



These are the people in your neighbourhood: Consistency and persistence in infants' exposure to caregivers', relatives', and strangers' faces across contexts



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ABSTRACT

Faces are a frequent part of young infants' visual environments. Three-month-old infants spend approximately 25% of their time exposed to faces (Sugden, Mohamed-Ali, & Moulson, 2014; Jayaraman, Fausey, & Smith, 2015). These faces belong primarily to familiar people, like their caregivers, and are heavily weighted towards female, adult-aged, and own-race faces. To date, descriptions of infants' exposure to faces have focused on frequency—both overall frequency and relative frequency of different face types (e.g., familiar vs. unfamiliar; own-race vs. other-race). It is less clear whether faces of different types distinguish themselves in other ways that have implications for infants' learning. Here, we move beyond an evaluation of frequency to determine the dimensions by which familiar faces (i.e., caregivers and relatives, as identified by parental report) differentiate themselves from unfamiliar (i.e., stranger's) faces in the infant's early visual environment. Measuring infants' natural visual ecology with head-mounted infant-perspective cameras, we found that 3-month-olds were exposed to faces 21% of the time. The primary caregiver was the most frequent face (44% of exposure time) and non-primary caregivers were often second most frequent (17% of exposure time). Caregiver faces also distinguished themselves by their consistency across both contexts and time. For example, the primary caregiver's face was most likely to appear across contexts and locations. Primary caregiver faces were less likely to persist in the field of view, as compared to non-primary caregiver and stranger faces. Thus, the socially important faces in the infant's visual environment distinguish themselves not only through their overall frequency, but also through their consistency across contexts. This has implications for understanding how the early visual environment shapes learning about faces.

William James famously said that “the baby, assailed by eyes, ears, nose, skin, and entrails at once, feels it all as one great blooming, buzzing confusion (James, 1980).” What assails infants' eyes are primarily faces; one quarter of infants' typical daily experience includes faces (at 1 and 3 months of age, Sugden, Mohamed-Ali, & Moulson, 2014), presented in ways that facilitate their resolution or attention (at 1 and 3 months of age, Sugden & Moulson, 2017), and belonging mostly to family members and caregivers (across the first year of life, Jayaraman, Fausey, & Smith, 2015; Rennels & Simmons, 2008). This is not surprising; altricial human infants' intense caregiving requirements demand caregiver attention. This creates opportunity for infants to learn about evolutionarily important visual stimuli, faces, and to differentiate important faces (e.g., caregivers, relatives) from faces that are not important (e.g., strangers) through the frequency and qualities of their presentation. Moreover, how faces are presented may build

upon and/or establish expectations about how and what aspects of their environment are important to learn.

Infants begin learning about the faces in their environment shortly after birth. Newborn infants show a preference for their mother's face over a female stranger's face (Bushnell, Sal, & Mulhn, 1989; Field, Cohen, Garcia, & Greenberg, 1984; Pascalis, de Schonen, Morton, Deruelle, & Fabre-Grenet, 1995), and can discriminate between two female faces following familiarization with one of them (Pascalis & de Schonen, 1994; Turati, Macchi Cassia, Simion, & Leo, 2006). Face learning continues throughout the first year: By 3 months, infants show a preference for faces that match the gender of their primary caregiver (female over male faces for infants with female primary caregivers; male over female faces for infants with male primary caregivers; Quinn, Yahr, Kuhn, Slater, & Pascalis, 2002). They also show a preference for faces of their own race (Kelly et al., 2005) and develop differential

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discrimination of familiar and unfamiliar face types (Sugden & Marquis, 2017). By 6 months, they discriminate between individual faces of their own race and some but not all faces of other races, despite equal familiarity 3 months prior (Kelly et al., 2007). When tested on the same task, 9-month-old infants show discrimination of only own-race faces and a failure to discriminate other-race faces. A similar trajectory of perceptual narrowing—gradual loss or stagnation of ability with unfamiliar, as compared to familiar, face types (Scott, Pascalis, & Nelson, 2007)—has been found for other-species faces (Heron-Delaney, Wirth, & Pascalis, 2011; Pascalis, de Haan, & Nelson, 2002; Scott & Monesson, 2009).

