolute fit indices are also reported. The main advantage offered by both *CFI* and *SRMR* compared to other fit indexes is that they are relatively independent of sample size (Chen, 2007). Tucker-Lewis index (TLI) was not considered due to its high correlation with *CFI* (Kline, 2016). A good model fit was considered with *RMSEA* and *SRMR* values below .05 and *CFI* higher than .95. *RMSEA* and *SRMR* values between .05 and .08, while *CFI* values between .90 - .95 were considered as an acceptable fit (Little, 2013).

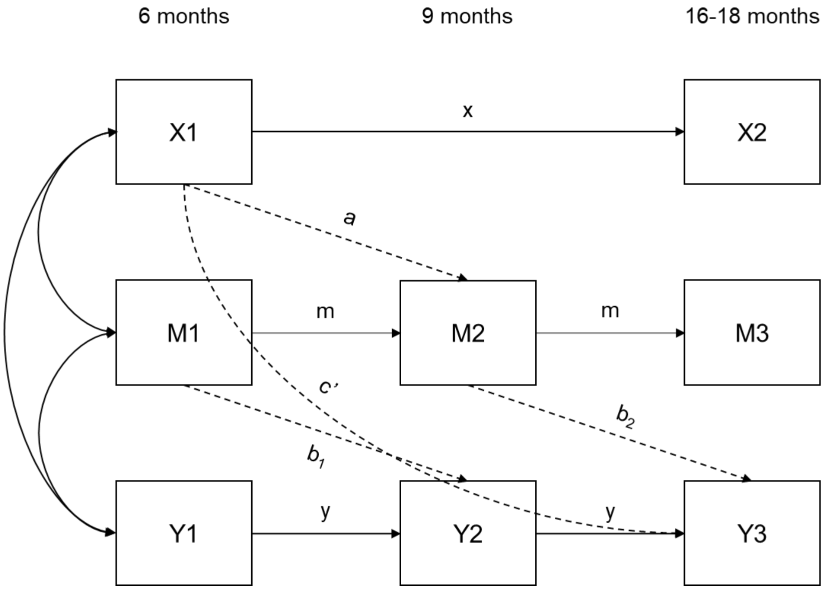

Figure 4.1. Three-waves cross-lagged panel model. X_2 is not represented in the figure as environmental factors were not measured at 9 months.

4.6.3. Results

4.6.3.1. Disengagement cost

As none of the environmental factors were found to be a statistically significant predictor, no CLPM was tested.

4.6.3.2. Disengagement failure

Two CLMPs models were built to test the mediating role of infants' ORC over the effects of CHAOS and SES on disengagement failure at 16-18 months of age. For the first model, we introduced SES at 6 months as an independent variable, ORC at 9 months as a mediator, and disengagement failure at 16-18 months as the outcome. Neither the indirect ($\beta = .01$, $p = .71$, 95% CI [-.06, .09]), direct ($\beta = -.25$, $p = .10$, 95% CI [-.57, .06]) nor total effects ($\beta = -.24$, $p = .15$, 95% CI [-.58, .09]) were found to be statistically significant. A non-statistically significant chi-squared test suggested a good model fit ($\chi^2 = 19.98$, $df = 16$, $p = .22$), followed by fit indices (*CFI* = .95, *RMSEA* = .05, *SRMR* = .09) indicating an acceptable fit.

The second model was similar to the first one, although introduced CHAOS at 6 months as independent variable. The indirect effect was not found statistically significant ($\beta = .04$, $p = .40$, 95% CI [-.06, .14]). Although, both direct ($\beta = -.36$, $p < .01$, 95% CI [-.63, -.12]) and total effects ($\beta = -.32$, $p = .01$, 95% CI [-.59, -.08]) reached statistically significance. Chi-squared test ($\chi^2 = 19.72$, $df = 16$, $p = .23$), and fit indices (*CFI* = .93, *RMSEA* = .05, *SRMR* = .10) indicated an acceptable model fit.

4.6.3.3. Stimulus fixations

As none of the temperamental factors were found to be statistically significant predictors of stimulus fixations at 16-18 months, no CLMP model was tested.

4.6.3.4. Reactive looks

For reactive looks at 16-18 months, we tested a CLPM with PAS at 9 months as a mediator on the effect of maternal depression measured at 6 months. The indirect effect was not found statistically significant ($\beta = .04$, $p = .44$, 95% CI [-.07, .16]). Both the direct ($\beta = .37$, $p < .01$, 95% CI [.15, .58]) and the total effects ($\beta = .42$, $p < .01$, 95% CI [.16, .65]) were found statistically significant. Both, chi-squared test chi-squared test (χ^2 =

47.31, *df* = 16, *p* < .01), and fit indices (*CFI* = .74, *RMSEA* = .16, *SRMR* = .11) indicated a poor model fit.

4.6.3.5. Correct anticipations

Two CLPMs were tested for correct anticipations. First, PAS at 9 months was introduced as a mediator on the association between CHAOS at 6 months and correct anticipations at 16-18 months. Only direct (*β* = -.41, *p* < .01, 95% CI [-.71, -.12]) and total (*β* = -.40, *p* = .01, 95% CI [-.73, -.08]) effects were found statistically significant. A statistically significant chi-squared test (χ^2 = 35.37, *df* = 16, *p* < .01), and fit indices (*CFI* = .48, *RMSEA* = .13, *SRMR* = .12) indicated a poor model fit.

Second, the same model was fitted introducing maternal depression at 6 months as a predictor and keeping PAS as a mediator. The indirect effect was not found statistically significant (*β* = .04, *p* = .44, 95% CI [-.15, .06]), but the direct (*β* = -.36, *p* < .01, 95% CI [-.57, -.14]) and total effects (*β* = -.40, *p* < .01, 95% CI [-.65, -.15]). As in the previos model, both chi-squared test (χ^2 = 46.49, *df* = 16, *p* < .01) and fit indices (*CFI* = .74, *RMSEA* = .16, *SRMR* = .12) indicated a poor model fit.

4.6.3.6. Total anticipations

Regarding total anticipations, a CLPM model tested the mediating role of PAS at 9 months over the effects of CHAOS at 6 months on total anticipations at 16-18 months. The indirect effect was not statistically significant (*β* < .01, *p* = .97, 95% CI [-.15, .16]). The direct effect was statistically significant (*β* = -.37, *p* = .04, 95% CI [-.72, -.02]), while the total effect (*β* = -.36, *p* = .05, 95% CI [-.74, .01]) did not reached statistically significance. A poor model fit was found for both, the chi-squared test (χ^2 = 35.37, *df* = 16, *p* < .01), and fit indices (*CFI* = .48, *RMSEA* = .13, *SRMR* = .12)

4.6.3.7. Easy correct anticipations

A CLPM model was fitted introducing NA at 9 months as a mediator on the effects of SES at 6 months over easy correct anticipations at 16-18 months. The indirect effect of the model was not found statistically significant (*β* = .03, *p* = .49, 95% CI [-.06, .11]). Direct (*β* = .27, *p* = .04, 95% CI [.01, .54]) and total effects (*β* = .29, *p* = .04, 95% CI [.01, .60]) were statistically significant. A good model fit was indicated by both, the chi-squared test (χ^2 = 13.15, *df* = 12, *p* = .36) and fit indices CFI and RMSEA, but acceptable for SRMR (*CFI* = .98, *RMSEA* = .03, *SRMR* = .08)

4.6.3.8. Complex correct anticipations

For complex correct anticipations, two CLPMs tested the mediating role of PAS at 9 months on the effects of SES and CHAOS at 6 months over complex correct anticipations. First, PAS was introduced as a mediator on the association between SES and complex correct anticipations. The indirect (*β* = .01, *p* = .59, 95% CI [-.03, .06]) and total effect (*β* = -.28, *p* = .06, 95% CI [-.58, .01]) did not reach statistical significance, but the direct effect (*β* = -.29, *p* = .04, 95% CI [-.59, -.01]). Chi-squared test was found to be non-statistically significant (χ^2 = 16.83, *df* = 12, *p* = .15) with a general acceptable model fit (*CFI* = .90, *RMSEA* = .07, *SRMR* = .08).

The same models were built replacing the independent variable for CHAOS. Introducing PAS as a mediator resulted in a non-statistically significant effect (all *ps* > .35). A statistically marginal chi-squared test was found indicating a poor model fit (χ^2 = 20.75, *df* = 12, *p* = .05) along with fit indices (*CFI* = .70, *RMSEA* = .10, *SRMR* = .10).

4.6.3.9. Pre-switch block: correct anticipations

As either temperamental or environmental factors were not found to be statistically significant predictors of correct anticipations in the pre-switch block, no CLPM was tested.

4.6.3.10. Pre-switch block task criterion

Similar to the previous case, as no temperamental factors were found to contribute to the task criterion on hierarchical regression models, no CLPM was built.

4.6.3.11. Post-switch block: perseverations

Regarding perseverative errors in the post-switch block, CLPM was tested with CHAOS as an independent variable and ORC as the mediator. Although the indirect effect was not statistically significant (β = -.10, *p* = .28, 95% CI [-.28, .08]), both direct (β = .66, *p* < .01, 95% CI [.34, .90]) and total effects (β = .55, *p* < .01, 95% CI [.11, .82]) were found statistically significant. A chi-squared test indicated a good model fit (χ^2 = 10.76, *df* = 16, *p* = .82), with an acceptable-good model fit suggested by fit indices (*CFI* = .90, *RMSEA* = .07, *SRMR* = .09)

4.7. Discussion

Multiple factors, from intrinsic (e.g. temperament) to extrinsic (e.g. environment) to the child are likely to impact early cognitive and behavioural development (Fox & Calkins, 2003). In the current Chapter, we aimed to study the effect of temperamental individual differences, as well as environmental factors (i.e. SES, CHAOS, and maternal depression), on infants' and toddlers' attentional development from 6 to 16-18 months of age. Moreover, we investigate the interplay between temperamental and environmental factors over attentional outcomes through longitudinal mediation models. For ease of the reader, in the next paragraphs, we will refer to 6, 9, and 16-18 months of age as middle infancy, late infancy, and toddlerhood, respectively.

4.7.1. Stability of temperament

First, we tested the stability of temperament and environmental factors from middle infancy to toddlerhood. Results partially supported our hypothesis. We found some stability for the three factors in line with previous literature (Nakagawa & Sukigara, 2013; Putnam et al., 2006; Putnam et al., 2013). Stability was found to be higher between consecutive testing ages (i.e. 6 to 9 and 9 to 16-18 months). From middle to late infancy, ORC; PAS, and NA were found to be stable, while only ORC in late infancy was found to correlate with itself (i.e. EC) during toddlerhood. Stability in the long run, that is, from middle infancy to toddlerhood (i.e. 6-to 16.18 months) was only found for PAS/SUR. In general, temperament seems to offer stability between infancy and toddlerhood. Individual changes with age, which could be expected to be higher between infancy and toddlerhood, as well as a lower sample size in certain comparisons (i.e. 6 vs. 16-18 months), could have led to some instability in the observed correlation patterns.

We found a systematic positive correlation between ORC/EC and PAS/SUR within-age. This pattern has been previously found during the first year of life in infant samples from 6-to 7-month-olds (Posner et al., 2012), 3-to 12-month-olds (Gartstein & Rothbart, 2003), and 12 months of age (Gartstein et al., 2013). Regarding between-age correlations, this positive association between ORC and PAS/SUR was found between middle and late infancy, but not from late infancy to toddlerhood. Previous research has also found a positive correlation between both factors from infancy to toddlerhood (Putnam et al., 2008), with only Gartstein & Rothbart (2003) reporting a negative correlation between ORC and PAS in the first year of life.

With age, there seems to be a transference of PAS factors to later EC emergence. For instance, Gartstein & Rothbart (2001) found ORC's perceptual sensitivity to load on the PAS factor during infancy, while during childhood it was found to integrate into EC (Rothbart et al., 2001). Moreover, Komsi et al. (2006) found infant's PAS to be predictive of both, SUR and EC during middle childhood, while Putnam et al. (2008) found most of PAS's subscales to predict toddlers' EC. This last author suggests that infants with a higher PAS could tend to be exposed to more situations that could be cognitively and emotionally more challenging. This experience would grant infants more opportunities to develop an effortful regulation of cognition, behaviour, and emotion. This view is also supported by Rothbart et al. (2001), who suggested that infants' PAS contributes to the development of self-controlled attentional abilities due to a higher reliance on the orienting network during infancy. With age, this control would lie on EC and the EA network, once it starts to be fully functionally active during toddlerhood and early childhood. This positive association between ORC/EC PAS/SUR tends to be reversed later in development, with both factors being found to be negatively associated from 36 months of age onwards (Papageorgiou et al., 2015; Papageorgiou et al., 2014; Posner et al., 2012; Putnam et al., 2008).

Regarding NA, we found a positive correlation with ORC and PAS only during middle infancy. Variability in the correlations between NA and other temperamental factors has been reported at different ages, with some studies reporting negative correlations (Gartstein et al., 2013; Posner et al., 2012), positive associations between NA and PAS (Gartstein & Rothbart, 2003) or no correlation at all (Ahadi et al., 1993; Gartstein et al., 2013; Putnam et al., 2006; Putnam et al., 2008). This association of NA with PAS could be driven by more reactive components of these factors during infancy. Putnam et al. (2008) reported positive correlations between components of infants' PAS and toddlers' NA. In particular, PAS's activity level and smiling and laughter were found to be positively associated with NA's motor activation and falling reactivity. Gartstein & Rothbart (2003) also reported positive correlations of PAS's activity level with NA's fear, distress to limitations, and sadness during the first year of life. As PAS and ORC seem to be targeting overlapping temperamental components, it is also dragged to this positive association with NA.

4.7.2. Stability of environmental factors

Concerning stability of environmental factors, SES, CHAOS, and maternal depression were found to be highly stable from middle infancy to toddlerhood. The high correlation between socioeconomic variables also supported the creation of a composite SES index. We also found a lack of correlation between SES with CHAOS and maternal depression, both within and between waves. As suggested by previous literature (Hart et al., 2006; Moyano et al., 2022; Petrill et al., 2004), these results suggest independency of the effects of SES with respect to CHAOS and mother's depression, which is not necessarily related to families' socioeconomic background. In this sense, SES could scaffold early cognitive development accounting for distal characteristics of infants' environment related to social and economic capital (i.e. social position, economic and educational resources; Conger & Donnellan, 2007). However, household disorganization and maternal depression could account for more proximal effects of the environment on cognitive development, considering aspects of noise and confusion in the household, as well as the quality of mother-infant interaction.

4.7.3. Associations between temperament and early environment

Regarding cross-correlations between temperament and environment, a higher families' SES and income-to-needs in middle infancy were found to be associated with a lower temperamental reactivity during toddlerhood (i.e. SUR). Unexpectedly, a higher parental educational level in middle infancy was associated with higher negative affectivity during middle infancy. However, previous studies have reported a higher SES to be related to a lower NA during toddlerhood (Conejero & Rueda, 2018). This association was not replicated during middle infancy or toddlerhood.

Supporting our hypothesis, more disorganization at home in middle infancy was related to a lower regulatory capacity and positive affectivity at this age. Disorganization and noise at home could negatively affect children's EF (Andrews et al., 2021), as well as effortful behavioral control (Lecheile et al., 2020; Vernon-Feagans et al., 2016). The fact that these associations were found only during middle infancy, could restrict the effects of the early environment on infants' regulatory capacity and positive affect on this developmental period in the studied age range. Surprisingly, higher CHAOS during middle infancy was correlated with a lower negative affect during toddlerhood. At older ages, a negative correlation between CHAOS and children's EC has been reported, but positive with NA (Moyano et al., 2022). However, the lack of infant studies exploring the associations between early temperament and CHAOS calls for future replication of this result.

As expected, a higher maternal depressive symptomatology in middle infancy was associated with a lower regulatory capacity and positive affect at the same age, but a higher negative affect in late infancy. These associations suggest that the negative impact that maternal depression could have, is observable early in development over infants' regulatory capacity and positive affect. However, the effects on negative affect could not be distinguishable in the short run, needing more time to unveil. Previous research has found that infants exposed to higher maternal depressive symptoms have a generally difficult temperament at 2 and 6 months of age (McGrath et al, 2008), higher negative emotionality at 12 months of age (Melchior et al., 2012), and during late childhood (Comas et al., 2014). Although not all of our hypotheses were supported, we replicated a general association between exposure to a more adverse environment and a more difficult temperament in the early stages of development.

4.7.4. Effects of temperament and environment over attention disengagement

Measures for disengagement cost and disengagement failure were obtained in the gap-overlap task across the three ages tested. Although neither temperament nor environmental factors were found to predict disengagement cost at any age, some associations were found in line with our hypothesis. Interestingly, a higher regulatory capacity and positive affect in middle infancy were associated with a lower disengagement cost at this age, but a higher disengagement cost during toddlerhood. This pattern of results resembles Nakagawa & Sukigara's (2013) findings. In a longitudinal study, these authors found that a higher ORC at 12 months was associated with a lower cost to disengage in the overlap condition. This association was reversed during toddlerhood, with a higher ORC being related to higher disengagement cost in the same experimental condition. Although the correlations are not consistent across age, this could suggest that infants with a higher regulatory capacity and positive affect early in the first year of life, will easily disengage to explore a novel peripheral target. However, during toddlerhood, children would prefer to remain in the central stimulus when a novel one is displayed. This would suggest a higher ability to inhibit attention to be captured and reoriented by a peripheral target to remain to explore the foveated stimulus. No statistically significant correlations were found between families' SES index at 6 months and visual disengagement, but only some tendencies in the data. Specifically, SES shows a tendency to be associated with a lower disengagement failure at 16-18 months. Interestingly, a higher parental occupation at 6 months was found to be associated with a lower disengagement failure at 16-18 months. Previous studies have also reported effects of parental occupation on infants' cognitive development. For instance, Tomalski et al. (2013) found that a lower maternal occupation was related to lower power in gamma-band in frontal electrodes in 9-month-old infants, suggesting an impact on cognitive development. Effects of SES in disengagement latencies have been recently reported at 5 months of age (Siqueiros Sanchez et al., 2021). Infants from higher-income families, measured through maternal education level, showed higher disengagement latencies in the overlap condition. However, in the current study we did not replicate this result

Contrary to our hypothesis, homes with higher levels of CHAOS at 6 months were also associated with a lower disengagement failure at 16-18 months.

Temperament and environmental factors were not found to contribute to predicting disengagement failure during late infancy but during late toddlerhood. Temperamental regulatory capacity in late infancy predicted a higher disengagement failure during toddlerhood. This is in line with our previous interpretation of correlation data for disengagement cost, reminding Nakagawa & Sukigara's (2013) findings. That is, infants with a higher regulatory capacity would inhibit the peripheral target in order to remain focused on the current central stimulus being attended, leading to a higher disengagement failure. This is interesting, as this temperamental switch for regulatory capacity in relation to attention control could be already found at 9 months instead of 18 months of age, as indicated by Nakagawa & Sukigara (2013). Contrary to our hypothesis, higher CHAOS during middle infancy predicted a lower disengagement failure in toddlers. Children growing up in households with higher levels of household disorganization are likely to be exposed to overstimulating conditions. These more chaotic environments are characterized by a lack of predictability of the events at home, which could lead to hypervigilant states and determine a more reactive attentional style (Wass, 2022). Children exposed to more chaotic homes could also be more dependent on contextual information, displaying a tendency to withdraw more often from their immediate environment (Evans, 2006). A recent study has reported this higher tuning towards contextual information of children exposed to higher levels of chaotic home environments. Moyano et al. (2022) found that CHAOS predicted more visual anticipations in conditions with a high cognitive load, that is, during complex visual sequences that required context monitoring. These authors argue that the unpredictable characteristics of chaotic home environments could have predisposed children to be oriented towards contextual information available in the environment, in an attempt to try finding contingencies to make their home environment more predictable. Although in this case higher degrees of CHAOS at home could have had a positive effect on performance due to task dependency on contextual information, it could jeopardize attentional control in other situations in which the most adaptive response would be to ignore or suppress other information available in the environment. In general, a higher exposure to homes with higher levels of CHAOS could increase visual disengagement independently of the speed of the visual orienting process. This could be related to a higher attentional reactivity and susceptibility of these toddlers to contextual information. This could promote a higher visual disengagement, with attention being captured by new peripheral stimulation that competes for the infant attentional resources.

It should be noted that the disengagement failure metrics haven’t been previously employed, and results should be interpreted cautiously and be replicated in future studies.

