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Influence of the environment on the early development of attentional control

Sebastián Moyano [a,d,*], Josué Rico-Picó [a,d], Ángela Conejero [b,d], Ángela Hoyo [a,d], María de los Ángeles Ballesteros-Duperón [c,d], M. Rosario Rueda [a,d]

[a] *Department of Experimental Psychology, University of Granada, Granada, Spain*
[b] *Department of Developmental & Educational Psychology, University of Granada, Granada, Spain*
[c] *Department of Psychobiology, University of Granada, Granada, Spain*
[d] *Mind, Brain and Behavior Research Center (CIMCYC), University of Granada, Granada, Spain*

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ABSTRACT

The control of visual attention is key to learning and has a foundational role in the development of self-regulated behavior. Basic attention control skills emerge early in life and show a protracted development along childhood. Prior research suggests that attentional development is influenced by environmental factors in early and late childhood. Although, much less information is available about the impact of the early environment on emerging endogenous attention skills during infancy. In the current study we aimed to test the impact of parental socioeconomic status (SES) and home environment (chaos) in the emerging control of orienting in a sample of typically-developing infants. A group of 142 (73 female) 6-month-old infants were longitudinally tested at 6, 9 ($n = 122$; 60 female) and 16–18 ($n = 91$; 50 female) months of age using the gap-overlap paradigm. Median saccade latency (mdSL) and disengagement failure (DF) were computed as dependent variables for both overlap and gap conditions. Also, composite scores for a Disengagement Cost Index (DCI) and Disengagement Failure Index (DFI) were computed considering mdSL and DF of each condition, respectively. Families reported SES and chaos in the first and last follow-up sessions. Using Linear Mixed Models with Maximum Likelihood estimation (ML) we found a longitudinal decrease in mdSL in the gap but not in the overlap condition, while DF decreased with age independently of the experimental condition. Concerning early environmental factors, an SES index, parental occupation and chaos at 6 months were found to show a negative correlation with DFI at 16–18 months, although in the former case it was only marginally significant. Hierarchical regression models implementing ML showed that both SES and chaos at 6 months significantly predicted a lower DFI at 16–18 months. Results show a longitudinal progression of endogenous orienting between infancy and toddlerhood. With age, an increased endogenous control of orienting is displayed in contexts where visual disengagement is facilitated. Visual orienting involving attention disengagement in contexts of visual competition do not show changes with age. Moreover, these attentional mechanisms of endogenous control seem to be modulated by early experiences of the individual with the environment.

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* Correspondence to: Mind, Brain and Behavior Research Center, University of Granada, Campus de Cartuja, S/N, Granada 18011, Spain.
E-mail address: smoyano@ugr.es (S. Moyano).

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1. Introduction

Controlling attention is one of the main cognitive challenges that infants face in the first months of life. Orienting attention to relevant objects and locations is a necessary condition for learning about the environment and the nature of objects and events. Orienting in the visual space has been decomposed in different subfunctions, namely: *engaging* attention at a particular stimulus or spatial location; *disengaging* of attention from a stimulus/location, and *shifting* attention from one stimulus/location to another (Colombo, 2001; Posner et al., 1987). From birth, infants can deploy attention to stimulation available in the environment (e.g. faces or objects), showing an ability to exogenously orient their attention. However, during the first months of life, infants experience great difficulty to voluntarily disengage attention from one event and shift to a different event that might be of interest. This particular process of attention disengagement is a more sophisticated one, as it implies an effortful intent to terminate attention to an object or event in order to allocate it to a different one (i.e. endogenous attention). Thus, in the first weeks of life attention is primarily exogenously controlled by external stimulation, mostly provided by caregivers. It is not until about the third-to-forth month of life that babies begin to show rudimentary endogenous attention skills, such as disengaging and shifting attention or anticipating attention to a location in which they expect something to appear (Johnson et al., 1991). The different developmental trajectories of attentional engagement and disengagement in this early period of life have to do with the maturation of differentiated brain structures. While attentional shifting and engagement have been associated with early-developing subcortical structures of the brain, such as the pulvinar and superior colliculus in the thalamus, disengaging visual attention from stimuli has been associated with the function of posterior cortical regions of the parietal cortex (Özyurt & Greenlee, 2011), which take some more time to be functionally active (Csibra et al., 1997).

Tasks involving overt orienting to visual stimuli are commonly utilized to study voluntary attention in infancy. These experimental procedures register infant's gaze either with video recordings for offline coding of looking behavior, or with computerized automatic eye-tracking systems. The latter technology has led to an improvement in temporal and spatial precision in the acquisition of infant's looking behavior. With the aim of analyzing the longitudinal development of endogenous attention control and its stability from 6 to 18 months of age, in the current study we monitored infant's gaze with eye-tracking while they are presented with a sequence of visual events designed to measure attentional disengagement (i.e. Gap-Overlap paradigm). Also, as infants' environment is known to impact early cognitive development (Conejero & Rueda, 2018; Tomalski et al., 2017), as a second goal we examined the contribution of the household environment to disengagement abilities at this early age.

1.1. Attention disengagement in infancy and toddlerhood

Infants' overt visual disengagement and its development has been mostly studied with the gap-overlap paradigm (Hendry et al., 2019). This procedure consists in presenting a central attractive stimulus that engages infants' attention and then observing their looking behavior to either simultaneous or sequential (following a short time elapse) presentation of a peripheral target. Thus, disengagement is studied in two different conditions: 1) the peripheral target is presented while the central stimulus remains on the screen (overlap trials or visual competition); 2) the central stimulus offset is followed by a temporal gap before the onset of the peripheral target (gap trials or non-visual competition; Hood & Atkinson, 1993). The overlap condition requires infants to voluntarily disengage attention from the attractive central stimulus in order to reorient attention towards the novel peripheral target, while both remain visible in the visual space. The increased cognitive effort to disengage attention in the overlap is considerably reduced in the gap condition. One reason for this is that the disappearance of the central stimulus, before the onset of the peripheral target, acts as an alerting cue for saccade planning. This facilitates the orienting of attention to the peripheral target after its onset (Csibra et al., 1997; Kingstone & Klein, 1993). Recent infant studies also support this view. Infants between 3 and 12 months of age have been recently found to benefit from a visual non-directive double-cue to orient attention (Ellis et al., 2021). As double-cues act as a general facilitating alerting signal, infants recruited brain areas known to be involved in the voluntary control of attention (i.e. right anterior cingulate and lateral occipital cortex) following the presentation of such cues (Ellis et al. 2021). There is also converging evidence from studies measuring pupil dilation. For instance, López Pérez et al. (2020) found 8-month-old infants to display lower pupil dilatation to the use of double-cue in comparison to no-cue at all. All together, these studies suggest that already in the first year of life, infants benefit from non-directive attentional cues, leading to a fast and low-effort orienting.