The bulk of the literature investigating the effects of experience on face perception equates exposure with frequency; that is, infants learn about the faces that are most frequent in their environment. For example, it is presumed that infants gain expertise with own-race faces and lose ability with other-race faces because of the differing frequency of exposure to own-race versus other-race faces. Early learning about faces is likely driven by the natural statistics embedded in early exposure to faces. We know that even newborn infants are sensitive to the frequency of face presentation: Infants with more exposure to their mother show a greater preference for her (Bushnell, 2001). This ability to track frequency appears in numerous studies of infant ability across multiple domains. At the most basic level, the habituation-dishabituation paradigm, in which infants are exposed to a single stimulus until they no longer show an interest in it and then are shown a new stimulus to which they show recovery of interest, highlights their ability to track the relative novelty and familiarity of events. Newborn infants show this basic sensitivity (Slater, Morison, & Rose, 1984).

In addition to frequency, length of exposure also influences learning. Here, we are not referring to amount of time with a given stimulus across multiple exposures; rather, the length of time a single instance of a stimulus persists in the infant's field of view. Habituation and familiarization studies of infant memory reveal that the length of exposure to a stimulus is directly related to infants' ability to learn the stimulus and demonstrate recognition in a subsequent test (Hunter, Ames, & Koopman, 1983; Rose, Gottfried, Melloy-Carminar, & Bridger, 1982). In studies of word learning, objects for which the child learned the name were held in the field of view longer than objects for which the child did not learn the name (Pereira, Smith, & Yu, 2014).

It is likely that the faces that infants encounter differentiate themselves in other ways as well, and it is unclear which aspects of exposure are likely to be most prognostic of developing ability. How might familiar faces distinguish themselves in the early visual ecology of the infant, other than by their frequency? Here, we can gain insight from studies of infant learning outside of the domain of face perception. Studies of infant memory demonstrate that context influences learning. For example, location of training and test both influence memory. If 3-month-old infants are asked to remember a visual object, they can only do so if the training occurs in the same location as the test (Rovee-Collier & Dufault, 1991). The exception to this is that if they are trained in multiple different locations, then their memory is not tethered to any one context and they are able to show memory in a novel context. Similarly, auditory context can facilitate or disrupt 3-month-olds' memory (Fagen et al., 1997). Infants trained with conjugate mobile reinforcement showed retention of the training only if the same and not if different music was played during a memory test that occurred 7 days later.

Face experience provides some of the same cues that facilitate learning in other domains. Early face experience provides repeated presentations of specific face types, typically female, own-race, and adult-aged (Sugden et al., 2014), in ways that promote attention (Sugden & Moulson, 2017). Furthermore, it represents few people, primarily infants' primary caregiver and other family members, who are encountered often (Jayaraman et al., 2015; Rennels & Simmons, 2008). Akin to the argument of cross-situational word learning (Smith & Yu, 2008), consistency across contexts may be a cue that disambiguates caregiver from non-caregiver faces in the infants' early

environment. Additionally, the length of time different faces persist in the field of view might be a particularly important metric by which important faces distinguish themselves, especially since faces are complex stimuli, which typically take longer for infants to process (Richards, 2010).

The goal of the current investigation was to determine whether factors that facilitate learning in other domains are also present in infants' early face experience, and critically, serve to differentiate "important" faces (i.e., caregivers) from other faces that the infant encounters. Specifically, we investigated whether caregiver faces distinguish themselves not only through their frequency in the infant's early visual environment, but also through their persistence in time and their consistency across contexts. Important faces likely distinguish themselves in other ways as well: For example, caregivers are likely to have qualitatively different social interactions with the infant, potentially facilitating face learning through this social congress (Scherf & Scott, 2012), and caregiver faces are likely to co-occur with other important faces (e.g., siblings, other relatives). For the purposes of the present investigation, however, we focused on overall frequency, persistence within a single exposure, and consistency across contexts.

The current study used infant-perspective head-mounted cameras to document the early visual ecology of 3-month-old human infants. Although there are many ways to capture infants' early experience, the infant perspective is unique and important. To truly appreciate that perspective requires a method that captures the rich wealth of infant-perspective information with high fidelity. Head-mounted infant-perspective cameras provide this data. There is a growing body of research that uses child-perspective head-mounted cameras to capture, describe, quantify, and relate experience to learning (for a review, see Smith, Yu, Yoshida, & Fausey, 2015). Importantly, an adult or bird's eye view are not predictive of learning whereas the child perspective predicts what the child will learn (Pereira et al., 2014; Yurovsky, Smith, & Yu, 2013). Growing from this methodology, there is an understanding of the uniqueness of an infant's perspective, the importance of that perspective, and how the natural visual statistics of the infant's environment distinguish the familiar from the unfamiliar, the important from the unimportant, and the learned from the unlearned.

