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How Infants Direct Their Gaze to Faces in the Presence of Other Objects: The Development of Face Preference Between 4 and 7 Months After Birth

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ABSTRACT

From early in development, infants process faces in their environment differentially from other items. By around 6 months of age, they are able to orient toward faces in the presence of distractor items. This paper aimed to assess whether this preferential looking toward faces was observable prior to 6 months of age, and whether there were developmental trends. We assessed this using the face pop-out task, a free viewing eye-tracking experiment in which infants viewed arrays containing an image of a face, alongside four distractor items. We assessed whether infants at 4, 5, 6 and 7 months ($n = 1585$ participants) differed in the proportion of first looks, total dwell time, and frequency of fixations to faces compared to other items. All three outcome variables were significantly higher toward faces than toward any of the other items in all the age groups. Moreover, there were age-related differences across all measures—the older the infants were, the more pronounced their face preferences were. These age-related differences could not be attributed to differences in data quality, and thus suggest that face preference is observable at 4 months of age but shows a strong development until 6 months.

1 | Introduction

Faces provide infants with cues that are important for their interactions with others, and hence their development (Johnson and de Haan 2015). From birth onwards, infants are shown to preferentially fixate faces compared with other items in their visual environment (Goren et al. 1975; Johnson et al. 1991). This early preferential orientation to faces is hypothesized to facilitate the detection and establishment of eye contact with social partners (Farroni et al. 2002 2005). Preferential fixation of faces has been studied in various ways, including the presentation of faces or non-faces in the absence of competing objects (e.g., Johnson et al. 1991), or in multi-objects displays such as in the face pop-out task (e.g., Gliga et al. 2009). Multiple studies using the face pop-out task have found that infants at 6 months direct their first fixations to faces above chance level, as well having a higher total dwell time to faces than to the other items (Elsabbagh et al. 2013). However, few studies have tested this phenomenon in infants younger than 6 months. The current study aimed to address whether there are developmental trends in how infants between the ages of 4 and 7 months of age preferentially fixate to faces that are presented alongside other items.

Preferential fixation to faces presented alongside other items seems a very stable phenomenon: it is observable across various stimuli (e.g., videos and pictures) and in multiple age groups (Elsabbagh et al. 2013; Frank et al. 2009; Gliga et al. 2009). This includes fixating to human faces when these are presented alongside animal faces, which infants are shown to do as young as 3 months of age (Simpson et al. 2019). Between the age of 3 and 12 months, infants are shown to have improved detection and increased interest in faces that are presented in visually complex scenes (Kelly et al. 2019). This is shown to be the case even when the faces are not the most visually salient part of the scenes. Studies have also found that between 3 and 9 months of age, there are increases in the frequency of looking to faces (Frank et al. 2009, 2014).

In a previous study from Gliga et al. (2009), 6-month-old infants were similarly found to direct their first saccades toward faces, when these were presented alongside other items. This study tested preferential looking to the face using a task known as the face pop-out, which is a free viewing experiment where a face is presented alongside other items. During this task, the looking behavior of infants to the face and items on the screen can be recorded. Despite the name 'face pop-out', the task does not assess the pop-out phenomenon, which is a measure of search time efficiency whilst participants look for an item among homogeneous distractors (Treisman and Souther 1985). Instead, the 'face pop-out' can be used to assess infants' preferences to fixate to faces compared to other items. The advantage of presenting a face alongside other items (as opposed to, e.g., presenting the face on its own) is that it is shown to elicit face preference in older infants, who, in order to show a face preference, tend to require more realistic representations of faces (Gliga et al. 2009; Johnson et al. 1992). The findings of Gliga et al. (2009) have been replicated in multiple studies that have used comparable experimental set-ups of the face pop-out paradigm (de Klerk et al. 2014; Elsabbagh et al. 2013; Gluckman and Johnson 2013; Telford et al. 2016), also with larger groups of infants (Hendry et al. 2018; Kwon et al. 2016; Lopez-Pérez et al. 2018).

Some studies have looked at preferential fixation to faces prior to 6 months of age using comparable set-ups to the face pop-out task. A study looking at infants' performance on the face pop-out task prior to 6 months showed that 5-month-old infants' first fixations to faces, their number of fixations to faces, and their total dwell time on faces were all above chance level (Portugal et al. 2022). A study examining 4-, 6-, and 8-month-old infants observed that face preference in younger infants was more influenced by the physical salience of the images: face preference was only observed in the 4-month group when arrays contained two items, and the competitor (to the face) had a relatively low salience. In contrast, 6- and 8-month-olds' looking behaviors to faces were not strongly influenced by physical salience (Kwon et al. 2016). Another study from Di Giorgio et al. (2012) found that 3-month-old infants' proportion of total fixations and proportion of total fixation time to faces were not significantly above chance level, though the same measures of 6-month-old infants and adults were. This suggested a developmental transition between 3 and 6 months of age in the looking behaviors toward faces (Di Giorgio et al. 2012). However, the authors have suggested that their findings are not directly comparable to other face pop-out studies due to the stimuli used: whereas other studies used colored stimuli, the Di Giorgio et al. (2012) study used gray-scale stimuli. Nevertheless, these studies suggest that there might be a developmental transition around 4 months of age (i.e., after 3 months Di Giorgio et al. 2012; Kwon et al. 2016) and before 5 months (Portugal et al. 2022). However, this needs to be confirmed on a broader and larger sample, which includes 4-month-olds, and uses similar stimuli as implemented in other studies looking at infants' preference for faces.

There are good reasons to expect the emergence of face preference in the Face pop-out task in the first few months of life. Although new-borns are shown to already orient toward simple schematic face-like stimuli (Johnson et al. 1991, 2005), a preference for faces in more complex presentations, such as when presented among other items in the face pop-out task, might develop only after birth. In the two-process theory of face processing (Morton and Johnson 1991), it is theorized that the subcortical mechanism underlying newborn face preference (referred to as 'conspec') ensures appropriate input for the development and specialization of cortical mechanisms underlying face preference in older infants (referred to as 'conlern') (Morton and Johnson 1991; Reynolds and Roth 2018; Shah et al. 2013). The latter 'conlern' is therefore an acquired system for processing faces (such as face recognition) that is influenced by experience and learning, whereas the former 'conspec' is an innate system which biases infants' visual gaze toward faces (Reynolds and Roth 2018). As infants get older, their face preference (as measured using the face pop-out task) may develop from being driven by conspec, to being driven by a combination of conspec and conlern mechanisms. The development and specialization of face preference during the first year of life can also be seen in other experiments, which find that infants' scan paths become more elaborate over the course of the first year of life, being increasingly driven by prior knowledge and less by the low-level salience of visual stimuli (Frank et al. 2009).