Right after birth, infants experience great difficulty in the voluntary disengagement of visual attention once fixated on a stimulus, a phenomenon labelled as "*obligatory fixation*" or "*sticky fixation*" (Stechler & Latz, 1966). It is around the third month of life when infants start displaying improvements in disengagement ability (Atkinson et al., 1992). In spite of this improvements, still a greater difficulty to visually disengage in overlap trials is consistently found during the first half of the first year of life. For instance, in a large sample of 5-month-old infants Siqueiros Sanchez et al. (2021) found higher disengagement latencies in the overlap compared to the gap condition, and latencies to disengage in a context of visual competition keep showing decreases at 6 months of age (Colombo & Cheatham, 2006). However, successful disengagement is not yet fully achieved by this age (Csibra et al., 1998). Between infancy and toddlerhood, significant changes take place in relation to endogenous control of attention Hendry et al., (2016). Although further gains in visual disengagement could be expected to take place in the transition between these developmental periods, previous studies have not found further decreases in the latency to disengage in the overlap condition. In two studies covering from 6 to 36 months of age, Nakagawa & Sukigara (2013, 2019) found saccade latencies in the overlap condition to be higher compared to the gap one, although no age-related significant improvements were found for any of the disengagement conditions.

Visual attention disengagement is of special relevance not only for typical, but also for atypical development. Disengagement ability has been found to be an important predictor of developmental disorders during toddlerhood and early childhood, especially for autism spectrum disorder (ASD). Attention disengagement in infants from 9-to 10 months of age with siblings diagnosed of ASD (high-risk infants) differ from a control low-risk group. Employing the gap-overlap task with ASD population, Elsabbagh et al. (2009) found that infants at risk showed longer disengagement latencies and less facilitatory effect (i.e. reduction of latency to disengage when the central stimulus is removed). Likewise, Zwaigenbaum et al. (2005) reported that infants at high risk of ASD, who showed an impairment in disengagement between 6 and 12 months, were more likely to be later classified inside of the autistic spectrum at 24 months, with performance at 12 months being predictive of this classification. Further studies replicated this result, supporting the notion that differences in attention disengagement between high and low-risk groups arise at 12–14 months rather than 6–7 months of age (Bryson et al., 2018; Elsabbagh et al., 2013). Authors have argued that different information processing styles are linked to these differences in visual disengagement, leading high-risk infants to focus visual attention on local aspects of the environment, instead of adopting a more flexible and exploratory approach (Elsabbagh et al., 2013).

Visual disengagement is an important function and one of the first manifestations of attentional control during early development. Moreover, previous research has found attention to be permeable to infants' early experiences with their environment during the first years of life.

1.2. 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 9–12-month-old infants, Conejero and 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.

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). The use of this measure 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 24–48-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.

1.3. Aims

In the current research we aimed at studying longitudinal changes in visual disengagement from infancy to toddlerhood, as well as its association with early environmental factors. To the best of our knowledge, only Nakagawa and Sukigara (2013, 2019) have employed longitudinal and cross-sectional methodologies to study changes in disengagement in a similar period. However, both studies counted with small sample sizes of less than 30 infants at each age, not finding age-related differences across experimental conditions. We intended to increase statistical power by recruiting a larger sample of infants to study changes in disengagement ability in different visual contexts (overlap vs. gap). Also, we aimed at analyzing longitudinal effects of families' SES and the degrees of experienced CHAOS at home over visual disengagement. These factors have been found to impact on early attentional control, although its longitudinal effects on disengagement ability have not been previously analyzed in a single study, especially in the case of CHAOS. For these purposes, a sample of infants completed a series of longitudinal evaluations with the gap-overlap task at 6, 9 and 16–18 months of age. Two measures were computed for each experimental condition: 1. Median saccade latency (mdLS), encoding infants' latency to orient from the central towards the peripheral target; 2. Disengagement failure (DF), capturing a lack of disengagement from the central stimulus during the presentation of the peripheral target. We believe that DF could target different aspects of visual disengagement compared to disengagement latencies. In this sense, this measure encodes the plain ability that characterizes attention control, that is to terminate a fixation over a foveated stimulus to visually shift attention. Conversely, disengagement latencies provide information concerning the speed of the visual disengagement process, being only computed for those trials in which disengagement actually occurs. Additionally, Disengagement Cost Index (DCI) and Disengagement Failure Index (DFI) were also computed as composite scores of mdSL and DF for each condition, respectively (see Section 2.3. for a detailed description of measures). These two scores considered how much more disengagement latency or disengagement failure infants displayed in the overlap (i.e. visually competitive disengagement) compared to the gap condition (i.e. visually facilitated disengagement).

We expect a higher mdSL in the overlap compared to the gap condition at each age of evaluation. As subcortical structures related to visual attentional engagement show a higher and earlier level of specialization compared to cortical regions involved in visual disengagement (Johnson, 1990), infants are expected to show more age-related improvements in cognitive functions dependent on the later. In this sense, we hypothesize a steeper longitudinal decrease in mdSL for the overlap condition, due to its dependence on cortical areas, compared to the gap which relies on subcortical areas for attentional engagement. We expect infants to benefit more from non-directive alerting cues with age, with the disappearance of the central stimulus in gap trials resembling this type of cues. Concerning DF, we hypothesize it to be higher in the overlap compared to the gap condition independently of the age of evaluation. We also hypothesize a longitudinal decrease in DF for the overlap condition. Despite of the increased inhibition capacity of toddlers to disengage from the central stimulus, we don't expect age-related difference in DF for the gap condition.

