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Sustained looking at faces at 5 months of age is associated with socio-communicative skills in the second year of life

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Abstract
Efficiently processing information from faces in infancy is foundational for nonverbal communication. We studied individual differences in 5-month-old infants' (N = 517) sustained attention to faces and preference for emotional faces. We assessed the contribution of genetic and environmental influences to individual differences in these gaze behaviors, and the association between these traits and other concurrent and later phenotypes. We found an association between the mean duration of looking at a face (before looking away from it) at 5 months and socio-communicative abilities at 14 months ($\beta = 0.17$, 95% CI: 0.08; 0.26, $p < 0.001$). Sustained attention to faces predicted socio-communicative abilities over and above variance captured by mean fixation duration. We also found a statistically significant but weak tendency to prefer looking at smiling faces (relative to neutral faces), but no indication that variability in this behavior was explained by genetic effects. Moderate heritability was found for sustained attention to faces ($A = 0.23$, CI: 0.06; 0.38), while shared environmental influences were non-significant for both phenotypes. These

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findings suggest that sustained looking at individual faces before looking away is a developmentally significant 'social attention' phenotype in infancy, characterized by moderate heritability and a specific relation to later socio-communicative abilities.

1 | INTRODUCTION

A tendency to orient toward social stimuli, such as faces, is present already in early infancy (Farroni et al., 2006; Gliga et al., 2009), and is believed to be an evolutionary adaptive, innate mechanism that facilitates interaction with caregivers. This orienting mechanism is thought to be mediated by subcortical processes based on bottom-up sensory information, such as brightness and colors (Johnson, 2005). Over the first year of life, infants increasingly attend to faces in complex displays, while low-level salience has a decreasing influence on where infants look (Frank et al., 2014; Frank et al., 2009; Kwon et al., 2016). These findings suggest that mechanisms involved in top-down processing become increasingly important throughout the first year of life, aiding infants in guiding their attention to stimuli in their environment.

A preference for attending to faces (vs. non-social objects) is considered an important and evolutionary conserved aspect of social communication in infancy, and a requirement for more complex social capacities (Klin et al., 2015). One longitudinal study found that reduced face preference at 5 weeks of age predicted callous-unemotional traits at 2.5 years (Bedford et al., 2015), suggesting that, already very early in life, attention to social stimuli is important for later development. Another study of infant twins found that face preference at 5 months was heritable and linked specifically to verbal competence at 14 months (Portugal et al., 2023). The same specificity has been found for the tendency to look at either the eyes or the mouth, another social attention phenotype that has been found to be highly heritable in both toddlerhood (Constantino et al., 2017) and infancy (Viktorsson et al., 2023). A preference for looking at eyes (vs. the mouth) at 5 months is independent from concurrent development and specifically related to later language comprehension (Viktorsson et al., 2023). These findings suggest that social looking in infancy consists of multiple distinct mechanisms that may be, at least partially, heritable and linked to specific outcomes. It is notable that considerable individual differences in attention to faces have been found at such a young age, considering the importance of face perception for social development (Klin et al., 2015). This points to the need for further research into potential social attention phenotypes that might predict later development. Although some aspects of infant social looking have been studied, few early social attention measures that predict later socio-communicative abilities have been found, and the etiology of social looking in infancy is still largely unknown. If early social attention measures are influenced by genetic factors it could imply that infants either prioritize or deprioritize the social environment partly based on their individual genotypes (e.g., by looking at different aspects of the environment), potentially leading to cascading developmental effects (Kennedy et al., 2017). This type of gene-environment interplay might explain how seemingly small individual differences in early childhood may lead to vastly different developmental trajectories later in life.

Sustained attention to faces (i.e., maintained visual attention once the infant looks at a face) has been consistently reported in 4- to 8-month-olds (DeNicola et al., 2013; Escudero et al., 2013; Libertus & Needham, 2011), when the emergence of top-down processing enables the infant to shift attention between faces and other stimuli in the environment. Longer sustained attention to faces gives the infant an opportunity to scan the face more extensively, potentially giving them more information about communicative cues. Although associations between sustained attention to faces and later developmental traits have not yet been extensively studied, some studies have looked at similar phenotypes, such as fixation duration (i.e., the duration of a single gaze fixation on a specific location; White et al., 2022). One such study found that mean fixation duration at 7.5 months was associated with effortful control, surgency, and inattention-hyperactivity at 3.5 years of age (Papageorgiou et al., 2014). Another study found that 6-to 9-month-old infants with an elevated likelihood of autism displayed shorter fixation durations than typically developing infants, and that the shortest fixations were found in those later diagnosed with autism (Wass et al., 2015). Arguably, merely fixating on a specific location is not the same as scanning the entire face, and might not give the same type of information about the other person. Therefore, it is important to explore whether sustained attention can be distinguished from fixation durations, and whether there are individual differences in this measure that are associated with later development.