Between birth and 6 months, there is therefore a developmental change in how infants preferentially orient to faces when presented alongside other items, and this development requires further exploration. This paper assessed whether the face preference is observable prior to 6 months of age, and whether there are developmental trends between the ages of 4 and 7 months. The study is pre-registered (link: https://osf.io/47cgx/). As face sensitivity in eye tracking research can be indexed in a number of ways, we examined various indices of face preference: specifically, conforming with our pre-registration, we researched whether younger infants make first fixations to faces above chance; make more and longer fixations to faces; and spend more time looking at faces compared to any of the other items. In addition, we conducted exploratory analyses on whether the time for infants to first gaze to faces was faster compared to other items. For this, we used data from the YOUth cohort, collected from infants who were between 4 and 7 months old (Onland-Moret et al. 2020). We explored the impact of two types of analyses on the outcome measures. First, we report ANOVA analyses that many previous studies had applied to similar experimental set-ups (e.g., Gliga et al. 2009). Second, for the outcome variable 'infants' first fixations' we ran an additional analysis, which we refer to as the T_{50}, which allowed a simultaneous description of (1) when each item in a pop-out trial is first fixated and (2) the percentage of participants that fixated on an item, regardless of whether each item is fixated on every trial or not (Hessels et al. 2016; Hooge and Camps 2013). In brief, this analysis consists of (1) determining an empirical cumulative distribution curve of the time to first fixate an area of interest across all trials of all infants and (2) determining the time at which the face was fixated on 50% of the trials. Simultaneously assessing both variables was a more rigorous approach to identifying variability across age groups in their first fixations to the face and other items.

For both analysis methods, it was assessed whether the results were impacted by different data quality exclusion criteria. We applied less and more conservative exclusion criteria based on the eye-tracking data quality, respectively taken from the original (i.e., Gliga et al. 2009) versus recent studies assessing the face preference (Lopez-Pérez et al. 2018; Portugal et al. 2022). This approach was taken because data quality is expected to be lower in younger infants (Hessels and Hooge 2019). As such, a more conservative standard could control whether any observed developmental differences could be (partly) explained by data quality differences.

By working with data from the YOUth cohort, it was possible to include hundreds of participants per age group, ensuring that the analyses had sufficient statistical power. Working with a large sample size also made it possible to check for whether face preference could be robustly observed in data of different quality levels. Checking the robustness of the findings was important because of the lower data quality that can come from younger children, which can introduce systematic errors into the findings (Hessels et al. 2016; Hessels and Hooge 2019; Wass and Smith 2014). As such, this paper aimed to assess how infants' face preference developed across a wider age range than previously looked at, and aimed to check the robustness of the face preference phenomenon when the data quality differences between younger and older infants were controlled for.

2 | Methods

The current data are part of the YOUth study, a longitudinal cohort study of which the Baby & Child cohort follows infants from pre-birth until 7 years of age (Onland-Moret et al. 2020). An overview of all measurements conducted in the YOUth study is available from https://www.uu.nl/en/research/youth-cohort-study. Part of the overall methodology description for the YOUth cohort is available on this website. The current study is pre-registered (https://osf.io/47cgx/).

2.1 | Participants

For this study, we acquired infant data that was collected around the first infancy wave, that we binned into four age categories (4, 5, 6, 7 months). Infants were excluded from the study if they were born preterm (< 37 weeks, n = 86), or if they had auditory impairments (n = 5). In total, 1585 infants contributed their data in the less conservatively processed sample, and 1329 in the more conservatively processed sample—more information about this sampling can be found in the section 'Data Pre-Processing/Exclusion' section. The exact participant numbers are provided in Table 1 per sex and per age group. The YOUth study aimed to include 3000 participants (see Onland et al. 2020). We used all available data for the face pop-out task, which allowed us to have a much higher power to pick up subtle age-related differences than earlier studies (Elsabbagh et al. 2013; Frank et al. 2009; Gliga et al. 2009). 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 involving human subjects in this study were approved by the Medical Research Ethics Committee at the University Medical Center Utrecht.

2.2 | Materials

2.2.1 | Apparatus

Infants' gaze location on screen was recorded using the Tobii Pro TX300 (n = 1531 infants) eye-tracker with an integrated 23-inch monitor (1920 by 1080 pixels; 60 Hz refresh rate) or the Tobii Pro Spectrum (n = 221 infants) eye tracker with an integrated 23.8-inch monitor (1920 × 1080 pixels, 60 Hz). The TX300 recorded gaze position at 300 Hz and the Spectrum at 600 Hz. Communication with the eye trackers was handled with the Tobii SDK, and stimulus presentation with PsychToolbox version 3 (Brainard 1997), both through MATLAB.

2.2.2 | Face Pop-Out Task

The face pop-out task is a free-viewing experiment where infants are presented with an array containing a face alongside four other items. The five-item arrays consisted of a: 1. Human face; 2. Car; 3. Mobile phone; 4. Bird; 5; Phase-scrambled face (See Figure 1 for an example). The phase-scrambled face is an image that is generated from the face presented in the same

TABLE 1 | The number of participants, split across the level of data processing.

Pre-processing	4 months	5 months	6 months	7 months
Less conservative	447 (217 boys)	684 (362 boys)	397 (193 boys)	57 (33 boys)
More conservative	367 (175 boys)	555 (289 boys)	356 (170 boys)	51 (29 boys)
Original amount of data	492 (243 boys)	747 (391 boys)	441 (216 boys)	64 (38 boys)

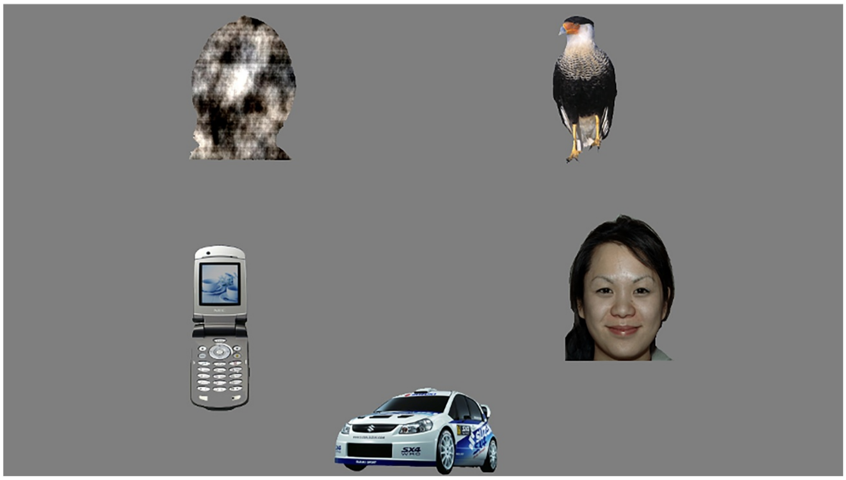

FIGURE 1 | An example array of the face pop-out task, taken from Gliga et al. (2009).

array, by randomizing the phase spectra of the face while keeping the amplitude and color spectra constant (Elsabbagh et al. 2013; Halit et al. 2004). We used 6 different displays, each containing new exemplars of the five items. The array composition was counterbalanced, with each item (face, car etc.) being presented at different locations in the different arrays. Each array was accompanied by a different instrumental song.

2.3 | Procedure

2.3.1 | Positioning

Infants sat in a car seat approximately 65 cm (TX300) or 67 cm (Spectrum) away from the eye-tracker. Testing occurred in a bright small room (300-350 Lux, Temperature 18–25 C), which did not have windows.