Regarding measures stability, we expect it to decrease for larger temporal gaps between evaluations (i.e. from 6 to 16–18 months). This is hypothesized due to the great number of developmental changes that infants and toddlers experience during between infancy and toddlerhood. Finally, we expect a higher SES and a home with lower levels of CHAOS to be associated with a higher disengagement ability, that is lower DCI and DFI, both concurrent and longitudinally.

2. Material and methods

2.1. Participants

Families were recruited through advertisements in public health centers and the Maternity Hospital of Granada (Spain).

Table 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)

Researchers provided information about the general purpose of the study and a detailed leaflet to interested parents. 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 sample if: 1. Weight at birth was higher than 2500 g, 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 1 for descriptive statistics). All infants were white Caucasian, except for one Latin and two Afro-European infants. 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 wave of the study.

2.2. *Apparatus*

Gaze was recorded using the remote mode of an EyeLink 1000 Plus (SR Research, 2013) corneal-reflection eye-tracker with a sampling rate of 500 Hz and 0.01° of spatial resolution with a 16 mm lens attachment and an 890 nm illuminator. Participants were located at 60 cm from the lens. At this distance, the remote mode offers a 35 (vertical) x 35 (horizontal) cm head movement tolerance for a lens of 16 mm. 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 × 1080 pixels (52 ×30 cm). A five-calibration points child-friendly procedure was initiated previously to stimulus presentation, using animated colorful shapes (1.97° x 1.97° 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 report 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 and 2° of RMS-s2s deviations, which is rarely over 3° in infant research (Hessels et al., 2017). As the I2MC algorithm provides with fixation data for each trial, to obtain the main dependent variables for each infant, we reduced it using a custom script written in Python 3 code. The following steps were defined: 1. Detect fixations inside of the pre-defined areas of interest (AOIs); 2. Classify trials either as valid or invalid; 3. Compute saccade latencies and failure to disengage of valid trials; 4. Remove saccade latencies below a threshold of 120 ms; 5. Group the data to obtain the total number of trials completed, valid trials, trials with disengagement failure and the median of saccade latencies for each infant (i.e. see Section 2.3 for a detailed description of the criteria used).

2.3. *Experimental task: gap-overlap task*

We used a similar procedure to the gap-overlap task previously developed by Holmboe et al., 2018 considering only gap and overlap conditions. We considered only the gap and overlap conditions as these have been proposed as a good measurement of

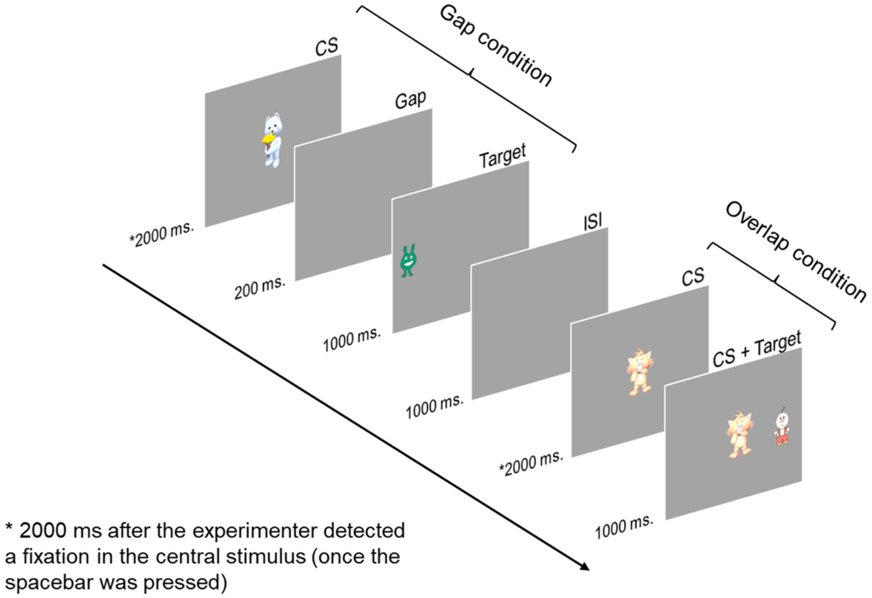

Fig. 1. Procedure of the gap-overlap task illustrating both gap and overlap conditions. Note. CS = Central stimulus. ISI = Interstimulus interval.

disengagement ability in infants (Cousijn et al., 2017). 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, the experimenter pressed a key 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 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 Fig. 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 stimulus, respectively.

Two 16.34° x 20.47° AOIs were created for the peripheral targets, while a 15.4° x 20.47° AOI was generated for the central stimulus. Following Holmboe et al. (2018), only those trials in which infants looked at the central stimulus during the last 200 ms before the peripheral target presentation were considered valid and were included in statistical analyses. Saccade latencies (SL) were computed on valid trials subtracting the onset of the first fixation on the peripheral target from the target onset. Saccade latencies below 120 ms were considered anticipatory and removed from 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. We considered that infants failed to disengage (DF) when only had a fixation 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. Additionally, we computed a DCI dividing the mdSL in the overlap by the mdSL in the gap condition in valid trials. This was applied for mdSL in order to correct as much as possible for infant's baseline saccadic latency (Holmboe et al., 2018). A DFI was also computed. However, as some infants did not have any failure to disengage in the gap condition, we subtracted DF in gap from the overlap condition to avoid dividing by zero. 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. Criterion 1 was not met by 25 infants at 6 months, 11 at 9 months and 6 at 16–18 months. Criterion 2 and 3 were met by 3 and 14 infants at 6 months.

2.4. Questionnaires

2.4.1. Socioeconomic status (6 and 16–18 months)

Parents were asked about their professional occupation and family's income at 6 and 16–18 months. Educational level was only required at 6 months of age as this factor wasn't expected to change in the 10 months gap in contrast with parents' employment situation, which could also affect income-to-needs. Following Conejero et al. (2016), education level was scored from 1 (No studies) to 7 (Postgraduate studies). Likewise, professional occupation was rated following the National Classification of Occupations (CNO-11) of the National Institute of Statistics of Spain (INE). An income-to-needs ratio was computed 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. Finally, a general SES index was calculated averaging the z-scores of the three socioeconomic aspects assessed at 6 months, while at 16–18 months we considered the education level reported by parents at 6 months.