4.7.5. Effects of temperament and environment over anticipatory attention and context monitoring

Different aspects of anticipatory attention were measured employing the VSL task, from sustained attention (i.e. stimulus fixations) to exogenous (i.e. reactive looks) and endogenous attention control (total and correct anticipations). Moreover, context monitoring (i.e. complex correct anticipations) was targeted in late infancy and toddlerhood with the distinction between easy and complex trials in the VSL task. This attentional ability is thought to reflect an engagement of executive attention control to monitor the context and task dynamics (Posner & DiGirolamo, 1998)

Concerning the effects of temperamental individual differences on later attentional control, several outcomes were found. First, infants' temperament in middle infancy was not found to be predictive of attentional performance in late infancy. Temperament is a psychobiological construct, and as such different temperamental tendencies could be identified since birth (Rothbart, 1981). However, at early stages of development, temperament offers a lot of variability in infants' behavioural reactions to the environment (Rothbart, 2007). This early variability could affect the prediction of later attentional abilities. The current results could follow this notion. We can see how it is temperament in late, but not in middle infancy, the one with predictive power over later attentional skills.

In line with our hypothesis, infants' positive affect in late infancy was found to predict lower exogenous attention (i.e. less reactive looks), but a higher endogenous attention control (i.e. more total anticipations, correct anticipations, and complex correct anticipations) during toddlerhood. Results concerning complex correct anticipations should be interpreted cautiously, as the increase in model fit was found to be marginally significant. As stated in previous literature, infants' positive affect shows a contribution over endogenous attention control. (McConnell & Bryson, 2005; Putnam et al., 2008). The positive impact of positive affect on measures of endogenous attention places this temperament factor on the early emergence of infants' self-control over attentional systems. Infants' tendencies towards a positive affect could turn into higher abilities for attention control (Putnam et al., 2008). They could be exposed to more situations requiring an effortful control of cognition and behaviour, contributing to the emergence of voluntary control with age (Putnam et al., 2008).

However, for context monitoring, we expected infants' regulatory capacity to be the most relevant predictive factor, due to its close relation with executive attention control (Rothbart et al., 2011; Rueda et al., 2005). During early childhood, it is regulatory capacity/effortful control which is associated with correct anticipations in the VSL task (Rothbart et al., 2003), and attentional control (Rothbart et al., 2011). In this respect, positive affect does not seem to have a unique contribution to early endogenous attention control, but also to more sophisticated mechanisms related to executive attention. Although regulatory capacity was not found to be a predictor of attentional outcomes, a positive correlation between this factor in middle infancy and total anticipations in toddlerhood was found.

Unexpectedly, infants' negative affect in middle infancy was found to be positively correlated with correct anticipations at this age. Additionally, negative affect in late infancy also contributed to predict more easy correct anticipations in toddlerhood. As for complex correct anticipations, the increase in model fit was found to be statistically marginal, so results should be read cautiously. A certain connection between negative affect and attention control seems to exist. In a sample of 12-month-old infants, Gartstein et al. (2013) reported a positive correlation between infants' negative affect and the duration of object manipulation. The reactivity accounted for negative affect during infancy could be related to a higher orientation and awareness of the context at this age. This would facilitate learning deterministic transitions (i.e. easy trials in the VSL task). With age, this association is reversed. During toddlerhood, negative affect is associated with less easy, but more complex correct anticipations. Perhaps, once infants gain the ability to monitor the context, this contribution of negative affect could transfer to complex transitions. In general, these associations are interesting, as previous studies have not found genuine correlations of negative affect with attentional outcomes in the VSL task (Moyano et al., 2022; Posner et al., 2012; Rothbart et al., 2003). Nevertheless, they also call for replication studies.

Regarding environmental effects, early SES contributed to predict more easy, but less complex correct anticipations in toddlerhood. Infants from higher socioeconomic backgrounds have been previously found to display a higher visual attentional control (Clearfield et al., 2013; Siqueiros-Sanchez et al., 2021). The positive effects of early SES on attention could initially impact those abilities that are first mastered by infants and toddlers (i.e. learning easy transitions). This could lead to a detrimental effect over complex correct anticipations, as its effects could be delayed and not be observable until toddlers acquire the ability to learn complex transitions. As this ability seems to emerge between the end of toddlerhood and the beginning of young childhood, the positive contribution of SES on complex correct anticipations could be observed from this age onwards.

Home disorganization in middle infancy was also found to predict less endogenous attention (i.e. stimulus fixations, correct, total, and complex correct anticipations) in toddlerhood. Also, it was found to be positively correlated with exogenous attention. Although studies covering the effects of chaotic home environments over attentional development are scares, our results are consistent with recent research. For instance, Tomalski et al. (2017) found a reduced visual attention ability in 5-month-old infants exposed to more chaotic households. Children exposed to higher levels of disorganization at home are more likely to withdraw from their environment (Evans et al., 2006) which could explain more reactive attentional tendencies, shaped by over-stimulating conditions at home. The negative effect of CHAOS over complex correct anticipations is opposite to the results found by Moyano et al. (2022) in a sample of young children. In their study, children exposed to higher levels of CHAOS were found to perform more complex correct anticipations. Authors suggest that these children could be more prone to look for contingencies between events in order to reduce the unpredictability of their home environment. The current results seem to highlight a changing role of disorganization at home during development. That is, it has a negative effect during infancy and toddlerhood. Once children gain more control over attention with age, the cognitive tune towards contingent learning could boost their ability to uncover and learn more complex relations between events.

In parallel to the effects to home chaos, maternal depression in middle infancy predicted more exogenous attention (i.e. reactive looks), and less sustained (i.e. stimulus fixations) and endogenous attention (i.e. correct anticipations) in toddlerhood. It is likely that mothers with depressive symptomatology could display fewer positive interactions with their infants (Coyl et al., 2002; Jameson et al., 1997). This has been found to negatively impact children’s behavioural (Leckman-Westin, 2009; Rigato et al., 2022) and cognitive development (Power et al., 2021). Recently, Oh et al. (2020) found maternal depression from pregnancy until 2 years after birth to negatively impact children’s EF from early to late childhood. Also, Hughes et al. (2012) reported chronic maternal depressive symptomatology to have a detrimental effect over children's EF between 2 and 6 years of age. Although there is a lack of scientific literature covering the effects of mothers' depression over attentional development, the current results are in line with the reviewed literature.

4.7.6. Effects of temperament and environment on attention flexibility

For the switching task, we did not find neither temperament nor environmental factors to significantly predict correct anticipations. However, infants' positive affect in late infancy was negatively correlated with correct anticipations at the same age. This result goes in the opposite direction to our hypothesis and to previous results found in the VSL. Although both tasks target anticipatory gaze as a proxy for attention control, the approach is relatively different. In the VSL, a sequence of more than one possible spatial location is used, with stimuli changing locations as the sequence goes on. Yet, in the switching task the stimulus is repetitively presented on the same location during the entire pre-switch block. For the former task, we found positive affect in late infancy to predict more correct anticipations during toddlerhood. The attentional demands to keep track of a stimulus when its spatial location changes over time is higher than when it is presented always on the same location. Thus, the attentional control captured by this temperamental factor could be deployed for the VSL task. In the switching task, positive affect could target aspects of temperament related to impulsivity and reactivity, with infants performing less anticipations in the task, due to a less engaging and dynamic configuration.

Additionally, temperament did not predict the pre-switch block criterion (i.e. trial in which infants reach three correct anticipations), or perseverations. For the pre-switch block criterion, infants' previous performance in late infancy, positively predicted a higher criterion during toddlerhood. This result suggests a lack of improvement in this ability with age, as infants that need more time to learn the contingency in the pre-switch block would not learn it faster during toddlerhood. Nevertheless, infants' SES in middle infancy could boost a faster learning, as infants with a higher SES were found to display a lower pre-switch block criterion in toddlerhood.

Contrary to our hypothesis, neither temperamental nor environmental factors were found to be associated or contribute to predict perseverations. Previous studies had found a higher family's SES and a lower toddlers' negative affect to be associated with less perseverative errors in the switching task (Conejero & Rueda, 2018). Similarly, a negative impact of a low SES level has been found on perseverative behaviour during infancy (Clearfield & Jedd, 2013; Clearfield & Niman, 2012). The lack of association in our study is surprising, indicating the necessity of further replication on these effects during infancy and toddlerhood in future studies.

4.8. Conclusion

In the current Chapter, we focused on testing the association and predictive power of temperament and families' environment on attention control. We found multiple associations of both temperamental and environmental factors with attention disengegament, as well as with anticipatory attention and context monitoring. Nevertheless, we did not find any effect over attention flexibility per se, that is over perseverative errors, but on learning of event contingencies. In general, we found positive contributiong of infants' regulatory capacity and positive affect on endogenous attention control. This result is not suprising as both temperamental factors are known to be positively correlated during these developmental stages (Gartstein & Rothbart, 2003; Gartstein et al., 2013; Posner et al., 2012; Putnam et al., 2008), capturing early aspects of endogenous control of attention. While SES seems to have a positive predictive power over attention control, CHAOS and maternal depression negatively impacted endogenous attention. Nevetheless, there are some counterintuitive results that need future replication. Additionally, we did not find any longitudinal mediation effect of temperament on the effect of environmental factors on attentional control.

The longitudinal design and multidisciplinary methodology offer a high strength to this study, yet some limitations remain. Concerning limitations of the sample, the generalization of the study is limited to white Caucasian infants, with the presence of other ethnicities being limited in the current sample. Also, temperamental factors were obtained through parent reported questionnaires. Although this is one of the most widely used methods to obtain information about infant's and toddler's temperament, response biases can be introduced by parent's when reporting their own child's behaviour. For instance, in a sample of 4.5-to 6.5-month-old infants, Seifer et al. (2004) reported significant differences between independent observers and parents when rating infants' behaviour. Interestingly, these differences were non-existent when rating the behaviour of anonymous children. Additionally, Gartstein & Marmion (2008) found a high correlation between parent-reported and laboratory-based measures of 6-month-old's fear, but not for other components such as smiling and laughter. These results could suggest that some aspects of infant's temperament could be more prone to bias, specially when it involves distinguishing specific behaviours of infants. Additionally, differences could be likely to be found between first-time and experienced mothers in identifying those behaviours. Adopting more ecological approach, using videotaped mother-infant interactions and independent raters, could help to reduce potential biases. This approximation could be extended to aspects of the home environment. Employing at-home observations of the level of disorganization, routines or noise in the household would help to eliminate potential biases in parent-reported questionnaires. Moreover, additional variability of other relevants aspects of the context in which infants grow could be captured using this approach.

In relation to the gap-overlap task methodology, research on infant attention have used two- and three-dimensional stimuli on experimental tasks. Differences between these two types of stimuli should be considered in relation to their capacity to capture attention, especially in young samples (Richards, 2010). Due to the independence of the effects measured by the CHAOS and SES scales, it is challenging to detect differences in household disorganization among different socioeconomic backgrounds using this instrument. Perhaps, going beyond questionnaire measures could be a solution to this matter as proposed previously. Testing the effects of chaotic households measured with more ecological measures such as at-home observations, could capture additional variability of the rearing environment. It should be noted that the measure provided by the CHAOS scale is culturally rooted, aligning with prototypically white, middle-class households' norms with a nuclear rather than a generational family structure. Households that reflect different cultural norms may be penalized for circumstances that may actually be beneficial for these particular family units. In the current study, families come mostly from a cultural background in which a nuclear structure is predominant, reducing the potential effect that cultural differences in respect to the family structure could have on the reported effects of CHAOS. Future studies should also consider incorporating other factors that are known to have an impact on early cognitive development. Individual differences in attention control have been found to be associated with differences in genes, such as the dopamine transporter (DAT1) and the catechol-O-methyltransferase (COMT). Children with the long allele of this gene display a higher attentional control (Rueda et al., 2005). In infants, the methionine/methionine (Met/Met) polymorphism, which indicates less COMT metabolization of dopamine in the prefrontal cortex, contributes to a higher visual attention control, compared to infants with the valine/valine (Val/Val) polymorphism that allows for a high activity of this gene (Holmboe et al., 2010). Finally, other aspects of infants' environment are also known to be associated with cognitive development, such as nutrition, quality of sleep or physiological stress (Roosa et al., 2005). For instance, 7-month-old infants with higher level of salivary cortisol showed less executive function at 3 years of age (Blair et al., 2011). Also, 12-month-olds with a poor sleep quality also display a lower executive attention control in a spatial conflict task at 3-4 years of age (Sadeh et al., 2015). Considering more ecological and proximal psychobiological factors, could add to explain additional variability on early visual attention control during infancy and toddlerhood.

Chapter 5: Development of visual attention control in early childhood: Associations with temperament and home environment.

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5.1. Introduction.

Attention is key for selecting the relevant information from the environment and controlling both information processing and behavior (Posner and Rothbart, 1998). Classical (Posner, 1980; Posner and Petersen, 1990) as well as more recent (Corbetta and Shulman, 2002) models of attention differentiate between exogenous and endogenous control of attention. Exogenous orienting is a bottom-up process that occurs when salient stimuli or changes in the environment draw and direct attention automatically (i.e. stimulus-driven). This type of orienting differs from shifts of attention that are based on expectancies or internal goals, which are referred to as endogenous or top-down orienting. The central role of attention within the cognitive system makes the development of this function crucial to children’s learning. Further, attention is related to other spheres of the child’s functioning during development, such as academic achievement and socio-emotional adjustment (Simonds et al., 2007; Rueda et al., 2010). These associations are found from early infancy (Rothbart et al., 2011; Blankenship et al., 2019), and appear to be predictors of children’s functioning in adulthood (Moffitt et al., 2011).

Previous research on the early development of visual attention has mainly focused on initial transitions from exogenous to endogenous forms of control in infancy. Evidence suggests that primary aspects of visual exogenous orienting emerge early in life. At around 1 month of age, infants are already able to fixate on and follow moving stimuli in the absence of visual competition (Aslin, 1981; Atkinson and Braddick, 1985), with changes in exogenous control as top-down processes gains weight over volitional control. However, changes with age in exogenous attention are still unclear in early childhood. In this sense, Ristic and Kingstone (2009) found that exogenous orienting of 36-to 72-month-old children upon non-predictive cues was similar to adults. Nevertheless, Iarocci et al. (2009) reported that 60-month-old children displayed a higher tendency to engage exogenous orienting in comparison to 7, 9 and 24-year-olds participants. This suggests that as older cohorts gain control over endogenous orienting, it will allow for a modulation of exogenous attention. Yet, no previous research has covered changes in exogenous orienting between toddlerhood and preschool ages, in relation to changes in endogenous control.

Conversely, the development of endogenous orienting is more protracted in time, emerging around 3-to 6 months of age (Johnson et al., 1991; McConnell and Bryson, 2005). The recruitment of crucial areas for endogenous attention control, such as frontal and parietal regions, have been found already in 3-month-olds infants (Ellis et al., 2021). Although, endogenous control seems to show an increased stability from the preschool years onwards (Rothbart et al., 2003; Colombo and Cheatham, 2006). The relevance of endogenous orienting also lies in its conception as a precursor for the development of more complex mechanisms for attention control, such as those involved in the voluntary regulation of thoughts and behavior, particularly in interference-rich contexts. These mechanisms are known to be mostly dependent on executive attention (Rothbart et al., 2011), which shares common neural substrates with endogenous orienting (Rueda et al., 2015). One of these more sophisticated mechanisms of control that has been scarcely studied during toddlerhood and preschool is referred to as context monitoring. Monitoring describes the ability to track the course of events (Petersen and Posner, 2012), and is related to the quality and flexibility with which attention control is engaged, providing a more effective detection of these target events (Chevalier and Blaye, 2016). Moreover, it is a crucial control process during learning and memory creation (Nelson and Narens, 1990), as tracking the events that occur around us is a necessary condition to form expectations about the environment. This is particularly important in more complex settings, allowing to orient the attentional focus toward areas or objects of interest in rich but predictable environments.

Previous research has found that since toddlerhood, children are already able to monitor the environment in search of regularities to create expectations. To study this, Rothbart et al. (2003) presented visual sequences of spatial locations to toddlers from 24-to 36 months of age. They found that 24-month-olds were already able to monitor complex sequences, in which the location of the next stimulus was correctly predicted only if the child was able to monitor the previous location to the current one, that is engaging mechanisms of context monitoring. However, between 36-to 60 months of age, Freier et al. (2017) showed that the ability of children for sequence monitoring is still evolving. In their study, children’s goal-oriented behavior was measured employing a sequence coloring task, with children being required to use a set of colors equally often while coloring all the animals in a sequence presented on paper. They found younger children to deviate earlier in the task from goal-directed responses compared to 60-month-olds, suggesting a lower ability to monitor the distal goal of the task. Also, it is likely related to age differences in the monitoring of previous actions, that is colors already used, for the implementation of future steps. Differences in task performance were not found to be related to working memory capacity, but to the engagement of endogenous attention control during the selection of the appropriate actions at lower-levels of task requirements to achieve the final goal.

Due to the relevance of attention during development, in the current research we aimed to study the transition from exogenous to endogenous orienting to context monitoring through the visual modality. For this, we evaluated children from 24-to 48 months of age, a developmental period in which executive attention is proposed to start emerging as the main supervisory system of attention (Posner and Rothbart, 2007; Rothbart et al., 2011). Is this transition towards executive attention which supports the engagement of more sophisticated mechanisms of control. We aim at doing this with a single task: the Visual Sequence Learning (VSL).

5.1.1. Measuring attention orienting during development.

The so-called visual expectation paradigm (VExP; Haith et al., 1988) is one of the first experimental protocols suitable for infants and young children that allows for the measurement of both exogenous and endogenous orienting of attention. This paradigm involves the presentation of a set of visual stimuli in different spatial locations, following a fixed sequence, while the direction of the participants' gaze is being recorded. Exogenous shifts of attention are measured through reactive looks, which are observed after the stimulus onset. In contrast, anticipatory looks to a particular location, that is before the stimulus onset, reflect an expectancy-based endogenous orienting of attention. The accuracy of anticipatory looks hinges on whether there is an effective learning of the regularities available in the context, such as the repeated sequence of events (Rothbart et al., 2003).

To detect these regularities, sustained attention and context monitoring are key abilities that will drive the detection and knowledge acquisition of events' frequencies, to form accurate expectations of upcoming occurrences. To explore higher-level attention mechanisms involved in monitoring during sequence learning, Clohessy et al. (2001) developed the VSL. The procedure of the VSL involves the presentation of several attractive events in different spatial locations that appear in a fixed sequence. A common one used with toddlers is 1-2-1-3-1-2-1-3- and so on, where each number represents a particular location. The original study employed a set of three screens to define each spatial location, placing a camera between them to record infants' gaze. Similar to the VExP, it enables to measure exogenous orienting through reactive looks. Furthermore, this particular sequence allows for the distinction of anticipatory looks during easy (unambiguous) transitions, given that locations 2 and 3 are always followed by location 1, and complex (ambiguous) transitions, given that location 1 can be followed by location 2 or 3, depending on the previous location to 1. Thus, complex transitions require a greater engagement of context monitoring processes (i.e. maintaining information in mind about previous locations) in order to correctly anticipate the location of the upcoming event.

The VSL was designed as a suitable task for children of different ages. As no verbal instructions are needed, the experimental protocol is free of limitations due to instructions comprehension. It has been used with infants from 4 months of age (Clohessy et al., 2001; Sheese et al., 2008), although only Rothbart et al. (2003) focused on studying age differences, specifically between 24 and 36 months of age. In a cross-sectional study, Clohessy et al. (2001) analyzed each cohort independently studying differences between easy and complex transitions for 4, 10 and 18-month-olds, as well as adults. In a single exposition to the task, they found that 4 and 18-month-olds showed a similar percentage of anticipatory looks in easy transitions to adults. However, only adults showed differences between easy and complex transitions, showing more correct anticipations to complex compared to easy. In a further study, Rothbart et al. (2003) found that it is between 24 and 36 months of age when children appear to exhibit an increase in correct anticipations for complex but not for easy transitions. This indicates that compared to complex, easy transitions require less endogenous control of attention reaching adult-like levels earlier in infancy, while increases in complex transitions are protracted until toddlerhood.

The resolution of ambiguity, such as the one that complex transitions require, demand greater attentional control. In sequence-learning studies with adults, employing a key press response instead of anticipatory gaze, participants fail to learn the sequence when they perform a concurrent task that demands attentional resources (Curran and Keele, 1993). It has been proposed that solving this ambiguity to correctly anticipate in complex transitions provides a measure of context monitoring, a supervisory process associated with a higher attentional control provided by executive attention (Posner and DiGirolamo, 1998; Botvinick et al., 2001). Previous results with the VSL also support this notion, as the percentage of correct anticipations in complex transitions has been found to correlate with a lower interference effect in a spatial conflict task in 36-month-old children (Rothbart et al., 2003). This suggests that endogenous orienting of attention in a task entailing context monitoring also taps into executive attention processes.