2.3.2 | Calibration and Experiment

An operator-controlled 5-point calibration was run, which consisting of expanding and contracting colorful spirals that were accompanied by a sound. The spirals were presented at the four corners and the center of the screen. A webcam was used to monitor the participant. When the operator judged the participant to be looking at the spiral, a button was pressed, after which the spiral contracted and was calibrated (details of the calibration stimuli are given in Hessels et al. 2015). The operator judged the calibration output from the Tobii SDK, after which a decision was made to accept the calibration or re-calibrate. Once the eye tracker was calibrated, the experimenter closed the curtain that divided the room in two halves, and sat in the other half of the room, behind a desk with the stimulus computer. The experimenter could also see the child via a closed-circuit camera. A trial started with a small central animation (central fixation point). Then in random order, with random pairings between sound and visual, an array appeared for 10 s, accompanied by an instrumental song. There were six trials in total. When the child's attention started waning, experimenters could play attention getters consisting of brief audio files or a video. For this experiment, usually no attention getters were needed, as it was sufficiently engaging for the infants. The total duration of the experiment was 1 min, excluding time required for positioning and calibration.

2.4 | Eye-Tracking Data Processing

From the gaze position signals we derived (1) several measures of eye-tracking data quality to assess and report the quality of our recordings (Dunn et al. 2023) and (2) several gaze measures to describe infants' gaze behavior. For data quality, we estimated precision and data loss. Precision was operationalized as the median root mean square sample-to-sample deviation in the gaze position signal using a 0.1 s moving window per trial. The sample-to-sample deviation was computed separately for the horizontal and vertical coordinate of each eye, and then summed using Pythagoras' theorem. Data loss was operationalized as the proportion of invalid samples (i.e., no gaze coordinate). Accuracy was not computed separately for this study, but is extensively reported in De Kloe et al. (2022). The median accuracy reported for the 5-month-old age group in this study was 2.7° for recordings using the TX300 and 1° for the Spectrum. We did not deem this inaccuracy to be problematic for AOI assignment, as it is much lower than the AOI radius that is used in the current study (see below).

Infants' gaze behavior was characterized by the number of fixations on each item; the proportion of first fixations on an item; and the total dwell time on each of the items. In addition we estimated the time at which an item was first fixated within a trial, irrespective of fixations made before on other items, across 50% of all trials across all infants (T_{50}, see below for details). To derive these measures, fixations were defined as periods of relatively still gaze position on screen (Hessels et al. 2018), operationalized using the Identification by 2-Means Clustering algorithm (I2MC; Hessels et al. 2017), version 2.0 using default parameters. The I2MC algorithm was designed to accomplish fixation classification in noise of variable quality, as may be the case in infant eye-tracking research.

Fixations were assigned to Areas of Interest, one for each item (face, scrambled face, car, phone, and bird), using the Limited-

Radius Voronoi Tessellation method (LRVT; Hessels et al. 2016). The LRVT radius was set to 7° (285 pixels), meaning that each fixation was assigned to the closest AOI center, provided it did not exceed 7°.[1] The average distance between each AOI center and its closest neighbor (or AOI span; Hessels et al. 2016) was 491 pixels.

After AOI assignment, the number of fixations per AOI, the proportion of first looks to an AOI, and the total dwell time per AOI (sum of all fixation durations within an AOI) were computed.

2.5 | Data Pre-Processing/Exclusion

As previous studies differed in the data quality criteria (e.g., see Gliga et al. 2009; Portugal et al. 2022), we assessed whether the outcomes of the analyses depended on data quality. This is relevant as data quality in younger infants is known to be lower than in older infants. Furthermore, there are also larger differences across younger infants in their data quality (Hessels and Hooge 2019). We therefore ran our analysis twice, first with a less conservative pre-processing of the data and then with a more conservative pre-processing of the data. The pre-processing of the data involved a set of exclusion criteria for trials and/or infants. By running a less and more conservative pre-processing, we were able to carefully pick apart if observed differences in outcome measures between age-groups were due to actual developmental effects or to data quality differences. The less conservative and the more conservative criterions for data pre-processing are outlined below, and the sample sizes for each criterium can be found in Table 1.

2.5.1 | Less Conservative Data Pre-Processing

In the less conservative criteria, infants were excluded if: there was an experimental error; failure to complete testing due to fussiness; infants never looked at any of the items (or areas of interest, AOI); infants did not fixate to the center of the screen before trial onset in more than 4 trials. Moreover, trials were excluded if the center of the screen was not fixated at the start of the trial.

2.5.2 | More Conservative Data Pre-Processing

In the more conservative approach, we used the exclusion criteria of the less conservative approach stated above, as well as: excluding any trials with a proportion of valid data (non-missing) less than 25%; only averaging measures across trials if at least 4 out 6 trials are valid; and finally, excluding first fixations on the face with a latency shorter than 120 ms from the calculations of the mean latency of first fixations to the face. Note that in the pre-registration, we included an additional exclusion criterion, namely to remove participants in which data is lost for more than 50% of trial duration. However, this obviates the criterion of excluding trials with a proportion of valid data less than 25%. Indeed, additional analyses revealed that our conclusions are invariant to adding this additional (more conservative) criterion. As such, we decided to no longer use the 50% trial duration criterion in the here-reported analyses.

2.6 | Statistical Analysis

To investigate whether the face preference is observable in infants prior to 5 months of age, we looked at the following outcome variables: infants' first fixation, infants' total dwell time and infants' frequency of fixations. We also conducted explorative analyses looking at infants' time to first fixation at the outcome variable. We computed these outcome variables for each of the items that were presented in the array. Next, we conducted two types of analyses: one replicating the approach of previous studies using the face pop-out task to assess face preference (specifically the approach of Gliga et al. 2009), and the second through an approach known as the T_{50}. For the replication, all three outcome variables were assessed in separate mixed ANOVAs. For the T_{50} analysis, the frequency of fixating an object and the time to fixate that object were assessed concurrently (for details see section *The T_{50} analysis* below). Both analyses were run twice: once with data that was pre-processed less conservatively and once with data that was pre-processed more conservatively.

2.6.1 | Mixed ANOVA

For the outcome variable infants' first fixations, we ran a mixed ANOVA with item (2 levels: face, all other items) as a within-subject factor, and age (4 levels: 4, 5, 6, 7 months) as a between-subject factor. Furthermore, we included trial block (2 levels: first 3 trials, last 3 trials) as a covariate. The within subject factor 'item' was conceptualized differently in the outcome variable 'infants first fixations' than in the outcome variables total dwell time and infants' frequency of fixations because we wanted to match the approach of Gliga et al. (2009) as closely as possible. The level 'all other items' of the independent variable 'item' was therefore calculated by averaging the proportion of first looks that were directed to all other items that were not the face. We ran an additional explorative mixed ANOVA, where the outcome variable was the time taken to first saccade, with item (2 levels: face, all other items) as a within subject factor and age (4 levels: 4, 5, 6, 7 months) as a between subject factor, and trial block (2 levels: first 3 trials, last 3 trials) as a covariate.