2.4.2. Confusion, hubbub and order scale (6- and 16–18 months)

We used a previously adapted Spanish version (Moyano et al., 2022) of the CHAOS scale (Matheny et al., 1995) 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, $\alpha = .87$ at 6 months and $\alpha = .85$ at 16–18 months) ranging from 1 (Completely agree) to 6 (Completely disagree). A total score of CHAOS was computed by adding the scores for each item. The higher the score, the higher the reported level of experienced CHAOS at home.

2.5. Procedure

Families were received in the Developmental Cognitive Neuroscience Lab located in the Mind, Brain and Behavior Research Center of the University of Granada. Parents/legal guardians were provided with detailed information 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 begin the first half of the session. This part of the session comprised three eye tracking tasks, with the gap-overlap task being the last of them. At 6- and 9-months of age, 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, they were seated on her/his caregiver's lap. At 16–18 months, infants remained seated in the parent's lap during tasks administration due to increased infant mobility at this age. Parents were asked to remain in silence and avoid any interaction with the infant during the procedure. Researchers controlled the administration of experimental tasks from an adjacent room, monitoring infant's 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. Once finished the eye-tracking procedure, infants completed a set of behavioral tasks at 9- and 16–18-months followed by an electroencephalography (EEG) protocol at all ages. Behavioral and EEG data are not presented in the current paper. At the end of the visit, researchers informed parents/legal guardians about the online questionnaires to be completed at home. The present research is part of a larger longitudinal study that 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. Families were given a 10€ voucher at each session for educational toys in compensation for their time.

2.6. 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). For model building we followed the top-down strategy proposed by Verbeke & Molenberghs (2000), removing predictors and effects without a significant contribution to the model. First, a full model was fitted with all fixed and random effects, as well as the interaction of fixed effects. Second, we introduced a backwards deletion of fixed effects from the full model to test if a more parsimonious one (reduced model) increased model fit. A Likelihood Ratio Test (LRT) considering the − 2 Log Likelihood index was applied to assess model fit, evaluating the contribution of the effects in terms of significant differences between the full and the reduced model (Long, 2012; West et al., 2015). A statistically significant result of this test adds support for the full model, indicating that the removed effects significantly contributed to model fit and should be retained. If the test was not found statistically significant, the effects were removed and the reduced model was considered as the new full model for subsequent comparisons. As suggested by Long (2012), we first tested the deletion of interaction effects, followed by main effects. Also, different covariance structures for the model were tested as recommended by Shek & Ma (2011) for unequally spaced longitudinal data (see Supplementary Materials). Satterthwaite approximation was employed to compute degrees of freedom. Marginal (i.e. variance explained by fixed factors) and conditional (i.e. variance explained by fixed and random factors) pseudo-R^2 is reported as an effect size measure for LMM (Nakagawa & Schielzeth, 2013).

Two-tailed pairwise correlation analyses were run to test the stability of disengagement measures across testing sessions. Similarly, we used the same analysis strategy to measure the relation between early environmental factors and disengagement. Due to the high stability of SES and CHAOS from 6 to 16–18 months, we only considered these factors measured at the first wave of data collection (see Section 1 of Supplementary Materials). Finally, we followed Bernier et al. (2016) approach to build hierarchical regression models to predict attentional disengagement in the DCI and DFI at 9 and 16–18 months. The following steps were taken to build the model: 1. Infant's previous performance and 2. Environmental factors. To predict disengagement at 9 months, previous performance and environmental factors at 6 months were considered in the model. Likewise, to predict attention disengagement at 16–18 months we considered performance at 9 months, while environmental factors were only considered at 6 months as they were not measured in the 9 months session. 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 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 χ^2 distributions. Thresholds of.10,.30 and.50 defined small, medium and large effect sizes for Cohen's w, respectively.

3. Results

3.1. Missing values

As LMM requires that data is 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. It is worth noting that the sample at 6 months diminished from 100 to 90 cases (Table 2). This is due to infants with data not suitable for estimation through ML at 9 or 16–18 months (see Supplementary Materials). In this sense, from the initial 100 cases, $n = 5$, $n = 3$ and $n = 2$ did not have data suitable for estimation at 9, 16–18 months or both, respectively. We followed the next steps to test data missingness: 1. Little's MCAR test was performed to analyze if data was MCAR, 2. Explore whether gender had an influence on the pattern of data missingness, and 3. Explore if differences in missing data are found in relation to sociodemographic factors. As none of the test indicated significant effects of neither sociodemographic nor other variables, data were assumed to be missing at random (see Section 2 of Supplementary Materials).

Table 2
Descriptive statistics of the sample at each age 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 (*31.11%*)	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, 16–18 months or both, were excluded from analyses. 2. *n* and percentage of participants with missing data over participants with data at 6 months ($n = 90$).

3.2. Descriptive statistics

First, we test for gender differences in the visual disengagement measure of the gap-overlap task, followed by an exploration of the normal distribution of the variables. Infants did not differ by gender in the number of trials completed (*all ps* $>.52$) or valid trials (*all ps* $>.13$) between conditions at each age (see Table 3). Moreover, no gender differences were found neither for mdSL (*all ps* $>.10$) nor DF (*all ps* $>.09$) at any age.

Regarding data distribution, only mdSL in the overlap condition at 6 and 16–18 months followed a normal distribution. Consequently, we adjusted the distribution based on Tukey's Ladder of Power (Tukey, 1977) with a logarithmic transformation and a square root transformation for mdSL and DF, respectively. For questionnaire measures, the SES index and CHAOS followed a normal distribution (see Table 4 for descriptive statistics).

