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Preferential looking to eyes versus mouth in early infancy: heritability and link to concurrent and later development

Charlotte Viktorsson,[1] Ana Maria Portugal,[2] Danyang Li,[2,3] Maja Rudling,[1] Monica Siqueiros Sanchez,[2,4] Kristiina Tammimies,[2,3] Mark J. Taylor,[5] Angelica Ronald,[6] and Terje Falck-Ytter[1,2,7]

[1]Development and Neurodiversity Lab, Department of Psychology, Uppsala University, Uppsala, Sweden; [2]Division of Neuropsychiatry, Department of Women's and Children's Health, Center of Neurodevelopmental Disorders (KIND), Karolinska Institutet, Stockholm, Sweden; [3]Astrid Lindgren Children's Hospital, Karolinska University Hospital, Stockholm, Sweden; [4]Department of Psychiatry and Behavioural Sciences, Center for Interdisciplinary Brain Sciences Research, Stanford University, Stanford, California, USA; [5]Department of Medical Epidemiology & Biostatistics, Karolinska Institutet, Stockholm, Sweden; [6]Department of Psychological Sciences, Birkbeck, University of London, London, UK; [7]Swedish Collegium for Advanced Study, Uppsala, Sweden

Background: From birth, infants orient preferentially to faces, and when looking at the face, they attend primarily to eyes and mouth. These areas convey different types of information, and earlier research suggests that genetic factors influence the preference for one or the other in young children. **Methods:** In a sample of 535 5-month-old infant twins, we assessed eye (relative to mouth) preference in early infancy, i.e., before neural systems for social communication and language are fully developed. We investigated the contribution of genetic and environmental factors to the preference for looking at eyes, and the association with concurrent traits and follow-up measures. **Results:** Eye preference was independent from all other concurrent traits measured, and had a moderate-to-high contribution from genetic influences ($A = 0.57$; 95% CI: 0.45, 0.66). Preference for eyes at 5 months was associated with higher parent ratings of receptive vocabulary at 14 months. No statistically significant association with later autistic traits was found. Preference for eyes was strikingly stable across different stimulus types (e.g., dynamic vs. still), suggesting that infants' preference at this age does not reflect sensitivity to low-level visual cues. **Conclusions:** These results suggest that individual differences in infants' preferential looking to eyes versus mouth to a substantial degree reflect genetic variation. The findings provide new leads on both the perceptual basis and the developmental consequences of these attentional biases. **Keywords:** Twin design; visual attention; eye-mouth index; language comprehension.

Introduction

Looking behavior is important in infants' interactions with their surrounding world, as it is the earliest capacity to act on the environment by discriminating and selecting inputs for learning (Amso & Scerif, 2015; Conejero & Rueda, 2017; Hendry, Johnson, & Holmboe, 2019). Earlier research shows that children at a very young age preferentially attend to social stimuli such as faces (Farroni, Menon, & Johnson, 2006), and that upright faces are scanned more extensively than both inverted and phase-scrambled faces (Gliga, Elsabbagh, Andravizou, & Johnson, 2009). Infants' preferential looking at faces in complex displays increase considerably over the first year of life, while low-level salience (such as brightness and motion) has a decreasing influence on where infants look (Frank, Amso, & Johnson, 2014; Frank, Vul, & Johnson, 2009; Kwon, Setoodehnia, Baek, Luck, & Oakes, 2016).

Different areas of the face convey partly different types of information. While the eyes transmit a range of sociocommunicative and emotional information (Calder et al., 2002), the mouth is more strongly associated with visual speech information (Yehia, Rubin, & Vatikiotis-Bateson, 1998). In the first months of life, infants prefer looking at the eyes (Lewkowicz & Hansen-Tift, 2012), and then gradually change their preferential attention from the eyes to the mouth during the first year (de Boisferon, Tift, Minar, & Lewkowicz, 2017; Wagner, Luyster, Yim, Tager-Flusberg, & Nelson, 2013). Further, infants' attention to the mouth increases when stimuli involve speech (Frank, Vul, & Saxe, 2012; Lewkowicz & Hansen-Tift, 2012; Tenenbaum, Shah, Sobel, Malle, & Morgan, 2013), and earlier studies indicate that a preference for the mouth from 6 months of age is associated with larger vocabulary (Tenenbaum et al., 2015; Tsang, Atagi, & Johnson, 2018; Young, Merin, Rogers, & Ozonoff, 2009).