Against this background, we studied infants' sustained attention to faces, measured as the average duration of looking at an individual face before disengaging from it. We were interested in whether sustained attention to faces in infancy can be a useful predictor of later abilities and traits, and to what extent this measure is influenced by genes and environment. We therefore asked parents of monozygotic and dizygotic twins to rate concurrent and later abilities related to social communication and language. We explored the association between sustained attention and socio-communicative behaviors and general development at 5 months. We also explored the association between sustained attention at 5 months and language comprehension and socio-communicative abilities at 14 months, as well as vocabulary and autistic traits at 24 months. We then estimated the influence of genes and (shared and unique) environment on the sustained attention measure. Due to the fact that many studies of early visual behavior have used fixation durations as a measure of sustained attention, we included mean duration of individual fixations to explore the specificity of the sustained attention measure.

Faces can convey many different types of information, including information about the emotions of others. Earlier research has shown that infants can discriminate both among different categories of emotional facial expressions (Barrera & Maurer, 1981; Soken & Pick, 1999) and within the same category (Bornstein & Arterberry, 2003; Kuchuk et al., 1986). Kahana-Kalman and Walker-Andrews (2001) showed that when contextual information (i.e., person familiarity) was available, infants as young as 3.5 months of age could distinguish happy and sad expressions. Whether there are stable individual differences in these early emerging skills, and to what extent such variability reflects differences in genetic and environmental factors, is not known.

A second aim of the study was therefore to investigate individual differences in infants' attentional biases toward emotional facial expressions, by showing them a picture with one happy face and two neutral faces. We expected, at a group level, to find a preference for looking at smiling faces, measured as the ratio of total looking time at the smiling face relative to all faces. Due to earlier findings of moderate heritability of emotion identification in adulthood (Routledge et al., 2018), we expected a preference for smiling faces to be a heritable trait, but we had no expectations regarding the level of heritability due to the lack of prior research. It is also plausible that infants' exposure to happy faces in their lives influences their subsequent orienting to such faces, and it is likely that parents differ substantially in terms of how much they show emotional expressions to their child. For example, it is known that parents who are depressed show less positive affect (Aktar et al., 2017). Although differences in parent behavior may be correlated with child genetics (via gene-environment correlation), it is not unlikely that also shared environment could play a role in forming individual differences in social looking.

Because a preference for smiling (vs. neutral) faces might reflect selective attention to social and emotional stimuli, we hypothesized that a preference for smiling faces at 5 months would be positively associated with language comprehension at 14 months and expressive vocabulary at 24 months. We also hypothesized that a preference for smiling faces would be positively correlated with general developmental level at 5 months. Furthermore, we explored the association between preference for smiling faces and socio-communicative abilities at 14 months and autistic traits at 24 months, although we had no directional hypothesis regarding these associations. While the eyes communicate a range of socio-communicative and emotional information (Calder et al., 2002), the mouth is associated more specifically with visual speech information (Yehia et al., 1998). Because both a preference for the eyes (relative to mouth) and a preference for emotional faces might reflect an active seeking of emotional information, we also hypothesized that a preference for looking at the eyes would be associated with a preference for smiling faces.

The second aim of the paper was formally pre-registered (https://osf.io/du263/), while the first aim relating to sustained attention was not pre-registered.

2 | METHODS AND MATERIALS

2.1 | Participants

The Babytwins Study Sweden (BATSS) consists of 622 same-sex twins (311 pairs) that were recruited from the national population registry (only the greater Stockholm area was selected). In total, 29% of the invited families participated in BATSS. Data collection was performed at the Center of Neurodevelopmental Disorders at Karolinska Institutet (KIND) in Stockholm. See Table 1 for sample demographics (in-depth demographics are reported elsewhere; Falck-Ytter et al., 2021). The present study was conducted according to guidelines laid down in the Declaration of Helsinki, with written informed consent obtained from a parent or guardian for each child before any assessment or data collection. All procedures in this study were approved by the regional ethics board in Stockholm.

General exclusion criteria for the study were opposite-sex twin pairs, diagnosis of epilepsy, known presence of genetic syndrome related to autism, uncorrected vision or hearing impairment, very premature birth (prior to week 34), and presence of developmental or medical condition likely to affect brain development (e.g., Cerebral Palsy, hydrocephalus). Among the recruited and tested infants, three twins were excluded from analysis because they subsequently were found not to fulfill the above general criteria due to seizures at the time of birth ($n = 2$ twins) and spina bifida ($n = 1$ twin). In addition, for this analysis we excluded infants due to twin-to-twin transfusion syndrome ($n = 12$ pairs) and birthweight below 1.5 kg ($n = 1$ twin). Further, some infants did not provide any data due to technical reasons, lack of room or testing time during the visit to the lab, or infant being too tired or too fussy ($n = 7$ pairs + 5 twins). Lastly, some infants did not have enough valid data for the task (58 twins, see section *Eye tracking* for details). The final sample consisted of 517 infants (see Table 1). There were no

TABLE 1 Descriptive statistics.