3.3. Median saccade latency (mdSL)

In order to test hypothesis concerning longitudinal changes in mdSL across conditions, we built 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. As the LRT was statistically significant ($\Delta{-2LL} = 169.26$, $df = 2$, $p < .001$, $w = .97$), it added support for the full model and to retain the interaction term. 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 interaction term Age x Condition, including a random intercept and UN covariance structure (see Section 3.1 of Supplementary Materials). Restricted Estimation Maximum Likelihood (REML) was implemented to obtain unbiased estimates. 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 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 across ages were found for the gap condition ($F(2, 63.37) = 151.84$, $p < .001$) being slower to disengage at 6 months compared to 9 months ($p < .001$) and 16–18 months ($p < .001$). Moreover, 9 months old infants needed more time to disengage compared to 16–18 months ($p < .001$). However, no statistically significant differences across age were found in the overlap condition ($F(2, 62.55) = 1.94$, $p = .15$; see Fig. 2). 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. Residuals of the model displayed a normal distribution in histograms and Q-Q plots.

As the interaction Age x Condition was found statistically significant, we computed the linear growth rate by condition. We fitted a LMM introducing Age as a continuous variable in this case. Age factor was centered as recommended by Shek & Ma (2011) with 6 months = 0, 9 months = .25, and 16–18 months = .83, in order to keep the proportional distance across ages. Age and Condition were entered as a fixed effect in order to test growth rate differences between conditions, allowing the intercept to vary between subjects. Due to data trend seen in plots between ages, we decided to include a quadratic Age factor (Age^2) in the model to test whether it offered a better fit to the data (see Section 3.2 of Supplementary Materials). We found a significant effect of the intercept ($\beta = 2.65$, $SE = .01$, $t(327.20) = 322.33$; $p < .001$). Centered Age slope was also statistically significant ($\beta = -.19$, $SE = .03$, $t(2.74) = -5.23$; $p = .02$), along with Age^2 slope ($\beta = .29$, $SE = .03$, $t(2.74) = 5.90$; $p < .001$). 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 ($\beta = -.15$, $SE = .02$, $t(19.54) = -8.63$; $p < .001$) in comparison to the overlap condition, with the quadratic slope anticipating a plateau phase in the decrease of disengagement latencies for the gap condition.

Table 3
Descriptive statistics for performance measures in the gap-overlap task at each age.

	Mean (*SD*)		
	6 months	9 months	16–18 months
mdSL gap (ms)	275.59 (*30.18*)	245.38 (*23.65*)	222.37 (*22.27*)
mdSL overlap (ms)	451.84 (*100.40*)	441 (*93.11*)	461 (*84.09*)
DF gap (%)	6.71 (*7.02*)	6.19 (*5.86*)	2.86 (*3.84*)
DF overlap (%)	13.92 (*9.16*)	13.04 (*9.01*)	13.46 (*9.73*)
DCI	1.64 (*.35*)	1.80 (*.36*)	2.08 (*.39*)
DFI	7.21 (*9.88*)	6.85 (*9.93*)	10.60 (*9.72*)
Trials completed gap	22.37 (*3.28*)	22.28 (*2.90*)	22.40 (*3.47*)
Trials completed overlap	22.50 (*3.09*)	22.21 (*2.78*)	22.24 (*3.95*)
Valid trials gap	11.85 (*4.01*)	12.17 (*4.11*)	13.74 (*4.32*)
Valid trials overlap	11.88 (*3.94*)	11.44 (*4.11*)	13.45 (*4.40*)

Note. Median saccade latencies (mdSL) are reported in milliseconds without being log transformed. Disengagement failure (DF) is reported as the percentage of trials without disengagement from the central stimulus based on all trials completed for each condition. DCI = Disengagement Cost Index; DFI = Disengagement Failure Index.

Table 4
Descriptive statistics for questionnaire measures of environmental factors at 6 months.

	n valid	Mean (*SD*)	Min (*Max*)
SES index† (z-score)	112†	0.08 (0.*82*)	-1.50 (*1.90*)
Parental education	126	3.82 (*1.48*)	1 (*6*)
Parental occupation	127	4.25 (*2.45*)	0 (*8*)
Income-to-needs	120	1.32 (*.71*)	0 (*3.13*)
CHAOS	130	41.0 (*13.07*)	15 (*81*)

Note. †As some families did not report one of the three indices (parental education, parental occupation or income-to-needs) considered for the computation of the SES index, in those cases it was not computed. SES = Socioeconomic Status

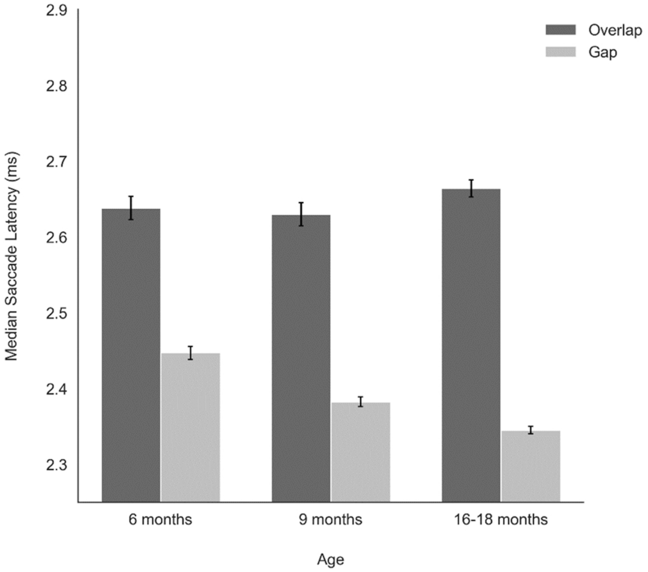

Fig. 2. Bar plot showing median saccade latency (log transformed) for infants at each age of data collection for overlap and gap conditions.

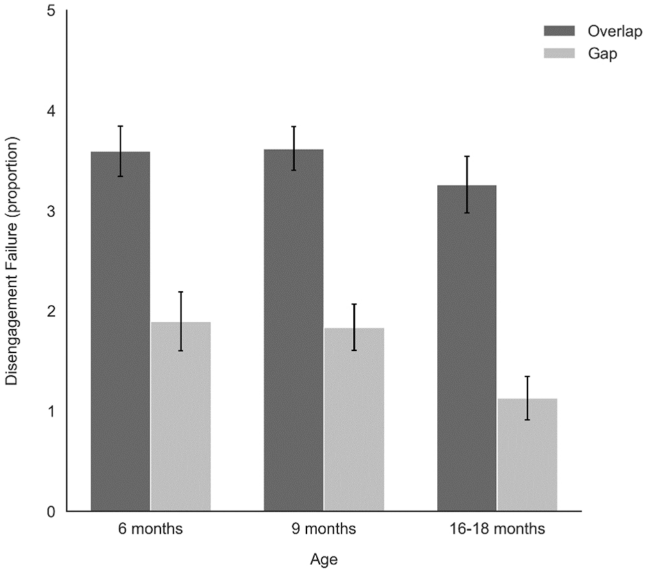

Fig. 3. Bar plot showing the Disengagement Failure (squared root transformed) for infants at each age of data collection.