A recent study has suggested substantial heritability of eye and mouth preference in toddlers aged 18–24 months (Constantino et al., 2017). However, to the best of our knowledge, no study has yet investigated the genetic and environmental contribution to eyes-versus-mouth preference in the first

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year of (postnatal) life, when visual input is critical for shaping brain development, and before infants can actively select their environment by other means (crawling or walking). Therefore, the primary aim of this study was to establish the relative role of genetic and environmental influences on eye preference (relative to mouth) in early infancy, using eye tracking. Because infants tend to look at either the eyes or the mouth when viewing faces, we operationalized viewing preference as a single measure of total looking time at the eyes relative to the total looking time at both the eyes and the mouth (Figure 1) when infants saw videos (each 4–12 s long) of a woman singing, talking, and being still. Given the high monozygotic twin concordances found in the previous study of eye and mouth preference in toddlers (Constantino et al., 2017), we expected to find a moderate-to-high genetic contribution in young infants. This would provide evidence for active niche-picking very early in life, whereby selective visual attention on aspects of the others' faces is a heritable trait, which may shape subsequent learning and development (Kennedy et al., 2017).

Given the link between attention to the mouth and language development, we expected a positive association between a preference for looking at the mouth and follow-up measures of early language skills. Further, there is substantial, although inconsistent, evidence of atypical face-scanning in children and adults with autism spectrum disorder (ASD), and we therefore tested whether there is an association between eyes relative to mouth preference and later sociocommunicative difficulties. We did not, however, have a directional hypothesis in this case due to conflicting results in the literature (Chita-Tegmark, 2016; Falck-Ytter & von Hofsten, 2011). ASD can be seen as the extreme end of a continuum spanning the whole population (Robinson et al., 2011, 2016); therefore, studies of autistic traits are relevant also for our understanding of autism as a clinical condition, and vice versa. All above-mentioned hypotheses were preregistered in OSF (https://osf.io/s8y74/). Informed consent was obtained from the parents of all the twins who participated. The study was approved by the regional ethics board in Stockholm and was conducted in accordance with the Declaration of Helsinki.

Methods

Participants

The Babytwins Study Sweden (BATSS) consisted 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 Centre of Neurodevelopmental Disorders at Karolinska Institutet (KIND) in Stockholm, Sweden. Sample demographics are fully reported elsewhere (Falck-Ytter et al., 2021). Zygosity was estimated based on DNA sampled via saliva from all infants.

General exclusion criteria for the study were opposite-sex twin pairs, diagnosis of epilepsy, known presence of genetic syndrome related to ASD, uncorrected vision or hearing impairment, very premature birth (prior to week 34), presence of developmental or medical condition likely to affect brain development (e.g., cerebral palsy, hydrocephalus), and infants where none of the biological parents were involved in the infant's care. Among the recruited and tested infants, three

