Visual disengagement in young infants in relation to age, sex, SES, developmental level and adaptive functioning

Abstract:

Visual attention plays a key role in infants' interaction with the environment, and shapes their behavioral and brain development. As such, early problems with flexibly switching gaze from one stimulus to another (visual disengagement) have been hypothesized to lead to developmental difficulties (e.g. joint attention and social skills) over time. This study aimed to identify cross-sectional associations between performance in the Gap task (gaze shift latencies and visual attention disengagement) and measures of development and adaptive behavior in conjunction to any sex or socioeconomic status effects in infancy. We measured visual attention disengagement in 436 5-month-old infants and calculated its association with cognitive developmental level, adaptive behaviours, socioeconomic status (SES) and biological sex. In the Gap task, participants must redirect their gaze from a central stimulus to an appearing peripheral stimulus. The three experimental conditions of the task (Gap, Baseline and Overlap) differ on the timepoint when the central stimuli disappears in relation to the appearance of the peripheral stimulus: 200ms before the peripheral stimulus appears (Gap), simultaneously to its appearance (Baseline), or with peripheral stimulus offset (Overlap). The data from the experimental conditions showed the expected pattern, with average latencies being the shortest in the Gap and longest in the Overlap condition. Females were faster (p=.004) than males in the Gap condition, which could indicate that arousal-related effects differ as a function of biological sex. Infants from higher SES were slower (p=.031) in the Overlap condition compared to lower SES infants. This suggests that basic visual attention may differ by socio-cultural background, and should be considered when studying visual attention and its developmental correlates. We observed no significant association to concurrent developmental level or adaptive function. Given its large sample size, this study provides a useful reference for future studies of visual disengagement in early infancy.

Key words: eye-tracking, infancy, development, SES, visual disengagement, behaviour

1. INTRODUCTION

Attention can be conceptualized as a selection process that renders certain aspects of the world focused while others are filtered out (Desimone & Duncan, 1995; Raz & Buhle, 2006). Thus attention is a core mechanism that gates how environmental stimuli are selected and prioritized for later processing. While some basic aspects of attention, like orienting to faces, are present from birth, the ability to flexibly switch visual attention develops somewhere around 3 and 6 months (Bhatt, Bertin, & Gilbert, 1999; Johnson, Posner, & Rothbart, 1991), but continues to improve. This ability follows an earlier period where infants struggles to shift their gaze from one stimulus to another, a process often termed “sticky fixation” or “obligatory attention” (Johnson & De Haan, 2015). Visual attention engagement and disengagement are processes encompassed by the orienting attention subsystem (Posner & Petersen, 1990). This subsystem is one of the earliest tools infants have to explore the world given that it is active as early as 4 months of age (Johnson & De Haan, 2015). In early development, vision is the primary sense through which infants can shape their own experience of the environment, given that communicative skills are limited (Colombo & Mitchell, 1990). Thus, individual differences in early-emerging skills such as visual disengagement could have a substantial cascading effect on learning and development (Johnson et al., 1991).

Control of visual attention in infancy may provide a foundation for the development of later higher-order cognitive and executive systems. Indeed, individual differences in early visual attention can be predictive of later high level cognitive functions, educational outcomes and socio-communicative skills (Veer, Luyten, Mulder, van Tuijl, & Sleegers, 2017). For instance, early attention is predictive of later inhibitory skills (Reck & Hund, 2011), literacy (Blankenship et al., 2019) and numeracy (Steele, Karmiloff-Smith, Cornish, & Scerif, 2012). This is consistent with a hierarchical organization of higher order functions, where basic cognitive functions and their interactions underlie more complex functions. According to this view, selectively engaging attention on goal relevant information is a prerequisite for goal-directed behavior (Garon, Bryson, & Smith, 2008). In addition, typically developing infants' "first look" (as in the duration of an infant's first look to a novel stimulus) has been linked to expressive communication and overall adaptive communication later on (Arterberry, Bornstein, Midgett, Putnick, & Bornstein, 2007). Basic aspects of visual attention may form building blocks for the later development of joint attention, which is known to be critical in language development (Morales, Mundy, Crowson, Neal, & Delgado, 2005; Salley et al., 2016). Similarly, slowed visual disengagement in infants has been linked to a later ASD diagnosis (Elsabbagh et al., 2013) and early oculomotor atypicalities seem to be related to impairments in pivotal skills for language acquisition (e.g. pointing) in William Syndrome (Karmiloff-Smith, 2009). However, despite the apparent longitudinal link between visual attention with and socio-communicative skills, the cross-sectional relation between infant oculomotor disengagement and infant socio-communicative skills is unknown.