For the outcome variables infants' total dwell time and infants' frequency of fixations we ran a mixed ANOVA with item (5 levels: face, scrambled face, mobile phone, car, bird) as a within-subject factor, and age (4 levels: 4, 5, 6, 7 months) as a between-subject factor. Furthermore, we included trial block (2 levels: first 3 trials, last 3 trials) as a covariate. Both analyses had sphericity violations, which were corrected using Greenhouse-Geisser, a correction that adjusted the degrees of freedom to account for the violation of sphericity, making the test more conservative. For significant findings in relation to the independent variable 'age', post-hoc paired comparisons were planned to identify where the age group differences lay.

Regardless of the outcomes of the ANOVA, we also ran per age-group one-sample *t*-tests against chance (i.e., 1/5 objects or 20%) to investigate if infants fixated first to the face or any of the other items, above what would be expected by chance.

2.6.2 | The T_{50} Analysis

The T_{50} analyses are based on empirical cumulative functions that both describe (1) when each item in a pop-out trial is first fixated and (2) the proportion of trials on which an item was fixated (i.e., not every items needs to be fixated on every trial). The T_{50} describes at which point in time an AOI such as the face was first fixated on within a trial (irrespective of fixations made before on other AOIs) across 50% of all trials across all infants. Previously, inferential analyses of the face pop-out task (using analyses such as the mixed ANOVA) have looked solely at where infants direct their first fixations when presented with an array on the screen. Face preference was found to occur if infants directed their first fixations to faces on more trials than was expected by chance. However, depending on the number of trials in the task, this measure of the face preference may fail to capture variability across age groups. e.g., if an experiment has 6 trials, infants' first fixation to faces (i.e., how frequently they fixate first to the face in a trial) will be a value between 0 and 6. As such, we may not observe much variability across age groups in this outcome measure of first fixations.

More variability may be observed across age groups when we assess not only the frequency with which infants direct their first gaze to the face, but also the time taken for a proportion of infants to first fixate to the face. Using the T_{50} analysis, we assess the time taken for infants to fixate an item (e.g., the face) on 50% of all trials across all infants. For each item, a cumulative function was plotted that describes the time at which this item was first fixated on each trial (minimum of 0 s, maximum of 10 s). Between-item and between-age group differences in the T_{50} were then assessed statistically using bootstrapping techniques. Specifically, we determined the 95% confidence intervals of the time to fixate an AOI on 50% of the trials using 1000 bootstrap samples and the standard MATLAB *bootci* function.

3 | Results

3.1 | Eye Tracking Data Quality

We follow the guidelines by Dunn et al. (2023) for reporting eye-tracking data quality. Median precision across all trials was 0.91° (std = 0.67°) for the left eye signal and 0.89° (std = 0.68°) for the right eye signal. Small differences between ages were observed: The median precision (highest value of the two eyes) was respectively 0.98°, 0.95°, 0.79°, 0.85° for 4, 5, 6, and 7-month-old infants. These values are within the expected operating range of the I2MC fixation classification algorithm (Hessels et al. 2017).

Median proportion of data loss across all trials was 0.33 (std = 0.31) for the left eye and 0.33 (std = 0.31) for the right eye. Again, small differences between age groups were observed: the median data loss (highest value of the two eyes) was respectively 0.37, 0.37, 0.25, and 0.26 for the 4-, 5-, 6-, and 7-month-old infants. Part of the data loss problem is dealt with by the I2MC algorithm, in the case of short (< 100 ms) bursts, which are interpolated prior to fixation classification. Part is addressed through the more and less conservative data quality exclusion criteria. As detailed above, accuracy is extensively reported in De Kloe et al. (2022) and not further addressed here.

3.2 | Infants' First Looks

ANOVA. For both the less and more conservative processing, the mixed ANOVA revealed a small and significant main effect of age, whereby as age increased, infants' first looks to the items increased (less conservative: F (3, 3048) = 95.41, $p < 0.001$, $\eta^2 = 0.024$; more conservative: F (3, 2571) = 65.99, $p < 0.001$, $\eta^2 = 0.020$). There was also a significant and small main effect of item, with infants directing more of their first looks to faces than to other items (less conservative: F (1, 3048) = 665.94, $p < 0.001$, $\eta^2 = 0.138$; more conservative: F (1, 2571) = 661.85, $p < 0.001$, $\eta^2 = 0.159$). There was no main effect of trial block (less conservative; F (1, 3048) = 0.28, $p = 0.595$, $\eta^2 < 0.001$; more conservative F (1, 2571) < 0.01, $p = 0.984$, $\eta^2 < 0.001$).

An interaction was observed between age and item that was significant and small (less conservative: F (3, 3048) = 95.41, $p < 0.001$, $\eta^2 = 0.065$; more conservative: F (3, 2571) = 65.99, $p < 0.001$, $\eta^2 = 0.054$). Post-hoc analyses were run to examine the interaction. These revealed that the proportion of first looks that were directed to the face were significantly higher than the proportion of first looks directed to any other items in all age groups (both less and more conservative: $p < 0.001$ for all age groups). Furthermore, as age increased from 4 to 5, 5 to 6, and 6 to 7 months, there were significant increases in the proportion of first looks that were directed to faces (both less and more conservative: all $p < 0.01$). There were no additional interactions observed between the variables.

One sample *t*-tests. For both the less and more conservative processing, the proportion of first looks directed to the face was significantly higher than chance level of 20%, across all age groups (less conservative and more conservative: all $p < 0.001$). The proportion of first looks directed to one of the other items was significantly lower than chance level across all age groups (less and more conservative: $p < 0.001$). For the exact proportions of first looks that were directed to faces and other items, see Tables 2 and 3 respectively.

3.3 | Explorative Analyses: Infants Time to First Looks

ANOVA. For both the less and more conservative processing, the mixed ANOVA revealed a small and significant main effect of age, whereby as age increased, infants' time to first looks to the items decreased (less conservative: F (3, 3016) = 23.53, $p < 0.001$, $\eta^2 = 0.010$; more conservative: F (3, 2571) = 34.50, $p < 0.001$, $\eta^2 = 0.016$). There was also a significant and small main effect of item, with infants directing their first looks faster

TABLE 2 | Proportions of looks directed to the face, split across the age groups, with 95% confidence intervals in the brackets.

	4 months	5 months	6 months	7 months
Less conservative	0.23 (0.22–0.24)	0.31 (0.30–0.31)	0.38 (0.38–0.39)	0.49 (0.47–0.52)
More conservative	0.26 (0.25–0.27)	0.33 (0.33–0.34)	0.40 (0.39–0.41)	0.49 (0.47–0.51)

TABLE 3 | Proportions of looks directed to the other items, split across the age groups, with 95% confidence intervals in the brackets.

	4 months	5 months	6 months	7 months
Less conservative	0.19 (0.19–0.19)	0.17 (0.17–0.18)	0.15 (0.15–0.16)	0.13 (0.12–0.13)
More conservative	0.19 (0.18–0.19)	0.17 (0.17–0.17)	0.15 (0.15–0.15)	0.13 (0.12–0.13)

to faces than to other items (less conservative: F (1, 3016) = 1023.65, $p < 0.001$, $\eta^2 = 0.161$; more conservative: F (1, 2571) = 1035.37, $p < 0.001$, $\eta^2 = 0.193$). There was no main effect of trial block (less conservative; F (1, 3016) = 0.32, $p = 0.572$, $\eta^2 < 0.001$; more conservative F (1, 2571) = 0.03, $p = 0.869$, $\eta^2 < 0.001$).