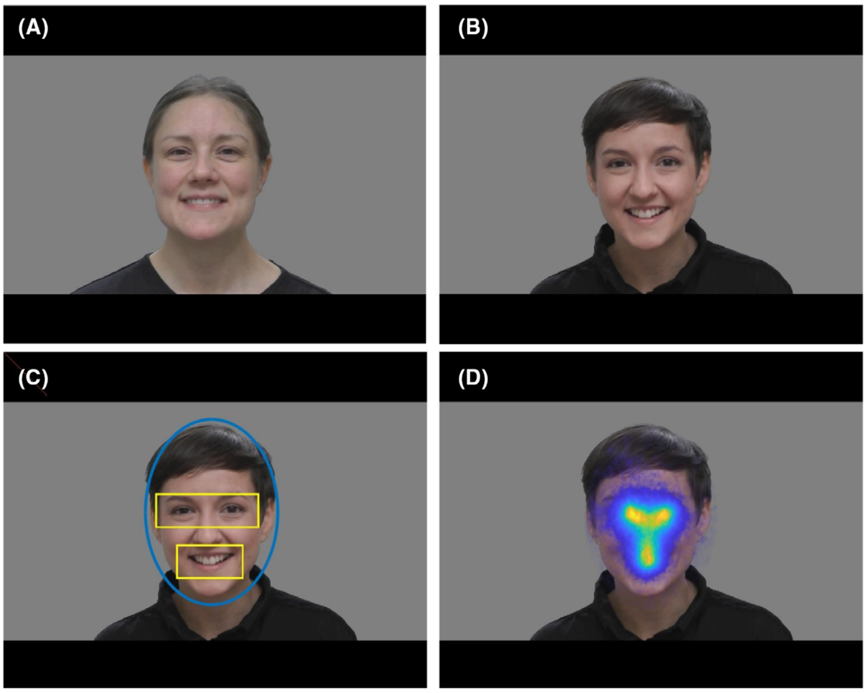

Figure 1 Experimental stimuli. (A, B) The videos comprised a set of face stimuli (still, speaking, singing) with the natural voice sound included, from two different models. (C) Areas of interests (AOIs) used for analysis. (D) An aggregated gaze heatmap of data inside the face AOI from all infants from all stimuli superimposed on one stimulus

twins were excluded from analysis because they subsequently were found not to fulfill the general criteria (above) 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), birthweight below 1.5 kg ($n = 1$ twin), and non-Swedish-speaking parents ($n = 1$ pair). Further, some infants did not provide any data due to technical reasons ($n = 3$ pairs), lack of time ($n = 3$ pairs + 1 twin), lack of room ($n = 1$ pair), infant being too tired or too fuzzy ($n = 4$ twins), and infant not having enough valid data for the task (38 twins, see section Eye tracking for details). The final sample consisted of 535 infants (see Table 1).

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

Measures

Eye tracking. Gaze data were recorded using the Tobii T120 Eye-tracker with a sampling rate of 60 Hz, using a standard Tobii monitor at native resolution (1,024 × 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.

For the main eye tracking analysis, each infant viewed 20 stimuli videos in a pseudo-random order. The videos comprised three conditions: Singing (12 videos of a woman singing common Swedish nursery rhymes); Talking (four videos of a woman saying common Swedish rhyme verses); and Still (four videos of a woman smiling). In all videos, a woman was centered in the video and the background was gray (there were two women, each of them contributing equally to all conditions). The length of the videos ranged from 4 to 12 s.

Data were analyzed using custom scripts written in MATLAB (available upon request). Because the dependent measures were measures of accumulated looking time, we did not apply fixation filters (Kennedy et al., 2017). After data collection was finished, the data from the additional 5-point calibration video were evaluated via ocular inspection, and a simple linear transformation of data was performed when linear drifts were detected (using custom MATLAB scripts). Then, the total amount of looking time at the screen for each trial was calculated. Areas of interest (AOIs, i.e., face, eyes, and mouth) were created to move dynamically in coordination with the stimuli (using custom scripts in MATLAB), and were validated using visual inspection of their coordinates superimposed on the video stimuli. The face AOI was an ellipse with a horizontal radius of 200 pixels and a vertical radius of 280 pixels. Both the mouth AOI and eyes AOI were rectangles, 200 × 100 pixels and 310 × 100 pixels, respectively (see Figure 1).

Our primary dependent variable was the eye-mouth-index (EMI), which was calculated as the mean amount of gaze in the eyes AOI, divided by the mean amount of gaze to both the eyes AOI and the mouth AOI (i.e., 1 = only eyes looking; 0 = only mouth looking). The reason for using data from both the eyes and mouth region in the same metric (rather than separate them) is partly due to the use of the EMI in earlier studies (Young et al., 2009). In addition, the EMI is independent of differences in total gaze or stimuli duration. Constantino et al. (2017) did not report the EMI in their study, but instead reported separately preference for eyes and preference for mouth (each relative to the whole screen). Because infants tend to look predominantly at the eyes and the mouth when looking at a face, these two measures are highly and inversely correlated; hence, the current EMI can be seen as largely analogous to the information reflected in the two measures reported in Constantino et al. (2017). Indeed, Constantino et al. reported that looking time in these two areas represented around 80% of infants' looking time to the stimuli when observing videos with a single face included (the type of stimulus used for heritability estimation in their study). To verify that the infants focused mostly on the mouth and eyes region (instead of other regions of the face, e.g., chin or nose) we created an aggregated heatmap of gaze data inside the face AOI from all infants for all trials, which shows that the eyes and mouth were the primary regions of interest (Figure 1). Further, we concluded that the eyes and mouth AOIs combined made up 75% of the gaze data toward the face (Table 1). See Figure S1 for the distributional properties of the EMI. As an additional check of reliability, we created aggregated heatmaps of all gaze data inside the face AOI for participants with extreme scores on the EMI (defined as lower than 0.10 or higher than 0.90), as well as all participants in-between (Figure 2). See also the descriptive statistics for the two extreme groups in Table S1.