		Mean (SD)[a] [min–max]	
	***N* (total)**	**MZ**	**DZ**
N females (%)	248	132 (46.3%)	116 (50.0%)
Age (in days)[b]	517	167.6 (8.5) [149–191]	167.9 (9.0) [145–203]
Parental education[c]	517	3.28 (0.75) [1.5–4]	3.30 (0.71) [1.5–4]
Family income[d]	501	6.44 (2.26) [1–10]	6.77 (2.40) [1–10]

[a]Except for *N* females, which shows the frequency.

[b]5 twin pairs differed in age, in these cases the mean age was used.

[c]Education level on a scale from 1 to 4, where 1 = Primary, 2 = Secondary, 3 = Undergraduate (≤3 years) and 4 = Postgraduate level (>3 years).

[d]Family income per month. Scale 1–10 where 1 = <20K, 2 = 20–30K, 3 = 30–40K, 4 = 40–50K, 5 = 50–60K, 6 = 60–70K, 7 = 70–80K, 8 = 80–90K, 9 = 90–100K and 10 = >100K (SEK).

statistically significant differences between the included infants and the infants excluded due to lack of valid data regarding age, sex, parental education or family income.

The eye-tracking procedure and the experimenter-rated developmental assessment were conducted during the initial 5-month lab visit (Falck-Ytter et al., 2021). During this visit, the twins performed different tasks at the same time, in separate rooms. Several parent-report measures were administered again at 14 and 24 months as part of the larger aims of the study to track development.

2.2 | Stimuli and measures

Eye tracking: Gaze data was recorded using the Tobii T120 Eye-tracker with a sampling rate of 60 Hz, using a standard Tobii monitor at native resolution (1024 × 768). The infant was seated in a baby chair or in the parent's lap, approximately 60 cm from the screen. Before the eye tracking session, a 5-point calibration video was presented, and the experimental task did not begin until a successful calibration was achieved. Another 5-point video for offline calibration validation purposes was shown once in the beginning of the eye tracking session.

The infants were presented with six images in a pseudo-random order, interspersed with other social and non-social stimuli not directly related to the current research question (for details, see Falck-Ytter et al., 2021). The images contained three different faces, of which two displayed a neutral facial expression and one displayed a happy facial expression Figure 1; pictures of faces were obtained from the FACES-database (Ebner et al., 2010). Each image was shown for 5 s. The location of the smiling face was balanced across trials.

Data were analyzed using custom scripts written in MATLAB (available upon request). After data collection was finished, the data from the additional 5-point calibration video were evaluated via ocular inspection, and three categories of calibration quality were created; (1) OK (N = 179), (2) OK with correction (N = 148; a simple linear transformation of data was

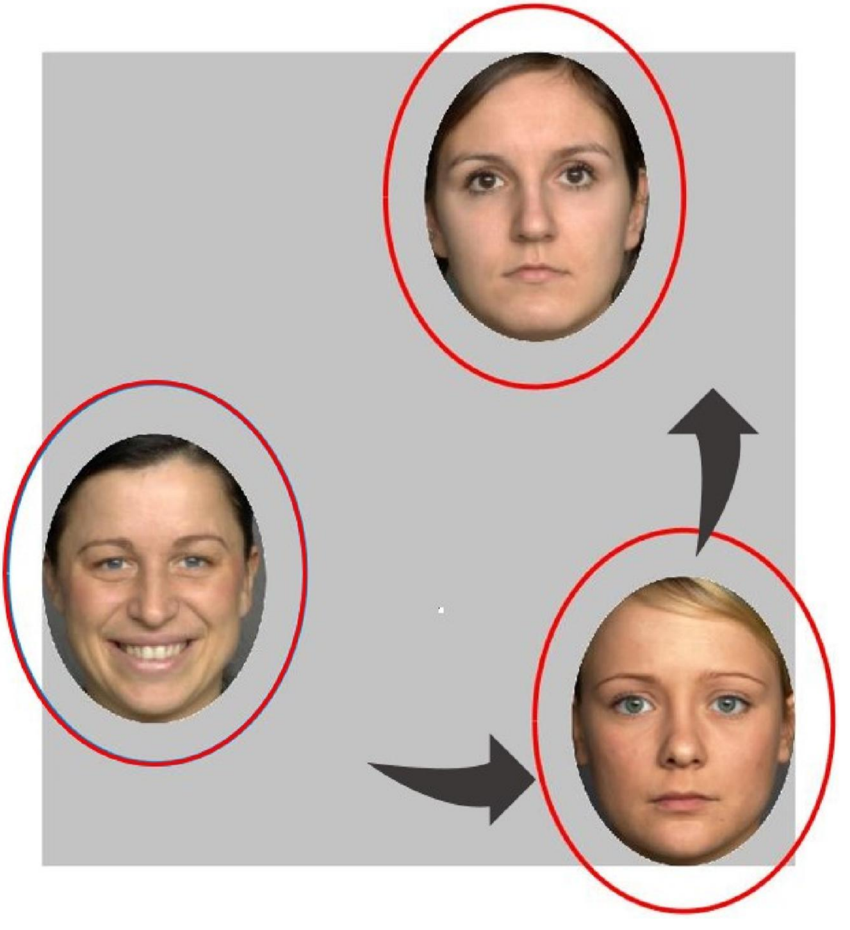

FIGURE 1 The areas of interest (AOI) plotted on a stimuli image. The sustained attention measure is illustrated by the arrows showing the gaze entering and exiting an AOI.

performed using custom MATLAB scripts), and (3) unclear ($N = 231$). Categories "OK" and "OK with correction" were combined when used in further analyses. Areas of interest (AOIs) were created for each image, each an ellipse with a horizontal radius of 180 pixels and a vertical radius of 230 pixels (Figure 1).