When assessing early visual attention skills, we typically use oculomotor behavior as output modality due to the high overlap of neural areas underpinning attentional and oculomotor functions. Thus, it is likely that there are observable associations with more general motor development. Gaze control is indeed tightly intertwined with volitional motor action and motor development, as visual attention is required to guide a movement in addition to muscle control, motivational and integrative processes (von Hofsten, 2004). In fact, visually guided reaching, a key motor skill in early infancy, requires the integration of a series of skills including visual attention. For infants to reach for something they see, they must execute an accurate eye movement (implying adequate control/activation of extraocular muscles (Groh, 2001)), foveate the object, be capable of perceiving it (beyond the self), possess a desire to reach for it, have the gross motor dexterity, balance and muscle strength to do so and to plan the action itself (Smith & Thelen, 2003; von

Hofsten, 2004). Therefore, a link between motor (gross and fine) and oculomotor and cognitive development even in early infancy seems empirically plausible. Longitudinally, research shows poorer visual disengagement in infancy (6m) is associated with poorer motor skills during school age, including balance and handwriting (Hitzert, Van Braeckel, Bos, Hunnius, & Geuze, 2014). However, we know little about how these visual disengagement and early motor skills relate in early infancy.

The evidence so far suggests that individual differences in infant visual attention relate to later cognitive, language, motor, social abilities and behavior (Papageorgiou, Farroni, Johnson, Smith, & Ronald, 2015; Papageorgiou et al., 2014). However, alternative early factors may influence individual differences in visual attention or, rather visual attention may act as a mediator of distal early risk factors on cognitive and developmental abilities. Two factors that may be relevant because they affect behavioral trajectories and are present from birth are sex and SES. Sex differences have been noted in cognitive functions. For instance, boys display faster (shorter) reaction times than girls in the Attention Network Test (ANT), a 30-min task designed to evaluate alerting, orienting and executive functioning that combines Posner's cued reaction time task and the flanker test (where participants typically choose between response keys in response to compatible, incompatible and neutral flankers) (Mezzacappa, 2004). Oculomotor responses seem to also follow this pattern, with young male adults exhibiting faster prosaccades than females (Bargary et al., 2017). Sex differences have also been found in saccadic reaction times in response to cueing effects during cueing visual orienting paradigms. In one study, females had an enhanced response to cueing on an adaptation of the Posner's cueing paradigm – with faster saccadic response times following valid central directional cues to peripheral targets, regardless of their social (gaze) or non-social (arrow) quality when compared to non-valid cues, meaning that non-informative cues were more distracting for women (Bayliss, di Pellegrino, & Tipper, 2005). Another study, using a mix of the go/no-go task and the flanker task had similar results (Stoet, 2010). In said study (Stoet, 2010), incompatible flankers had a more pronounced distracting effect (slower reaction times, higher mistake average) in females in contrast to neutral/compatible flankers and to male participants. Thus, females had longer average reaction times in trials with incompatible flankers and higher overall errors in that task, a pattern also observed by others in the ANT (Mezzacappa, 2004). Furthermore, functional magnetic resonance imaging research shows evidence of sex related differences on the brain structures recruited by males and females in visuospatial attention allocation (Rubia, Hyde, Halari, Giampietro, & Smith, 2010). Since, research has shown how intertwined cognitive functions and neural structures are and how this relation is bidirectional and dynamic, with neural structures influencing cognition and cognition (e.g. learning) influencing neural changes (Newman, 2016). Thus it may be that while sex differences result in cognitive differences and structural brain differences, individual differences may also be experience-dependent rather than a consequence of sex differences. However, very few studies have researched sex differences in basic visual attention measures in early infancy, and thus prior to experiences being shaped by gender – for example with visual spatial ability, evidence of boys being more often exposed to toys that promote mental rotation skills (e.g. lego) may be the cause of adult males outperforming females in visuospatial tests, rather than gender (Newman, 2016).

Another sociodemographic factor associated to individual differences in visual attention is socioeconomic status (SES). SES appears to impact different behavioral attentional measures in early childhood, with higher SES children outperforming their low SES peers (Hampton Wray et al., 2017; Mezzacappa, 2004). For instance, researchers observed faster average reaction times, improved accuracy in response to cues and lower interference of incongruent cues in high SES when compared to low SES children (Mezzacappa, 2004). Selective attention appears to also be affected by lower SES, with low SES children lagging in comparison to high SES same-aged children and displaying a divergent attentional developmental trajectory (Hampton Wray et al., 2017). SES also explained a significant portion of the variance in visuospatial skills in young children, as well as other neurocognitive abilities, particularly maternal education (Noble, McCandliss, & Farah, 2007). Moreover, it appears that SES which is typically present since birth may moderate attentional functions already in infancy.