5.1.2. Individual differences in attention control in relation to temperament and environmental factors.

Emerging control over attention relates to multiple aspects of life, including social adjustment and academic performance during childhood (Rueda et al., 2010), as well as socioeconomic success or personal and emotional wellbeing in adulthood (Moffitt et al., 2011; Daly et al., 2015). An aspect inherent to the child and strongly associated with individual differences in attention control is temperament (Rueda et al., 2011). Effortful control (EC) is one dimension of temperament defined as the child's capacity to exert voluntary control over reactive systems of approach (surgency and/or aggression) and withdrawal (negative affectivity, such as fear and/or shyness) (Posner and Rothbart, 2007). Previous research has shown empirical links between EC and attention control. Children scoring high in EC tend to exhibit a better attentional ability during toddlerhood (Gerardi-Caulton, 2000; Rothbart et al., 2003; Nakagawa and Sukigara, 2013) and late childhood (Simonds et al., 2007). Also, High-EC children are more able to self-regulate behavior (Kochanska et al., 2000), which in turn favors learning and context monitoring processes (Pintrich et al., 2000; Ursache et al., 2012). In contrast, temperamental reactive systems such as surgency (SUR) and negative affectivity (NA) have been mostly negatively related to attention and EC from very early life (Rothbart and Rueda, 2005; Rothbart et al., 2011). Surgency refers to individual differences in positive emotionality and approach, including impulsivity and sensation seeking (Posner and Rothbart, 2007). Early attention control during infancy has been found to show a negative association with SUR, but positive with EC, during childhood (Papageorgiou et al., 2014, 2015). Also, high-SUR toddlers tend to perform fewer anticipations in both easy and complex transitions in the

VSL task, indicating a lower control over endogenous orienting (Rothbart et al., 2003). On the other hand, NA integrates children's negative emotionality, including behavioral reactivity related to discomfort, anger/frustration and fear (Posner and Rothbart, 2007). This factor shows a consistent negative association with attention control in infants (Johnson et al., 1991; McConnell and Bryson, 2005), toddlers and even young children (Gerardi-Caulton, 2000; Rothbart et al., 2003).

Recent research has reported effects of not only temperament, but also in conjunction with environmental factors on early visual attentional abilities (Conejero & Rueda, 2018). Different aspects of the home environment are known to have an impact on the development of children's attention. For instance, previous studies inform of an association between higher chaos at home and poorer executive functioning (Vernon-Feagans et al., 2016). Matheny et al. (1995) defined chaotic home environments as those characterized by high levels of background noise, crowded spaces, and disorganized timetables or lack of routines, which increase the levels of environmental confusion. It has been suggested that children exposed to home chaos are more likely to disconnect from their immediate context, as they grow up under over-stimulating conditions (Evans, 2006). However, only one study has explored the effects of chaotic environments over attention. Tomalski et al. (2017) reported detrimental effects of chaos over infants' processing speed measured through visual attention. Their results highlight that the characteristics of the home environment play a significant role on infants' attentional skills. Although chaos seems to be closely related to other environmental factors such as socioeconomic status (SES; Evans and Schamberg, 2009), chaos has been found to predict independent effects over early cognitive functioning than those of SES (Petrill et al., 2004; Hart et al., 2007).

5.1.3. Aims and hypothesis

Endogenous attention continues to improve until at least late childhood (Abundis-Gutiérrez et al., 2014; Pozuelos et al., 2014). Nevertheless, research investigating age differences in exogenous, endogenous orienting and context monitoring between toddlerhood and preschool-ages is sparse. Analyzing children's gaze in the VSL task allows to study differences in multiple components of visual attention control through these developmental stages. We aim to provide measures of exogenous (i.e. reactive looks) and endogenous orienting of attention (i.e. sustained attention and general anticipations) no previously reported with this paradigm. Furthermore, the dissociation between anticipatory looks in easy and complex transitions will be informative of differences in children's endogenous orienting under different levels of context monitoring demands. We intend to do this adapting the VSL task to an eye-tracking protocol to gain in temporal and spatial precision. Measures of child's temperament and family's home chaos were also included in order to test their contribution to attention. To the best of our knowledge, no previous study has investigated the effects of chaos on children's orienting of attention, neither its contribution with temperament at these ages.

For this purpose, a cross-sequential design of 5 cohorts was used. The within- and between-groups design of the study aims at testing both age differences as well as within-subject stability of attentional measures. We expected to find no contribution of age to reactive looks as a measure of exogenous orienting. Given that the task entails the presentation of a repeated number of sequences over some time, the percentage of stimuli fixations may provide a measure of sustained attention to the task. We hypothesized an increased percentage of stimuli fixations with age. Also, anticipatory looks provide a measure of the development of endogenous orienting as voluntary attempts to anticipate an upcoming event, independently of the accuracy of the expectation. Thus, we expected to observe an increase with age in total anticipations. In addition, we hypothesized an increase in correct anticipations with age, with a higher contribution of age to the monitoring of complex transitions. We reason that age-related increases in executive attention control would favor context monitoring of the visual sequence. However, the contribution of age for correct anticipations in easy transitions would be less prominent (see Table 5.1 for a summary of attentional processes measured in the VSL task). Although no a priori hypotheses were established, we will explore whether there is individual stability of all different attentional processes involved in the VSL task between sessions. Regarding the secondary aim of the study, we expected temperamental EC to positively contribute to endogenous orienting and context monitoring, whereas negative contributions for surgency and negative affectivity were anticipated. Concerning home environment, we hypothesized a negative contribution of chaos to children’s attentional abilities, particularly in task conditions with higher loads of context monitoring.

Table 5.1.

Summary of the main dependent variables of the VSL task and their associated attentional process.

Dependent variable	Attentional process
Stimulus fixations	Sustained attention
Reactive looks	Exogenous orienting
Total anticipations	Endogenous orienting
Easy correct anticipations	Endogenous orienting-based learning
Complex correct anticipations	Endogenous orienting + monitoring-based learning

5.2. Method.

5.2.1. Participants.

Toddlers and young children (*n* = 150) between 24 and 48 months of age were recruited from kindergartens and primary schools in the city of Granada (Spain) and its metropolitan area. Some children were excluded due to preterm birth (e.g.e.g. before the 37th gestational week; *n* = 1), suspected developmental disorder (*n* = 6) or data fuzziness (*n* = 8). The final sample of 135 (*n* = 69 female) children was divided into five age groups of 24, 30, 36, 42 and 48-month-olds. All participants except for the 48-month-old group were called for a follow-up session that took place 6 months after the first session. Despite families' willingness to return to the second session, some children could not be evaluated due to a national lockdown during the COVID-19 pandemic (*n* = 14; see Table 5.2 for sample descriptive statistics).

Table 5.2.

Sample descriptive statistics for the first and follow-up session of each age group.

	First session			Follow-up session		
Age group	*n*	Sex	*Mean age*	*n*	Sex	*Mean age*
24 months	24	10 males; 14 females	24	18	8 males; 10 females	24
30 months	23	12 males; 11 females	30	21	10 males; 11 females	30
36 months	32	15 males; 17 females	36	22	11 males; 11 females	36
42 months	32	13 males; 19 females	42	29	13 males; 16 females	48
48 months	24	16 males; 8 females	48	N/A	N/A	N/A

Note. N/A = Not applicable

5.2.2. Eye tracker.

We used the SensoMotorics Instruments (SMI) RED250 Mobile (Sensomotoric Instruments GmbH, 2011) corneal-reflection eye tracker in the current study. Gaze was recorded with iView X Hi-Speed software with a sampling rate of 250Hz and 0.03º of spatial resolution. A LED LG Flatron E2210PM 22-inch monitor (50-60 Hz) with a native resolution of 1680 x 1050 pixel (480 x 300 mm) was used for stimuli display controlled through SMI's Experiment Center software. Before stimuli presentation, the eye-tracker was calibrated following a five-calibration-point child-friendly procedure in which animated colourful shapes (75 x 75 px) accompanied with melodic sounds were presented in the four corners and centre of the screen. The calibration procedure was repeated in case the child moved or disengaged from the screen, until a successful calibration was achieved. SMI built-in software BeGaze was employed for event detection (saccades and fixations). Peak velocity threshold was set at 40º/s and minimum fixation duration at 50 ms (Conejero & Rueda, 2018). Fixation data was further aggregated with Python 3 custom written code. Scripts generated for data reduction are available from the author.

5.2.3. Visual Sequence Learning (VSL) task.

The VSL task consists of the presentation of looming stimuli in a fixed sequence in three locations on the screen: upper right corner (position 1, 13.21º x 4.84º eccentricity to the nearest edge of the full stimulus), upper left corner (position 2, 13.21º x 4.84º eccentricity) and central bottom (position 3, 0º x 4.84º eccentricity) in a specific sequence (1-2-1-3) following Clohessy et al. (2001) (see Figure 5.1A). Stimuli were presented during 1800 ms and consisted of a dynamic presentation of a picture varying in size (small-medium-small-medium-large stimulus size), to create a looming effect, similarly to Clohessy et al., (2001). The small (4.74º x 4.74º px) and medium (6.65º x 6.65º px) stimuli sizes were presented during 150 ms each to induce the looming effect, while the large size (9.47º x 9.47) remained for 1200 ms. The stimulus presentation was followed by a blank screen during 1000 ms that served as the anticipatory period between stimuli. Children were shown a total of 64 trials. The first 12 trials (3 sequences) were used for learning and were not included in the analysis. Thus, a total of 52 experimental trials (13 sequences) were computed for statistical analysis.

Three 20.25º x 14.11º areas of interest (AOI) were defined around each stimulus position in order to compute stimuli fixations, reactive looks and anticipations. The total number of fixations on the stimuli along the duration of the task were coded as stimuli fixations, which provide a measure of active engagement of the participant in the task. In order to identify reactive and anticipatory looks, we defined reactive and anticipatory periods (see Figure 5.1B). The reactive period started 200 ms after the stimulus onset and ended 200 ms after its disappearance, followed by the anticipatory period which was up to 200 ms after the onset of the following stimulus. Reactive looks are defined as a fixation on the stimulus that occurred during the reactive period, on condition that during the previous anticipatory period the child did not perform a correct anticipatory fixation (in such case the observed fixation on the stimulus would be anticipatory instead of reactive). However, if during the anticipatory period the child does not perform an anticipatory fixation (remains on the same position in which the stimulus had been presented) or performs an incorrect anticipatory fixation, a reactive fixation can occur during the presentation of the upcoming stimulus. Consequently, during the same trial, both an incorrect anticipation and a reactive look could be coded. On the other hand, fixations that occurred during the anticipatory period and were preceded by a stimulus fixation in the previous trial (either reactive or anticipatory) were considered anticipatory looks. As in previous research, anticipatory fixations that were performed in the first 200 ms of the blank screen between stimuli were not considered as such, as they might not reflect real expectations, whereas fixations occurring during the first 200 ms of the stimulus presentation were not considered reactive because the saccade must have been prepared before the stimulus presentation (Canfield and Haith, 1991). Additionally, using the 1-2-1-3 sequence we were able to measure two types of anticipations depending on whether the next stimulus position could be unambiguously predicted from the current position (i.e. position 2 and 3 are always followed by position 1), or the next position is ambiguous and requires monitoring the previous location (i.e. position 1 can be followed by position 2 or 3 depending on the previous position, see Figure 5.1A). We named these two anticipatory conditions as easy and complex, respectively, which presentation is alternated within the sequence. Participants were not given any instructions or feedback concerning their performance in the task.

We computed the percentage of stimulus fixation over the total number of experimental trials. The proportion of reactive looks and total anticipations were also calculated over the child's total number of stimulus fixations. Correct and incorrect anticipations reflect an intention to perform anticipatory looks to a location in which something is expected to occur, even if the expectation is not accurate, entailing a voluntary attention shift. In addition, we computed the proportion of correct anticipations based on total anticipations performed, for easy and complex transitions (Rothbart et al., 2003). Children with a percentage of trials with stimuli fixations below 50% (Rothbart et al., 2003) were excluded from further analysis in the first (24-month-olds, *n* = 1; 30-month-olds, *n* = 4, 36-month-olds, *n* = 4, 48-month-olds, n = 1) and the follow-up session (30-month-olds, *n* = 2; 36-month-olds, *n* = 2, 48-month-olds, *n* = 2).

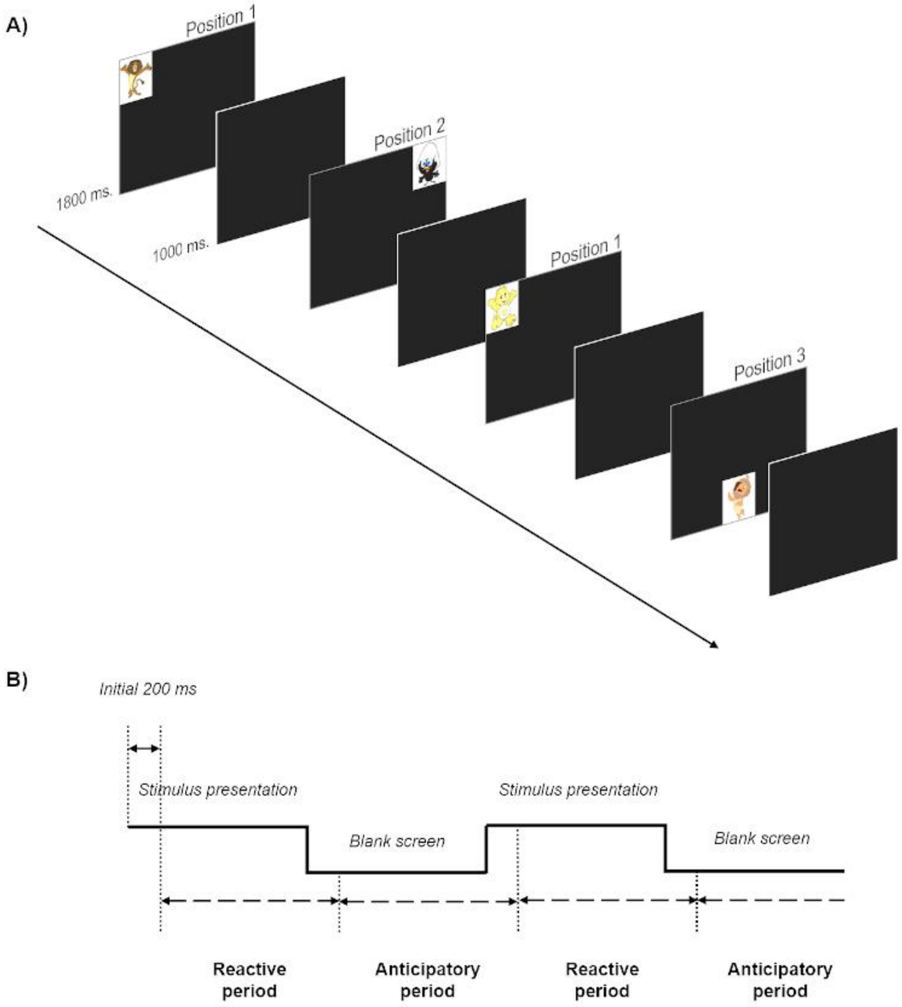

Figure 5.1. Task procedure of a complete sequence (1-2-1-3) following Clohessy et al. (2001). (A) Stimulus are presented in the figure in large size, although a transition through different sizes was employed to create a looming effect. Stimulus presentation (1800 ms) and anticipatory period (1000 ms) durations were fixed in the sequence. Complex (from Position 1-to Position 2 and Position 1-to Position 3) and easy transitions (Position 2-to Position 1, Position 3-to

Position 1) can be found in the figure. (B) Visualization of the definition of reactive (stimulus presentation) and anticipatory periods (blank screen). Cartoons by GraphicMama-team from Pixabay.

5.2.4. Parent-reported questionnaires.

5.2.4.1. Child temperament.

Parents of 24 and 30-month-olds children were asked to complete the Spanish Very-Short version of the Early Childhood Behavior Questionnaire (ECBQ; Putnam et al., 2006), while the Children Behavior Questionnaire (CBQ; Rothbart et al., 2001) was filled out by parents of 36- to 48-month-old children. These scales measure 3 temperamental factors: Effortful Control (EC), Surgency (SUR) and Negative Affect (NA). Cronbach's alpha for EC, SUR and NA for the ECBQ scales were .64, .62, and .42, respectively. Cronbach's alpha of the NA increased to .64 after removing items (10 and 16) with low internal consistency. Cronbach's alpha of the CBQ were .70, .76, .73 respectively for EC, SUR and NA.

5.2.4.2. Confusion, Hubbub and Order Scale (CHAOS).

A Spanish adaptation of the CHAOS scale (Matheny et al., 1995) was developed for the purpose of the study. This 15 items scale ($\alpha = .79$) was used to obtain a measure of children' home chaos. Parents were asked to report their level of agreement with statements that described the organization, environment and family routines at home in a Likert scale ranging from 1 (Completely agree) to 6 (Completely disagree). A final score for home chaos was obtained adding the scores of all the items. Higher scores indicate increased levels of chaos at home.

5.2.4.3. Sociodemographic information.

A SES general index was computed averaging the z-scores derived from parents’ education level, professional occupation and family income-to-needs ratio. Educational level was scored from 1 to 7, following Conejero et al. (2016): 1 (no studies); 2 (elementary school); 3 (secondary school); 4 (high school); 5 (technical degree/university diploma); 6 (university bachelor degree) and 7 (postgraduate studies). Professional occupation was rated following the National Classification of Occupations (CNO-11) of the National Institute of Statistics of Spain (INE) from 0 to 9 as follows: 0 (unemployed); 1 (elemental occupation); 2 (facilities and equipment operators); 3 (manufacturers and construction workers); 4 (qualified professionals in the livestock, agricultural, fishing and forestry sector); 5 (qualified professionals of the restaurant, service and sales industry); 6 (accountant and office workers); 7 (support professionals and technicians); 8 (health, teaching and research professionals;) and 9 (manager). Finally, the income-to-needs ratio was computed dividing the total annual family income by the official poverty threshold provided by the INE considering the number of members in the family unit.

5.2.4.4. Procedure.

Upon arrival at the laboratory, caregivers were provided with a brief description of the study and asked to complete the informed consent form for participation. The experimental session lasted approximately 1 hour and included other lab tasks not reported in the current article. Tasks and questionnaires were administered in a fixed order. Eye tracking tasks were presented first, followed by behavioral tasks. In this sense, children completed first the VSL task while their gaze was recorded with an eye-tracking device. At the end of the session, parents were required to complete temperament, home chaos and SES questionnaires. Due to the close relation between home chaos and SES, the latter environmental factor was also collected to be considered as a control variable. Eye tracking was performed in a semi-dark room, with children seated on a chair at approximately 60 cm from the display monitor. The caregiver was seated nearby behind the child and was instructed to remain silent and to avoid interaction with the child during the administration of the task. The experimenter monitored task administration from an adjacent control room. In order to test changes in attentional abilities and the short-term stability of the measures, the same procedure was repeated in a follow-up session taking place 6 months later and by the same experimenter in the first session. The study obtained ethical approval from the University of Granada Ethics Committee (Ref: 515/CEIH/2018) following the guidelines of the Declaration of Helsinki. Parents received a brief report of the child's performance and a 10€ voucher for educational toys.

5.2.5. Analysis plan.

Dependent variables were checked for normality and homogeneity of variance. As distributions of stimulus fixations and reactive looks were negatively skewed, a power transformation was applied to improve data distribution. SES was not found to be correlated with neither chaos nor attentional outcomes of the VSL task, so it was not considered as a covariate in subsequent analyses (see Table 5.9). To investigate the contribution of age, temperament and environmental chaos on attentional performance at Time 1, a series of stepwise regression models were built for each dependent variable. Model building followed the next steps: age was introduced as a continuous variable in the first step of the model, followed by temperamental factors (e.g.e.g. effortful control, surgency and negative affectivity) in the second step, and chaos in the third and final step. Considering the change in attentional performance between the first and follow-up session, change scores were computed subtracting performance at Time 1 from Time 2. Similarly, stepwise regression models were built following the same steps previously described, with the only difference being that performance at Time 1 was introduced after age in the second step. Finally, temperamental factors and environmental chaos were introduced in the third and fourth step, respectively.

Associations between temperament and environmental factors with attentional measures were analyzed through two-tailed partial correlations controlling by age for the hypothesized effects. Spearman Rank-Order correlation was applied when any of the dependent variables did not follow the normal distribution.

5.3. Results.

5.3.1. Descriptive statistics.

Tables 5.3 and 5.4 presents descriptive statistics in each age group for questionnaire and VSL measures, respectively. Also, percentages of stimulus fixations, and proportions of reactive looks, total anticipations in function of age group and assessment time are displayed in Figure 5.2, while correct anticipations for easy and complex transitions are displayed in Figure 5.3.