Sustained attention was operationalized as the mean duration of looking at one of the face AOIs (regardless of emotional expression) before looking away from that face (i.e., exit time minus entry time, averaged for all instances of looking at a face in each trial, then averaged across valid trials). Preference for smiling faces was operationalized as the mean ratio of looking at the smiling face, relative to all faces (giving us a scale from 0–1, where 1 means looking at the smiling face 100% of the time and 0 means looking at the neutral faces 100% of the time). The eye-mouth-index (EMI) was measured as the total amount of gaze toward the upper half of each face AOI divided by the total amount of gaze toward both the upper and the lower parts of the AOIs (again giving us a scale from 0–1, where 1 means looking at the eyes 100% of the time and 0 means looking at the mouth 100% of the time). If on a particular trial a participant looked at the screen for less than 1000 milliseconds or looked at the faces less than 70% of the time spent looking at the screen, the trial was considered to be invalid and was rejected. Only infants with at least three valid trials were included in further analyses. Additionally, we calculated the mean fixation duration (averaged over all included trials for each participant). Fixation durations were extracted from raw gaze data to the whole screen, and were analyzed using the fixation detection algorithm I2MC (Hessels et al., 2017), which facilitates two-means clustering. This means that the gaze position signal (within a moving window) are forced into two clusters. Few (but concentrated in time) cluster membership transitions during that window indicates a saccade, while more frequent and spread out transitions indicate a fixation (where membership transitions are driven by noise). For full details, see Hessels et al. (2017). Fixation durations were only considered valid if the temporal duration was 100 milliseconds or longer.

2.2.1 | Parent-rated questionnaires

The Vineland Adaptive Behavior Scales is a standardized measure of adaptive behaviors across four domains (Sparrow & Cicchetti, 1985). It was administered at 5 months, and we used the standard scores for Communication and Socialization domains to measure socio-communicative behaviors. Items included are, for example, whether the infant looks in the direction that the parent looks at or points at, and whether the infant looks at the parent when hearing their voice.

The CSBS DP Infant Toddler Checklist, ITC (Wetherby & Prizant, 2002), is a 24-item parent-rated questionnaire, used to identify children with any type of communication delay, including autism. Lower scores indicate a higher degree of socio-communicative delays. Items include, for example, questions on whether the parent knows when the child is happy or sad, and whether the child lets the parent know when they need help reaching an object. It was administered at 14 months, and we used the total score as a measure of socio-communicative behaviors linked to autism.

The Early Behavior Questionnaire, ECBQ (Putnam et al., 2006), is a measure of childhood temperament. The short form was administered at 14 months, and we used the subscale Effortful Control as a measure of inhibitory control and attention shifting. Items included in this subscale are, for example, whether the child can refrain from a behavior under instruction and whether the child can resist distractions.

The MacArthur Communicative Development Inventory, CDI (Fenson et al., 1993), is a parent-rated questionnaire that assesses early language development. It was administered at 14 months (the Words and Gestures form) and 24 months (the Words and Sentences form). As a measure of receptive vocabulary at 14 months, we used the total number of words (out of 370 words) that the infant could understand even though they might not produce them. At 24 months, we used the vocabulary checklist score as a measure of expressive vocabulary.

The Quantitative Checklist for Autism in Toddlers, Q-CHAT (Allison et al., 2008), is a normally distributed quantitative measure of autistic traits, which consists of 25 parent-rated items scored on a 5-point scale (0–4) and was administered at 24 months. The scores from all items are summed to obtain a total score, where higher scores indicate more autistic traits.

2.2.2 | Experimenter-rated developmental assessment

The Mullen Scales of Early Learning, MSEL (Mullen, 1995), was administered by an experimenter at 5 months. This is a standardized assessment commonly used in many areas of psychology as a measure of cognitive development. The Early Learning Composite Score was used as a measurement of general cognitive ability. See Table 2 for descriptive statistics on parent-rated questionnaires and the experimenter-rated developmental assessment.

2.3 | Statistical analyses

All phenotypic associations were calculated using the robust sandwich estimator in generalized estimating equations (GEE) in order to account for the correlation between twins in a pair (Carlin et al., 2005), using the drgee package in R (Zetterqvist & Sjölander, 2015). The variables used in these models were regressed on age and sex before these analyses. Due to the explorative nature of the phenotypic analyses including the sustained attention measure, we adjusted the *p* values for these analyses using Bonferroni correction, dividing the measures into two groups: concurrent measures (three analyses) and follow-up measures (five analyses). The original significance threshold was $p < 0.05$, meaning that the adjusted significance threshold for concurrent measures is $p < 0.017$ and for follow-up measures $p < 0.01$.