A recent review on the impact of SES in infant cognition and brain structure suggests that, to a large extent, low SES has a detrimental impact on behavioral tasks reflecting basic cognitive functions and EF precursors already in the first year of life (Hodel, 2018). As early as 6 months of age, lower levels of focused attention are observable in low-SES infants during free play when compared to high-SES peers (Clearfield & Jedd, 2013). Cognitive flexibility tasks seem to also be affected with low SES displaying a delayed switching pattern in reaching behaviors in comparison to high SES infants (6, 9, 12m) (Clearfield & Niman, 2012). Similarly, search and cross-modal object exploration show that infants from higher SES families performing better and show more complex exploratory behaviors than those from lower SES (Clearfield & Jedd, 2013; Roberts, Bornstein, Slater, & Barrett, 1999; Tacke, Bailey, & Clearfield, 2015). Studies on visual information processing tasks, specifically on habituation and novelty show a less clear picture of the effect of SES, with some indeed finding lower scores in infants from low SES (McCall, 1973; Susan A. Rose & Feldman, 1987), some only after 2 years of age (but not before) (Susan A Rose, Feldman, Wallace, & McCarton, 1989), and others no differences at all (Mayes & Bornstein, 1995). Other studies paint a more nuanced picture of the effects of SES on cognition in early infancy both in terms of the mechanisms studied or how SES itself is measured. For instance, while basic attention orienting is seemingly unaffected by SES, whether memory is impacted by SES or not depends on the attentional mechanism engaged during memory encoding (Markant, Ackerman, Nussenbaum, & Amso, 2016). Whether SES is defined as familiar income or parental education appears to also play a role, with family income but not parental education impacting attention orienting to faces and both feature and object based attention in infants (Markant et al., 2016; Werchan, Lynn, Kirkham, & Amso, 2019). It is worth noting that most studies tend to only measure SES in one way or another, with a majority focusing on parental education.

Behavioral findings of an effect of SES on cognitive abilities early in life are further strengthened by documented SES impact on brain structure and on neural electrophysiology. Imaging studies reveal smaller grey matter volumes and total regional volumes in frontal, prefrontal and parietal brain areas (which underpin attentional functions) in lower SES infants during the first years of life (Leijser, Siddiqi, & Miller, 2018). Electrophysiological studies results also illustrate through higher amplitude neural activity in response to distractors (Stevens, Lauinger, & Neville, 2009), dampened neural activity in the prefrontal cortex (Kishiyama, Boyce, Jimenez, Perry, & Knight, 2009), and frontal gamma power the effect of lower SES on attention-related brain development (Tomalski et al., 2013).

While discrepancies in the literature of the effect of SES on attention and cognitive functions exist, there appears to be a majority suggesting that there is indeed an effect even so early on in life. Discrepancies may be due to various aspects, such as the attentional mechanism at study, how SES was operationalized, or as suggested by Noble, Norman, and Farah (2005) on small sample sizes (as seen in their own work and several previous studies). Therefore, it seems highly plausible that there is an impact of SES on cognitive, and specifically attentional, functions in early infancy, thus warranting further exploring its effect in attentional orienting and disengaging.

Taken together, it is the aim of this study to deepen our understanding of how visual disengagement relates to other cognitive developmental processes and behaviors in early infancy. We used a widely employed measure of visual disengagement called the Gap task in a large group of 5-month-old infants (Jones et al., 2019). This paradigm requires the subject to fixate on a central stimulus and subsequently move their gaze onto an appearing peripheral stimulus; the key dependent variable is the latency of the gaze shift. The paradigm has three key experimental conditions: the no-competition condition, where the central stimulus disappears simultaneously with the presentation of the peripheral stimulus (Baseline), a preparatory condition in which the central stimulus disappears a brief period before the onset of the peripheral stimulus (Gap), and the competition condition, where the central stimulus remains displayed during and after the peripheral stimulus onset (Overlap). We expect to observe that gaze latencies follow a step-wise pattern (Gap<Baseline<Overlap). However, although we compute gaze latencies for all conditions we only test potential correlates with gaze latencies from the Gap and Overlap conditions, as previous research suggests that the Baseline condition may be less neutral than it was intended to be (Cousijn, Hessels, Van der Stigchel, & Kemner, 2017; Siqueiros Sanchez et al., 2019), and with the Visual Disengagement score. Despite these reservations about the Baseline condition, we decided to define visual disengagement score as the difference between mean latencies in the Baseline and Overlap conditions to maximize synergies and be able to readily draw parallels with previous studies (Elsabbagh et al., 2013; Jones et al., 2019). Based on the reviewed literature, we hypothesize that we will find that visual disengagement is negatively associated with motor, social and language skills, and adaptive behaviors. Furthermore, we hypothesize that we will observe an effect of SES on task performance as well as task performance sex differences.