3.4. Disengagement failure (DF)

To test for longitudinal changes in DF across conditions, the LMM was defined introducing fixed effects of Age (6 vs. 9 vs. 16–18 months) and Condition (overlap vs. gap) with random intercept, removing the interaction term as it was not found to significantly contribute to the model (see Supplementary Materials). UN covariance structure was employed implementing REML for unbiased estimates. A statistically significant main effect of Age was found ($F(2, 189.14) = 3.44, p = .03$). Infants at 6 months displayed a higher DF than at 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 ($p = .08$). The Condition main effect was found statistically significant ($F(1, 151.99) = 146.71$, $p < .001$). Infants showed a higher DF in overlap compared to gap condition ($p < .001$; see Fig. 3). As the interaction Age x Condition was removed during model building, it was not computed in the final model (see Supplementary Materials for the computation of the linear growth rate for DF). Marginal and conditional pseudo-R^2 was of 24% and 34%, respectively for DF.

3.5. Stability of visual disengagement

To test our hypothesis concerning the stability of the measures, a two-tailed pairwise correlations were computed. For mdSL, statistically significant positive correlations were found between 6 and 9 months for the overlap ($p < .05$, 95% CI [.06,.51]) and gap conditions ($p < .01$, 95% CI [.17,.58], Table 5). Between 9 and 16–18 months, only a statistically significant positive correlation for mdSL in the gap condition was found ($p < .01$, 95% CI [.29,.72]), while no statistically significant correlations were found between 6- and 16–18-months of age. In relation to DF across 6 and 9 months, only statistically marginal positive correlations were found for DF in the overlap ($p = .07$, 95% CI [−.04,.43]) condition. Statistically significant correlations were not found for neither DF between 9 and 16–18 months, nor 6 and 16–18 months of age.

3.6. Association between visual disengagement and environmental factors

Pairwise correlations were performed to test the association between early environmental factors measured at 6 months with infants' DCI and DFI at each age of data collection. Parental occupation was found to be negatively associated with the DFI at 16–18 months ($p = .04$, 95% CI [−.49, −.01]), while the SES index only showed a statistically marginal negative correlation ($p = .09$, 95% CI [−.48,.05]). Also, CHAOS displayed a statistically significant negative correlation with the DFI at 16–18 months ($p = .02$, 95% CI [−.52, −.04]; see Table 6). In general, results indicate that a higher level of parental occupation and higher degrees of CHAOS at home at 6 months of age were associated with a lower failure to disengage during toddlerhood.

3.7. Regression results

3.7.1. Predictors of disengagement cost

Next, we examined our hypothesis regarding the contribution of early environmental factors on DCI. First, we built regression models to predict DCI at both 9 and 16–18 months. At 9 months, infant's previous performance at 6 months was not found to be a statistically marginal predictor ($\beta = .23, p = .07$, 95% CI [−.02,.50]). Including environmental factors in the second step did not lead to an increase in model fit (ΔR^2=.01, $\Delta{-2LL}$ =.36, $p = .83$, w =.04), with only infant's performance at 6 months being found as a marginally significant predictor ($\beta = .22$, $p = .07$, 95% CI [−.02,.50]). The full model explained 6% of the variance for DCI at 9

Table 5
Two-tailed pairwise correlation coefficients for attention disengagement measures across testing sessions.

		9 months	16–18 months
mdSL overlap	6 months	**.30** * ($n = 65$)	.03 ($n = 45$)
	9 months	-	.06 ($n = 45$)
mdSL gap	6 months	**.39** * ** ($n = 65$)	.16 ($n = 45$)
	9 months	-	**.54** * ** ($n = 45$)
DF overlap	6 months	*.22#* ($n = 65$)	-.16 ($n = 45$)
	9 months	-	.07 ($n = 45$)
DF gap	6 months	.20 ($n = 65$)	.08 ($n = 45$)
	9 months	-	.06 ($n = 45$)

Note. Correlation coefficients were computed without replacing missing data. Sample size for correlations between gap-overlap measures was variable depending on valid data at both ages considered in the correlation analysis. mdSL = Median Saccade Latency; DF = Disengagement Failure
* ** $p < .001$; * * $p < .01$; * $p < .05$; #$p < .10$

Table 6
Two-tailed pairwise correlation coefficients between environmental measures at 6 months and gap-overlap variables at 6, 9 and 16–18 months.

		Disengagement Cost Index			Disengagement Failure Index		
		6 months	9 months	16–18 months	6 months	9 months	16–18 months
6 months	SES index	.01 ($n = 81$)	.02 ($n = 71$)	-.10 ($n = 51$)	.10 ($n = 81$)	-.03 ($n = 71$)	*-.23#* ($n = 51$)
	Parental education	-.08 ($n = 88$)	-.01 ($n = 80$)	-.07 ($n = 55$)	.04 ($n = 88$)	.03 ($n = 80$)	-.17 ($n = 55$)
	Parental occupation	.01 ($n = 89$)	.09 ($n = 81$)	.01 ($n = 56$)	.10 ($n = 89$)	-.01 ($n = 81$)	**-.26 *** ($n = 56$)
	Income-to-needs	.16 ($n = 88$)	-.02 ($n = 76$)	-.06 ($n = 55$)	.14 ($n = 88$)	-.09 ($n = 76$)	-.04 ($n = 55$)
	CHAOS	.07 ($n = 91$)	.08 ($n = 83$)	-.15 ($n = 57$)	.04 ($n = 91$)	.05 ($n = 83$)	**-.30 *** ($n = 57$)

Note. Correlation coefficients were computed without replacing missing data. Sample size for correlations between questionnaires and gap-overlap measures across ages was variable depending on completed/valid data for both measures considered in the correlation.
* ** $p < .001$; * * $p < .01$; * $p < .05$; #$p < .10$

months. Concerning DCI at 16–18 months, previous performance at 9 months was not found to be a significant predictor. Also, including environmental factors in the second step did not increase model fit (ΔR^2=.11, $\Delta{-2LL} = 2.53$, $p = .26$, w =.12). The full model explained 16% of the variance for DCI at 16–18 months (Table 7).