We used univariate twin models to estimate the genetic and environmental contribution to variation in each eye tracking measure. The sources of variation in a trait can be divided into additive genetic influences (A; heritability), non-additive genetic influences (D) or shared environment (C; environmental factors that increase twin similarity, for example family environment), and unique environment (E; i.e., environmental influences that make twins different from each other, including measurement error). C and D confound one another in the classical twin design, and so cannot be estimated simultaneously based on twin data alone. Since monozygotic (MZ) twins share 100% of their segregating DNA, while dizygotic (DZ) twins on average share 50% of their segregating DNA, a higher within pair similarity among MZ twins than DZ twins suggests genetic contribution to a trait. In order to explore genetic and environmental influences we calculated twin correlations and then fitted an ACE model (with AE, CE, and *E* nested models for comparison). Due to the sample size, resulting in insufficient power, ADE models were not considered. A fully saturated model was first fitted in order to test the assumptions of equality of means and variances across zygosity and twin order. Sex and age were incorporated as covariates in all twin analyses. Data analysis was performed in R 3.6.3 (Team, 2017), and twin model fitting was performed through maximum likelihood optimization with the R package OpenMx, version 2.17.2 (Neale et al., 2016).

3 | RESULTS

3.1 | Sustained attention to faces

The mean sustained attention to faces (i.e., mean looking time at a face before looking away) was 1.33 s, with a standard deviation of 0.60 (see Figure S1 for the distribution of the variable). Descriptive statistics of eye tracking measures divided by zygosity and sex are presented in Table 3 (statistics of these measures for the total sample as well as twin 1 and twin 2 of each pair are presented in Table S1).

Sustained attention at 5 months was positively associated with socio-communicative development as measured by the ITC at 14 months ($\beta = 0.17$, 95% CI: 0.08; 0.26, $p < 0.001$, $N = 406$; see Figure S2), but not significantly associated with MSEL, Vineland, CDI, or Q-CHAT

TABLE 2 Descriptive statistics for concurrently and subsequently measured traits.

	Number of infants	Mean (SD) [min–max]	Skewness	Kurtosis
MSEL 5 months (ELCS)				
Females	241	95.53 (9.94) [67–129]	0.67	0.84
Males	259	94.24 (8.82) [72–132]	0.78	2.45
Total	500	94.86 (9.39) [67–132]	0.73	1.53
Vineland[a] 5 months				
Communication				
Females	244	39.86 (2.66) [21–42]	−2.60	12.49
Males	266	40.18 (2.43) [32–46]	−0.94	0.87
Total	510	40.02 (2.55) [21–46]	−1.85	7.77
Socialization				
Females	244	50.48 (2.26) [45–57]	1.37	1.05
Males	266	51.01 (2.66) [45–57]	0.84	−0.36
Total	510	50.76 (2.49) [45–57]	1.07	0.11
CDI 14 months (comprehension)				
Females	195	94.49 (67.21) [1–382]	1.25	2.54
Males	211	75.68 (67.97) [3–332]	1.48	2.08
Total	406	84.72 (68.17) [1–382]	1.33	2.10
ITC 14 months				
Females	195	35.96 (6.30) [20–52]	−0.13	0.11

(Continues)

TABLE 2 (Continued)

	Number of infants	Mean (SD) [min–max]	Skewness	Kurtosis
Males	211	34.06 (7.77) [11–51]	−0.35	−0.17
Total	406	34.97 (7.16) [11–52]	−0.36	0.11
ECBQ 14 months				
Females	209	4.33 (0.59) [2.78–6.15]	0.40	0.49
Males	232	4.33 (0.56) [2.79–5.76]	−0.13	0.07
Total	532	4.31 (0.58) [2.40–6.15]	0.03	0.52
CDI 24 months (production)				
Females	164	246.98 (140.61) [26–624]	0.66	−0.18
Males	160	167.49 (161.00) [1–689]	1.08	0.18
Total	324	207.73 (155.95) [1–689]	0.72	−0.29
Q-CHAT 24 months				
Females	169	25.01 (6.91) [2–39]	−0.56	0.88
Males	158	29.22 (8.00) [9–52]	0.44	0.31
Total	327	27.04 (7.74) [2–52]	0.14	0.97

[a]The standard scores have been derived from norms for 2-year-olds, due to it being the lowest age for which there exists Swedish norms.

(see Table S2 for full results). After finding the association between sustained attention and socio-communicative development, we included the ECBQ effortful control measure, in order to discern whether sustained attention was uniquely associated with socio-communicative abilities. There was no statistically significant association between sustained attention at 5 months and effortful control at 14 months ($\beta = 0.02$, 95% CI: −0.08; 0.12, $p = 0.684$, $N = 441$). Calibration quality was not associated with the sustained attention measure ($\beta = 32.18$, 95% CI: −78.17; 142.53, $p = 0.57$, $N = 483$). As an additional quality control, we analyzed the association between sustained attention and ITC total score while only including trials where the infants

TABLE 3 Descriptive statistics of eye-tracking measures ($N = 517$).