We then implemented steps to exclude trials based on general distribution properties. Specifically, using the results from infants with good calibration data (including after linear transformation), we obtained the values for the 10th percentile

Table 1 Descriptive statistics

	Number of twins		Mean (*SD*)					
	MZ	DZ	MZ Males	MZ Females	DZ Males	DZ Females	Skewness	Kurtosis
N females (%)	139 (46.6%)	118 (49.8%)	–	–	–	–	–	–
Age (in days)[a]	298	237	167.2 (8.1)	167.8 (8.8)	167.3 (9.6)	168.0 (8.5)	.55	.41
Total EMI score	298	237	0.758 (0.283)	0.694 (0.324)	0.693 (0.323)	0.684 (0.314)	−.99	−.40
Ratio of viewing face relative to screen[b]	298	237	0.955 (0.024)	0.954 (0.024)	0.955 (0.024)	0.959 (0.022)	−.97	.78
Ratio of viewing eyes + mouth relative to face[c]	298	237	0.747 (0.099)	0.742 (0.104)	0.758 (0.088)	0.745 (0.108)	−.11	−.43

[a]4 twin pairs differed in age, in these cases the mean age was used.
[b]Ratio of viewing face relative to whole screen, averaged over all valid trials.
[c]Ratio of viewing eyes and mouth relative to face, averaged over all valid trials.

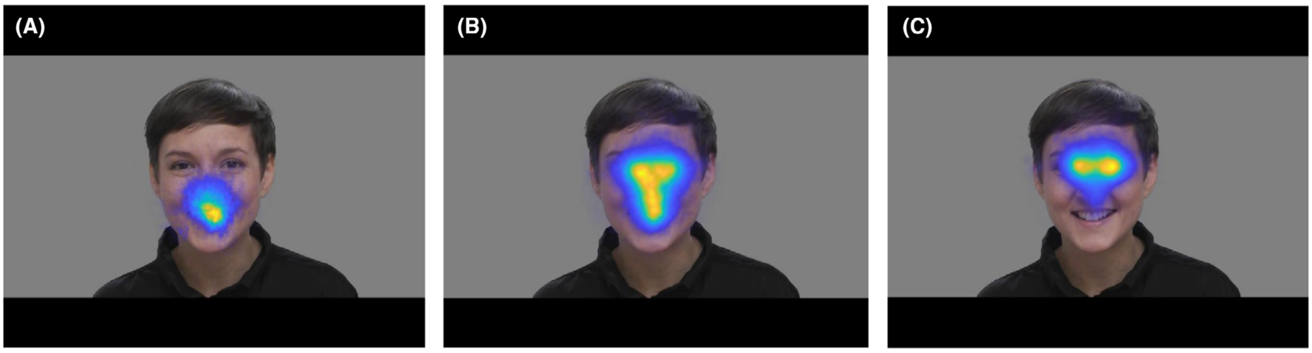

Figure 2 Aggregated heatmaps of data from selected groups. Aggregated heatmaps of gaze data from all trials for (A) participants that have an EMI score of <0.10, (B) participants that have an EMI score between 0.10 and 0.90, and (C) participants that have an EMI score of more than 0.90. The scales were adjusted individually for each heatmap, due to unequal group sizes

for time spent looking at the screen, the 10th percentile for the ratio of looking at the face (relative to the screen) and the 15th percentile for the ratio of looking at the eyes and mouth combined (relative to the face) for each trial. If on a particular trial a participant was below one of these cut-offs or looked at the screen for a total of <1,000 ms, the trial was considered to be invalid, regardless of the classification of the calibration. Infants with at least four valid trials (from any condition) were included in further analyses. The number of included trials was not significantly associated with the EMI (r = .017, p = .699, N = 535).