3.7.2. Predictors of disengagement failure

The same strategy was applied to test the contribution of environmental factors to DFI. For DFI at 9 months, previous performance at 6 months was found to be a statistically marginal predictor in the first step ($\beta = .21$, $p = .09$, 95% CI [−.03,.47]). The inclusion of environmental factors in the second step did not lead to statistically significant increase in model fit (ΔR^2=.01, $\Delta{-2LL}$ =.82, $p = .66$, w =.07). The full model explained 5% of the variance for DFI at 9 months. Regarding DFI at 16–18 months, performance at 9 months was found to be a statistically marginal predictor ($\beta = .26$, $p = .09$, 95% CI [−.04,.56]). The inclusion of environmental factors in step 2 significantly increased model fit (ΔR^2=.22, $\Delta{-2LL} = 7.53$, $p = .02$, w =.20), with a small effect size. Previous performance was found to significantly predict DFI at 16–18 months ($\beta = .36$, $p = .01$, 95% CI [.08,.64]). Also, both SES ($\beta = -.30$, $p = .03$, 95% CI [−7.17, −.41]) and CHAOS ($\beta = -.35$, $p = .01$, 95% CI [−.49, −.06]) were found to be statistically significant predictors. The full model explained 29% of the variance for DFI at 16–18 months (Table 8).

4. Discussion

Early endogenous control of orienting allows infants to voluntarily direct attentional resources in self-controlled manner. This voluntary form of orienting enables infants to engage in an effortful exploration and learning from the environment. In the first years of life, the ability to engage, disengage and shift visual attention are early demonstrations of infants' ability to endogenously control orienting. In the current study we aimed to analyze longitudinal changes in early attention control, specifically in visual disengagement, from 6-to-18 months of age, as well as its association with early environmental factors. We intended to study the longitudinal effects of early SES and CHAOS on infants' visual disengagement. These factors have been found to relate to visual attention control (Siqueiros Sanchez et al., 2021; Tomalski et al., 2017), although their longitudinal effects had not previously been analyzed.

Table 7
Hierarchical regression models predicting Disengagement Cost Index at 9 and 16–18 months.

	9 months ($n = 90$)		16–18 months ($n = 90$)	
	Step 1	Step 2	Step 1	Step 2
1. Previous age performance				
Disengagement Cost Index	*.23#*	*.22#*	.23	**.31 ***
2. Environment (6 months)				
SES index	-	.02	-	-.17
CHAOS	-	.07	-	-.23
ΔR^2	.05	.01	.05	.11
LRT (full vs. *reduced model†)*	-	$\Delta{-}2LL = .36$ $\Delta df = 2$ $p = .83$	-	$\Delta{-}2LL = 2.63$ $\Delta df = 2$ $p = .26$
Cohen's w	-	.04	-	.12

Note. †The comparison between steps is performed between the full model (model with more parameters: last step performed in the comparison) and the reduced model (previous step in the comparison).
* ** $p < .001$; * * $p < .01$; * $p < .05$; #$p < .10$

Table 8
Hierarchical regression models predicting Disengagement Failure Index at 9 and 16–18 months.

	9 months ($n = 90$)		16–18 months ($n = 90$)	
	Step 1	Step 2	Step 1	Step 2
1. Previous age performance				
Disengagement Failure Index	*.21#*	.19	*.26#*	**.36 ***
2. Environment (6 months)				
SES index	-	-.02	-	**-.31 ***
CHAOS	-	.11	-	**-.35 ***
ΔR^2	.04	.01	.07	**.22**
LRT (full vs. *reduced model†)*	-	$\Delta - 2LL = .82$ $\Delta df = 2$ $p = .66$	-	**$\Delta - 2LL = 7.53$** **$\Delta df = 2$** **$p = .02$**
Cohen's w	-	.07	-	**.20**

Note. †The comparison between steps is performed between the full model (model with more parameters: last step performed in the comparison) and the reduced model (previous step in the comparison).
* ** $p < .001$; * * $p < .01$; * $p < .05$; #$p < .10$

For this, latency and failure to disengage were measured under two experimental conditions in a gap-overlap task: 1. An overlap condition in which the central stimulus remained on screen while the peripheral target was displayed; and 2. A gap condition in which the central stimulus disappeared from screen, with the peripheral target being presented after a 200 ms temporal gap. To the best of our knowledge, only Nakagawa and Sukigara (2013, 2019) have studied visual disengagement with longitudinal and cross-sectional methodologies, with the latter in relation to phasic alertness. These studies are characterized by small sample sizes, with no age-related effects being found between conditions. We aimed at longitudinally testing a larger sampler of infants to increase statistical power, covering ages from the first and second year of life to further characterize its development and stability. Results showed a significant reduction with age in the latency to shift visual attention towards the peripheral target in the gap condition. Also, stability of measures was found to be higher for the gap condition between 6-to 9 months and 9–16–18 months, while the overlap condition only showed stability from 6-to 9 months. Finally, a higher family's SES and higher degrees of CHAOS at home at 6 months of age predicted a lower disengagement failure during toddlerhood.

4.1. *Longitudinal development of visual disengagement*

As hypothesized, a general decrease in disengagement latency occurred from 6 to 9 and 16–18 months. 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 6 and 9 months, as well as between 6 months and 16–18 months of age. The lack of differences in disengagement latency between 9 and 16–18 months suggests a reduction in the change rate with age, indicating a steadier progression in this ability entering the second year of life. 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 at 6 months displaying a higher failure to disengage compared to 16–18 months. We found an age-related decrease in disengagement failure, but only between the 6- and the 16–18-month-olds. 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 plain ability to terminate a fixation on a foveated stimulus. Although its characteristics, disengagement failure also offers interesting insights in relation to infants' ability to engage inhibitory control, especially during overlap trials for visual disengagement to actually take place.