	Mean (SD) [min–max]			
	MZ males	**MZ females**	**DZ males**	**DZ females**
Mean looking time at screen (seconds, out of maximum 5 s)	4.07 (0.71) [1.87–5.00]	4.19 (0.61) [1.97–4.99]	4.24 (0.55) [1.92–5.00]	4.09 (0.65) [2.09–5.00]
Mean ratio of looking at smiling face (relative to all faces)	0.345 (0.133) [0.000–0.680]	0.354 (0.132) [0.003–0.706]	0.347 (0.111) [0.000–0.657]	0.367 (0.146) [0.010–0.821]
Mean eye-mouth-index	0.509 (0.210) [0.054–0.973]	0.462 (0.211) [0.073–0.892]	0.477 (0.209) [0.120–0.964]	0.520 (0.202) [0.052–0.997]
Mean sustained attention to faces (seconds)	1.32 (0.64) [0.28–3.49]	1.33 (0.59) [0.29–3.10]	1.37 (0.62) [0.45–4.37]	1.33 (0.53) [0.47–3.60]
Mean fixation duration (milliseconds)	364.4 (62.8) [240.7–572.3]	365.9 (55.8) [282.7–617.1]	354.4 (50.2) [250.0–583.9]	351.9 (52.5) [262.9–527.0]

TABLE 4 Generalized estimating equations analysis with sustained attention and fixation duration as predictors and socio-communicative abilities as outcome variable ($n = 406$).

	β	95% CI	p
Sustained attention	0.15	−0.05; 0.24	0.003
Fixation duration	0.07	−0.05; 0.19	0.248

looked at the screen for at least 50% of the duration of the trial. The association was still statistically significant (see Supporting Information S1 for details).

The correlation between sustained attention and mean fixation duration was statistically significant but moderate ($r = 0.414$, 95% CI: 0.322; 0.493, $p < 0.001$), suggesting that these measures are not interchangeable. When adding both sustained attention and fixation duration as predictors of socio-communicative abilities (ITC) in the same model, only sustained attention was a statistically significant predictor ($\beta = 0.15$, 95% CI: 0.05; 0.24, $p = 0.003$), see Table 4 for details. This entails that sustained attention reflected variance predictive of the later trait beyond what was shared with fixation duration.

Twin correlations of the sustained attention measure suggested genetic influence (i.e., MZ correlation being higher than DZ correlation; rMZ = 0.35, 95% CI: 0.17, 0.50; rDZ = −0.14, 95% CI: −0.33, 0.05), and the assumptions of equality of means and variances across zygosity and twin order were met (Table S3). The ACE model, and all nested models, fitted significantly worse than the saturated model (which summarizes the observed data, see Table 5 for details). When considering only the nested models in comparison with the ACE model, the AE model did not fit significantly poorer than the ACE model, and it suggested moderate significant heritability ($A = 0.23$, 95% CI: 0.06; 0.38; $E = 0.77$, 95% CI: 0.62, 0.94).

To discern whether the sustained attention measure is face-specific or not, we included data from another task in the eye tracking session at 5 months. This face pop-out task consisted of 6 different complex displays of objects (in a fixed order, each shown for 20 s). One face was shown in each picture, interspersed with the non-social objects (see Supporting Information S2 for full

TABLE 5 Univariate twin model for the sustained attention phenotype.

Model	−2LL	# Parameters	*df*	AIC	Comparison model	Δ χ^2	Δ *df*	*p*	A (95% CI)	C (95% CI)	E (95% CI)
Fully sat.	1372.87	12	482	408.87	-	-	-	-	-	-	-
ACE	1387.72	6	488	411.72	Fully sat.	14.86	6	0.021	0.23 (0.02; 0.38)	<0.001 (<0.001; 0.13)	0.77 (0.62; 0.94)
AE	1387.72	5	489	409.72	ACE	0.00	1	1.00	0.23 (0.06; 0.38)	-	0.77 (0.62; 0.94)
CE	1392.15	5	489	414.15	ACE	4.43	1	0.035	-	0.11 (<0.001; 0.24)	0.89 (0.76; 1.00)
E	1394.86	4	490	414.86	ACE	7.14	2	0.028	-	-	1

Abbreviations: −2LL, minus 2 log likelihood fit statistic; AIC, Akaike Information Criterion, lower value denotes better model fit: df, Degrees of freedom; Δ df, Change in degrees of freedom between two models; Δ χ2, Change in −2LL statistic between two models, distributed as χ^2.

details on the stimuli and exclusion process). The mean duration of looking at the faces (i.e., sustained attention) was calculated as the average looking duration at a face AOI before looking away from that face. In the same way, mean duration of looking at any of the non-social objects was calculated. Age and sex were regressed out before further GEE analyses. These three analyses were not preregistered, hence an adjusted significance value of 0.0167 was used. A statistically significant association was found between sustained attention to faces in the original task and the corresponding sustained attention to faces in the face-pop-out task ($\beta = 0.29$, 95% CI: 0.16; 0.43, $p < 0.001$, $N = 482$). No statistically significant association was found between sustained attention to faces in the original task and sustained attention to non-social objects ($\beta = 0.06$, 95% CI: −0.04; 0.15, $p = 0.239$, $N = 482$). In order to discern whether the association with later socio-communicative abilities is specific to sustained attention to social stimuli or not, the association between ITC total score and sustained attention to non-social objects was analyzed. This association was not statistically significant ($\beta = -0.02$, 95% CI: −0.13; 0.09, $p = 0.769$, $N = 376$).