An interaction was observed between age and item that was significant and small (less conservative: F (3, 3016) = 116.47, $p < 0.001$, $\eta^2 = 0.061$; more conservative: F (3, 2571) = 114.23, $p < 0.001$, $\eta^2 = 0.073$). Post-hoc analyses were run to examine the interaction. These revealed that the time taken to first look to the face was faster than the first looks directed to any other items in all age groups (both less and more conservative: $p < 0.001$ for all age groups). Furthermore, as age increased from 4 to 5, 5 to 6, and 6 to 7 months, there were significant decreases in the time taken to first look to the face (both less and more conservative: all $p < 0.05$). As age increased from 4 to 5, 5 to 6, there was also a significant increase in the time taken to first look to the other items (both less and more conservative: all $p < 0.05$). There were no additional interactions observed between the variables.

3.3.1 | T_{50} Analyses

To examine infants' first looks during the face pop-out task more closely, we ran T_{50} analyses, which are based on empirical cumulative functions that both describe (1) when each item in a pop-out trial is first fixated and (2) the proportion of trials on which an item was fixated. The T_{50} describes at which point an AOI (such as the face) was fixated on for 50% of trials across all infants. In Figure 2, cumulative functions are shown for each of the items, with one age group per plot. As can be seen in Figure 2, the face (compared to other items) was the item that all infant age groups fixated to the most often and quickest. This was operationalized statistically by the confidence intervals for the time taken to fixate to faces (on at least 50% of trials, see horizontal dashed lines in Figure 2) not overlapping with the confidence intervals given for any of the other items (see Table 4). In Figure 3, separate plots are shown for each item, with each cumulative function within a plot describing one age group. Based on these plots and the 95% bootstrapped confidence intervals (Table 4), we conclude that the latency to fixate the face on 50% of the trials was lower in the older than younger age groups. This means that the older infants fixated to faces more quickly than the younger infants. Additionally, the 'proportion of trials' in which infants fixated to the face at all was higher (proportion by the end of the trial in the plots of Figure 2) in the older age groups than the younger age groups.

Thus, infants fixated faster to faces and in a higher proportion of trials than to all other items. However, there were additional differences in the proportion of fixations and fixation times across the other items (see Figure 2 and Table 4). In 4- and 5-month-old infants, it was observed that there was a larger proportion of trials in which the car was fixated to compared to all other items excluding the face. Furthermore, younger infants fixated faster to the car than to all other items excluding the face. In Figure 3 and Table 4 we can see that between 4 and 7 months of age, the earlier fixations to the face of older infants appeared to come at the cost of fixations to the Phone and Car items.

3.4 | Infants' Total Dwell Time to the Face

Figure 4 presents the total dwell time for all items for the less conservative data pre-processing. Mixed ANOVAs revealed that for the less conservative processing, there was a small and significant main effect of age, F (3, 3048) = 6.03, $p < 0.001$, $\eta^2 < 0.001$, with increasing total dwell time for older children. Contrastingly, for the more conservative processing, the main effect of age was not significant: F (3, 2571) = 1.21, $p = 0.306$, $\eta^2 < 0.001$. There was a significant and medium main effect of item for both levels of processing (less conservative: F (2.07, 6320.96) = 1696.24, $p = 0.001$, $\eta^2 = 0.319$; more conservative: F (2.08, 5348.39) = 2226.23, $p < 0.001$, $\eta^2 = 0.443$), with longer dwell time on faces than other items. There was also a small significant main effect of trial block, (less conservative: F (1, 3048) = 13.51, $p < 0.001$, $\eta^2 = < 0.001$; more conservative F (1, 2571) = 17.91, $p < 0.001$, $\eta^2 = < 0.001$), with a longer dwell time in the first three trials.

Furthermore, an interaction was observed between age and item that was significant and small (less conservative: F (6.22, 6320.96) = 48.57, $p < 0.001$, $\eta^2 = 0.039$; more conservative: F (6.24, 5348.39) = 17.80, $p < 0.001$, $\eta^2 = 0.019$). Post-hoc analyses revealed that infants looked for a longer duration to the face than to any of the other items in all age groups (for both less and more conservative: all $p < 0.001$). Furthermore, as age increased, the difference between the looks to the face versus other items increased. This was found across all comparisons between two following age groups (all $p < 0.001$), except