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 are required to engage inhibitory control in order to terminate a fixation on the foveated stimulus to allow attention to be shifted towards the peripheral target. Disengagement is eased in gap trials due to the disappearance of the central stimulus. 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 for the engagement of inhibitory control to voluntarily disengage attention when stimuli compete for attentional resources. 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. This could suggest that disengagement displays a steady development from 6 to 16–18 months of age. It is likely that differences could emerge around the end of the second year of life. It is at this age 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, perhaps leading to more noticeable differences in disengagement ability compared to younger infants. Although the prevalent reading of the overlap effect is that children would engage inhibitory control in order to terminate a fixation on the central stimulus to explore the novel peripheral one, other interpretations might also explain these results. Nakagawa and Sukigara (2013) found toddlers with a higher temperamental effortful control to display longer disengagement latencies in the overlap condition. This opens the possibility that an effective engagement of inhibitory control could be precisely to avoid exploring the peripheral target, with children voluntarily remaining on the central stimulus. This could also explain the lack of longitudinal differences in disengagement latency for the overlap condition. 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 and 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 and 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 and 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 proposed to be 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.

4.2. *Stability of visual disengagement*

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 6 and 9, as well as 9 and 16–18 months of age, but not for the longest temporal interval between sessions (i.e. 6–16–18 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 premature 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 6-to 9 months of age. 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 6- and 9-months session. 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.

4.3. Environmental effects on visual disengagement

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. 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. Moreover, both SES and CHAOS at 6 months were found to predict a lower failure to disengage during toddlerhood at 16–18 months, even after considering previous performance at 9 months.

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. These authors suggest that infants from higher-income backgrounds tend to slow the process of disengagement in order to prioritize a more accurate visual orienting towards the peripheral target. However, in the current study we did not replicate this result. In line with our hypothesis, infants from high-income families displayed a lower disengagement failure during toddlerhood. Our results are congruent with previous studies that have reported a positive effect of a higher-income backgrounds on infants' cognitive development in relation to focused attention (Clearfield & Jedd., 2013) and attentional flexibility (Clearfield & Niman, 2012; Lipina et al., 2005) during the first two years after birth. Additionally, higher levels of SES have been associated with positive longitudinal effects on the development of executive function (Hackman et al., 2015), as well as on frontal brain regions (Lawson et al., 2013) later in development. At older ages, Stevens et al. (2009) found a higher recruitment of neural resources during a selective attention task in 3-to 8-years-olds from high-income households, in comparison to children from lower-income homes. Similarly, in a sample of children between 7 and 12 years of age, Kishiyama et al. (2009) reported neural and behavioral results indicating a higher recruitment of prefrontal areas during an attention control task. During late childhood, children between the ages of 10 and 13 years from low-income backgrounds display a tendency to engage anterior cingulate control mechanisms to a lower degree in comparison to their children from higher-income homes (Farah et al., 2006), with similar results being reported by Noble et al. (2007) in children between 13 and 14 years of age. Hence, the current findings in infants and toddlers' attention control are in consonance with the suggested differential developmental trajectories for children of different socioeconomic backgrounds.

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.

The current study contributes to the understanding of the development of visual attentional disengagement, considering a large sample size as well as the impact of early environmental factors. Yet, it is not free of limitations. 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. Additionally, future research should consider a wider age range to test for age-related changes in visual disengagement in the overlap condition, as in the current range only changes in the gap condition were captured. Regarding methodological limitations, 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. 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. Finally, other aspects of infants' environment are also known to be associated with early cognitive development, such as maternal depression, nutrition, physiological stress or quality of sleep (Rigato et al., 2022; Roosa et al., 2005). Regarding physiological stress, one of the most common measures is salivary cortisol. In a longitudinal sample, 7-month-old infants with higher levels of cortisol I saliva showed lower scores in an EF battery at 3 years of age (Blair et al., 2011). Also, Sadeh et al. (2015) found that infants with poorer sleep quality at 12 months of age showed a lower executive attention in a spatial conflict task at 3–4 years of age. Considering these factors in future research could contribute to explain additional variability on early visual attention control.

5. Conclusion

Through infancy and toddlerhood, children have been found to show an improvement in general disengagement ability independently of the visual context (Nakagawa & Sukigara, 2013, 2019). However, no longitudinal changes in visual disengagement have been previously reported based on the context in which disengagement takes place in the experimental task. The current results show a longitudinal increase in visual attention shifting from infancy to toddlerhood in the absence of visual competition (gap condition). This is probably related to improvements in infants' ability to benefit from non-directive attentional cues, as well as maturing effects in the parietal cortex with age, leading to a faster and more efficient orienting of visual attention. However, disengagement in contexts of visual competition that require the engagement of control processes such as inhibitory control (overlap condition), show a steady development across these ages. It is likely that changes in this ability could be detected at older ages. Firstly, due to the emergence of executive attention as the main supervisory system of attention control around 2 years of age. Secondly, due to the protracted developmental course of prefrontal cortex, crucial for developmental improvements in cognitive control. Finally, disengagement abilities in contexts of visual competition seems to be influenced by the early environment at which infants are exposed to during the first year of life. This states the importance of the growing environment on later cognitive abilities, especially during early stages of development.

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CRediT authorship contribution statement

Sebastián Moyano: Investigation, Data curation, Formal analysis, Writing – original draft, Writing – review & editing, Visualization. **Josué Rico-Picó:** Investigation, Writing – review & editing. **Ángela Conejero:** Conceptualization, Investigation, Writing – review & editing. **Ángela Hoyo:** Investigation, Writing – review & editing. **M. A. Ballesteros-Duperón:** Conceptualization, Investigation. **M. Rosario Rueda:** Conceptualization, Funding acquisition, Supervision, Project administration, Writing – original draft, Writing – review & editing.

Declarations of interest

none.

Data availability

Data will be made available on request.

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.infbeh.2023.101842.

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