2. METHOD

2.1. Participants

The infants in this study were twins, but we analyzed phenotypic relations only (twin modelling will be reported in a later study). The final sample after exclusions of incomplete data in this study was of 436 five month old (mean= 167.39 days; SD= 8.73) infant same-sex pairs. Participants in this study are recruited from the BABYTWINS study. Babytwins is a longitudinal infant twin study with the purpose of understanding the relative contribution of genetic and environmental influences to early cognitive functions and behaviors. Babytwins has an inclusion rate of 29% of same sex twins from the larger Stockholm area and central Uppsala. Sociodemographic data on the infants and their families was collected on-site during the 5 month visit. The present sample is balanced in terms of sex (48.16% F). Socioeconomic status (SES), as assessed by maternal highest level of education attained, was high in comparison to maternal education level in the nation-wide population Child and Adolescent Twin Study in Sweden (CATSS) (Anckarsäter et al., 2011; Siqueiros Sanchez et al., 2019). Specifically, 54.81% of mothers in Babytwins had received tertiary education for at least three years. We split SES into two tiers (low and high) based on the number of years (and level) of education attained by mothers. In the low SES tier, we include families where mothers have only completed primary or secondary education. In the high SES tier, we include families where mothers have studied at least 1 year of tertiary education. All participants were born in Sweden to at least one Swedish-speaking parent. Only participants with complete data for the included variables were included in this study. Inclusion criteria for this study was to: (1) have at least one parent fluent in Swedish; (2) have at least one parent with detailed knowledge about the pregnancy (thus excluding surrogacy but not in-vitro); (3) be of the same sex. Exclusion criteria for this study were: (1) being born earlier than 34 weeks; (2) presence of known severe uncorrected hearing or visual impairment; (3) presence of a known significant medical condition likely to affect the child's ability to participate in the study or have an impact on brain development. The study was approved by the regional ethics board in Stockholm and was conducted in accordance with the Declaration of Helsinki.

2.2. General testing procedure

The testing protocol, follows to a great extent the Eurosibs study protocol at their five month time point (Jones et al., 2019). In sum, infants take part in a developmental assessment (the Mullen Scales of Early Learning - MSEL), a video-recorded Parent Child Interaction, two eye tracking sessions, and an electroencephalogram experiment. Parents also fill out questionnaires prior (online and on paper) and during the visit. During the experimental paradigms, parents were instructed to be attentive to child behavior and to inform the experimenter whenever the child needed a break. A testing session lasted four hours on average.

2.3. Measures

2.3.1. **Gap Task.** The Gap is a visual attention shifting paradigm and is included in this study to operationalize and measure visual disengagement. In this study, we included an infant friendly version of the task adapted from previous studies with infants (Elsabbagh et al., 2013; Johnson et al., 1991), featuring attractive and dynamic stimuli (a constricting-expanding cartoon clock) against a pink background and a gaze-contingent modality for the peripheral stimulus (sun, cloud, ball, star, dog). The central stimuli ranged between 2.1° x 2.1° and 3.3° x 3.3° visual degrees (°) in width, while the peripheral stimulus was 2.5° x 2.5° wide and appearing at a 19° eccentricity of visual angle from the center. The Gap task includes three conditions: Gap, Baseline and Overlap (although some studies only use the Gap and Overlap conditions). In all conditions, a central stimulus appears on a screen and is followed by a new stimulus that appears in the periphery. However, conditions differ on the timing of the onset of the peripheral stimulus in relation to the central stimulus. In the Gap condition, the central stimulus offsets 200ms before the onset of the peripheral stimulus (creating a stimuli-free gap in between stimuli). In the Baseline condition, the central stimulus offsets simultaneously to the onset of the peripheral stimulus. Finally, in the Overlap condition, the central stimulus remains displayed throughout the onset and presentation of the peripheral stimulus. In this gaze-contingent version of the task, the central stimulus remains displayed until the infant fixates on it. The task presents a random 600-700ms ISI. Screen side (right/left) for display of the peripheral stimulus was randomized. The main outcome variables for this study were: gaze shift latencies in the (1) Gap condition and in the (2) Overlap condition, and (3) visual disengagement score (the difference between mean latencies in the Baseline and Overlap conditions). Latencies were defined as the time it takes the gaze to shift from the central stimulus to the peripheral stimulus upon the onset of the latter and mean latencies for each condition and participant were computed.

The Gap task was part of a larger eye tracking battery (12 min in total) infants were seated on their caregiver's lap or on a car seat placed on the caregiver's lap facing the eye tracker and its screen. Experimenters adjusted the height and angle of the eye tracker until the infants gaze is centered and infant and caregiver are at an optimal distance from the display (approximately 65 cm). Once the infant's gaze is in an optimal position, a 5-point infant-friendly manually controlled calibration sequence is run. The calibration stimuli is composed of colorful dynamic spirals, with an onset diameter of ~6° of visual angle that shrink to a 0.5° diameter upon complete gaze measurement.

The task begun only after a calibration was deemed successful by the experimenter (repeated if necessary). Calibration stimuli were presented throughout the task battery (among which was the Gap task) at randomized positions. Infant behavior was monitored by the experimenters for the duration of the task. Experimenters were hidden from the infant's view behind a curtain but were able to monitor the infant's behavior in real time thanks to a camera placed on top of the eye-tracker. Whenever infants looked away from the screen or became fussy, experimenters redirected the infant's attention with the aid of auditory attention grabbers embedded in the script and produced with a key press. In case the child would become too fussy or upset the experimenter would pause the stimuli and offer a break, if the infant was not soothed promptly the experiment would be terminated.