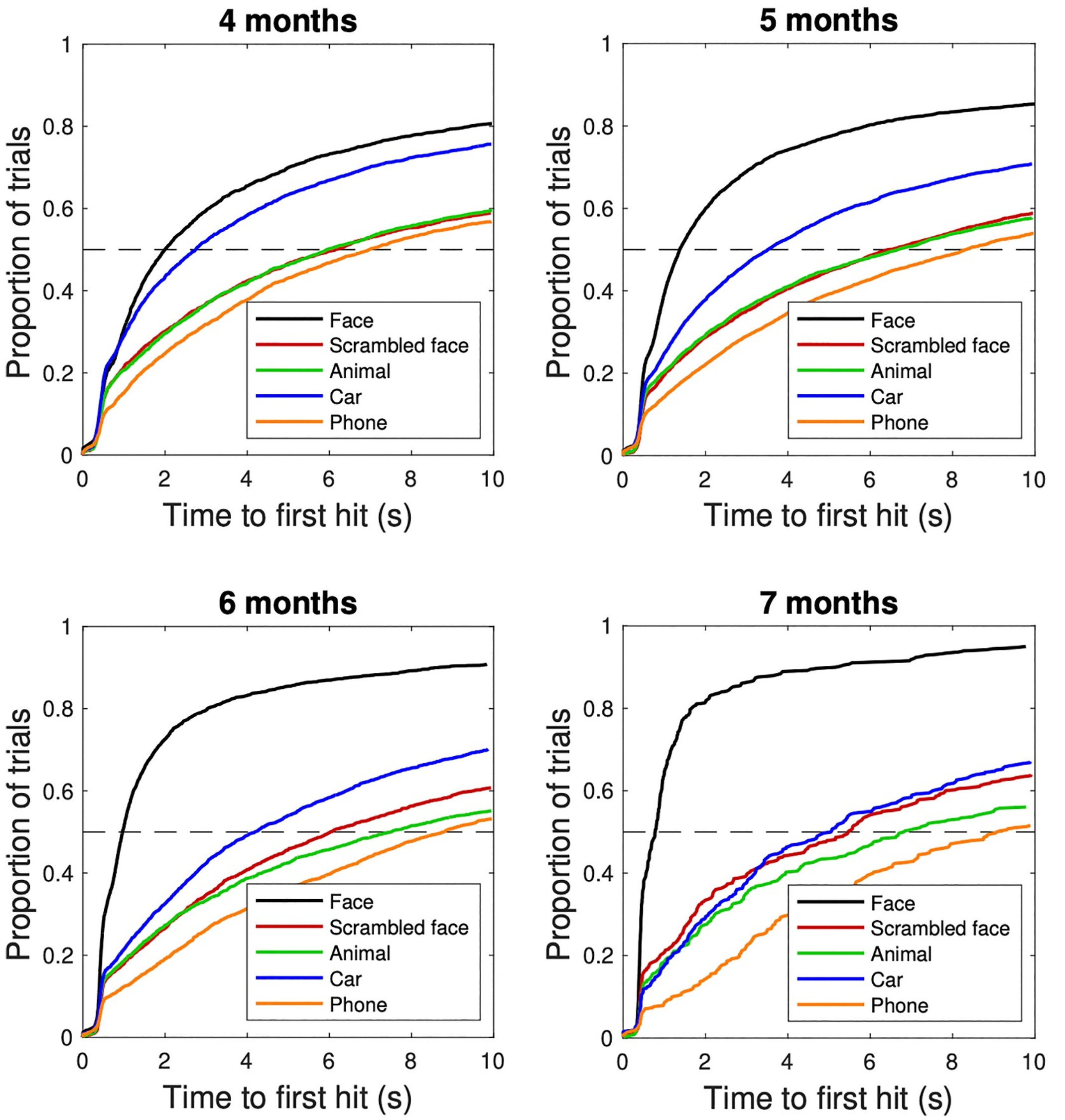

FIGURE 2 | Separate cumulative distribution plots for each age group which show the time to first hit (seconds) for each item on the screen across all trials of all infants. The horizontal dashed line indicates half of the trials. Where this line intersects with the cumulative distribution functions is the time at which each item was fixated on 50% of all trials. The data shown in this figure were less conservatively processed - the T_{50} results across the less versus more conservatively processed data were comparable.

TABLE 4 | The time to first fixation (seconds) for each item, split across the age groups, with 95% confidence intervals in the brackets.

	Age group			
Item	**4 months**	**5 months**	**6 months**	**7 months**
Face	2.00 (1.86–2.14)	1.37 (1.32–1.45)	0.96 (0.93–1.01)	0.78 (0.66–0.85)
Noise	6.16 (5.46–6.59)	6.45 (5.99–7.03)	6.03 (5.56–6.61)	5.47 (4.34–6.32)
Animal	5.94 (5.55–6.70)	6.68 (6.16–7.20)	7.51 (6.73–8.24)	6.83 (5.64–9.01)
Car	2.74 (2.52–2.98)	3.51 (3.27–3.74)	4.19 (3.80–4.54)	5.05 (3.82–6.03)
Phone	6.98 (6.37–7.56)	8.33 (7.91–8.87)	8.79 (8.08–9.41)	9.11 (7.44-NaN[a])

[a]For the Phone AOI at 7 months the upper boundary of the confidence interval could not be estimated. In some bootstrapping samples, the AOI was not fixated on 50% of the trials.

between the infant age groups of 6 and 7 months (less conservative: $p = 0.466$; more conservative: $p = 0.810$). When the data were more conservatively processed, there was also an interaction observed between item and trial block for the more conservative data processing F (2.08, 5348.39) = 3.12, $p = 0.042$, $\eta^2 = 0.001$; however, this effect was not observed when the data was processed less conservatively, F (2.07, 6320.96) = 1.30, $p = 0.274$, $\eta^2 < 0.001$). Post-hoc analyses showed that the items

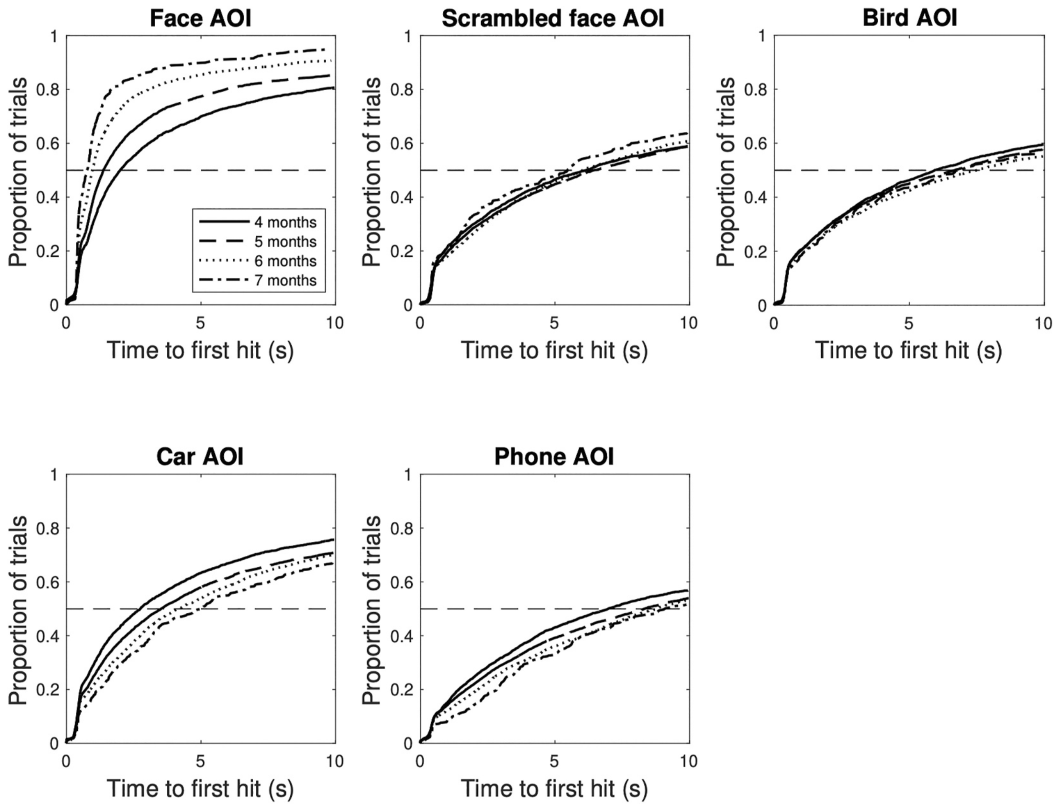

FIGURE 3 | Separate cumulative distribution plots for each item which show the time to first hit (seconds) each item on the screen separately for the age groups (4, 5, 6, 7 months) across all trials of all infants. The horizontal dashed line indicates half of the trials. Where this line intersects with the cumulative distribution functions is the time at which each item was fixated on 50% of all trials. The data shown in this figure were less conservatively processed - this conclusion is invariant to whether the less or more conservatively processed data were used.