Table 5.3.

Descriptive statistics for questionnaire measures at Time 1.

Age group	*n* (valid)	Effortful control		Surgency		Negative affect		CHAOS		SES index	
		Mean (SD)	**Min (Max)**	**Mean (SD)**	**Min (Max)**	**Mean (SD)**	**Min (Max)**	**Mean (SD)**	**Min (Max)**	**Mean (SD)**	**Min (Max)**
24 months	24	4.70 (.73)	3.70 (6.60)	5.67 (.63)	4.18 (6.91)	3.54 (.91)	2 (5.70)	43.79 (11.20)	23 (74)	-.10 (.94)	-1.35 (1.51)
30 months	23	4.82 (.59)	3.70 (6.10)	5.76 (.68)	4.58 (6.82)	3.53 (.74)	2 (5.40)	37.39 (10.37)	22 (64)	-.27 (.83)	-1.46 (1.14)
36 months	32	5.01 (.63)	3.60 (6.42)	4.57 (.82)	3 (6)	4.21 (.87)	2.08 (5.83)	39.93 (9.60)	15 (59)	.09 (.92)	-1.51 (1.86)
42 months	32	5.49 (.70)	4 (6.58)	4.60 (.84)	3.08 (6.50)	4.45 (.93)	2.33 (6.08)	40.50 (9.56)	23 (55)	-.09 (.81)	-1.37 (1.73)
48 months	24	5.32 (.79)	3.58 (6.58)	4.54 (1.03)	2.42 (6.58)	3.91 (.80)	2.25 (5)	38.33 (9.44)	19 (56)	.42 (.72)	-.92 (1.90)
Total	135	5.09 (.75)	3.58 (6.60)	3.98 (.92)	2 (6.08)	4.97 (.98)	2.42 (6.91)	40.04 (10.07)	15 (74)	.009 (.87)	-1.51 (1.90)

Table 5.4.

Descriptive statistics for attentional scores at Time 1 and Time 2.

Age group	***Valid n***		**Stimulus fixations (%)**		**Reactive looks (%)**		**Total anticipations (%)**		**Correct anticipations (%)**			
									Easy		**Complex**	
			T1	**T2**	**T1**	**T2**	**T1**	**T2**	**T1**	**T2**	**T1**	**T2**
	T1	**T2**	**Mean (SD)**	**Mean (SD)**	**Mean (SD)**	**Mean (SD)**	**Mean (SD)**	**Mean (SD)**	**Mean (SD)**	**Mean (SD)**	**Mean (SD)**	**Mean (SD)**
24 months	23	16	79.68 (10.76)	84.85 (10.48)	69.18 (14.97)	67.39 (14.98)	39.43 (12.91)	42.47 (13.18)	50.68 (17.64)	45.22 (19.49)	29.62 (15.58)	34.57 (11.53)
30 months	23	17	84.50 (12.43)	88.57 (10.36)	63.63 (10.70)	59.72 (8.51)	47.98 (11.95)	53.17 (9.17)	48.25 (10.87)	44.94 (12.99)	30.61 (9.43)	33.32 (7.78)
36 months.	28	19	87.65 (10.32)	85.93 (12.31)	66.23 (13.58)	61.75 (13.01)	45.71 (13.87)	50.09 (13.48)	43.08 (13.09)	48.74 (15.85)	36.30 (8.70)	35.38 (11.62)
42 months	28	21	90.93 (8.90)	89.28 (9.57)	60.61 (13.39)	57.36 (10.99)	51.68 (14.50)	55.80 (13.03)	47.57 (14.49)	43.18 (10.71)	33.36 (8.42)	37.21 (6.44)
48 months	23	N/A	87.71 (11.86)	N/A	61.33 (15.26)	N/A	49.58 (13.16)	N/A	43.31 (12.33)	N/A	38.32 (6.20)	N/A
Total	125	73	86.12 (11.15)	87.27 (10.65)	64.65 (13.35)	61.25 (12.34)	46.58 (13.88)	50.78 (13.10)	47.24 (14.14)	45.48 (14.69)	32.66 (10.76)	35.25 (9.41)

Note. T1 = Time 1; T2 = Time 2; N/A = Not applicable. Stimulus fixations are computed over the number of experimental trials. Reactive looks and total anticipations are computed as a proportion of stimulus fixations. Correct easy and complex anticipations are calculated as a proportion of total anticipations

5.3.2. Regression analyses.

5.3.2.1. Stimulus fixations.

Regarding stimulus fixations at Time 1, the model for the first step including age was found to be statistically marginal ($R^2 = .03$, $F(1, 123) = 3.93$, $p = .05$), with age being a marginal predictor ($\beta = .18$, $p = .05$, 95% CI [.06, 82.26]). Adding temperamental factors in the second step ($\Delta R^2 = .03$, $\Delta F(3, 120) = 1.35$, $p = .26$) and chaos in the final step ($\Delta R^2 < .01$, $\Delta F(1, 119) = .36$, $p = .55$) did not significantly increase the variance explained by the model. The final model explained 6% of the total variance for stimulus fixations at Time 1 (Table 5.5). Considering the change in stimulus fixations between Time 1 and Time 2, the model in the first step with age as a predictor was found statistically marginal ($R^2 = .04$, $F(1, 71) = 3.19$, $p = .08$) with age being a statistically marginal predictor ($\beta = -.21$, $p = .08$, 95% CI [-149.05, 8.16]). Introducing performance at Time 1 returned a statistically significant change in the model ($\Delta R^2 = .37$, $\Delta F(1, 70) = 43.65$, $p < .01$). Only previous performance was found as a statistically significant predictor ($\beta = -.65$, $p < .01$, 95% CI [-1.03, -.55]). Neither model change for the third step adding temperamental factors ($\Delta R^2 = .04$, $\Delta F(3, 67) = 1.59$, $p = .20$) nor in the fourth step including chaos ($\Delta R^2 < .01$, $\Delta F(1, 66) = .85$, $p = .36$) were found statistically significant. The final model explained 46% of the total variance for the change in stimulus fixations (Table 5.6).

5.3.2.2. Reactive looks

For reactive looks at Time 1, the model for the first step including age was found statistically significant ($R^2 = .03$, $F(1, 123) = 4.52$, $p = .04$), with age being predictive of reactive looks ($\beta = -.19$, $p = .04$, 95% CI [-

75.60, -2.70]). None of the subsequent steps led to a significant change in the model (all *ps* > .55). A total 5% of the variance for reactive looks at Time 1 was explained by the full model (Table 5.5). For the change in reactive looks between sessions, the first step in the model including only age as predictor was not found to be statistically significant ($R^2 < .01$, $F(1, 71) = .09$, $p = .76$). However, including performance at Time 1 led to a statistically significant change in the variance explained by the model ($\Delta R^2 = .38$, $\Delta F(1, 70) = 42.86$, $p < .01$). Age was found to be a statistically marginal predictor ($\beta = -.16$, $p = .09$, 95% CI [-94.14, 6.67]) of change in reactive looks, while performance at Time 1 was found statistically significant ($\beta = -.63$, $p < .01$, 95% CI [-.83, -.44]). Model change for the third step including temperamental factors was not found to be statistically significant ($\Delta R^2 = .01$, $\Delta F(3, 67) = .52$, $p = .67$), while for the final step adding chaos was found statistically marginal ($\Delta R^2 = .03$, $\Delta F(1, 66) = 3.70$, $p = .06$). In this case, previous performance at Time 1 was found to be a statistically significant predictor ($\beta = -.63$, $p < .01$, 95% CI [-.83, -.44]), while age ($\beta = -.24$, $p = .06$, 95% CI [-127.77, 2.87]) and chaos ($\beta = .19$, $p = .06$, 95% CI [-1.26, 68.35]) were found to be statistically marginal predictors. This final model explained 43% of the variance for change in reactive looks (Table 5.6).

5.3.2.3. Total (correct and incorrect) anticipations

Concerning total anticipations, the model for the first step including age was found to be statistically significant ($R^2 = .03$, $F(1, 123) = 4.40$, $p = .04$), with age being predictive of total anticipations ($\beta = .19$, $p = .04$, 95% CI [.02, .60]). However, none of the following steps increased the variance explained by the model (all *ps* > .53). The full model explained 5% of the total variance for total anticipations (Table 5.5). The first step for the model predicting the change in total anticipations including only age was not found to be statistically significant ($R^2 < .01$, $F(1, 71) = .03$, $p = .87$). Introducing previous performance at Time 1 led to a statistically significant change in the model ($\Delta R^2 = .34$, $\Delta F(1, 70) = 36.78$, $p < .01$). In this step, age was found to be a marginal predictor of change in total anticipations ($\beta = .19$, $p = .06$, 95% CI [-.06, .82]), while previous performance at Time 1 was a significant predictive variable ($\beta = -.61$, $p < .01$, 95% CI [-.82, -.41]). Subsequent changes in the model were not found to be statistically significant (all *ps* > .27). The final model explained 39% of the total variance of change in total anticipations (Table 5.6).

Table 5.5.

Regression coefficients for stimulus fixations, reactive looks and total anticipations at Time 1.

	Stimulus fixations			Reactive			Total anticipations		
	Step 1	Step 2	Step 3	Step 1	Step 2	Step 3	Step 1	Step 2	Step 3
		β			*β*			*β*	
1. Child variable									
Age	*.18#*	**.26***	**.25***	**-.19***	**-.28***	**-.28***	**.18***	**.27***	**.26***
2. Temperament									
Effortful Control	-	**.04***	.02	-	.08	.08	-	-.06	-.07
Surgency	-	*.20#*	*.20#*	-	-.12	-.12	-	.10	.10
Negative Affectivity	-	.02	.03	-	< .01	< .01	-	-.06	-.05
3. Environment									
CHAOS	-	-	-.06	-	-	< .01	-	-	-.06
ΔR^2	.03	.03	< .01	.03	.02	< .01	.03	.02	< .01
ΔF	*3.93#*	1.65	.36	**4.52***	.70	< .01	**4.40***	.73	.37

*** $p < .001$; ** $p < .01$; * $p < .05$; #$p < .10$

Table 5.6.

Regression coefficients for change between Time 1 and Time 2 for stimulus fixations, reactive looks and total anticipations.

	Stimulus fixations				Reactive looks				Total anticipations			
	Step 1	Step 2	Step 3	Step 4	Step 1	Step 2	Step 3	Step 4	Step 1	Step 2	Step 3	Step 4
	β				β				β			
1. Child variable												
Age	*-.21#*	.03	-.07	-.08	-.04	*-.17#*	**-.26***	*-.24#*	.02	*.19#*	**.30***	**.29***
2. Previous performance												
T1 performance	-	**-.65*****	**-.65*****	**-.65*****	-	**-.63*****	**-.64*****	**-.63*****	-	**-.61*****	**-.61*****	**-.62*****
3. Temperament												
Effortful Control	-	-	**.22***	*.19#*	-	-	.04	.11	-	-	.03	< .01
Surgency	-	-	-.07	-.07	-	-	-.10	-.08	-	-	*.22#*	*.21#*
Negative Affectivity	-	-	-.06	-.03	-	-	.06	< .01	-	-	-.01	.02
4. Environment												
CHAOS	-	-	-	-.09	-	-	-	*.20#*	-	-	-	-.11
ΔR^2	.03	.39	.41	.41	< .01	.38	.01	.03	< .01	.34	.04	.01
ΔF	*3.19#*	**43.65*****	1.59	.85	.09	**42.86*****	.52	*3.70#*	.03	**36.78*****	1.34	1.07

*** $p < .001$; ** $p < .01$; * $p < .05$; #$p < .10$.

Note. T1 = Time

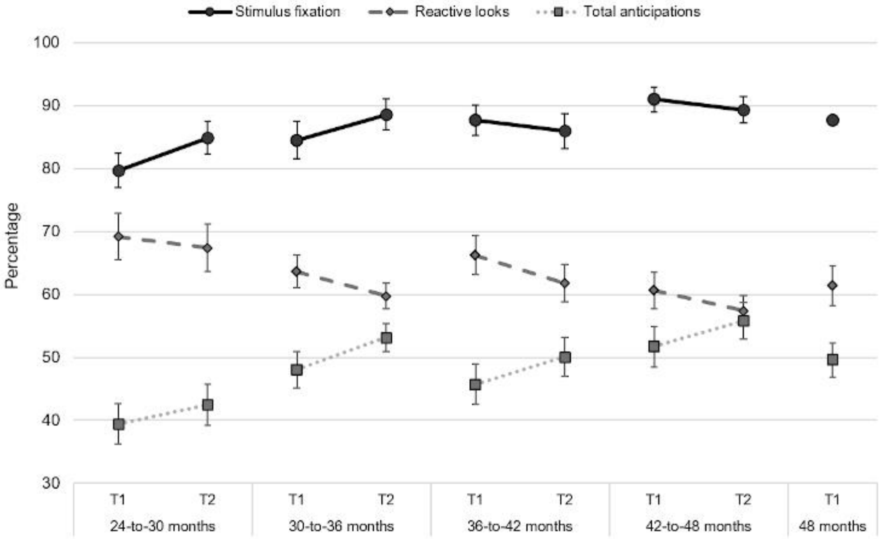

Figure 5.2. Stimulus fixations, reactive looks and correct anticipations for easy and complex trials. Scores are presented for each age group in the first (T1) and follow-up (T2) sessions. The 48-month-old group was only evaluated in the first session and not followed over time.

5.3.2.4. Correct anticipations

Models were built for both easy and complex anticipations. For easy correct anticipations, none of the steps were found to be statistically significant (all *ps* > .50), with the full model explaining only .08% of the total variance for easy correct anticipations. Concerning complex correct anticipations, the model in the first step with only age as a predictor was found to be statistically significant (R^2 = .05, F(1, 123) = 6.94, p = .01). Age was found to be predictive of complex correct anticipations (β = .23, p = .01, 95% CI [.07, .49]). Including temperamental factors in the second step did not lead to a significant change in the model (ΔR^2 = .02, ΔF(3, 120) = .96, p = .41), but adding chaos in the third step did (ΔR^2 = .03, ΔF(1, 119) = 4.63, p = .03). For this full model, both age (β = .27, p = .01, 95% CI [.07, .58]) and chaos (β = .20, p = .03, 95% CI [.02, .37]) were found to be statistically significant predictors of complex correct anticipations. The final model explained 11% of the total variance for complex correct anticipations (Table 5.7)

Likewise, models were built for the change in easy and complex correct anticipations. For easy correct anticipations, the model in the first step including age was not found to be statistically significant ($R^2 < .01$, $F(1, 71) = .23$, $p = .63$). Introducing previous performance at Time 1 in the model led to a statistically significant change ($\Delta R^2 = .47$, $\Delta F(1, 70) = 62.02$, $p < .01$). Only previous performance at Time 1 was found to be a statistically significant predictor ($\beta = -.68$, $p < .01$, 95% CI [-1.23, -.73]). Including temperament in the third step of the model led to a statistically marginal change ($\Delta R^2 = .05$, $\Delta F(3, 67) = 2.35$, $p = .08$), with previous performance in Time 1 being found to be a statistically significant predictor ($\beta = -.65$, $p < .01$, 95% CI [-1.18, -.68]), along with a statistically marginal predictive effect of effortful control ($\beta = -.19$, $p = .05$, 95% CI [-10.69, -.05]). Adding chaos in the final step of the model did not significantly increase the variance explained ($\Delta R^2 = .02$, $\Delta F(1, 66) = 2.36$, $p = .13$). Concerning the change in complex correct anticipations, the first step with age as a predictor was also not found statistically significant ($R^2 < .01$, $F(1, 71) = .27$, $p = .61$), but the change in the model for the second step including previous performance at Time 1 was ($\Delta R^2 = .57$, $\Delta F(1, 70) = 92.71$, $p < .01$). Only previous performance at Time 1 was found to be a significant predictor ($\beta = -.77$, $p < .01$, 95% CI [-1.23, -.81]). Subsequent steps did not change the model significantly (all *ps* > .38). Both full models for the change in easy and complex correct anticipations explained 54% of the total variance in each case (Table 5.8).

Table 5.7.

Regression coefficients for correct anticipations at Time 1.

	Correct easy anticipations			Correct complex anticipations		
	Step 1	Step 2	Step 3	Step 1	Step 2	Step 3
		β			β	
1. Child variable						
Age	-.05	-.05	-.06	**.23***	**.25***	**.27***
2. Temperament						
Effortful Control	-	< .01	-.03	-	-.14	-.09
Surgency	-	< .01	< .01	-	-.04	-.03
Negative Affectivity	-	.03	.05	-	.03	-.01
3. Environment						
CHAOS	-	-	-.07	-	-	**.20***
ΔR^2	< .01	< .01	< .01	.05	.02	.03
ΔF	.35	.04	< .01	**6.94***	.96	**4.63***

*** $p < .001$; ** $p < .01$; * $p < .05$; #$p < .10$.

Table 5.8.

Regression coefficients for change between Time 1 and Time 2 for correct anticipations.

	Correct easy anticipations				Correct complex anticipations			
	Step 1	Step 2	Step 3	Step 4	Step 1	Step 2	Step 3	Step 4
	β				β			
1. Child variable								
Age	.06	-.01	.01	< .01	-.06	.08	.07	.08
2. Previous performance								
T1 performance	-	**-.69*** **	**-.65*** **	**-.65*** **	-	**-.77*** **	**-.76*** **	**-.77*** **
3. Temperament								
Effortful Control	-	-	**-.20***	**-.24***	-	-	.05	.07
Surgency	-	-	-.13	-.14	-	-	.04	.05
Negative Affectivity	-	-	-.04	< .01	-	-	.04	.01
4. Environment								
CHAOS	-	-	-	-.14	-	-	-	.08
ΔR^2	< .01	.47	.05	.02	< .01	.57	< .01	< .01
ΔF	.23	**62.02*** **	2.35	2.36	.27	**92.71*** **	.24	.77

*** $p < .001$; ** $p < .01$; * $p < .05$; #$p < .10$.

Note. T1 = Time 1

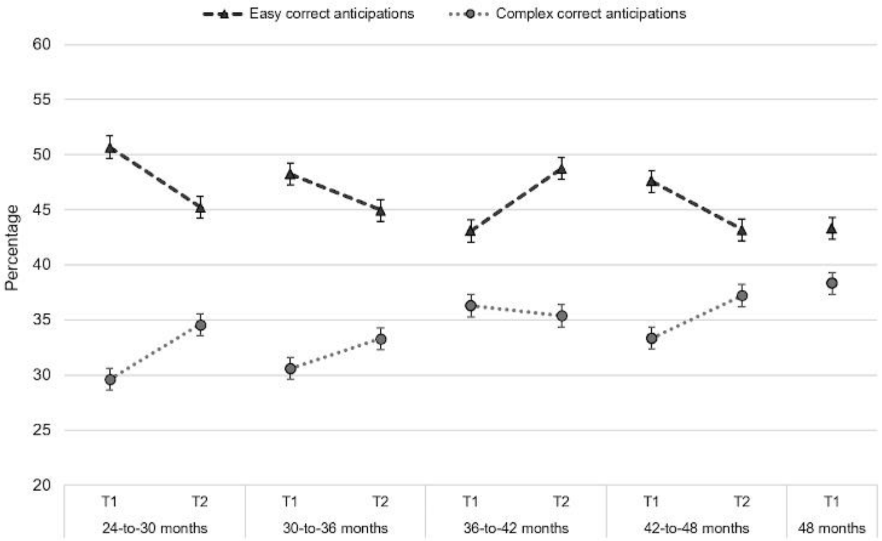

Figure 5.3. Proportion of easy and complex correct anticipations. Scores are displayed for each age group in the first (T1) and follow-up (T2) session. The 48-month-old group was only evaluated in the first session and not followed over time.

5.3.3. Correlation analyses.

Correlation analyses between temperament and attention revealed only a significant positive relation between stimulus fixations and temperamental surgency (r = .18, p = 04, 95% CI [.01, .35]). Concerning environmental variables, a statistically significant positive correlation was found between correct complex anticipations and chaos (r = .23, p < .01, 95% CI [.06, .39]). No other statistically significant correlations of attention with temperamental or environmental factors were found (see Table 5.9). Intercorrelations of task measures across sessions are reported in Table 5.10.

Table 5.9.

Two-tailed partial correlation coefficients, controlling by age, for attentional scores and child's temperament and environmental factors in the first session.