2.3.2. **Mullen Scales of Early Learning (MSEL).** Developmental level was assessed using the MSEL (Mullen, 1995). The MSEL were created to assess cognitive skills in infancy and childhood, from birth up to 68 months and consists of five subscales: Gross motor, Visual perception, Fine motor, Receptive language and Expressive language. The MSEL were administered and scored by an experienced experimenter (a trained psychologist, research assistant or nurse practitioner). Age adjustments for prematurity and both younger/older twins (4 to 6 months) were done when calculating scores in line with MSEL guidelines. Each twin was assessed by a different member of the experimental team on a majority of cases. Special care was taken on this measure as to ensure a blind assessment of each child in the twin pair. A total raw score consisting of the sum of the raw scores of these scales was used as proxy of developmental attainment at 5 months.

2.3.3. **Vineland Adaptive Behavior Scales Second Edition (VABS-II).** Current adaptive level was assessed via parental report using the translated questionnaire format of the VABS-II (Sparrow, Balla, & Cicchetti, 2005). Parents were instructed to complete a subset of items relevant to 5 month-old infants prior to the visit (questionnaire was mailed to them beforehand). The scales and respective items to be completed by the parents were the following: Listening and comprehension (items 1-5), Speaking and communicating (items 1-6), Self-care (items 1-5), Relationship skills (items 1-9), Play and free time (items 1-3), Gross motor (items 1-7), and Fine motor (items 1-5). A total raw score consisting of the sum of the raw scores of these VABS-II subscales was used as a proxy of adaptive level.

2.4. Analysis of eye tracking data

Eye movements were recorded using a TX-300 Tobii eye-tracker. Stimuli were displayed on a 23" monitor with a 1920 x 1080 pixel resolution. All data was processed and analyzed offline using MATLAB (MathWorks) scripts designed for the Eurosibs study (Jones et al., 2019). In short, raw eye tracking data were segmented around trial on/offset event markers. Left and right eyes were averaged where both were available. In order to consider a trial valid, the quality of the data needed to be sufficient to compute a latency and for the infant to effect the expected gaze shift (from the central to peripheral stimuli). Specifically, the following criteria had to be met: (1) a minimum of 24ms of gaze on the CS and the PS to count as a shift to either stimulus; (2) no more than 200ms of gaze samples could be missing when attending the central stimulus; (3) no more than 50ms periods of gaze samples could be missing when attending the central stimulus; (4) there were no anticipatory saccades (gaze moving in the opposite direction after exiting the central stimulus); (5) latency duration was in the 150ms-1200ms range. Trials not meeting this criteria were excluded.

2.5. Statistical analysis

Gaze latencies vary in length in response to the different experimental variations in each of the tasks conditions. Typically, the Gap condition elicits the shortest latencies, followed by the Baseline and lastly by the Overlap which, as the competition condition, elicits the longest latencies. As a first step in the analyses we assess if the latencies obtained in this sample replicate this increasing pattern using a repeated measures ANOVA including only one twin from each pair in order to not violate the independence of observations assumption. We only take this approach (selecting one twin per pair) for this analysis since it is not the main research question addressed by this study.

Analyzing twin and family data presents the challenge that data points are not independent. If one were to ignore this and assume independence, the standard errors (SE) will be too narrow. To address this issue in this study, we made use of GEE models which are typically regarded as an extension of the standard general linear model. GEEs are suitable for testing associations in twin and other clustered data since they can account for the non-independence of the data (twin pairs), in this case by computing cluster-robust SEs using the Sandwich Estimator which allows for each cluster (twin pair) to have its own variance, as residuals are not required to be homogeneous. Additionally, GEEs are able to handle a variety of data types (e.g. binary, continuous) which allowed us to analyze our full data set (n= 436) (Hardin & Hilbe, 2002; Homish, Edwards, Eiden, & Leonard, 2010). Twinning occurs in all sections of society and it has been broadly shown that findings from twin samples can generalize to singletons (Rijsdijk & Sham, 2002).

Associations between the dependent and independent variables were estimated using three general linear regression models within the generalized estimating equations (GEE) framework, using the drgee package from R (Zetterqvist & Sjölander, 2015). We conducted two rounds of analyses. The first round is a more general approach while the second round is more domain-specific. However, we proceed to the domain-specific second step only if meaningful associations are observed in the analyses in the first round. In each round we assess three models which solely differed on the dependent variable (gaze latency in the Gap condition, in the Overlap condition or the visual disengagement score). Our predictors for the models were sex and SES and, in the first round, the total raw scores from the MSEL and the VABS-II. Predictors in the second round were sex, SES and domain-specific subscale raw scores from both MSEL and VABS-II. We controlled for age in all analyses since there may be subtle developmental changes in this age range. All statistical analyses were performed in R (www.r-project.org).