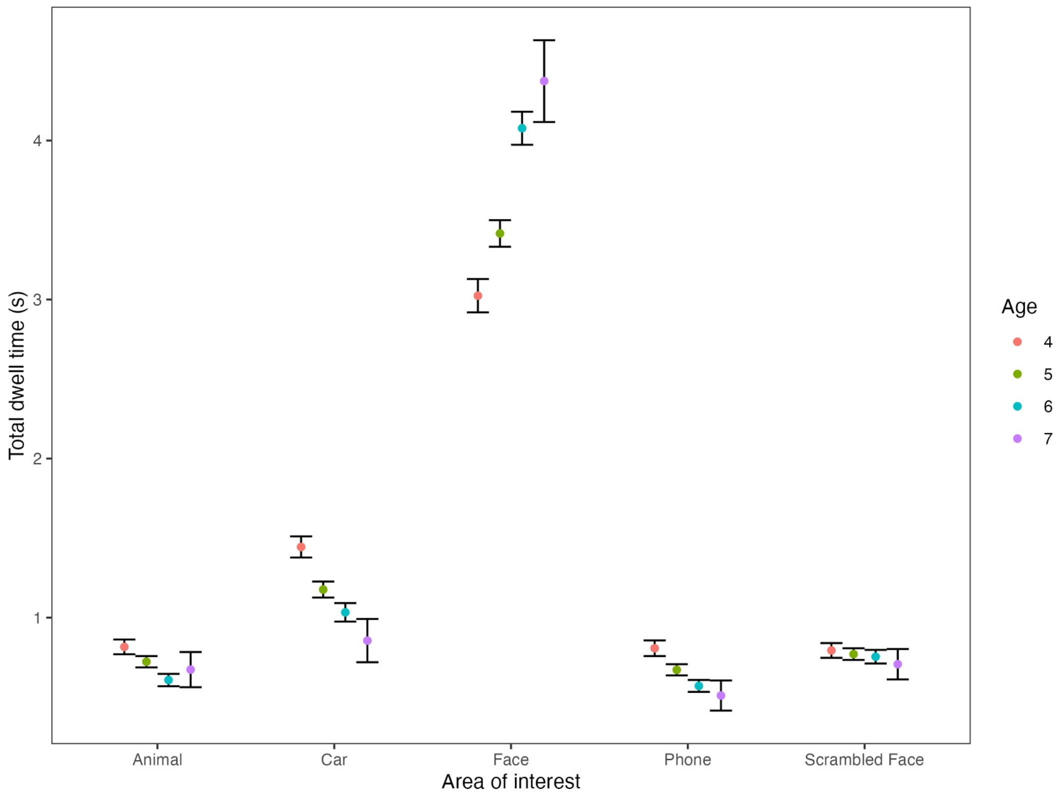

FIGURE 4 | Plot showing the mean total dwell time to each item during trials, with confidence intervals. The infants are split into age groups (4, 5, 6, 7 months). These results are taken from the less conservatively processed data.

'phase-scrambled face' and 'car' were fixated to for a significantly longer duration in the first three trials of the face pop-task than the last three trials ($p = 0.0020$ for the 'phase-scrambled face', $p = 0.0004$ for 'car'), but that there was no difference for the other items (all $p > 0.05$). Moreover, in both the first and last three trials, faces were fixated for a longer duration than other items ($p < 0.001$).

3.5 | Infants' Number of Fixations to the Face

Figure 5 presents the number of fixations to all items for the less conservative data pre-processing. For the less conservative processing, the mixed ANOVA revealed that the main effect of age was not significant (less conservative: F (3, 3048) = 2.54, $p = 0.055$, $\eta^2 < 0.001$. However, for the more conservative processing, the main effect of age was significant, F (3, 2571) = 2.84, $p = 0.037$, $\eta^2 < 0.001$). The main effect of item was significant and medium (less conservative: F (2.87, 8759.41) = 1149.56, $p < 0.001$, $\eta^2 = 0.239$; more conservative: F (2.97, 7647.61) = 1435.77, $p < 0.001$, $\eta^2 = 0.327$), with more fixations to faces than the other items. The main effect of the covariate trial number was significant and small (less conservative: F (1, 3048) = 48.30, $p < 0.001$, $\eta^2 = 0.003$; more conservative: F (1, 2571) = 46.05, $p < 0.001$., $\eta^2 = 0.002$), with a higher number of fixations in the first three trials.

Furthermore an interaction was observed between age and item that was significant and small (less conservative: F (8.62, 8759.41) = 38.92, $p < 0.001$, $\eta^2 = 0.031$; more conservative: F (8.92, 7647.61) = 17.75, $p < 0.001$, $\eta^2 = 0.018$). We assessed how infants' total fixations to face versus other items varied across the age groups. Infants in all age-groups looked at faces more frequently than to any of the other items (both less and more conservative were all $p < 0.001$). The post-hoc analyses also showed that there was a significant increase: as the infants became older, they directed more looks to faces (less conservative: all $p < 0.05$; more conservative: all $p < 0.05$, except for between the age groups 6 and 7 months, which was $p = 0.124$). No other interactions were observed (all $p > 0.05$).

4 | Discussion

The goal of this study was to assess whether face preference during the face pop-out task is observable prior to 6 months of age. We examined three measures of this phenomenon: infants' proportion of first looks to faces, their total dwell time to faces, and their number of fixations to faces. We additionally ran explorative analyses looking at time to first fixation as a measure. In line with the existing literature, we found that infants' first looks, total dwell time to the face, and number of fixations were significantly higher toward faces than toward any of the other items (de Klerk et al. 2014; Di Giorgio et al. 2012; Gliga et al. 2009; Hendry et al. 2018). Additionally, the time taken to first fixate to faces was significantly shorter than the time taken to first fixate to other items. Furthermore, the proportion of first looks that were directed to the face were significantly above chance level (i.e., 1 out 5 items). These findings were observed for all of the age groups. We thus found that infants preferentially fixated toward faces from 4 months onwards and replicated the existing findings from 5 to 7 months, showing that face

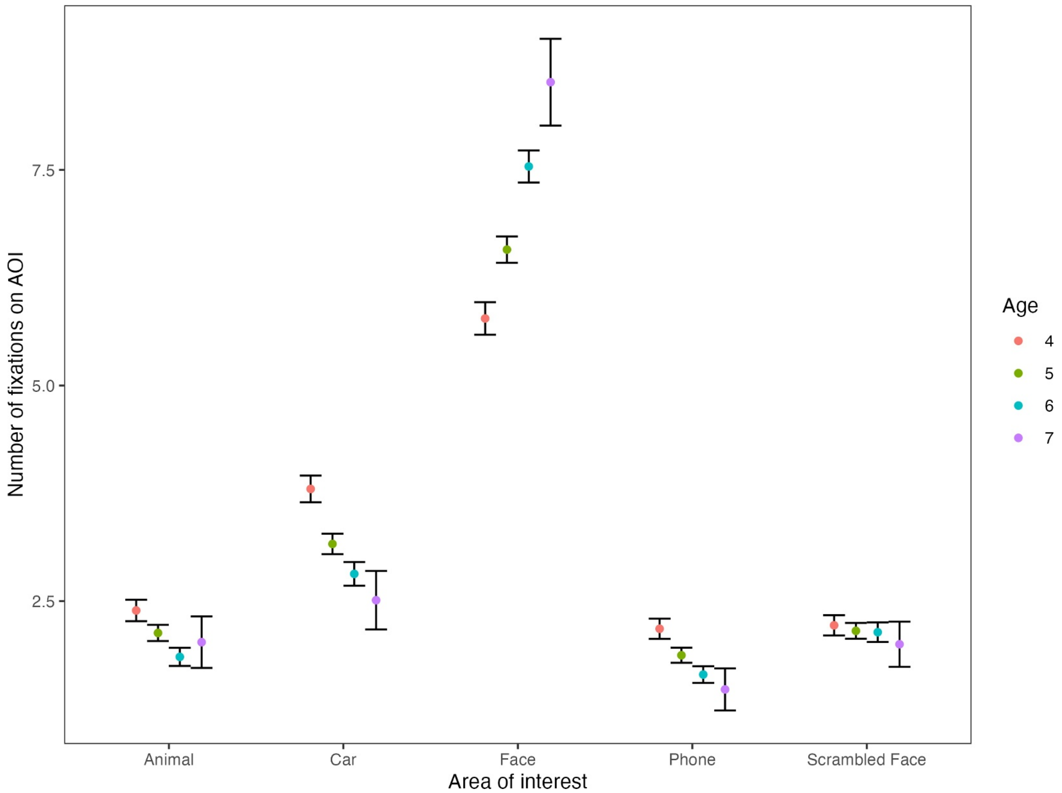

FIGURE 5 | Plots showing the mean number of fixations to each item during trials, with confidence intervals. The infants are split into age groups (4, 5, 6, 7 months). These results are taken from the less conservatively processed data.