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
1. Stimulus fixation	-									
2. Reactive looks	**-.39*****	-								
3. Total anticipations	**.33*****	**-.84*****	-							
4. Easy correct anticipations	*-.14#*	**-.42*****	.07	-						
5. Complex correct anticipation	*.16#*	-.09	.04	**-.50*****	-					
6. Effortful control	.10	.07	-.05	-.01	-.14	-				
7. Surgency	**.18***	-.10	.10	-.01	-.06	.07	-			
8. Negative affect	-.05	.03	-.09	.03	.04	.03	**-.28*****	-		
9. Chaos	-.07	.01	-.06	-.05	**.23****	**-.28*****	*-.15#*	**.22****	-	
10. SES index	-.02	.01	.03	.08	-.13	.04	-.04	**-.27****	-.09	-

*** $p < .001$; ** $p < .01$; * $p < .05$; #$p < .10$

Table 5.10.

Two-tailed partial correlation coefficients, controlling by age, for VLS scores in the first and follow-up sessions.

	1. T2	**2. T2**	**3. T2**	**4. T2**	**5. T2**
1. T1: Stimulus fixation	*.22#*	-.17	.18	.18	-.05
2. T1: Reactive looks	-.04	**.36*****	**-.34****	**-.32****	.06
3. T1: Total anticipations	.10	**-.44*****	**.41*****	**.26***	-.04
4. T1: Easy correct anticipations	-.13	-.06	-.07	.02	.09
5. T1: Complex correct anticipation	-.09	-.12	*.20#*	.16	-.02

*** $p < .001$; ** $p < .01$; * $p < .05$; #$p < .10$.

Note. T1 = Time 1, T2 = Time 2.

5.4. Discussion.

The goal of the present research was to study age differences in increasingly complex forms of visual attention control, from exogenous to endogenous orienting and context monitoring. The VSL task provides measures that allow for the analysis of these changes. Anticipatory gaze is conceptualized as a measure of endogenous orienting of attention that is based on the development of an expectation of where something is expected to occur. When these expectations require context monitoring, endogenous orienting has been shown to rely on executive control mechanisms (Curran and Keele, 1993). Previous results with the VSL task contributed to state the hypothesis that a transition from basic forms of endogenous orienting towards context monitoring, involving executive attention, emerge during toddlerhood (Rothbart et al., 2003). However, to our knowledge studies on changes of these specific forms of visual attention control between toddlerhood and the preschool period had not yet been addressed. In the current study, age differences were examined with a cross-sequential design mixing within- and between-subjects effects. Different cohorts of children between 24 and 48 months of age were evaluated in two sessions placed six months apart.

5.4.1. Development of visual attention control.

The percentage of stimulus fixations can be considered indicative of children's sustained attention, as it reflects their active engagement in the task over time. Contrary to our hypothesis, we did not find significant age-related changes in sustained attention. Although an age-related tendency for stimulus fixations to increase with age in the first session was found, the effect was not statistically significant. Increases with age in this attentional ability has been previously reported in toddlers (Ruff et al., 1998) and preschoolers (Graziano et al., 2011). These studies suggest that during these developmental stages, children are in the process of increasing their ability to remain task-engaged for a sustained period of time. The development of this sustained attention shows further enhancements along childhood for tasks of progressively longer durations (Betts et al., 2006). We only observed marginally significant age-associated changes in stimulus fixations between sessions. This effect of age was lost once performance in the first session was introduced in the model, accounting for most of the variance. It should be noted that stimulus fixations are already high the first-time children are exposed to the task, with 24-month-olds displaying 80% and 48-month-olds 88%. Perhaps differences in stimulus variability and presentation rate could have facilitated children to remain engaged, in comparison to other experimental procedures. However, children higher tendency to remain engaged in the task already in the first session, left less margin for change in six months.

Exogenous orienting was examined through reactive looks towards displayed stimuli, as a form of bottom-up orienting of attention. A significant decrease in reactive looks with age was found in the first session. Exogenous attention provides a generic mechanism to acquire basic knowledge of a novel context, which is in place from the first months of life. As children gain experience with the sequence and become better at anticipating the upcoming location of the target, the percentage of reactive looks is reduced. In fact, there is a negative correlation between the percentage of reactive and anticipatory looks both within and across sessions (see Table 5.9 and 5.10). Indeed, this might explain the reduction with age for reactive looks observed in the first session of our study, as a greater ability to engage anticipatory attention (total anticipations) is found with age in the same session. Although no age differences in reactive looks were anticipated, given that this form of orientation develops very early on (Colombo, 2001), it is expected that an increased capacity to anticipate gaze would result in reduced number of reactive looks as children engage in a more proactive orienting of attention. Employing a similar version of the VSL, Sheese et al. (2008) reported a higher percentage of reactive looks (79% on average) for 6- to 7-month-old infants, in comparison to the youngest (69%) and oldest (61%) cohorts of our sample. This likely reflects infants' reduced capacity for endogenous control, engaging in a more exogenous orienting of attention. Considering the change between sessions, age was only found to marginally predict a reduction in reactive looks once accounting for children's initial performance. One possible explanation is that the temporal gap between sessions could be too short for attentional changes to emerge at these ages. This idea is also supported by the marginal effect of age in the change of total anticipations between sessions. As both measures are negatively correlated, it suggests a trade-off between exogenous (reactive looks) and endogenous orienting (total anticipations). As stated before, perhaps a six-month window could be too narrow for differences in endogenous control to emerge, undermining changes in exogenous attention.

Endogenous orienting was measured with anticipatory looks, both total and correct. Total anticipations provide information about children's voluntary effort to anticipate, independently of the accuracy of their formed expectations. In line with our hypothesis, an increase in total anticipations with age was found in the first session. The oldest children of the sample showed a greater percentage of anticipatory looks compared to the younger groups, which reflects their increased capacity for endogenous control of orienting. When exposed to the sequence of stimuli for the first time, children might adopt an exploratory strategy in order to learn the underlying contingencies of the sequence. Children's exploratory behaviour is thought to rely on endogenous orienting at the beginning of the task, in an effort to make sense of the environment they are exposed to (Clohessy et al., 2001). As more sequences are repeated, children's attentional orienting is gradually internalized, moving towards a more proactive approach, increasing attempts to anticipate upcoming events (Chatham et al., 2009). These voluntary attempts would allow them to gather more precise information in an effort to engage in an active monitoring of the sequence. Once contextual information is acquired, it is used to deploy attention to spatially relevant aspects of the current visual context (Chun and Jiang, 1998) to correctly anticipate.

Correct anticipations also provide a measure of endogenous orienting, tapping into the learning of the sequence. Therefore, it is a measure of the active engagement of the child in the monitoring of the context to maximize the accuracy of the formed expectations. The sequence used in this study includes two types of transitions, those that are easy to track (i.e. unambiguous transitions: from location 2 or 3 the next stimulus always appears in location 1), and those that are more complex to track because they require monitoring the previous locations (i.e. ambiguous transitions: from location 1 the next stimulus location depends on what the previous one was). No age-related increases in correct anticipations were found for easy transitions. Therefore, children in the studied age range are equally able to predict the occurrence of a forthcoming event when learning relies on unambiguous contextual information. This result is not surprising, as infants and toddlers have been previously found to perform a similar number of anticipations in easy transitions as adults (Clohessy et al, 2001). At older ages, no differences have been found between 24 and 36-month-olds for these transitions or even between two blocks of the task (Rothbart et al., 2003). This indicates that toddlers are already able to learn this type of transitions early in the task, and that this ability remains relatively stable until, at least, the third year. The current results contribute to extend the stability for anticipations in context free settings up to 48 months of age. Additionally, age was not found to predict the change for easy correct anticipations between sessions. This emphasizes that those children with an initial high performance during the first session would increase less in the follow-up. These are straightforward findings, as children from the different studied cohorts were found to be equally able to anticipate and learn from easy transitions already during the first exposure to the task. Consequently, the change in the follow-up session could be expected not to change significantly in a six-month window.

As hypothesized, we observed a significant increase in complex correct anticipations with age. Similar results were previously observed by Rothbart et al. (2003) between cohorts of 24 and 36 months of age, observing an increase in complex correct anticipations. The current results replicate this finding, but also extend the period of development of context-dependent learning up to 48 months. We found a progressive increase with age in correct anticipations for complex transitions (from 30% at 24 months of age to 38% at 48 months of age in T1; see Table 5.4 and Figure 5.2). This suggests that 24-month-olds are less able to engage executive control mechanisms to monitor the context and control the orientation of attention accordingly, with this ability significantly progressing in the following years. Previous studies have also shown an important development of executive attention skills between 24 and 48 months of age, although most of them examine the development of action-regulation mechanisms, such as inhibitory control and cognitive flexibility (Gerardi-Caulton, 2000; Jones et al., 2003; Blakey et al., 2016). On the other hand, age was not found to predict the change in complex correct anticipations but only performance during the first session. To our knowledge, no prior study has examined the differences in context-dependent visual sequences in relation to control over orienting of attention between toddlerhood and preschool ages. This ability is strongly dependent on the development of fronto-parietal regions involved in top-down control of attention (Corbetta et al., 2008), which show a protracted developmental trajectory extending beyond childhood (Power et al., 2010). The proper adjustment of attention orientation to anticipate in complex transitions requires an important dose of sustained top-down attention as well as working memory in order to hold previous locations in mind in order to be able to predict the upcoming one. Using a different sequential task than the one used in this study, prior research has found that it is not until the end of the preschool period when children display a better capacity to monitor sequences of actions (Freier et al., 2017). The current findings also support this view, although applied to the monitoring of visual sequences, highlighting an improvement in the engagement of executive attention control from 24-to 48 months of age.

5.4.2. Individual differences in visual attention.

A secondary goal of the study was to examine the individual stability of visual attention and its association with child temperament and home environment, as potential factors with an impact on early attention. Concerning the stability of the measures, our results revealed positive correlations for reactive looks and total anticipations taken six months apart. As the ability to voluntarily control attention and recruit executive control mechanisms is suggested to be under development at these ages, processes more stablished as exogenous and more basic forms of endogenous control of orienting could show a higher stability. Regarding intercorrelations in the first session between attentional measures, we found a higher exogenous orienting (i.e. reactive looks) to be negatively associated with endogenous control of visual attention (i.e. less stimulus fixations, total anticipations and easy correct anticipations). Children with a more reactive approach seem more likely to disengage from the task and less prone to engage in a proactive anticipation of stimuli. This pattern is also observed between sessions, as reactive fixations in the first session were negatively correlated with total and easy correct anticipations in the follow-up. In this sense, a higher reliance on exogenous orienting may harm the learning of the sequence not only concurrently, but also in a period of six months. On the other hand, a higher sustained attention (i.e. higher percentage of stimulus fixations along the task) was positively correlated with a higher endogenous control (i.e. total anticipations), showing only a tendency to also be positively associated with the engagement of monitoring processes (i.e. complex correct anticipations). In general, these results highlight a trade-off between exogenous and endogenous attention, allowing for a clear dissociation between these processes. Furthermore, some indices of endogenous orienting were intercorrelated, suggesting that endogenous and executive control of attention, both necessary for context monitoring, support each other as mechanisms underlying the development of voluntary control.

Results show temperament to not contribute significantly to increase the variance already explained by age on measures of visual attention. Surprisingly, individual differences seem to have a limited role in capturing variability of children’s attentional abilities in this paradigm in the age range of study. Moreover, the hypothesized association between attention control and effortful control was not found. This suggests that the VSL task could be more permeable to the effects of contextual information in attention control rather than individual differences in self-regulatory abilities. Nevertheless, our data also yielded two general associations. On one hand, we found a positive correlation between surgency and sustained attention. Dimensions of surgency, such as extraversion and positive approach are known to be related to a higher proneness to respond to external stimulation. This could derive in an attentive style that may predispose children to engage in a more exploratory behaviour and active engagement with the task. Infants with high surgency scores have also been found to exhibit greater cognitive control, displaying shorter fixation durations which may be linked to a faster information encoding (Papageorgiou et al., 2014, 2015). At older ages, this temperamental trait has also been positively associated with sustained attention in preschoolers, presumably due to a positive task involvement (Rothbart and Posner, 2006).

Contrary to our hypothesis, we found home chaos to positively contribute to predict correct anticipations for complex transitions after accounting for age and temperament. This is an interesting result, as it may imply that children exposed to less predictable environments at home would show certain advantages when learning contingencies from the environment. Children exposed to more unorganized and unpredictable households could had increased their vigilance towards external events, engaging in a greater effort to try to create expectations on a daily basis. When exposed to more predictable conditions, this could constitute an advantage. In this regard, the temporal and predictable structure of the sequences in the task could ease the engagement of top-down control in these children, allowing them to orient attention towards information-rich aspects (Wass, 2022). Hence, they could outperform children with a lower exposure to unpredictable environments when required to learn context-dependent information. Nevertheless, this is an open interpretation that needs replication in future research. The lack of correlation between chaos and SES supports the idea that chaos can be distributed across different SES backgrounds, accounting as a more proximal factor to cognitive changes during early development (Valiente et al., 2007; Marsh et al., 2020). In this sense, previous research with preschoolers and school-age children have found chaos to predict independent effects on cognition than those of SES (Petrill et al., 2004; Hart et al., 2007). The current findings contribute to support this notion, as well to the understanding of the differential impact of home chaos over attentional abilities during early development.

Finally, we found a consistent relation between children's temperament and chaos at home. We observed an increased negative affectivity and lower effortful control to be associated with children raised in families scoring high in home chaos. This is congruent with previous data showing a negative association between SES and toddlers' negative affectivity (Conejero and Rueda, 2018). The negative associations of chaos with effortful control but positive with complex correct anticipation was surprising. This could imply that chaos could have a negative impact on the child's self-regulatory abilities and general attention control measured through effortful control. However, it could offer certain advantages when children are required to control attention more efficiently to learn from the context. Future studies should test this interpretation, also exploring how children raised at different levels of chaos at home are able to dismiss random noise within the sequence, especially for context-dependent transitions. Perhaps children exposed to higher levels of chaos will be less affected by this noise, as it could resemble the reduced number of contingent events that characterize disorganized households. Similarly, it would be important to consider children's awareness of the sequence and its association with correct anticipations in easy and complex transitions. As the latter would rely to a greater extent on an explicit knowledge of the sequence, it would be more dependent on executive attention resources.

The current study is not free of limitations. Although over 150 children took part in the study, five age groups were considered, turning out to be a limited sample size of approximately 20 children per cohort. Increasing the statistical power may help to clarify some tendencies in attentional measures found in the data. Concerning the anticipatory period, the chosen interval was fixed at 1000 ms, while previous studies have used times around 750 ms (Clohessy et al., 2001; Rothbart et al., 2003). This increased anticipatory period could have facilitated the processing of information and planning of anticipatory eye movements. It would be desirable for future studies to compare different anticipatory periods. This would help to disentangle if the time needed to plan and execute anticipatory looks could affect age differences, especially when considering different cohorts.

The key strength of the current study lies in the combination of mixed within- and between-subjects effects in a cross-sequential design, as well as the consideration of a wide range of ages. This approach facilitates to compare several age groups and to follow each cohort over time to test attentional changes and consider the stability of the attentional measures. Furthermore, employing eye-tracking technology was a technical improvement to the study of visual attention control with the VSL, compared to offline recordings employed in previous studies. This contributes to gain in temporal and spatial precision in the measures of visual attention derived from the task. Finally, although we found a contribution of temperament and home chaos to visual attention control, the variance explained by these factors remain relatively low. Other key factors could likely add to explain additional variance at these ages. Individual variations in dopamine genes, such as the dopamine transporter type 1 (DAT1), have been reported to be associated with the development of attention control during childhood. Specifically, those children with the long allele of the DAT1 show greater attention control (Rueda et al., 2005). Additionally, considering other elements of children’s environment, especially those found to be closely related to cognitive functioning in the first years, such as children’s nutrition, quality of sleep or physiological stress (Roosa et al., 2005), could add to increase the understanding of the effects of the early environment on visual attention control.

Chapter 6: General discussion.

6.1. Development of attention control

In the current doctoral dissertation, we have studied the development of early attentional control from a longitudinal perspective. We have analyzed age-related changes in attention disengagement, anticipatory attention, and context monitoring, as well as attentional flexibility from middle infancy (i.e. 6 months) to toddlerhood (16-18 months). Additionally, for anticipatory attention we have considered its development further than toddlerhood through an accelerated longitudinal study covering early childhood (i.e. 24 to 48 months of age). Finally, we have also considered the stability of attentional measures in their corresponding age range of study.

6.1.1. Attention disengagement.

To study attention disengagement, we collected infants' and toddlers' latencies and failure to disengage. These two dependent variables were collected under two experimental conditions, overlap and gap conditions. In the former, disengagement takes place under visual competition, as infants should disengage from the central stimulus to reorient attention. In the latter condition, disengagement is eased as the central stimulus is removed from infants' sight before the presentation of the peripheral target. Furthermore, the removal of the central stimulus is known to act as an alerting cue to prepare a saccadic response (Csibra et al., 1997; Kingstone & Klein, 1993).

Results revealed longitudinal changes in general latencies to disengage between middle infancy and toddlerhood. To our knowledge, only Nakagawa & Sukigara (2019) studied age-related changes between 6 and 36 months of age. However, in their study, 6-month-old infants were faster to disengage compared to 12-month-olds, while no differences were found with 24-month-olds. In contrast, our results show a decrease in the first year of life that continues up to 16-18 months. Regarding disengagement failure, infants also show age-related changes from middle infancy to toddlerhood. Results highlight a developmental trajectory that follows the trail of changes in disengagement latencies. As disengagement failure constitutes a novel form to measure another aspect of disengagement, it should be interpreted cautiously, with further research needed to replicate the current findings.

Despite our hypothesized effects, we did not find any age-related differences in latencies or failure to disengage in the overlap condition. Hence, there seems to be a steady change in disengagement ability under visual competition between middle infancy and toddlerhood. Perhaps, 6-month-old infants could experience difficulties to disengage under visual competition due to the low stability of inhibitory control (Holmboe et al., 2018), which could help attention to be reoriented faster. Towards the end of the first year of life, inhibitory control seems to stabilize (Holmboe et al., 2018), which could lead to a period of slow changes in disengagement ability towards toddlerhood. In this line, we would expect higher changes in the overlap condition from the end of the second year of life onward. Moreover, it is around toddlerhood when the EA network emerges as the main supervisory system of attention control (Posner et al., 2014), which could boost more complex attentional abilities. However, we should also consider alternative interpretations of the deployment of attention control in the overlap. For instance, Nakagawa & Sukigawa (2013) found toddlers with higher effortful control to be slower to disengage in the overlap at 18 and 24 months of age. Their results state the possibility that during overlap trials, attention contributes to the inhibition of the peripheral target, with children making a voluntary effort to remain in the central stimulus. Our results could be also interpreted within this perspective, suggesting that infants and toddlers already display an efficient ability to avoid attention being captured by potential distractors. Concerning the gap condition, we found longitudinal decreases in latencies and failure to disengage, with age-related increases in infants' ability to benefit from non-directive attentional cues to shift attention progressively faster. Similar improvements have been reported between 3 and 6 months of age (Hood & Atkinson, 1993; Johnson & Tucker, 1996). Our results support a protracted development course of the ability to benefit from non-directive attentional cues, matching with a developmental trajectory that starts in the first half of the first year of life.

Finally, analyses indicate individual stability of disengagement latencies between middle infancy and toddlerhood, but not for disengagement failure. We believe that differences in stability between both measures are due to disparities in the information that each one encodes. Disengagement latencies could be considered a more finely-grained measure compared to disengagement failure. If a measure is coarser, it could be more exposed to changes in different implicit aspects coded by the same (e.g. saccade speed, fixation termination, saccade planning, etc.). If some of these dimensions change at a different rate or direction, it would impact their stability over time. Consequently, more finely-grained measures could target more specific sources of individual variability (Shinya et al., 2022). In this respect, disengagement latencies are focused on the speed with which disengagement occurs, capturing more specific variability about disengagement, which could make it more individually stable. On the other hand, disengagement failure could engage several sources of variability as it is a rougher measure, which could impact the measure's stability.

Additionally, disengagement latencies in the gap were found to be more stable than those in the overlap condition. Attention orienting is supported by different brain areas, such as the superior colliculus, frontal eye fields, and the parietal cortex (Johnson, 1990), which are subject to significant developmental changes from 3 months of age (Johnson et al., 1991). The early maturational process of these brain areas would likely lead to disengagement in the gap condition that is subject to less abrupt individual changes from middle infancy onwards, reflected in higher individual stability over time. In the overlap condition, disengagement is mostly supported by the dorsal fronto-parietal network (dFPN; Corbetta & Shulman, 2022). The brain areas that participate in the dFPN network show a protracted developmental course in comparison to those involved in simple attentional orienting (e.g. gap condition; Casey et al., 2005), which would make disengagement to be more exposed to individual changes with age.