3.2 | Preference for smiling faces

There was a slight preference for looking at the smiling face (relative to all faces; Table 3), which was significantly different from chance level (1 in 3 = 0.333) for both twin 1 (mean = 0.350, t (260) = 2.05, $p = 0.041$) and twin 2 (mean = 0.356, t (255) = 2.82, $p = 0.005$). The preference for looking at smiling faces was not significantly associated with any concurrently measured trait and did not predict any follow-up measures (Table S4). Similarly, there was no significant association between preference for smiling faces and the eye-mouth-index ($\beta = -0.06$, 95% CI: −0.15; 0.03, $p = 0.21$, $N = 517$). Calibration quality was not associated with the preference for smiling faces ($\beta = <0.001$, 95% CI: −0.02; 0.03, $p = 0.91$, $N = 483$). As an additional quality control, we analyzed the preference for looking at the smiling face, while only including trials where the infants looked at the screen for at least 50% of the duration of the trial. The mean preference for looking at the smiling face was now slightly lower and not significantly different from chance level in either twin 1 (mean = 0.345, t (259) = 1.37, $p = 0.173$) or twin 2 (mean = 0.349, t (252) = 1.70, $p = 0.090$).

The twin correlation for the preference of looking at smiling faces was higher for monozygotic twins than dizygotic twins, but the confidence intervals for both correlations included zero (rMZ = 0.07, 95% CI: −0.11, 0.23; rDZ = 0.02, 95% CI: −0.17, 0.21), suggesting that this measure was not influenced by familial factors (either genetic or common environment). After fitting a fully saturated model (Table S5), we fitted an ACE model, along with nested models for comparison. All familial components (A and C) could be dropped without worsening the fit of the model (Table 6), suggesting that individual differences in this measure only reflected unique environment and/or error in the measurement.

4 | DISCUSSION

This study found that longer sustained visual attention to faces at 5 months, irrespective of emotional valence (and operationalized as average looking time at any face before looking away), was moderately heritable and associated with parent-reported socio-communicative abilities at 14 months. Other infant behaviors that have been linked to later social

TABLE 6 Univariate twin model for the preference for smiling faces phenotype.

Model	−2LL	# Parameters	*df*	AIC	Comparison model	*Δ χ2*	*Δ df*	*p*	A (95% CI)	C (95% CI)	E (95% CI)
Fully sat.	−623.69	12	482	−1587.69	-	-	-	-	-	-	-
ACE	−618.30	6	488	−1594.30	Fully sat.	5.39	6	0.49	0.06 (<0.001; 0.21)	<0.001 (<0.001; 0.17)	0.94 (0.79; 0.100)
AE	−618.30	5	489	−1596.30	ACE	<0.001	1	1.00	0.06 (<0.001; 0.21)	-	0.94 (0.79; 1.00)
CE	−618.21	5	489	−1596.21	ACE	0.09	1	0.77	-	0.05 (<0.001; 0.17)	0.95 (0.83; 1.00)
E	−617.72	4	490	−1597.72	ACE	0.57	2	0.75	-	-	1

Abbreviations: −2LL, minus 2 log likelihood fit statistic; AIC, Akaike Information Criterion, lower value denotes better model fit: df, Degrees of freedom; *Δ* df, Change in degrees of freedom between two models; *Δ χ*2, Change in −2LL statistic between two models, distributed as χ^2.

development are, for example, joint attention (e.g., Vaughan Van Hecke et al., 2007) and anticipatory smiling (Parlade et al., 2009). However, research on very early phenotypes predicting social development in typically developing infants is scarce, and the sample sizes are often considerably smaller than in the current study. Notably, we found that longer looking to faces before disengaging from them did not merely reflect fixation duration; the association with later socio-communication ability survived when entering fixation duration in the model. We also found that the sustained attention measure was related to a corresponding measure of sustained attention to faces in a different experiment, while not being related to mean looking time at non-social objects, suggesting that this measure is face-specific. We did not find an association between sustained attention to non-social objects and later socio-communicative abilities, suggesting that the face-specific sustained attention is independently predicting socio-communicative development. Further, we demonstrated that the association was specifically linked to social communication, and not effortful control. This high level of specificity suggests that the identified measure could be a valuable addition to the existing (small) set of meaningful 'social attention' phenotypes in developmental research, with potential applications in both studies of typical and atypical populations.