3. RESULTS

Complete observations were available for 436 participants, of which 261 were grouped into clusters of two (twin pairs). Descriptive statistics for the main variables of the full sample can be found in Table 1. We first report condition latency differences in the Gap task and then proceed to report association correlates between gaze latencies, visual disengagement and concurrent developmental measures and sociodemographic factors.

3.1. Condition effect in the Gap Task

As expected, a repeated measures ANOVA (*n*= 237) revealed a statistically significant differences in SRTs between conditions ($F(2, 708) = 449.77$, $p < 0.0001$, eta2[g] = 0.56). Latencies showed the expected stepwise effect of condition of this task. That is, where the shortest latencies are elicited by the Gap condition (M=306.27ms), followed by the Baseline (M=355ms), and lastly by the Overlap which elicits the longest (M=501.34ms) (Figure 1). Planned pairwise comparisons using Bonferroni correction for multiple comparisons confirmed mean latencies were significantly different between all conditions (p<.001).

[**Figure 1**]

3.2. Associations with development, adaptive skills, SES, sex and age

General Estimating Equation (GEE) models (*n*=436) showed statistically significant effects of both Sex and SES on Gap, Baseline and Overlap conditions latencies. Specifically, gaze shift latencies in the Gap condition were faster in girls than in boys (p=.004) (Figure 2). Gaze shift latencies in the Overlap condition were faster for indiviuals with lower family SES (p=.031) (Figure A.1). Gaze shift latencies in the Baseline were faster in girls than in boys (p=.009) and in individuals with lower family SES (p=.01). The interaction between Sex and SES was not significantly associated with gaze shift latencies in any of the conditions, thus this term was not included in the model. We observed no evidence of associations of visual disengagement and latencies in the Gap Task conditions with any of the behavioral variables included in the model (MSEL and VABS-II total scores) (Table 2). Therefore, as planned, we did not pursue further analyses (round 2 analyses). We observed Age, which was included as a covariate did not seem to significantly affect any of the eye tracking variables.

[**Figure 2**]

4. DISCUSSION

In this study, our aim was to investigate cross-sectional associations between performance in the Gap task in early infancy (gaze shift latencies and visual disengagement) on the one hand, and measures of development and adaptive behavior, sex and socioeconomic status effects, on the other. We found that, as expected based on the existing literature, mean latencies significantly differed from one condition to another in the following pattern Gap<Baseline<Overlap, replicating other infant studies using the Gap Task (Cousijn et al., 2017; Hood & Atkinson, 1993). In addition, mean latencies in the Gap Task were in line with those previously reported for the five month age group (Johnson et al., 1991; Jones et al., 2019). Disengagement, defined as the difference between overlap and baseline latency scores was almost identical to that reported in an infant multisite study using the same task (Jones et al., 2019). This confluence of measurements speaks to the generalizibility and stability of the Gap Task and its measures in infancy studies despite the complications that typically characterize data from this age group (Hessels & Hooge, 2019).

In terms of sex-related effects, we observed that female infants were faster than male infants in the Gap condition. The Gap condition in this paradigm is often thought to capture performance of the alerting network (Posner & Petersen, 1990), but also as a measure of oculomotor efficiency (Elison et al., 2013). The time gap which gives the Gap condition its name has been posited as both attention freeing (by the central stimulus offset) and as a cue (eliciting alertness). While it could be the case that at five months of age, females display more efficient oculomotor performance, it could also be that they are more receptive to cueing effects. Sex driven cueing effects may reflect sex differences in the Alertness, as in “readiness to react” or to “anticipate” an impending stimuli, which is closely tied to the noradrenergic system with the locus coerulues displaying differential activation patterns in anticipation periods (Colombo, 2001).

Alternatively, it could be that, at five months, females are more receptive to cues (the gap) than males in this condition. Whether this "receptiveness" is beneficial or not is up for debate. Previous studies featuring similar, yet more complex, cognitive tasks have reported that adult females may respond to cues differently than their male peers (Bayliss et al., 2005; Mezzacappa, 2004; Stoet, 2010). However, these studies report slower reaction times for females when it came to non-informative (similar to the gap) or incompatible cues. Interestingly enough, one of these studies reported no differences between male and female reaction times to neutral cues (much like the gap in our study) (Stoet, 2010), while another reported faster (although non-significant) reaction times in females than in males, to compatible cues (flankers) in the ANT task (Mezzacappa, 2004). Females were also more mistake prone than males during compatible trials (Mezzacappa, 2004). This higher mistake number could indicate that this "readiness" to cues perhaps comes at a cost of accuracy in females. Alternatively, it could be that this "enhanced" performance in infancy becomes unfavorable later in life resulting in higher susceptibility to distractors. Nonetheless, what is likely is that differential cueing effects on gaze latencies as a function sex are already observable at five months of age. However, since we did not have an accuracy metric for gaze shifts in this study, whether these "readiness" effects were favorable or detrimental remains unclear. No other sex effects were found on the other eye tracking variables.