In general, our data fills a gap in the developmental trajectory of general disengagement ability that could converge with more protracted changes in early childhood (Nakagawa & Sukigara, 2013). Although we did not find age-related changes in the overlap condition, our results add an important contribution to visual attention. In this sense, future research should focus on exploring the liability of the two possible readings on the form that attention control supports performance in the overlap condition, as our data is limited in this respect. Additionally, we report age-related changes in infants' ability to orient attention, with no previous research finding differences in disengagement ability for the gap condition (i.e. Nakagawa & Sukigara, 2013; 2019).

6.1.2. Anticipatory attention and monitoring

We employed the Visual Sequence Learning (VSL) task to measure different components of early attention control. Following a bottom-up to a top-down order, we collected measures for: 1) Exogenous attention (i.e. reactive looks); 2) Sustained attention (i.e. stimulus fixations); and 3)

Endogenous anticipatory attention (i.e. total anticipations; correct anticipations; easy correct anticipations); 4) Context monitoring (i.e. complex correct anticipations). Longitudinal and cross-sectional data were obtained from 6-to 16-18 months, and between 24 and 48 months of age, respectively. In the following paragraphs, we will discuss the developmental trajectory for each attentional component considering the results from both studies.

No age differences were found for reactive looks between middle infancy and toddlerhood, but a decrease in early childhood with age (i.e. from 24 to 48 months of age). Early decreases in visual exogenous attention have been reported in the first three months after birth (Krieber-Tomantschger et al., 2022). We expected the same trend to continue from middle infancy to toddlerhood, as a developmental period characterized by increases in endogenous attention. However, we found an age-related decline in exogenous attention between toddlerhood and early childhood, which would be related to increases in endogenous control. Also, our results could be related to learning effects. As young children gain experience with the sequence, they start relying less on exogenous control while engaging endogenous attention to a greater extent to visually anticipate.

Analyses did not reveal age-related changes in stimulus fixations between middle infancy and toddlerhood, but a trend to increase with age during early childhood. Developmental research has documented increases in sustained attention in infancy and toddlerhood (Richards, 1986; Ruff et al., 1998). The tendency found for sustained attention to increase with age during early childhood is in line with previous research conducted on preschoolers (Graziano et al., 2011) and young children (Ruff & Capozzoli, 2003). Our results could imply that further changes could be expected in sustained attention during childhood, especially once a solid control of attention by the EA network is established.

Total anticipations provide a measure of infants' and toddlers' ability to perform anticipatory attempts, without considering the accuracy of their expectations. We found an increase with age in total anticipations between infancy and toddlerhood, as well as during early childhood. The current results indicate that once the sequence starts to be internalized, children would transition from an exploration of the sequence, towards a more proactive interaction with the same, engaging active attempts to anticipate stimuli. This is of great interest, as Rothbart et al. (2003) haven't found differences in total anticipations between 24 and 36 months of age. In general, our data highlights a developmental trajectory for anticipatory attempts that initiates in infancy and extends towards early childhood.

So far, our results suggest an important presence of exogenous and endogenous attention during infancy and toddlerhood. Developmental improvements in attention control are known to be related to the maturation of the dFPN (Corbetta & Shulman, 2002). The early engagement of the dFPN network supports a top-down selection of relevant information, easing visual orienting in anticipation of an event. However, it is possible that the level of development of the dFPN at young ages is not robust enough to produce an efficient deactivation of areas of the ventral fronto-parietal network (vFPN), responsible for exogenous orienting. Hence, an endogenous (i.e. total anticipations) but also an exogenous (i.e. reactive looks) form of attention control could be predominant in infancy. Our interpretation remains an open question for future research, which would help to understand how dorsal and ventral forms of attention control coexist at the brain level at early ages.

Increases in anticipatory attempts would facilitate children's learning of relevant contextual information (Chun & Jiang, 1998), contributing to deploy attention control to correctly anticipate. Despite infants increase in total anticipations, we did not find age-related changes in correct anticipations between infancy and toddlerhood. Previous research has found a weak and not clear increase in the percentage of correct anticipations in the first year of life (Canfield et al., 1997). During this developmental period, data from the A-not-B tasks suggests that in the first year of life, there is still a significant development of the ability to form stable mental representations (Clearfield et al., 2006), which is like to impact infants' abilities to maintain the visual locations of stimuli, hindering an efficient guide of endogenous orienting towards accurate locations.

Concerning easy correct anticipations, they offer a way to test children's ability to anticipate during unambiguous transitions, avoiding the requirement of monitoring skills. We found a decrease in easy correct anticipations from middle infancy to toddlerhood. This reduction could be caused by an inhibition of return effect. It could be likely that with age, infants start to focus on context-dependent transitions, as already at 9 months of age they correctly anticipate more to context-free trials. This increased interest in complex transitions could be captured by the observed increase in total anticipations, as although infants could try to anticipate, they could not be skilled enough to do it, leading to a similar number of complex correct anticipations at both, 9 and 16-18 months of age. However, as a result to fixating complex locations, note that this does not have to be necessarily anticipating, they could avoid to return to the previously visited location (i.e. if they visited location 1 and move to location 2 – complex transition - they could avoid visiting again position 1 coming from position 2 – easy transition). During early childhood, no age-related changes in easy correct anticipations were found. Our results are in line with previous literature (Rothbart et al., 2003), as the ability to anticipate during deterministic-like sequences seems to be acquired by early infancy, reaching a similar performance to adults early during development (Clohessy et al., 2001).

Complex correct anticipations incorporate higher cognitive demands on visual attention, as the ambiguity of the transitions requires the engagement of context monitoring. As stated before, we did not find differences in correct anticipations for complex transitions between infancy and toddlerhood. The ability to anticipate during complex trials is highly dependent on EA control, supported by a fronto-parietal network responsible for top-down control of attention (Corbetta et al., 2008), which also shows a protracted development (Casey et al., 2005). Consequently, once emerging mechanisms of EA control become functionally active, children could increase the number of correct anticipations during context-dependent sequences, and indeed this is what we found. Especifically, during early childhood we see an increase in correct anticipation for complex transitions between 24 and 48 months of age. Again, these results are coherent with Rothbart et al. (2003) study, replicating their finding of an increase in complex anticipations between 24 and 36 months of age.

Finally, we found individual stability for stimulus fixations between late infancy and toddlerhood, but only partial stability during early childhood. Our results are in line with previous results showing sustained attention to be stable during infancy and toddlerhood (Gaertner et al., 2018; Lawson & Ruff, 2004). Moreover, we found stability for reactive looks and total anticipations in early childhood, suggesting that the underlying attentional process to these measures starts to settle during early childhood. The lack of stability in additional measures of the VSL task in infancy and toddlerhood suggests an impact of high individual variability. The continuous increase in endogenous attention control and the development of the dFPN network could generate enough individual variability to reduce measures' stability. However, it should be also considered that the current metrics are based on fixations, making them less finely grained compared to others that show higher stability (e.g. median saccade latencies in the gap-overlap task), as discussed earlier.

The current results are a relevant contribution to scientific literature, as we have analyzed several measures of attention control in the VSL task which have not been previously considered (i.e. reactive looks or stimulus fixations). However, due to their novelty, it is advisable to interpret the current results cautiously, until further replication. To our knowledge, this is the first longitudinal study to compare measures of visual exogenous and endogenous attention from infancy to toddlerhood and early childhood. Results indicate a progressive increase in certain measures of endogenous control that extends toward early childhood. Nevertheless, future replication studies should use a unique and common version of the VSL task from infancy to childhood, easing the detection of age-related changes that could not be impacted by differences between visual sequences (Canfield et al., 1997).

6.1.3. Attention flexibility

Endogenous attention and attentional flexibility were targeted using the switching task (Kóvacs & Mehler, 2009). Correct anticipations and the trial at which infants reached three cumulative correct anticipations in the pre-switch block were collected as measures of endogenous attention control. Additionally, we measured visual perseverations in the post-switch block as a proxy for attention flexibility.

Results revealed age increases in correct anticipations between middle infancy to toddlerhood. Although, we did not find significant differences in the ability to achieve the criterion of three correct anticipations. However, in middle infancy, there is a trend to reach the criterion slightly later than in toddlerhood. The small tendency found could have led toddlers to learn the stimulus contingency earlier in the task, having more trials available to correctly anticipate compared to young infants. As there is no previous evidence of developmental differences in the switching task, we need to rely on analogous data. Employing the VSL task, Clohessy et al. (2001) did not find differences between 4 and 18-month-olds in correct anticipations for easy trials. It should be noted that although the endogenous attention mechanism in both tasks is the same, the experimental procedure is slightly different. That is, learning the contingency of a stimulus that does not change location between trials (i.e. after fixating the central attractor, a stimulus will be displayed at the right/left side during all trials of the pre-switch block) is easier compared to when the stimulus appears on a different location on each trial. In the latter case, infants would be also required to internalize the sequence to anticipate the location. This methodological difference could likely explain the disparity in results for correct anticipations. Moreover, our results suggest that correct anticipations in both tasks seem to be measuring different aspects of endogenous attention.

No age-related changes in correct anticipations between middle and late infancy, as well as between late infancy and toddlerhood were found. Infants acquire the ability to correctly anticipate from 2 months of age (Canfield & Haith, 1992). Moreover, Wass et al. (2011) did not find differences in correct anticipations in the switching task after applying a 15-day attentional training program to 11-month-olds. It seems that the ability to correctly anticipate visual events starts developing early, with slow changes at the end of the first year of life onwards (i.e. no detectable changes even after training attention). Also, the proposed slow progression in correct anticipations is supported by an equal ability to create accurate expectations at a similar rate between these ages (i.e. trial at which infants reach 3 cumulative correct anticipations). In this sense, it is likely that the change rate from 6 to 9 and 9 to 16-18 months is too small to detect significant differences, only emerging when comparing the two more distal ages of the current study, involving a comparison between the first and second year of life.

Regarding attention flexibility, we did not find differences in perseverations between middle and late infancy. Nevertheless, data shows a trend for perseverations to increase towards late infancy, with a further significant decrease towards toddlerhood. Our results resemble data from the A-not-B task. During the first years of life, researchers have found an improvement in infants' ability to form stable traces of visual representations (Clearfield et al., 2006; Clearfield & Niman, 2012). Consequently, they become more able to bring previously learned information to the present. However, as previous knowledge (i.e. A trials/pre-switch) is no longer adaptive for the current context (i.e. B trials/post-switch), its engagement leads to an increase in perseverations when infants do not count with the flexibility to update it and overcome previously learned responses. As attentional flexibility increases, infants experience a decrease in perseveration, especially from the end of the first year onwards (Clearfield & Niman, 2012; Diamond, 1985). In the switching task, the ability to reduce perseverative looking emerges at the end of the first year of life. At 12 months of age, Shinya et al. (2022) found infants to reduce their looking time towards the incorrect location in the post-switch throughout the block. Our results replicate previous findings in the A-not-B and switching tasks, but also establish that perseverations show a protracted developmental course. Moreover, the change in perseverations seems to slow down as children grow older, suggesting entering a plateau phase towards toddlerhood. Surprisingly, we did not find individual stability for any of the measures of the switching task. As mentioned earlier, we believe that metrics based on simple fixations make them too coarse that they confound multiple aspects of visual attention control. As a result, they could be more exposed to different sources of individual variability, reducing their individual stability.

In general, the current data support an increase in correct anticipations, but a decrease in perseverations in the transition between infancy and toddlerhood. Our results constitute an important contribution to the understanding of endogenous attention development, especially as early attentional control represents an important building block for the emergence of later EA abilities (Posner et al., 2014). To our knowledge, our study is the first one to analyze the longitudinal development of endogenous and attentional flexibility in the switching task. Moreover, we found the switching task to be a reliable adaptation of the A-not-B task logic, capturing similar developmental changes without relying on motor responses. Future studies should address if the decrease in perseverations intensifies during early childhood, which could indicate a protracted developmental course of attention flexibility that we are not able to detect with the current age range.

6.2. Impact of temperament and environmental factors

Apart from characterizing the typical development of attention control, we also aimed at studying the impact that individual differences in temperament, as well as the early home environment, have during attentional development. For this, we analyzed the predictive power of early temperament (i.e. effortful control - EC; surgency - SUR; negative affectivity - NA) and environmental factors (i.e. socioeconomic status – SES, CHAOS, and maternal depression) over later attentional abilities (i.e. attention disengagement, anticipatory attention, and attention flexibility).

For attention disengagement, we computed two indexes: 1) Disengagement cost index (DCI), measuring how much slower children disengage in the overlap than in the gap condition; and 2) Disengagement failure index (DFI), measuring how many failures to disengage children display in the overlap compared to the gap condition. Neither temperament nor environmental factors were found to predict the DCI at any age, however, some associations were found. Interestingly, EC and SUR were negatively associated with DCI in middle infancy, but positively with the DCI during toddlerhood. Our results replicate Nakagawa & Sukigara's (2013) findings. At young ages, EC seems to support an exploratory mode of attention, disengaging faster to fixate on the novel peripheral target. However, as infants grow older, EC starts to support a more executive-controlled mode of attention, assisting infants in their intention to remain to explore the attractive central stimulus, leading to a slower disengagement. The association with SUR is not surprising as during infancy and toddlerhood, SUR overlaps with certain dimensions of EC (Gartstein & Rothbart, 2003; Putnam et al., 2008).

In relation to the DFI, we found EC in late infancy together with CHAOS in middle infancy to predict toddlers' DFI. In line with our results for the DCI, EC predicts a higher toddlers' predisposition to remain in the central stimulus when the peripheral target is displayed, leading to a higher failure to disengage. Again, our results support Nakagawa & Sukigara's (2013) findings, highlighting that the main tendency of infants with a higher temperamental control is to remain on the central stimulus at older ages. Hence, the role of attention control seems to change from infancy to toddlerhood, leading to a lower tendency to disengage from an attractive stimulus during visual competition. Moreover, the change in EC, that is to support disengagement in infants but in relation to attention control during visual disengagement seems to emerge around the end of the first year of life, instead of during toddlerhood as found by Nakagawa & Sukigara (2013). However, being early exposed to a higher level of chaos at home leads to a lower failure to disengage during toddlerhood. Higher levels of disorganization at home generally imply a greater exposure to disorganization and unpredictability in the home environment, which negatively impacts children's executive functions (EF; Andrews et al., 2021) and self-regulatory abilities (Lecheile et al. (2020). Nevertheless, the study of the impact of CHAOS on attention control is relatively scarce. To our knowledge, only Tomalski et al. (2017) reported a detrimental effect of the exposure to higher levels of CHAOS on infants' attention. Our results are in line with previous literature. Children exposed to higher levels of household disorganization are more prone to disengage from their immediate environment (Evans et al., 2006), due to overstimulating conditions and a more reactive attentional style (Wass, 2022). Moreover, the lack of predictability of events at home could make them more susceptible to being oriented towards the environment, trying to find contingencies that help them to predict future events. Our results contribute to expand an unstudied area of research while replicating the negative effects of home disorganization on infants' and toddlers' attention control.

In general, our results contribute to increase the limited knowledge available concerning the early effect of temperament and home environment over attention disengagement. We also analyzed their effects on a novel measure of disengagement (i.e. DFI), which should be cautiously interpreted and subject to further replication. Moreover, the current data support the view of Nakagawa & Sukigara (2013), suggesting that a higher attention control during toddlerhood is reflected in a reduced tendency to explore the peripheral target during overlap trials in the gap-overlap task. Hence, we contribute to reshape how the effects of the gap-overlap task are generally interpreted, which seems to change across development. Finally, it is interesting that temperamental EC only emerges as a statistically significant predictor when accounting for environmental factors in our regression model, which suggests some interaction between both. Although we did not find any longitudinal mediation for DFI, it would be interesting in future studies to explore the possibility of a longitudinal moderation to account for the interaction between temperament and environment.

Regarding anticipatory attention, we found early temperament to have predictive power over later attentional abilities. Specifically, temperamental SUR in late infancy was found to predict less exogenous (i.e. reactive looks), but more endogenous attention (i.e. correct anticipations, total anticipations) and context monitoring (i.e. complex correct anticipations) during toddlerhood. Interestingly, no predictive effects of EC were found over anticipatory attention. During infancy, attentional control is mostly under the supervision of the orienting network (Posner et al., 2014), with SUR significantly contributing to early control of attention (McConnel & Bryson, 2005). Our findings support this notion, with SUR showing the highest prediction over early control of attention. Moreover, SUR and EC show a consistent positive correlation during infancy and toddlerhood (Putnam et al., 2008), which we also replicate. The early overlap between SUR and EC (Gartstein & Rothbart, 2001) could lead the former to account for part of the variance of the latter in relation to attention control. Concerning results during early childhood, although we did not find temperament to be predictive of anticipatory attention, we found a positive correlation between SUR and sustained attention (i.e. stimulus fixations). Hence, it seems possible that SUR accounts for most of the variance of endogenous control of attention through infancy and early childhood. The emergence of EC as the main temperamental factor related to attention control is likely to occur during childhood (Putnam et al., 2008). According to our results, it is likely that a segregational process between SUR and EC already starts in early childhood, as the positive correlation between both factors at 16-18 months is lost between 24 and 48 months of age. Moreover, Rothbart et al. (2003) have also reported a positive relation between young children's EC and complex correct anticipations.

Unexpectedly, infants' NA in late infancy positively contributed to predicting easy correct anticipation during toddlerhood. Additionally, we found a tendency for temperamental NA and SUR to be positively correlated in late infancy, a result that replicates previous findings (Gartstein et al., 2003; Putnam et al., 2001). Hence, we could infer a possible overlapping between factors of NA and SUR. Previous studies have reported inconsistent loads of NA and SUR factors. For instance, Perceptual Sensitivity and Shyness are found to load into SUR or NA depending on children's age (Putnam et al., 2008). Also, a positive correlation has been found between IBQ's subscales of Perceptual Sensitivity (SUR) and Fear (NA; Gartstein et al., 2003), which could highlight a common substrate of reactivity between both factors. As an alternative explanation, Putnam & Rothbart (2006) previously pointed out that inconsistencies in temperament scales could arise due to differences in socioeconomic status between children. Although the recruited sample in the present research is mainly of middle and high SES, we can not discard the effects of infants' social and economic background.

We also found environmental effects over endogenous and anticipatory attention. Early exposure to maternal depression was found to predict less sustained and anticipatory attention (i.e. correct anticipations), and more exogenous attention during toddlerhood. Our results are in line with the reported negative effects of infants' early exposure to maternal depressive symptomatology on EF development (Hackman et al., 2010). Effects of maternal depression on infants' cognitive development are mostly canalized through a decrease in the quality of mother-child interactions (Coyl et al., 2002). During the first years of life, parents significantly contribute to stimulate infants' attentional abilities (Harman et al., 1997). Mothers experiencing depressive symptoms could see a reduction in their proneness to stimulate infants as a consequence of the emotional disorder, leading to a decrease in infants' opportunities to engage in more voluntary forms of attention control through different levels of interactions (i.e. talk and looks to the infant, play and stimulate through toys, etc.).

Additionally, CHAOS also contributed to predict less anticipatory attention (i.e. correct anticipations and total anticipations). The current results are in line with our results highlighting a detrimental effect of early exposure to higher levels of disorganization at home over attentional disengagement. In this sense, a higher home disorganization would promote a more exploratory and even reactive control of attention, that is a lower failure to disengage and even a tendency to show more reactive looks in the VSL task. Although, it should be noted that the contribution of CHAOS over exogenous attention was marginally significant.

Early SES and CHAOS were found to be predictive of a lower context monitoring ability (i.e. complex correct anticipations). The former effect was contrary to our hypothesis, as SES has been previously related to a higher attentional control (Farah, 2017). The negative contribution of SES to complex correct anticipations could be related to its positive contribution to easy correct anticipations, although in the latter case model change was not found to be statistically significant. In this sense, early SES could boost infants' performance in easy trials, with infants being more engaged in learning context-free transitions, although with a detrimental effect in context-dependent ones. It could be interesting to explore if the contribution of SES to complex transitions changes with development, as it could be likely to find a positive contribution following the emergence of executive attention in early childhood.

The negative contribution of CHAOS to later context monitoring abilities is in line with the anticipated hypothesis. Exposure, during early infancy, to higher levels of disorganization at home could promote a more reactive and less self-controlled attentional style in infants and toddlers. This attentional style would hinder anticipations in more attentional demanding trials, such as context-dependent transitions. Nevertheless, we found CHAOS to predict a higher ability for context monitoring during early childhood in the VSL task. The change in the effects of CHAOS on children's monitoring ability could be related to how CHAOS interacts with attention at different ages. The higher level of unpredictability of the home environment seems to be detrimental during infancy and toddlerhood, a period when endogenous attention control starts emerging. In these early years, infants could need a more stable and predictable environment for attention to establish a solid foundation on which to grow. However, once children establish and gain greater control over attention, higher levels of lack of contingencies and unpredictability could boost attentional control. That is, they are forced to engage endogenous control to a higher degree, making voluntary efforts to find contingencies in the context that potentiates learning to be able to predict their immediate environment.