In all three conditions, on group level, the infants preferred looking at the eyes (mean EMI singing condition = 0.71, SD = 0.32; mean EMI talking condition = 0.67, SD = 0.33; mean EMI still condition = 0.75, SD = 0.31). Because the phenotypic correlations between the three conditions were high (0.871–0.925), we created one variable consisting of data from all infants with at least four valid trials (from any condition) and used this variable in all further analyses.

Parent-rated questionnaires. At 5 months, parents filled in the questionnaire version of the Vineland Adaptive Behavior Scales (Sparrow & Cicchetti, 1985). It is a standardized measure of adaptive behaviors across four domains. We used the standard scores for Communication and Socialization to measure sociocommunicative behaviors.

The MacArthur Communicative Development Inventory (CDI; Fenson et al., 1993) is a parent-rated questionnaire that assesses early language development and was administered at 14 months (the Words and Gestures form) and 24 months (the Words and Sentences form). As a measure of expressive vocabulary at 14 months, we used the total Production Score, which is the number of words (out of 370 words) that the infant can produce. Parents also reported which were the words (out of the 370) that the infant could understand, and this total Comprehension Score was used as a measure of receptive vocabulary. At 24 months, we used the vocabulary checklist score as a measure of expressive vocabulary.

The 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 ASD. Lower scores indicate a higher degree of sociocommunicative delays. It was administered at 14 months, and we used the total score as a measure of sociocommunicative behaviors linked to ASD.

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.

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 as an early measure of cognitive development. The MSEL consists of five subscales (gross motor, fine motor, visual reception, receptive language, and expressive language). See Table S1 for descriptive statistics on parent-rated questionnaires and the experimenter-rated developmental assessment.

Statistical analyses

An analysis plan was preregistered in OSF (https://osf.io/s8y74/) after data collection but prior to data analysis. We used a univariate twin model to estimate the genetic and environmental contribution to variation in EMI. The sources of variation in a trait can be divided into genetic influences (A; heritability), shared environment (C; e.g., family environment), and unique environment (E; i.e., environmental influences that makes twins different from each other, including measurement error). 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. The overall EMI score was used for the univariate twin model as well as all further analyses. Sex and age were incorporated as covariates. Data analysis was performed in R 3.6.3 (R Core Team, 2017), and model fitting was performed through maximum likelihood optimization with OpenMx, version 2.17.2 (Neale et al., 2016).

Associations between EMI at 5 months and concurrent and follow-up measures 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, Gurrin, Sterne, Morley, & Dwyer, 2005). The variables used in these phenotypic associations were regressed on age and sex before further analyses.

Genome-wide polygenic scores

We also calculated polygenic scores for IQ, educational attainment, and ASD, using the PRS-CS (polygenic prediction via Bayesian regression and continuous shrinkage priors) method (Ge, Chen, Ni, Feng, & Smoller, 2019). Three separate GEE analyses were performed to assess the association between polygenic scores and EMI. Sex, age, and the first 10 principal components of ancestry were included as covariates. See Table S2 for details on the polygenic scores analysis.

Results

Overall, the participants looked almost exclusively at the face, focusing on the eyes and the mouth. In general, they preferred looking at the eyes (see Table 1 and Figure S1).

Genetic analyses

The twin correlations for the EMI score were higher for MZ twins than DZ twins (rMZ = .55, 95% CI: 0.42, 0.65; rDZ = .34, 95% CI: 0.16, 0.49), suggesting genetic influence. A fully saturated model was first fitted in order to test the assumptions of equality of means and variances across zygosity and twin order (see Table S3). Based on the twin correlations, we fitted an ACE model, along with AE, CE, and E models for comparison. Based on the likelihood-ratio test and the AIC value, the best-fitting model was an AE model, where the shared environment component was dropped (Table 2). The AE model's estimates suggested a moderate-to-high heritability of the preference for looking at eyes versus mouth ($A = 0.57$; 95% CI: 0.45, 0.66), with a moderate contribution of non-shared environment ($E = 0.43$; 95% CI: 0.34, 0.55). Further, we tested the association between EMI and polygenic scores for autism spectrum disorder, educational attainment, and IQ. None of these associations were statistically significant (Table S2).