preference is a robust phenomenon observable in multiple age groups. Furthermore, our analyses were run following two levels of data quality, as eye-tracking data quality has been shown to be contingent on the age of the infant (Hessels and Hooge 2019). We wanted to assess whether our observations were age related versus related to the differences in data quality across the age groups. The observations between the data that was processed less versus more conservatively were comparable and are thus robust even if only participants with high data quality are included.

In addition to the findings on face preference which replicated the existing literature, age-related differences were also observed across all of the measures taken from the face pop-out task. The proportion of first looks that infants directed to faces increased significantly between 4 versus 5 and then between 5 versus 6 months, and the time taken to first fixate to the face decreased significantly between 4 versus 5 and then between 5 versus 6 months. From the T_{50} analyses, we found that the time taken for infants to first fixate to the face on 50% of the trials was significantly different across all the age groups, with younger infants taking longer to direct their first fixations to the face. Therefore, for older infants, the proportion of first looks to the face and the speed at which they directed their first fixation to the face increased. Most previous studies assessed face preference in homogeneous samples of infants from the same age, at around 6 months of age (de Klerk et al. 2014; Elsabbagh et al. 2013; Gliga et al. 2009; Gluckman and Johnson 2013) and at 5 months (Portugal et al. 2022). An exception was the cross-sectional study by Di Giorgio et al. (2012), which found that infant's proportion of fixations to the face was greater than chance at 6 months, but not 3 months (Di Giorgio et al. 2012). Another exception was Kwon et al. (2016), who observed that in 4-month-old infants, visual preference for faces was influenced by physical saliency (Kwon et al. 2016). These studies indicate that the physical salience of the image plays a stronger role in the preferential fixation to faces of younger infants. In line with these findings, this current analysis observed not only that infant's preferential fixation to the face increased over the course of development, but also that their preferential looking behaviors to the car, a physically salient item, decreased significantly with age.

In this current study, we assessed face preference in 4-, 5-, 6- and 7-month-old infants. However, it was not possible to assess whether infants younger than 4 months showed a face preference when tested on the face pop-out task. Future research could confirm whether age-related differences are observable prior to 4 months, to provide a more comprehensive picture of how infants' capacities for face preference develop.

In addition to the proportion of first looks, both the total dwell time to the face and the number of fixations to the face was longer and more frequent (respectively) for older infants. More specifically, the total dwell time to the face increased between 4 and 6 months but reached plateau by 6 months. For the number of fixations to the face, the findings differed depending on whether a less or more conservative data processing criterion was used, and thus hinges on data quality: it increased until 7 months for the less conservative, and until 6 months of age for the more conservative criterion. Nevertheless, for most of the findings in this study, data quality did not appear to have an impact on the conclusions. In part, the robustness to data quality of the statistical analyses may be due to the data processing methods that were chosen. For example, the fixation classification algorithm (I2MC: Hessels et al. 2017) that was run to extract the fixation locations prior to the pre-processing of the data was specifically designed for data of variable quality, which means that the outcome measures are robust to some differences in data quality across ages. In addition, we used large AOIs, which are not very susceptible to noise for the measures of total dwell time and number of fixations to the AOI (Hessels et al. 2016). Finally, for both total dwell time and number of fixations, there was a significant effect for trial number—infants dwelled longer and directed more fixations in the first 3 trials than in the last 3 trials. The differences in the gaze behavior of the infants in the earlier compared to later trials could have been due to the array (or set-up) changing from novel to familiar for the infant (Houston-Price and Nakai 2004).

The age-related increase in the fixations that infants directed to the face (i.e., first fixations, time to first fixations, total dwell time, and frequency of fixations) may corroborate the two-process theory of face development (Morton and Johnson 1991). This model proposes that new-borns have a predisposition ('conspec') to orient toward faces and that older infants additionally have an acquired specialization ('conlern') of cortical circuits for face processing. In this model, the former 'conspec' mechanism feeds into the latter 'conlern', by biasing the attention of newborns and younger infants to faces, which subsequently biases the input to the developing cortical circuitry (Morton and Johnson 1991; Reynolds and Roth 2018). It has been suggested that around 4 months of age, infants might be in the process of acquiring the specialized 'conlern' circuitry (Johnson 2000). Consequently, what may contribute to the increasing fixations that infants direct to the face, is the emergence of 'conlern' mechanisms alongside the 'conspec' mechanisms (which remain and can still be observed in adults; Shah et al. 2013). In addition to the development of mechanisms that are specialized to face processing, more domain general mechanisms undergo developmental changes in the first year of life (in particular, an increase in attentional control) that likely contribute to the age-related differences we observe in this study (Johnson et al. 2015).

In this paper we explored age-related changes between 4 and 7 months in how infants fixated to faces on the face pop-out task and to assess whether data quality impacted the observed results. We replicated the findings from existing studies using the face pop-out task, showing that in all age groups, infants directed their first fixations to the face more frequently, directed their first fixation to the face faster, dwelled on the face for a longer time, and had higher number of fixations to the face than to any other item. Crucially, we further observed a developmental trajectory, whereby all outcome measures indexing face preference increased as a factor of age until 6 months of age. These differences as a factor of age remained largely stable regardless of whether the data was processed less or more conservatively, suggesting that these findings were robust despite the data quality differences between the age groups. As such, this paper presents a more fine-grained look at how infants gaze behavior to faces develops in the first year of life.

Author Contributions

Z. Belteki: conceptualization, formal analysis, investigation, methodology, project administration, visualization, writing–original draft, writing–review and editing. **R. S. Hessels:** conceptualization, data curation, formal analysis, methodology, visualization, writing–review and editing. **C. M. M. Junge:** conceptualization, funding acquisition, supervision, writing–review & editing. **C. Kemner:** conceptualization, data curation, funding acquisition, supervision, writing–review and editing. **C. van den Boomen**: conceptualization, formal analysis, funding acquisition, methodology, project administration, supervision, writing–review and editing.

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Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

Data subject to third party restrictions: The data that support the findings of this study are available from the YOUth cohort study. Restrictions apply to the availability of these data, which were used under license for this study. Data are available at (https://www.uu.nl/en/research/youth-cohort-study/request-youth-data) with the permission of the YOUth Management Team.

Endnotes

[1] Angles are reported under the assumption that participants remained at exactly 65 cm (TX300) or 67 cm (Spectrum) from the screen, and relative to the centre of the screen (the small angle approximation).

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