To sum up, most infant and child research is focused on the effects of maternal depression over EFs, with no previous studies explicitly addressing its impact on attention. Our results establish a significant negative contribution of the early exposure to maternal depressive symptomatology on toddlers' attention control. Additionally, we replicated previous results stating the negative impact of CHAOS on infants' attention (Tomalski et al., 2017). However, the role of home chaos seems to change with age, with a likely negative impact during infancy and toddlerhood, but positive towards early childhood.

Interestingly, we did not find significant effects of temperament or environment on correct anticipations and perseverations in the switching task. The former case is interesting, as we did find effects of both factors over correct anticipations in the VSL task. It should be considered that in the switching task, correct anticipations are based on infants' learning of contingent and deterministic events (i.e. after fixating the central attractor, a stimulus will be consistently displayed at its right/left side in all trials). However, in the VSL task, correct anticipations entail internalizing a sequence of events, which could be either deterministic (i.e. easy transitions) or require monitoring abilities (i.e. complex transitions). As stated before, correct anticipations could be measuring different components of endogenous attention based on the task employed. Although there is no significant change in the model, we can see that a higher EC in late infancy predicts more correct anticipations during toddlerhood. This is in line with the positive contribution of SUR in late infancy to toddlers' correct anticipations in the VSL task, as both temperamental factors are positively correlated in late infancy. Again, although the model change was not found statistically significant for perseverations, we found EC in late infancy to predict less visual perseveration during toddlerhood.

We found a significant effect of SES in the pre-switch block task criterion. Specifically, infants from high-SES families need a lower number of trials to reach three correct anticipations in the pre-switch block. In an infant longitudinal study, Clearfield & Jedd (2013) found infants from low-SES households to display higher levels of inattention at 6, 9, and 12 months of age, compared to infants from high-SES families. In our study, infants from low-SES households could display higher levels of inattention compared to infants early exposed to higher levels of SES, which would affect their speed on learning task contingencies. In conclusion, our results seem to highlight a boosting effect on learning (i.e. faster learning) of an early exposure to high-SES environments.

6.3. Conclusion

Attentional control is a core cognitive process of great importance for a person's functioning on a daily basis. The relevance of attention control increases during the first years of life, when mainly the functional foundations of attention are established, as the structural grounds are in place at birth. The current doctoral dissertation focused on studying the development of three main attentional abilities from a longitudinal (i.e. from 6 to 9 and 16-18 months of age) and cross-sectional (i.e. between 24 and 48 months of age) perspective: 1) Attention disengagement; 2) Anticipatory attention and context monitoring; and 3) Attention flexibility. Our research adds a valuable contribution to scientific literature, indicating the existence of longitudinal changes in children's performance in the three attentional skills between infancy and toddlerhood. In the case of attention disengagement, to the best of our knowledge, no previous study has reported longitudinal changes based on the disengagement scenario (i.e. visual competition vs. facilitated disengagement), between the first and second year of life. Moreover, our findings replicated the developmental pattern of perseverations found in other experimental paradigms (i.e. A-not-B task). From middle infancy towards the end of the first year of life, infants experience an increase in perseveration, to decrease during toddlerhood as they gain attention flexibility. In this sense, our results also support the switching task as a reliable eye-tracking procedure for the study of attentional flexibility. Longitudinal and cross-sections results for anticipatory attention indicate a protracted developmental course from infancy toward early childhood. Through these developmental periods, children increase their ability to perform anticipatory looks based on acquired expectancies.

Additionally, we analyzed the contribution of early temperament and environmental factors to attentional development. However, besides the contribution of temperament and the home environment to attentional development (i.e. attention disengagement and anticipatory attention), we did not find temperament to be a mediator in the longitudinal effects of the early effects of environmental factors over later attentional control. Future research should focus on targeting some open questions left in the current doctoral dissertation. For instance, do disengagement latencies and failure to disengage increase or remain stable during early childhood in competition contexts? Does the contribution of SES and CHAOS change from infancy to early childhood in complex transitions? Similarly, embracing more ecological measures of temperament (e.g. video recordings of infants' and toddlers' behaviour in naturalistic settings) and environmental factors (e.g. experimenter-rate home environment) could contribute to disentangle unexpected results, such as the positive contribution of CHAOS to later attentional development. Expanding developmental attentional research to cover other key aspects of early cognitive development (e.g. infants' nutrition, sleep, mother-infant interactions, etc.) usually understudied is of special relevance for the growth of the research field.

Chapter 7: Resumen en español.

El objetivo de la presente tesis doctoral ha sido estudiar el desarrollo del control endógeno y ejecutivo de la atención en etapas tempranas. En concreto, nos centramos en dos periodos de desarrollo: 1. Un periodo temprano, implicando edades desde los 6 hasta l6-18 meses; y 2. Un periodo pre-escolar, el cual abarca desde los 24 hasta los 48 meses de edad. Durante el periodo temprano, también exploramos en que medida diferences aspectos del control atencional se encuentran inter-relacionadas. Esto se realiza con el objetivo de explorar la posibilidad de derivar un único índice de atención ejecutiva desde los primeros meses de edad. Finalmente, en ambos periodos analizamos el impacto que las diferencias individuales a nivel de factores constitucionales y ambientales tienen sobre el desarrollo atencional. De esta forma, nos planteamos intentar resolver las siguientes preguntas de investigación:

En relación al desarrollo atencional en los dos primeros años de vida:

1. ¿Existen diferencias en el desarrollo de diversos aspectos del control endógeno de la atención en este periodo?
2. ¿Muestran estabilidad las habilidades atencionales tempranas durante los dos primeros años de vida?
3. ¿Se encuentran inter-relacionadas diferentes medidas de control atencional entre los 6 y 16-18 meses de edad? ¿Es posible combinar estas medias en un único índice de atención ejecutiva?
4. ¿Cómo contribuye el temperamento y el ambiente temprano en la predicción de las habilidades atencionales futuras?
5. ¿Es el temperamento en el primer año de vida capaz de mediar la relación entre el ambiente temprano y las habilidades atencionales durante el segundo año?

Con respecto al estudio del desarrollo atencional durante el periodo pre-escolar:

1. ¿Contribuye la edad a predecir el control endógeno y ejecutivo de la atención entre los 24 y 48 meses de edad?
2. ¿Cómo contribuye la edad a predecir el cambio en medidas atencionales entre dos sesiones de evaluación espaciadas por un periodo de 6 meses?
3. ¿Muestran estabilidad las medidas de control endógeno de la atención en un plazo de 6 meses?
4. ¿Contribuyen los factores temperamentales y ambientales a la predicción de las habilidades atencionales?

Investigación previa muestra que el control atencional experimenta cambios significativos durante los dos primeros años de vida (Hendry et al., 2019). De acuerdo al modelo atencional de Posner (Posner & Petersen, 1990), existen tres redes cerebrales responsables de las funciones atencionales: 1. La red de alerta, la cual ayuda a mantener un estado de activación del sistema atencional; 2. La red de orientación, permitiendo orientar la atención para filtrar la información del entorno, seleccionando solo aquella que es considerada relevante; y 3. La red ejecutiva, la cual permite imponer un control voluntario y más flexible sobre las habilidades atencionales. Durante los primeros años de vida, es la red de orientación la que supervisa y facilita a los bebés el poder ejercer un control voluntario sobre la atención (Posner et al., 2014). Al mismo tiempo, es el funcionamiento temprano de esta red la que contribuye al surgimiento de la red ejecutiva como principal mecanismo supervisor de control hacia el final del segundo año de vida (Posner et al., 2014). Esto se debe a que ambas redes comparten sustratos neurales (Rueda et al., 2015).

Las primeras manifestaciones de un control voluntario de la atención se observan sobre la alerta atencional en los primeros meses tras el nacimiento. Durante este periodo temprano, gran parte del control atencional sobre los bebés se realiza de forma exógena. Por ejemplo, es común que los padres/cuidadores empleen estímulos externos (p.e., mover un sonajero) para captar y dirigir la atención del bebé. En estos primeros meses, también se osberva un incremento en el control voluntario de la alerta, específicamente sobre la alerta tónica. Este mayor control les permite mantener un estado de alerta hacia el entorno sostenido en el tiempo. Estudios previos han observado como las horas que los bebés pasan despiertos, manteniendo voluntariamente un estado de alerta hacia su entorno, incrementa de forma progresiva en los primeros años de vida (Figueiredo et al., 2016), continuando durante la etapa pre-escolar (Paavonen et al., 2020).

Mejoras en la alerta atencional durante el desarrollo postnatal van seguidos de incrementos en otras habilidades atencionales, como la orientación atencional. La habilidad para ejercer control sobre orientación visual es una de las principales medidas para evaluar incrementos en el control endógeno de la atención en etapas muy tempranas de desarrollo, debido a las limitaciones motoras de los bebés. Durante los 2 primeros meses de vida, los bebés muestran dificultades para desenganchar y reorientar la atención de forma voluntaria (Johnson, 1990). En esta etapa, es la estimulación externa la que les permite desenganchar de un estímulo previamente fijado visualmente, y reorientarse hacia la nueva estimulación (Johnson et al., 1991). Este periodo se conoce como “*fijación obligatoria o pegajosa*” (Stechler & Latz, 1966). Alrededor del tercer mes de vida se comienzan a observar indicios tempranos de un control voluntario sobre el desenganche atencional. Empleando la tarea gap-overlap, Atkinson et al. (1992) compararon la ejecución entre bebés de 1 y 3 meses de vida. Para ello emplearon dos condiciones: 1. Condición gap, en la cual el desengache era facilitado; y 2. Condición overlap, en la cual el desengache se producía en un contexto de competencia visual. Los investigadores observaron que cuando el desenganche era facilitado, no se observaban diferencias en la ejecución entre estas edades. Sin embargo, bebés de 3 meses mostraban un mayor control para desenganchar en contextos de competencia visual, en comparación a los bebés más pequeños. A partir de los 3 meses en adelante, se han observado mejoras continuadas en el desenganche atencional bajo competencia estimular hasta, al menos, los 6 meses de edad (Colombo & Cheatham, 2006; Csibra et al., 1998). Sin embargo, estudios previos no han detectado diferencias entre los 6 y 36 meses de edad en estas dos condiciones (desenganche facilitado vs. competitivo; Nakagawa & Sukigara, 2013; 2019).

De forma paralela, otras habilidades atencionales relacionadas con el control endógeno de la atención visual muestran incrementos con la edad. Al igual que el desenganche atencional, la atención visual anticipatoria ha permitido observar cambios en el control endógeno desde edades muy tempranas. En base a la premisa de que los bebés son sensibles a patrones estadísticos (Aslin et al., 1998; Saffran et al., 1996) o secuencias visuales (Kirkham et al., 2002), el uso de anticipaciones constituye una medida apropiada para el estudio del control atencional en bebés. Esta capacidad cognitiva implica anticipar visualmente un evento del cual el individuo ha generado una cierta expectativa en base a eventos previos. Es decir, se realiza una orientación voluntaria de la atención hacia la posición espacial en la cual se espera que ocurra el evento antes de su inicio. Bebés de 2 meses de edad muestran ya capacidad para anticipar eventos visuales sencillos en base a expectativas adquiridas (Canfield & Haith, 1991). La atención anticipatoria visual muestra mejoras madurativas a lo largo de los 2 primeros años de edad. Asimismo, se ha observado que el porcentaje de anticipaciones correctas en bebés de 4 y 18 meses ante secuencias sencillas es similar al porcentaje de anticipaciones de adultos (Clohessy et al., 2001).

También se han observado incrementos con la edad en la capacidad de flexibilidad atencional. Esta habilidad permite adaptar conductas o patrones atencionales que se juzgan como no adaptativos en el contexto actual, a pesar de que si lo fueran en contextos previos (Stahl & Pry, 2005). De esta forma, la flexibilidad atencional permite disponer de un control más dinámico sobre la atención, permitiendo al individuo seleccionar cursos de acción en base a objetivos, que puedan considerarse más adaptativos ante contextos cambiantes (Conejero & Rueda, 2018). Estudios previos han empleando la tarea A-no-B (Diamond, 1990) para evaluar esta capacidad en bebés durante el primer año de vida. Durante un primer bloque de la tarea, el experimentador/a esconde un objeto en una posición inicial (A), animando al bebé a buscar el objeto durante varios ensayos. Tras varios ensayos recuperando el objeto de forma correcta, el experimentador/a cambia la localización en la que se esconde el objeto (B). Durante este segundo bloque de ensayos, se mide la capacidad de flexibilidad del bebé a través del número de perseveraciones que muestra buscando el objeto en la localización previa (A). Resultados de varios estudios han observado mejoras en la flexibilidad atencional entre los 5 y 12 meses de edad (Cuevas & Bell, 2010; Clearfiel et al., 2006). Sin embargo, las aún limitadas habilidades motoras durante este periodo de desarrollo, ha llevado a la formulación de tareas basadas en movimientos oculares que siguen la misma lógica que el paradigma A-no-B. Uno de estos casos es el desarrollo de la tarea switching por Kóvacs & Mehler (2009). En esta tarea de seguimiento ocular, a los bebés se les enseña a anticipar un evento en una localización espacial concreta durante un primer bloque de ensayos (bloque pre-cambio). Una vez se ha producido aprendizaje, es decir, anticipan correctamente el evento, se presenta un segundo bloque de ensayos (bloque post-cambio) en el cual se cambia la localización espacial de presentación. Cuanto mayor sea la flexibilidad atencional de los bebés, menor será el número de perseveraciones en la localización previa durante el segundo bloque, y antes empezaran a anticipar en la nueva localización. Estudios recientes han observado con esta tarea que bebés de 12 meses nacidos de forma muy prematura, muestran una menor flexibilidad atencional en comparación a bebés nacidos a término (Shinya et al., 2022). Otros estudios han empleado esta tarea para evaluar mejoras en flexibilidad atencional tras la aplicación de un programa de entrenamiento en bebés de 11 meses (Wass et al., 2011). Sin embargo, no existen investigaciones que haya empleado esta tarea para evaluar el desarrollo de la capacidad de flexibilidad atencional en bebés.

Como mencionamos anteriormente, durante los dos primeros años de vida el control endógeno de la atención está bajo supervisión de la red de orientación (Posner et al., 2014). Sin embargo, la red de atención ejecutiva también se encuentra activa durante este periodo (Ellis et al., 2021; Fiske et al., 2022). Su reclutamiento se observa ante tareas muy específicas de control inhibitorio (Fiske et al., 2022) o detección de errores (Berger et al., 2006; Conejero et al., 2016). Es a partir del final del segundo año de vida cuando la red ejecutiva comienza a emerger como principal mecanismo supervisor del control atencional, sustituyendo a la red de orientación (Posner et al., 2014). A pesar de que ésta última queda relegada de dicha función, sigue siendo reclutada para diversas funciones en las cuales ofrece una respuesta más adaptativa (Rothbart et al., 2011). Este cambio de actor supervisor lleva a al incremento de otras habilidades cognitivas más sofisticadas, como la monitorización. La capacidad de monitorización constituye la habilidad para seguir el curso de eventos (Petersen & Posner, 2012), estando asociado al control ejecutivo atencional (Posner & DiGirolamo, 1998; Botvinick et al., 2001) y a la flexibilidad con la que dicho control es aplicado (Chevalier & Blaye, 2016). Estudios previos muestran que bebés de 6 meses presentan cierta capacidad de monitorización de eventos, ignorando incluso información contextual cuando esta no es relevante para el objetivo actual (Haaf et al., 1996). Sin embargo, es a partir de la edad pre-escolar cuando estos mecanismos comienzan a ser más extensamente visibles. Por ejemplo, Rothbart et al. (2003) emplearon secuencias visuales complejas para medir esta capacidad. En este caso, para anticipar la localización espacial del siguiente evento de forma correcta, era necesario monitorizar la localización de eventos previos. Es decir, la siguiente localización dependía de cuales habían sido las localizaciones previas de presentación del evento. Ante esta configuración, observaron que las anticipaciones correctas ante este tipo de secuencias no aumentaban entre los 4 y 18 meses (Clohessy et al., 2001), pero si entre entre los 24 y 36 meses de edad (Rothbart et al., 2003). Además, Rothbart et al. (2003) observaron que un mayor porcentaje de anticipaciones correctas ante secuencias complejas, estaba asociado a un menor efecto de interferencia en una tarea de conflicto espacial. Estos resultados sugieren un incremento madurativo en el control ejecutivo en estas edades, dado que el control atencional bajo demandas de monitorización parece implicar recursos ejecutivos. Sin embargo, no se conoce se la evolución en la habilidad de monitorización más allá de los 36 meses con esta tarea.

El desarrollo cognitivo, y más concretamente el atencional, no se produce de forma aislada a otros factores intrínsecos o extrínsecos al individuo con capacidad para impactar sobre el mismo. De esta forma, inherente al propio campo del desarrollo cognitivo es el debate naturaleza-crianza (Johnson et al., 2015; Johnson et al., 2011). Por un lado, la perspectiva de naturaleza defiende que el desarrollo de la cognición se debe a la expresión de la información contenida en los genes de la persona. Por otro lado, la perspectiva de crianza defiende que no son solo los genes, sin no las experiencias únicas de cada individuo con su entorno lo que determina su desarrollo cognitivo. Décadas de investigación al respecto han demostrado que no es solo la base genética, o el ambiente de crianza lo que determina el desarrollo cognitivo, si no la interacción entre ambos (Finkel et al., 2021; Tucker-Drob & Briley, 2014).

De esta forma, podemos observar efectos de factores consitutionales al individuo, como el temperamento. Este constructo tomado de la psicología de la personalidad se define como las tendencias emocionales, las diferencias individuales en reactividad, y habilidades del individuo para auto-regularse a nivel conductual, emocional y atencional (Rothbart, 1981). Durante el desarrollo, el factor temperamental de control esforzado es el que más se ha asociado con un mayor control de la atención (Rothbart & Ahadi, 1994), tanto en bebés (Geeraerts et al., 2019; Johnson et al., 1991; McConnel & Bryson, 2005; Nakagawa & Sukigara, 2013; Papageorgiou et al., 2014; Sheese et al., 2008), como en edades pre-escolares (Rothbart et al., 2003; Gerardi-Caulton, 2000; Kochanska et al., 2000). El factor de surgencia también tiende a asociarse con un mayor control de la atención en bebés (McConnel & Bryson; 2005; Putnam et al., 2008). Sin embargo, esta relación se invertirse desde las edades pre-escolares en adelante (Rothbart et al., 2003). Finalmente, el factor de afecto negativo muestra una relación negativa con el control atencional independientemente de la etapa de desarrollo (Conejero & Rueda, 2018;

Gerardi-Caulton, 2000; Harman et al., 1997; Johnson et al., 1991; McConnell & Bryson, 2005; Rothbart et al., 2003).

En relación a factores ambientales, el ambiente de crianza es otro aspecto que modula el desarrollo de diversas habilidades cognitivas (Conger & Donnellan, 2007). Uno de los factores ambientales más extensamente estudiados es el estatus socioeconómico familiar. Esta medida ambiental recoge el nivel educativo de los padres, el nivel de su puesto laboral o los ingresos para necesidades (Farah, 2017). Se ha visto que el estatus socioeconómico es capaz de impactar tanto sobre el desarrollo cognitivo como cerebral, con un menor nivel socioeconómico estando generalmente asociado a un desarrollo cognitivo menos maduro (Hackman & Farah, 2009). Efectos negativos de un bajo estatus socioeconómico se han observado sobre el desenganche atencional en bebés de 5 meses (Siqueiros-Sanchez et al., 2021) o sobre flexibilidad atencional durante el primer y segundo año de vida (Clearfield & Niman, 2012; Conejero & Rueda, 2018). Igualmente, otros factores ambientales menos estudiados muestran capacidad de impactar negativamente sobre el desarrollo cognitivo temperano. Es el caso del nivel de caos y desorganización en el hogar, y la depresión materna. Estudios recientes han mostrado que mayores niveles de caos en el hogar se han asociado con una menor capacidad atencional en bebés de 5.5 meses (Tomalski et al., 2017), así como con menores funciones ejecutivas a lo largo del desarrollo (Andrews et al., 2021). En el caso de la depresión maternal, bebés expuestos a mayores niveles han mostrado un menor desarrollo cognitivo en edades posteriores, principalmente a nivel de funciones ejecutivas (Hughes et al., 2013; Hutchison et al., 2019; Leckman-Westin et al., 2009; Rigato et al., 2022; Oh et al., 2020).