Longitudinal phenotypic associations

Contrary to the hypothesis, a trend toward a *positive* association was found between the EMI and the CDI production score ($\beta = .10$; 95% CI: −0.01, 0.21; $p = .064$; $N = 419$). However, the production score from the CDI had a considerable floor effect, reflecting the fact that most infants produced none or only a few words. Therefore, in a deviation from the preregistered plan, we analyzed the CDI comprehension score as well, which showed a statistically significant positive association with EMI ($\beta = .16$; 95% CI: 0.05, 0.27; $p < .01$; $R^2 = .03$; $N = 419$). No significant association was found between autistic traits (the total score on ITC) and the EMI ($\beta = .08$; 95% CI: −0.03, 0.19; $p = .175$; $N = 418$).

Secondary phenotypic analyses

In light of the results above, we conducted a series of follow-up analyses, to probe the degree of independence of the EMI measure from other concurrent developmental domains, and of the specificity of the association between EMI and language development at 14 months. First, we tested the association with expressive vocabulary at 24 months (this time-point was excluded from the original preregistration due to the increasing attrition rate with age). This measure was not associated with the EMI at 5 months ($\beta = .02$; 95% CI: −0.11, 0.15; $p = .783$; $N = 341$), suggesting that the link may be specific to parental ratings of verbal competence in early toddlerhood. Second, we followed-up the lack of association regarding autistic traits at 14 months (ITC) by analyzing scores on the Q-CHAT at 24 months, and again, no significant association was detected ($\beta = -.02$; $p = .696$; $N = 343$). Next, we tested whether the EMI was associated with general development and sociocommunicative behavior at 5 months using the MSEL (a standardized assessment of cognitive development consisting of five subscales: gross motor, fine motor, visual reception, receptive language, and expressive language) and the Vineland Adaptive Behavior Scales (a standardized measure of adaptive behavior from which we used the Communication domain and the Socialization domain). We found no significant association between the EMI and any of these concurrent measures (Table S4).

Finally, we tested the specificity of the association between EMI and 14-month language comprehension in light of the other concurrent 5-month measurements available. A GEE analysis with multiple predictors showed that experimenter-ascertained gross motor ability (MSEL gross motor scale at 5 months), parental ratings of social skills (Vineland Socialization scale at 5 months), and the EMI (5 months) all had unique contributions to the CDI comprehension ratings at 14 months (Table 3).

Table 2 Univariate twin model of the eye-mouth-index

Model	−2LL	# Parameters	*df*	AIC	Comparison model	$\Delta\chi^2$	Δdf	*p*	A	C	E
Fully sat.	199.46	12	523	−846.54	–	–	–	–	–	–	–
ACE	202.76	6	529	−855.24	Fully sat.	3.29	6	.77	.47	.09	.44
AE	**203.01**	**5**	**530**	**−856.99**	**ACE**	**0.25**	**1**	**.61**	**.57**	–	**.43**
CE	209.21	5	530	−850.79	ACE	6.45	1	.01	–	.45	.55
E	263.27	4	531	−798.73	ACE	60.51	2	<.01	–	–	1

−2LL, Fit statistic, the lower the better fitting is the model; AIC, an alternative fit index, lower value denotes better model fit; *df*, degrees of freedom; Δdf, difference in degrees of freedom between two models; $\Delta\chi^2$, difference in −2LL statistic between two models, distributed χ^2.

Table 3 A GEE analysis with receptive vocabulary (language comprehension) at 14 months as outcome variable, including eight predictors measured at 5 months (n = 401)

	Beta	95% CI	p
EMI	.13	0.03, 0.22	**.011***
MSEL			
Gross motor	.12	0.01, 0.23	**.040***
Visual reception	.08	−0.03, 0.18	.138
Fine motor	.02	−0.08, 0.12	.672
Receptive language	.01	−0.08, 0.10	.816
Expressive language	.01	−0.09, 0.11	.897
Vineland			
Communication	.12	−0.00, 0.24	.059
Socialization	.19	0.06, 0.32	**.003***