In addition, we observed an effect of SES on latencies in the overlap condition of the task. SES was operationalized as maternal highest level of education and split into two tiers(low/high). Results showed a significant effect of SES, where infants with mothers who were highly educated displayed slower Overlap latencies. While this result may appear counterintuitve (since faster latencies are typically seen in the literature as "better" performance in older subjects), it could be that slower disengagement in the overlap condition does not mean "worse performance", particularly in infancy. Gaze shifts to a target are typically imprecise, with an undershooting bias (making saccades that fall short from the target) the norm rather than the exception. In infancy, saccadic accuracy is substantially poorer and the tendency to wholly undershoot is considerably greater with several catch-up eye movements following the initial one (Harris, 1995). As mentioned previously, evidence has shown that faster latencies are not necessarilly better when it comes to accuracy in the Gap overlap task (Siqueiros Sanchez et al., 2019). Thus, it could be that speed comes at a cost of accuracy, and that in early infancy this cost is higher. A potential reason for this increased latencies in the Overlap condition could be that highly educated mothers make a point of interacting more meaningully with their infants thus engageing in more stimulating activities that result in a more efficient visual system, albeit slower. This potential association could be tested by comparing "scaffolding" behaviors during play time with infants across different SES levels. This result and its interpretation should be, nonetheless, taken with caution as our study sample has a comparably higher SES than samples from other European sites and countries (Jones et al., 2019), thus warranting caution to the generalizability of our findings.

Additionally, we observed that gaze shift latencies in the Baseline condition were associated with both SES and sex. Since the observed pattern was similar to that in other conditions, infants in families with lower SES and girls having faster gaze shift latencies, this could reflect that these effects are not clearly linked to one condition. It may be that it rather reflects a shared factor between all conditions, such as basic aspects of oculomotor efficiency or function (Elison et al., 2013).

Contrary to what we expected, we did not find associations to observed developmental level (MSEL) nor to adaptive behavior levels (VABS-II) at 5 months of age. This apparent lack of corrleation between measures would suggest that skills develop independently from each other (at least to a certain extent) at this 5m time point. One potential explanation is that the demands at this age are simply not complex enough for visual atypicalities to play a strong enough role. However, it should be taken into consideration that extreme outliers were removed (up to 3 SDs) for the final analyses - when outliers were included in the analyses we observed significant associations between latencies in the Gap and the MSEL raw total score. The observed non-significant associations upon outlier removal suggest that these outliers were the ones driving the associations to MSEL scores. Therefore, it appears plausible that in cases of extreme visual atypicality, these would impact on other skills but not when variation is within a “typical” range. Alternatively, it could be that performance on the Gap Task is heavily influenced by the physical characteristics of the stimuli (e.g. salience, brightness, etc.) and thus the degree/ease of disengagement may vary across situations (Hunnius, 2007). Thus in this case, the experimental paradigm may be elicitng non-ecological responses that are not associated with behaviors assessed in the MSEL and the VABS-II. This, however, does not rule out that a more ecological measure of disengagement (that reflects infant experiences more accurately) would correlate with higher order behaviors of which it is an essential part of.

This study is not without limitations. Contrary to eye-tracking studies in adult populations where many trials are available (up to ~100s trials per participant) (Fischer, Gezeck, & Hartnegg, 1997), infant research usually must rely on significantly fewer trials per participant due to the challenges that infant participants convey (Wass, Forssman, & Leppänen, 2014). However, by including a large sample of participants we hope to mitigate the effect of lower trials per participant. Another limitation is the generalizability of our results. First, while our sample may be representative of Stockholm, and perhaps the Nordic countries in general, in terms of SES (a majority of high SES), this may not extended to other regions where wealth disparity is further pronounced and that are known to have an impact (Forssman et al., 2017). Second, our findings are based on twins rather than singletons and the assumption that our findings will generalize too all children. Typically, this is a fair assumption as results from twin studies are generalizable to singletons with the exception of certain traits/events more common in twins (e.g. obstetric complications) (Rijsdijk & Sham, 2002). Therefore although we attempt to provide some normative knowledge of the associations between oculomotor and visual attention functions with broader developmental outcomes, we are in fact limited in the conclusions we can draw for those infants growing up in less privilged circumstances.

5. CONCLUSION

Our study shows that visual attention is associated with biological sex and SES in early infancy. Sex-related differences in basic visual skills may reflect differential responses to cueing effects. We observed a link between visual attention and SES, although we note that this effect was small. Our results suggest that visual attention and visual disengagement in early infancy are uncorrelated to observable developmental level and adaptive skills. Given its large sample size, this study should provide a useful reference base for future studies of this task in young infants.