Para responder a las preguntas de investigación planteadas y en base a la evidencia encontrada hasta el momento, se llevaron a cabo dos estudios experimentales. Un primer estudio longitudinal en el que se evaluó la capacidad de control atencional endógeno y ejecutivo en una muestra inicial de 160 bebés a los 6 (*n* = 142), 9 (*n* = 122) y 16-18 (*n* = 91) meses de edad. Para ello, se emplearon 3 tareas de seguimiento ocular: 1. La tarea gap-overlap (Holmboe et al., 2018); 2. La tarea visual sequence learning (VSL; Clohessy et al., 2001); y 3. La tarea switching (Kóvacs & Mehler, 2009). A través de la tarea gap-overlap evaluamos el desenganche atencional con medidas de latencia y fallo de desenganche. Esta habilidad se evalua en contextos de competición visual (condición overlap) y donde el desenganche es facilitado (condición gap). La tarea VSL nos permitió medir la capacidad de los bebés para anticipar la localización espacial de eventos visuales en diferences condiciones de monitorización. Específicamente, empleamos secuencias determinísticas, donde la carga de monitorización es baja, combinado con secuencias complejas donde el requerimento de monitorización es mayor. Finalmente, la tarea switching nos proporcionó información sobre la flexibilidad atencional a través de medidas de conducta visual perseverativa durante el bloque post-cambio de la tarea. Al mismo tiempo, se recogió información sobre el temperamento de los bebés y ambiente en el hogar a través de cuestionarios completados por los padres/ cuidadores legales, en cada una de las edades de evaluación. El segundo estudio contó con un diseño longitudinal acelerado, evaluándose el control atencional en una muestra inicial de 150 niños en edad pre-escolar, divididos en 5 cohortes de 24 (*n* = 24), 30 (*n* = 23), 36 (*n* = 32), 42 (*n* = 32) y 48 (*n* = 24) meses. Para ello se empleó la tarea VSL (Clohessy et al., 2001) con el objetivo de medir la habilidad visual anticipatoria ante eventos visuales con diferentes cargas de monitorización de forma similar al estudio previo. Adicionalmente, cada cohorte fue evaluada a los 6 meses de la primera evaluación para medir el cambio en las medidas atencionales y su estabilidad en el tiempo. Al igual que el estudio previo, se obtuvieron datos de temperamento de los niños y ambiente en el hogar a través de cuestionarios completados por los padres/cuidadores legales.

En relación a las preguntas de investigación planteadas y los resultados encontrados para el estudio longitudinal llevado a cabo con bebés de 6 a 16-18 meses:

1. El desenganche atencional se potencia a lo largo de los dos primeros años de vida. Tanto la latencia como el fallo de desenganche muestras mejoras con la edad. Además, entre los 6 y 16-18 meses de edad, los bebés parecen incrementar su habilidad para beneficiarse de claves atencionales para reorientar la atención (condición gap). En contextos de competencia visual (condición overlap), no se producen cambios madurativos en la habilidad de desenganche. Desde los 6 hasta los 16-18 meses de edad los bebés incrementan el número de anticipaciones que son capaces de realizar, independientemente de que sean correctas o incorrectas. Resultados de la tarea switching, pero no de la VSL, indican que los bebés incrementan el número de anticipaciones correctas entre el primer y segundo año de vida. Sin embargo, no encontramos diferencias en la capacidad de monitorización ante secuencias complejas. Finalmente, la flexibilidad atencional también mejora en este rango de edad, incrementando desde los 6 hacia los 9 meses, para disminuir posteriormente hacia los 16-18 meses de edad. Este patrón se ha observado previamente en la tarea A-no-B, sugiriendo un cambio madurativo inicial en la capacidad de mantener representaciones mentales, seguido de una mejora en el control atencional.

2. La latencia de desenganche atencional es la única medida que muestra estabilidad entre el primer y segundo año de vida. La latencia de

desenganche en contextos de competición visual muestra estabilidad solo entre los 6 y 9 meses de edad. Sin embargo, en contextos donde el desenganche es facilitado, la estabilidad se encuentra tanto desde los 6 a los 9 meses, como de 9 a 16-18 meses de edad. Tanto las medidas de anticipación visual, como las de flexibilidad atencional no muestran estabilidad entre las diferentes edades estudiadas.

3. No se encuentra correlación entre las medidas atencionales derivadas de las tres tareas empleadas. Por lo tanto, esta falta de asociación no hace fiable el cómputo de un único índice de atención ejecutiva derivado de la combinación de los tres aspectos atencionales estudiados. Esto puede deberse a que medimos habilidades que dependen tanto de la red de orientación y ejecutiva, cuya disociación puede no estar aún clara en estas edades.

4. Nuestros resultados sugieren que tanto el temperamento como el ambiente contribuyen a la predicción del desenganche atencional. Se encuentra una contribución positiva del factor de control esforzado a los 9 meses, pero negativa del caos en el hogar a los 6 meses sobre el fallo de desenganche a los 16-18 meses. En relación a la atención anticipatoria, una mayor surgencia temperamental a los 9 meses y un menor caos en el hogar a los 6, predicen un mayor número de anticipaciones totales a los 16-18 meses. De forma similar, una mayor surgencia a los 9 meses, y menores niveles de caos en el hogar y depresión materna a los 6 meses predicen un mayor número de anticipaciones correctas a los 16-18 meses. No se observan efectos de temperamento ni ambiente temperano en la predicción de la flexibilidad atencional.

5. No se observan efectos mediacionales del temperamento de forma longitudinal. Es decir, el temperamento a los 9 meses no parece mediar los efectos del ambiente temprano sobre las habilidades atencionales a los 16-18 meses de edad.

Con respecto a las preguntas planteadas en relación al desarrollo atencional durante el periodo pre-escolar:

1. Entre los 24 y 48 meses de edad, observamos que la edad predice un incremento en las anticipaciones totales que los niños son capaces de realizar. Además, la edad también predice un incremento en las anticipaciones correctas complejas, lo cual es indicativo de una mejora madurativa en la capacidad de monitorización, dependiendo de la red de atención ejecutiva. Sin embargo, la edad no predice cambios en las anticipaciones correctas sencillas.

2. Con respecto al cambio en las medidas en un intervalo temporal de 6 meses, la edad predice solo un incremento en el número de anticipaciones totales, pero no en anticipaciones correctas.

3. En relación a la estabilidad de las medidas, se observa que en un periodo de 6 meses las anticipaciones totales muestran estabilidad, junto con las miradas reactivas, las cuales miden componentes exógenos de control atencional. No se observa estabilidad en anticipaciones correctas ante secuencias sencillas o complejas.

4. A pesar de que no se observan contribuciones de medidas temperamentales sobre anticipaciones totales, encontramos que el caos en el hogar

contribuye a predecir un mayor número de anticipaciones correctas complejas.

Chapter 8: References.

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Chapter 9: Appendix.

Appendix

S.1.1. RESULTS COMPARING FULL AND REDUCED MODEL, COVARIANCE STRUCTURE AND LINEAR AND QUADRATIC TERMS FOR MEDIAN SACCADE LATENCIES IN THE GAP-OVERLAP TASK ANALYSES.

Table S.1.1.1.

-2LL fit index for the full and reduced models for median saccade latency in the gap-overlap task. LRT is reported comparing both models.

	-2LL	**Parameters**
Full model	-1139.74	28
Reduced model	-970.48	26
LRT (*full vs. reduced model*)	Δ-*2LL* = 169.26; *df* = 2; *p* < .001; *w* = .97	

Note. -2LL = -2 Log Likelihood, LRT = Likelihood Ratio Test.

Table S.1.1.2.

-2LL fit index for UN, CS and AR1 for the median saccade latency model in the gap-overlap task. LRT is reported comparing the covariance structure with the largest number of parameters with the rest. the UN vs. CS and UN vs. AR1

	-2LL	**Parameters**
UN	-1100.82	28
CS	-935.45	9
AR1	-935.53	9
LRT (*UN vs. CS*)	Δ-*2LL* = 165.37; *df* = 19; *p* < .001; *w* = .31	
LRT (*UN vs. AR1*)	Δ-*2LL* = 165.29; *df* = 19; *p* < .001; *w* = .31	

Note. -2LL = -2 Log Likelihood; UN = Unstructured Covariance Structure; CS = Compound Symmetry Covariance Structure; AR1 = First-Order Autoregressive Covariance Structure; LRT = Likelihood Ratio Test.

Table S.1.1.3.

-2LL fit index for the linear and the linear+quadratic term models for median saccade latency in the gap-overlap task. LRT is reported comparing both models.

	-2LL	**Parameters**
Linear + Quadratic model	-1046.42	27
Linear model	-979.67	26
LRT (*Linear vs. Linear + Quadratic model*)	Δ-*2LL* = 66.75; *df* = 1; *p* < .001; *w* = .87	

Note. -2LL = -2 Log Likelihood; LRT = Likelihood Ratio Test.

S.1.2. RESULTS COMPARING FULL AND REDUCED MODEL, COVARIANCE STRUCTURE AND LINEAR AND QUADRATIC TERMS FOR DISENGAGEMENT FAILURE IN THE GAP-OVERLAP TASK ANALYSES.

Table S.1.2.1.

-2LL fit index for the full and reduced models for disengagement failure in the gap-overlap task. LRT is reported comparing both models.

	-2LL	**Parameters**
Full model	1363.13	28
Reduced model	1367.87	26
LRT (*full vs. reduced model*)	Δ-*2LL* = 4.74; *df* = 2; *p* = .09; *w* = .16	

Note. -2LL = -2 Log Likelihood; LRT = Likelihood Ratio Test.

Table S.1.2.2.

-2LL fit index for UN, CS and AR1 for the disengagement failure model in the gap-overlap task. LRT is reported comparing the covariance structure with the largest number of parameters with the rest. the UN vs. CS and UN vs. AR1.

	-2LL	**Parameters**
UN	1425.58	26
CS	1409.57	7
AR1	1407.97	7
LRT (*UN vs. CS*)	Δ-*2LL* = 16.01; *df* = 19; *p* = .65; *w* = .10	
LRT (*UN vs. AR1*)	Δ-*2LL* = 15.61; *df* = 19; *p* = .68; *w* = .09	

Note. -2LL = -2 Log Likelihood; UN = Unstructured Covariance Structure; CS = Compound Symmetry Covariance Structure; AR1 = First-Order Autoregressive Covariance Structure; LRT = Likelihood Ratio Test.

Table S.1.2.3.

-2LL fit index for the linear and the linear+quadratic term models for disengagement failure in the gap-overlap task. LRT is reported comparing both models.

	-2LL	**Parameters**
Linear + Quadratic model	1320.49	27
Linear model	1321.39	26
LRT (*Linear + Quadratic vs. Linear model*)	Δ-*2LL* = .90; Δ*df* = 1; *p* = .34; *w* = .10	

Note. -2LL = -2 Log Likelihood; LRT = Likelihood Ratio Test.

S.1.3. RESULTS COMPARING COVARIANCE STRUCTURE AND LINEAR FOR STIMULUS FIXATIONS IN THE VISUAL SEQUENCE LEARNING TASK ANALYSES.

Table S.1.3.1.

-2LL fit index for UN, CS and AR1 for stimulus fixations model in the visual sequence learning. LRT is reported comparing the covariance structure with the largest number of parameters with the rest. the UN vs. CS and UN vs. AR1.

	-2LL	**Parameters**
UN	100.76	11
CS	103.41	7
AR1	103.12	7
LRT (*UN vs. CS*)	Δ-*2LL* = 2.65; *df* = 4; *p* = .62; *w* = .10	
LRT (*UN vs. AR1*)	Δ-*2LL* = 2.36; *df* = 4; *p* = .67; *w* = .09	

Note. -2LL = -2 Log Likelihood; UN = Unstructured Covariance Structure; CS = Compound Symmetry; AR1 = First-Order Autoregresive Covariance Structure; LRT = Likelihood Ratio Test.

S.1.4. RESULTS COMPARING COVARIANCE STRUCTURE FOR REACTIVE LOOKS IN THE VISUAL SEQUENCE LEARNING TASK ANALYSES.

Table S.1.4.1.

-2LL fit index for UN, CS and AR1 for reactive looks model in the visual sequence learning. LRT is reported comparing the covariance structure with the largest number of parameters with the rest. the UN vs. CS and UN vs. AR1.

	-2LL	**Parameters**
UN	1216.83	11
CS	1229.53	7
AR1	1228.80	7
LRT (*UN vs. CS*)	Δ-*2LL* = 12.70; *df* = 4; *p* = .01; *w* = .22	
LRT (*UN vs. AR1*)	Δ-*2LL* = 11.97; *df* = 4; *p* = .02; *w* = .21	

Note. -2LL = -2 Log Likelihood; UN = Unstructured Covariance Structure; CS = Compound Symmetry; AR1 = First-Order Autoregresive Covariance Structure; LRT = Likelihood Ratio Test.

S.1.5. RESULTS COMPARING COVARIANCE STRUCTURE FOR CORRECT ANTICIPATIONS IN THE VISUAL SEQUENCE LEARNING TASK ANALYSES.

Table S.1.5.1.

-2LL fit index for UN, CS and AR1 for correct anticipations model in the visual sequence learning task. LRT is reported comparing the covariance structure with the largest number of parameters with the rest. the UN vs. CS and UN vs. AR1.

	-2LL	**Parameters**
UN	1194.10	11
CS	1226.06	7
AR1	1225.60	7
LRT (*UN vs. CS*)	Δ-*2LL* = 31.96; *df* = 4; *p* < .001; *w* = .34	
LRT (*UN vs. AR1*)	Δ-*2LL* = 31.50; *df* = 4; *p* < .001; *w* = .34	

Note. -2LL = -2 Log Likelihood; UN = Unstructured Covariance Structure; CS = Compound Symmetry; AR1 = First-Order Autoregresive Covariance Structure; LRT = Likelihood Ratio Test.

S.1.6. RESULTS COMPARING COVARIANCE STRUCTURE AND LINEAR AND QUADRATIC TERMS FOR TOTAL ANTICIPATIONS IN THE VISUAL SEQUENCE LEARNING TASK ANALYSES.

Table S.1.6.1.

-2LL fit index for UN, CS and AR1 for total anticipations model in the visual sequence learning task. LRT is reported comparing the covariance structure with the largest number of parameters with the rest. the UN vs. CS and UN vs. AR1.

	-2LL	**Parameters**
UN	1296.11	10
CS	1301.25	6
AR1	1301.24	6
LRT (*UN vs. CS*)	Δ-*2LL* = 5.14; *df* = 4; *p* = .27; *w* = .14	
LRT (*UN vs. AR1*)	Δ-*2LL* = 5.13; *df* = 4; *p* = .27; *w* = .14	

Note. -2LL = -2 Log Likelihood; UN = Unstructured Covariance Structure; CS = Compound Symmetry; AR1 = First-Order Autoregresive Covariance Structure; LRT = Likelihood Ratio Test.

Table S.1.6.2.

-2LL fit index for the linear and the linear+quadratic term models for total anticipations in the visual sequence learning task. LRT is reported comparing both models.

	-2LL	**Parameters**
Linear + Quadratic model	1307.85	10
Linear model	1309.74	9
LRT (*Linear + Quadratic vs. Linear model*)	Δ-*2LL* = 1.89; *df* = 1; *p* = .17; *w* = .17	

Note. -2LL = -2 Log Likelihood; LRT = Likelihood Ratio Test.

S.1.7. RESULTS COMPARING FULL AND REDUCTED MODEL, AND COVARIANCE STRUCTURE FOR EASY AND COMPLEX CORRECT ANTICIPATIONS IN THE VISUAL SEQUENCE LEARNING TASK ANALYSES.

Table S.1.7.1.

-2LL fit index for the full and reduced models for easy and complex correct anticipations in the switching task. LRT is reported comparing both models.

	-2LL	**Parameters**
Full model	2211.82	15
Reduced model	2222.84	14
LRT (*full vs. reduced model*)	Δ-*2LL* = 11.02; *df* = 1; *p* < .001; *w* = .38	

Note. -2LL = -2 Log Likelihood; LRT = Likelihood Ratio Test.

Table S.1.7.2.

-2LL fit index for UN, CS and AR1 for easy and complex correct anticipations model in the visuals sequence learning task. LRT is reported comparing the covariance structure with the largest number of parameters with the rest. the UN vs. CS and UN vs. AR1.

	-2LL	**Parameters**
UN	2196.09	15
CS	2246.26	7
AR1	2241.17	7
LRT (*UN* vs. *CS*)	Δ-*2LL* = 50.17; *df* = 8; *p* < .001; *w* = .29	
LRT (*UN* vs. *AR1*)	Δ-*2LL* = 45.08; *df* = 8; *p* < .001; *w* = .27	

Note. -2LL = -2 Log Likelihood; UN = Unstructured Covariance Structure; CS = Compound Symmetry; AR1 = First-Order Autoregresive Covariance Structure; LRT = Likelihood Ratio Test.

S.1.8. RESULTS COMPARING COVARIANCE STRUCTURE AND LINEAR AND QUADRATIC TERMS FOR CORRECT ANTICIPATIONS IN THE SWITCHING TASK ANALYSES.

Table S.1.8.1.

-2LL fit index for UN, CS and AR1 for correct anticipations model in the switching task. LRT is reported comparing the covariance structure with the largest number of parameters with the rest. the UN vs. CS and UN vs. AR1.

	-2LL	**Parameters**
UN	1894.57	10
CS	1905.20	6
AR1	1904.97	6
LRT (*UN vs. CS*)	Δ-*2LL* = 10.63; *df* = 4; *p* = .03; *w* = .18	
LRT (*UN vs. AR1*)	Δ-*2LL* = 10.40; *df* = 4; *p* = .03; *w* = .18	

Note. -2LL = -2 Log Likelihood; UN = Unstructured Covariance Structure; CS = Compound Symmetry Covariance Structure; AR1 = First-Order Autoregressive Covariance Structure; LRT = Likelihood Ratio Test.

Table S.1.8.2.

-2LL fit index for the linear and the linear+quadratic term models for correct anticipations in the switching task. LRT is reported comparing both models.

	-2LL	**Parameters**
Linear + Quadratic model	1908.94	10
Linear model	1908.95	9
LRT (*Linear vs. Linear + Quadratic model*)	Δ-*2LL* < .01; *df* = 1; *p* = .92; *w* = .01	

Note. -2LL = -2 Log Likelihood; LRT = Likelihood Ratio Test.

S.1.9. RESULTS COMPARING COVARIANCE STRUCTURE FOR PRE-SWITCH BLOCK CRITERION IN THE SWITCHING TASK ANALYSES.

Table S.1.9.1.

-2LL fit index for UN, CS and AR1 for pre-switch block criterion in the switching task. LRT is reported comparing the covariance structure with the largest number of parameters with the rest. the UN vs. CS and UN vs. AR1.

	-2LL	**Parameters**
UN	683.70	10
CS	691.35	6
AR1	689.74	6
LRT (*UN vs. CS*)	Δ-*2LL* = 7.65; *df* = 4; *p* = .10; *w* = .16	
LRT (*UN vs. AR1*)	Δ-*2LL* = 6.04; *df* = 4; *p* = .19; *w* = .14	

Note. -2LL = -2 Log Likelihood; UN = Unstructured Covariance Structure; CS = Compound Symmetry Covariance Structure; AR1 = First-Order Autoregressive Covariance Structure; LRT = Likelihood Ratio Test.

S.1.10. RESULTS COMPARING COVARIANCE STRUCTURE, AND LINEAR AND QUADRATIC TERMS FOR PERSEVERATIONS IN THE SWITCHING TASK ANALYSES.

Table S.1.10.1.

-2LL fit index for UN, CS and AR1 for perseverations model in the switching task. LRT is reported comparing the covariance structure with the largest number of parameters with the rest. the UN vs. CS and UN vs. AR1.

	-2LL	**Parameters**
UN	800.22	10
CS	803.61	6
AR1	803.33	6
LRT (*UN vs. CS*)	Δ-*2LL* = 3.39; *df* = 4; *p* = .50; *w* = .15	
LRT (*UN vs. AR1*)	Δ-*2LL* = 3.11; *df* = 4; *p* = .54; *w* = .14	

Note. -2LL = -2 Log Likelihood; UN = Unstructured Covariance Structure; CS = Compound Symmetry Covariance Structure; AR1 = First-Order Autoregressive Covariance Structure; LRT = Likelihood Ratio Test.

Table S.1.10.2.

-2LL fit index for the linear and the linear+quadratic term models for perseverations in the switching task. LRT is reported comparing both models.

	-2LL	**Parameters**
Linear + Quadratic model	819.38	6
Linear model	827.28	5
LRT (*Linear vs. Linear + Quadratic model*)	Δ-*2LL* = 7.90; *df* = 1; *p* < .01; *w* = .45	

Note. -2LL = -2 Log Likelihood; LRT = Likelihood Ratio Test.

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