CDI, Communicative Development Inventory (Words and Gestures form); EMI, eye-mouth index; MSEL, Mullen Scales of Early Learning; Vineland, Vineland Adaptive Behavior Scales.5 The bold values indicates statistically significant of * = $p < .05$

Discussion

This study suggests that individual differences in young infants' preference for specific parts of others' faces (specifically the preference for eyes vs. mouth, EMI) in part reflect genetic variation in the population. The contribution of nonshared environment (which also includes error of measurement) was moderate, while shared environment did not appear to influence infant social viewing in this context. Twin heritability represents the upper bound of the possible heritability, and it is possible that the observed heritability of EMI includes some variance attributable to gene–environment correlation and interaction. For example, earlier phenotypic differences reflecting genetic variability may cause differences in the social environment (i.e., evocative gene–environment correlation), which in turn affect where infants look at 5 months of age. Notably, our finding indicates that before infants can select their environment by means of crawling or walking, they select aspects of the social environment that they look at largely based on their individual genotypes; that is, in itself a type of active gene–environment correlation operating at short time scales via gaze behavior (Kennedy et al., 2017).

We found that eye versus mouth preference was highly correlated (~.9) across conditions. Thus, it appears that individual differences in EMI at this age were largely independent of the exact stimulus properties such as movement and audio-visual synchrony (that differed between the conditions), a finding which is in line with the patterns of results observed by Constantino et al. in toddlers (Constantino et al., 2017). Possibly, infants may use basic invariant face properties as a basis for their preference, such as face-like configurations "eyes over mouth", to which infants are sensitive from very early on (Quinn & Tanaka, 2009; Schwarzer, Zauner, & Jovanovic, 2007).

Eye preference did not correlate with other concurrent traits assessed in the study, including developmental domains directly assessed by the experimenter (motor, perceptual, communication) as well as parent-rated skills (social communication). This suggests that eye-versus-mouth preference at 5 months reflects a highly independent, and partly heritable, socioattentional trait. The fact that we did not find any links between EMI and concurrent or later sociocommunicative development in our sample speaks against social motivation as an explanation for our results (Chevallier, Kohls, Troiani, Bordkin, & Schultz, 2012).

We found that preference for the eyes at 5 months was positively correlated with parents' assessment of vocabulary at 14 months, measured with the CDI. This result is unexpected given previous research showing an association between large vocabulary and a preference for looking at the mouth (Tenenbaum et al., 2015; Young et al., 2009). It is notable, however, that we assessed EMI at a somewhat earlier age compared to previous studies. At around 5 months, infants learn to follow other people's gaze (Del Bianco, Falck-Ytter, Thorup, & Gredeback, 2019), which is known to facilitate word learning (by following gaze, infants will attend to the same things as their caregivers, and hence more quickly understand what they refer to when they name objects and events). Thus, our results indicate that at this early age, attending to cues relevant for joint attention is more important for later language, than attending to speech cues linked to the mouth. However, due to the correlational nature of our design, we cannot prove a developmentally causal link between EMI and later traits. This general problem applies to all observational studies, including a recent adult twin study finding that different social abilities (face processing and biological motion processing) were linked at the genetic level (Wang et al., 2020; see also Shakeshaft & Plomin, 2015).

It is notable that eye preference predicted parents' ratings of language comprehension over and above variance captured by other scales at 5 months, suggesting that the relationship between eye preference and language is independent of other developmental domains. The results presented in Table 3 are in line with the idea that jointly occurring liabilities can give rise to neurodevelopmental delays (Constantino, Charman, & Jones, 2021), but we want to emphasize that extreme mouth looking was quite common in the sample and clearly not pathological.

Eye looking predicted ratings of language ability at 14 months, while associations with ratings at 24 months were nonsignificant. This pattern is consistent with the concept of equifinality in development (Cicchetti & Rogosch, 1996): while infants who attend to the mouth rather than eyes may have a temporary disadvantage in terms of vocabulary development, over time they catch up. Such diversity in developmental pathways (which may be differentially adaptive in different contexts) may also help explain why the genetic variance has remained in the population.