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8. FIGURES LIST

9. TABLES

	Mean (SD)	Range	Mean valid trials	Skewness	Kurtosis
Demographics					
Age (days)	167.40(8.73)	145 , 203	-	0.59	3.61
Sex	Males *n* = 226 Females *n* = 210	-	-	-	-
SES		-	-	-	-
1	*n*= 71	-	-	-	-
2	*n*= 365	-	-	-	-
Developmental and Adaptive Behavior					
MSEL	34.25 (2.88)	26 , 45	-	0.31	3.83
VABS-II	44.29 (7.67)	26 , 73	-	0.43	3.37
Eye tracking					
Gap gaze shift latency	306.27 (40.83)	216.57 , 437.71	15.61	0.67	3.33
Baseline gaze shift latency	355 (58.17)	245.4 , 627.5	16.23	1.11	5.31
Overlap gaze shift latency	501.34 (108.75)	296.20 , 790.60	15.18	0.39	2.40
Visual disengagement	146.31 (93.10)	-53.44 , 456.46	-	0.52	2.84

Table 1. Descriptive statistics. SES= Socioeconomic status; this variable is split into two levels: (1) Primary education and Secondary education and (2) Tertiary education 1-3+ years of post-secondary education. Frequencies are reported for SES categories. MSEL=Mullen Scales of Early Learning, raw total scores. VABS-II= Vineland Adaptive Behavior Scales 2nd Ed., raw total scores. Eye tracking variables are reported in ms, with Visual disengagement being a difference score (Overlap – Baseline).

	Gap		Overlap		Visual Disengagement	
	Estimate	*P*	Estimate	*P*	Estimate	*P*
MSEL	-1.2 (-2.8, 0.3)	0.125	-2.9 (-6.7 , 0.9)	0.123	-1.36 (-4.4, 1.7)	0.39
VABS-II	0.3 (-0.3, 0.9)	0.299	0.1 (-01.4 , 1.6)	0.887	-0.57 (-2, 0.7)	0.391
Sex	**6.2 (1.9, 3.8)**	**0.004**	6.3 (-5.1, 17.1)	0.315	-2.22 (-12.1, 7.7)	0.66
SES	-0.9 (-6.5 , 4.7)	0.744	**-14.9 (-28.5, -1.4)**	**0.031**	-6.9 (-18.5, 4.8)	0.248
Age	0.1 (-0.4 , 0.5)	0.817	-0.6 (-2 , 0.7)	0.410	-0.8 (-1.9 , 0.4)	0.19

Table 2. GEE models of Gap Task conditions (Gap and Overlap) as well as the Visual Disengagement difference score. MSEL= Mullen Scales of Early Learning Raw total score; VABS-II= Vineland Adaptive Behavior Scales 2nd Ed.; SES=Socioeconomic Status.

APPENDIX A

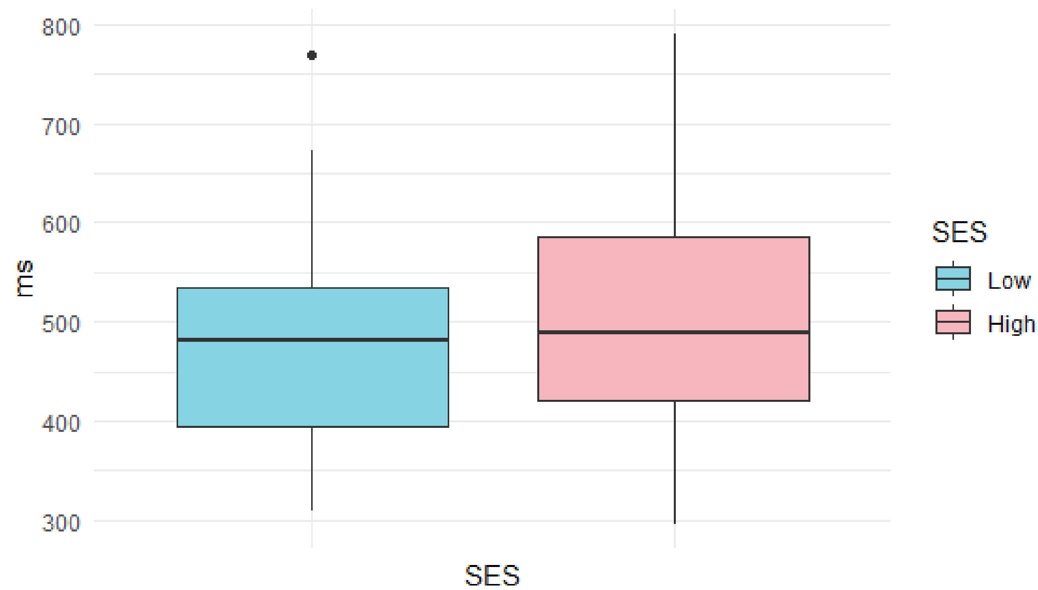

Figure A.1. Comparison of mean latencies (in ms) in the Overlap condition against Socioeconomic status (SES); SES is split into two tiers depending of years of maternal education: Primary education and Secondary education (Blue) and Tertiary education 1-3+ years of post-secondary education (Pink).