At a psychological level, what could the variability in our sustained attention to faces measure reflect? First, it might be that longer looking times at faces reflect higher motivation to look at social stimuli. Because infants who spend more time looking at social objects presumably will learn more from them, this can also explain the positive association with later socio communicative ability. Secondly, it is possible that the variability reflects differences in the ability to inhibit reflexive orienting to faces in the periphery. Such basic social orienting is supposed to be governed by a sub-cortical neural circuit functional already at birth. This explanation fits rather well with the age of the infants, as at around 5 months face processing is increasingly under cognitive control, but there may be individual differences in the pace of this transition. Third, in principle, longer or shorter looks to faces could reflect the underlying duration of individual fixations. This explanation would be in line with the results of Wass et al. (2015), who found that infants later diagnosed with ASD showed significantly shorter fixation durations to social and non-social static stimuli than typically developing infants. Additionally, they found that shorter fixation durations during early infancy were associated with higher levels of socio-communicative difficulties at 36 months. However, although we found a statistically significant association between mean fixation duration and sustained attention to faces, the correlation was only moderate, suggesting that these two measures are not identical. And importantly, when adding both sustained attention and fixation duration as predictors of socio-communicative abilities, sustained attention predicted socio-communicative abilities over and above variance captured by fixation duration. Several studies have also found associations between fixation durations in infancy and temperament and behavioral difficulties in childhood (Papageorgiou et al., 2014, 2015). In contrast, we did not find a statistically significant association between sustained attention at 5 months and effortful control at 14 months. Thus, taken together, sustained attention to faces as operationalized here is a different phenotype than average fixation duration. Finally, we would argue that it is unlikely that the variability reflects individual differences in disengagement ability, because earlier studies show that infants with high likelihood of autism tend to move their gaze away from objects *slower* than other infants when something new appears in the periphery (e.g Elsabbagh et al., 2013; Zwaigenbaum et al., 2005). Thus, if this was the case, one would expect a positive correlation between socio-communicative difficulties and longer looking times on objects (including faces), reflecting a reduced flexibility in gaze behavior.

The twin correlations for the sustained attention measure suggested genetic influence (MZ correlation being higher than DZ correlation), indicating that individual differences in time spent looking at a face before looking away is partly based on differences in genotypes. This finding indicates that young infants may select how they view faces based on their genotype, which might influence what information they will be subjected to. For example, infants that scan faces for a long period of time might pick up on important social cues that may be missed by infants who quickly move their gaze away from faces. Formal twin modeling suggested moderate heritability, but shared environment did not seem to influence sustained attention to faces. However, these results were inconclusive, meaning that this finding should be interpreted cautiously.

There was a weak but statistically significant tendency to prefer looking at a smiling face (relative to neutral faces) at 5 months of age (although this tendency was not evident when using a more conservative exclusion criteria). Individual differences in this preference predominantly reflected non-shared environment (including measurement error), meaning that there was no indication that genetic influences or shared environment had any effect on variability in this behavior. The preference for looking at smiling faces was not associated with any concurrently measured traits or follow-up measures, such as socio-communicative skills, general development, vocabulary, or autistic traits. Similarly, it was not associated with preference for looking at eyes (vs. mouth) at 5 months. Taken together, this pattern indicates that while statistically significant at the group level in our large sample, preference for emotional (happy faces) at this age may not represent a reliable measure of individual differences. Earlier studies have shown that infants already at around 3 months of age can distinguish among different facial expressions in a habituation paradigm (Barrera & Maurer, 1981) and in simultaneously presented faces when hearing a familiar voice (Kahana-Kalman & Walker-Andrews, 2001). However, we cannot rule out that our sample, perhaps due to our experimental setup, may not have discriminated happy faces from neutral faces, hence precluding a reliable measure of preference.

4.1 | Limitations

A limitation of the current study is the homogeneity of the sample with regards to living area and SES. In order to discern the generalizability of our findings, the current study needs to be replicated in other samples. In addition, many earlier studies using non-social stimuli to measure sustained visual attention in infancy have focused on outcomes such as information processing and intelligence scores (e.g., Geeraerts et al., 2019; Sigman et al., 1997), rather than socio-communicative behaviors. An important focus of future studies is therefore to further address the specificity of this visual attention measure both at the predictor level (social vs. non-social stimuli) and the outcome level (e.g., cognition, socio-communicative behaviors, executive functions). Relatedly, it will be important to include assessment of later development at older ages and via other means than parent report.

4.2 | Conclusions

This study finds that longer sustained attention to a face (regardless of emotional expression) in infancy is associated with socio-communicative abilities in toddlerhood, and that this association shows a high level of specificity. In addition, we found a weak but statistically significant tendency to look longer at smiling than neutral faces in early infancy, but this measure is unlikely to be useful as a measure of individual differences, at least in our experimental setup at 5 months of age. These results are important for our understanding of different aspects of infants' social looking behavior, their etiology, and their potential role in long term development.

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CONFLICT OF INTEREST STATEMENT

All authors declare no conflict of interest.

DATA AVAILABILITY STATEMENT

This study was preregistered at https://osf.io/du263/. Deviations from the preregistration are discussed in the text. Custom-made scripts for pre-processing and statistical analyses will be made available upon reasonable request to corresponding author. Note that sharing of pseudonymized personal data will require a data sharing agreement, according to Swedish and EU law.

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