A limitation of our protocol is the reliance on parental ratings of language development in toddlerhood and early childhood. However, the CDI scores have been shown to be stable over time and associated with later language ability (Berglund & Eriksson, 2000; Eriksson, 2001; Fenson et al., 1993, but see Houston-Price, Mather, & Sakkalou, 2007). In addition to differences in true ability, CDI ratings may reflect parents' *perception* of ability. Infants' eye movements are visible to others—where they look in the face may also influence their parents' impression of them (Constantino et al., 2017; Kennedy et al., 2017). Nevertheless, the results are important because they demonstrate that a heritable trait in infancy predicts how caregivers perceive their offspring's competence almost a year later. Future research is needed to test if our findings generalize to a live setting (live interaction instead of during prerecorded videos; Nyström, Thorup, Bölte, & Falck-Ytter, 2019).

The lack of association between the EMI and later sociocommunication difficulties is consistent with the results of Constantino et al. (2017), who found that toddlers with ASD did not have an atypical preference for the eyes versus the mouth, but rather looked less at both these areas when observing complex scenes with multiple competing objects (the ASD sample was only tested using complex stimuli with multiple people and objects). What may be most pronounced in ASD (or in individuals with high autistic traits) is not atypical eye-versus-mouth preference, but reduced attention to faces overall (e.g., Guillon et al., 2016; Shic, Macari, & Chawarska, 2014). To the best of our knowledge, only one study (also from our group) has investigated heritability of face (vs. object) preference directly (Portugal et al., 2022), finding moderate contribution of genetic factors to this phenotype. Future studies currently in preparation in our group will investigate the link between several social and nonsocial phenotypes from the BATSS sample (Falck-Ytter et al., 2021), in order to provide a comprehensive view of the organization of attention and visual preferences in infancy.

As noted above, our heritability estimate may include gene–environment interplay, and nonshared environmental effects were significant in our study; hence our findings do not suggest that the early environment is unimportant. Because the infant brain is thought to be susceptible to environmental influences, future studies should investigate potential environmental factors that may interact with genetic susceptibilities. Estimates of nonshared environment in twin modeling includes measurement error. In light of the reliability of our EMI measure (see, e.g., Figures 1 and 2, the MZ correlation, as well as correlations across stimulus types), it is likely that true nonshared environmental factors explain EMI in addition to measurement error.

The heritability and specificity of the eye (vs. mouth) preference found at 5 months in this study raises the question of to what extent other brain and behavioral traits are equally heritable early in life, and to what extent those genetic factors are general or phenotype specific. Our results point to the promise of combining genetically informed designs with state-of-the-art infant research technology.

Supporting information

Additional supporting information may be found online in the Supporting Information section at the end of the article:

Figure S1. Distribution of the EMI variable (N = 535 infants).
Table S1. Descriptive statistics for the variables included in the phenotypic analyses.
Table S2. Phenotypic analyses between EMI and polygenic scores for autism spectrum disorder (ASD), educational attainment (EA), and IQ.
Table S3. Analyses of covariates and assumptions for the univariate twin model of EMI.
Table S4. Phenotypic analyses of EMI and MSEL/Vineland.

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Author contributions

The hypotheses and goals of this study were conceptualized by C.V., A.M.P., M.R., A.R., and T.F.-Y. Data were analyzed by C.V., with input from A.M.P., M.J.T., A.R., M.S.S., and T.F.-Y. Software was programmed by P.N.,

M.J.T., and C.V. Polygenic scores were derived by D.L. and K.T. The research was supervised by T.F.-Y., C.V. and T.F.-Y. drafted the manuscript, and all of the authors reviewed, edited, and approved the final manuscript for submission.

Correspondence

Charlotte Viktorsson, Von Kraemers allé 1A, 75237 Uppsala, Sweden; Email: charlotte.viktorsson@psyk.uu.se

Key points

- Infants orient toward faces from birth, and they attend specifically to eyes and mouth—two areas that convey different types of information.
- In a sample of 535 infants, we found a moderate-to-high genetic influence on the preference for looking at eyes (relative to mouth). Eye preference was independent of all concurrently measured traits, but predicted parent ratings of language comprehension in toddlerhood.
- These findings suggest that variation in eye-looking reflects a form of biological niche-picking, which emerges before infants can select their environments by other means (crawling or walking). Our results point to the promise of combining genetically informed designs with state-of-the-art infant research technology.

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