Infants quickly learn important faces, but how familiar are important faces? Does their frequency, persistence in time, or consistency across contexts differentiate them from faces that are not as personally important to the infant? We hypothesize yes on all fronts. We expect that important faces, like caregivers, differentiate themselves through their relatively greater statistical probability in the environment overall, longer persistence of each single experience of a face, and greater reliability of occurrence across multiple contexts. We posit that there are likely degrees to this, radiating out from the primary caregiver, to other caregivers, to relatives, and to strangers. Moving beyond a description of frequency to investigate other ways by which familiar faces distinguish themselves in the infant's environment will further our understanding of the face experience of the human infant, which will in turn constrain predictions about how experience shapes face learning.

1. Method

1.1. Participants

Forty (13 female) 3-month-old participants were recruited from a database of families who had previously expressed an interest in developmental research. Infants were 88 days old ($M = 88.28$ days, $SD = 10.13$) when they began the study and 99 days ($M = 98.88$ days, $SD = 11.37$) when they ended their participation. They had the camera for an average of 10.6 days ($SD = 5.95$). The infants all lived in a large, diverse metropolitan area and reflected that diversity; parents reported infants' background as: 23 White, 3 Black, 3 Chinese, 4 East Asian-White, 3 Black-White, 1 Spanish-White, 1 Mexican-White, 1 Pakistani-Egyptian, and 1 Arabic-White. Although all infants had a female



Fig. 1. Infant wearing upside-down-smiley-face head-mounted camera on a fuzzy red headband. *Note: reproduced with permission from the parent.

primary caregiver, the other people with whom they lived was highly heterogeneous. For example, two infants did not have more than one caregiver and two did not have a male caregiver, living with extended family or two female parents.

1.2. Equipment

Parents were provided with two miniature inconspicuous cameras with which to record. The camera was in the shape of a yellow happy-face pin (see Fig. 1), with the recording aperture concealed in the black-coloured left eye of the face. The lightweight camera was 5 cm in diameter. This camera was chosen because it looked more like an infant clothing accessory than a camera. The camera was clipped onto a fuzzy elasticized headband, which was worn on the infant's head. In a few cases, parents chose to clip the camera onto a hat, hairband, or other head accessory (e.g., balaclava in the winter). To be able to best capture the infant's field of view the camera was placed at or slightly above the bridge of the infants' nose, between the infant's eyebrows. Small sponges on the back of the camera were used to adjust the camera angle to best capture the infant's field of view. The camera was oriented upside-down, to ensure that the eye of the camera was as near as possible to the infant's eye. The camera recorded at either 8 or 30 frames per second with an image resolution of 1536×2048 pixels. Videos were coded at the frame rate at which they were recorded; this decision was made because although this meant that some infants provided more frames for the same duration of video, it allowed us to maximally exploit the available data to the finest possible grain. Additionally, we checked the point at which down-sampling the 30 fps videos resulted in a 5% difference in face density – this inflection point did not occur until after 1 frame per minute for primary caregiver, secondary caregiver, or stranger faces (Makani, Sugden, & Moulson, 2017). Video was recorded in .AVI to a 16 GB microSD memory card. The video included audio and was in full colour. Parents were also provided with a charging cable with which to recharge the battery, a small bag in which to store the equipment, printed instructions for the camera, and a photograph of an infant wearing a properly placed camera as an exemplar for camera placement.

Parents were also given a 'daily diary', which included a series of questions to be answered about each day they spent with the camera. The questions inquired about the number of times they recorded with the camera, the people the infant saw, the locations the infant visited, a

brief description of the infant's activities, and any notes about the camera or recording. The daily diary also included reminders about privacy concerns related to recording.

1.3. Procedure

Parents were contacted by telephone or email and invited to participate in the study. If they were interested, two visits were booked. The first visit was at the parent's home, lab, or another location convenient to the parent (e.g., spouse's place of work, grandparent's home). The second visit was in the lab. If an additional visit was necessary (e.g., lost equipment, see below), this always occurred at the family's home.

At the first visit, the parent provided informed consent for participation, answered a brief questionnaire that included demographics questions, and was trained in the operation of the camera in four steps: 1) The researcher would show the parent how to operate the camera by following printed step-by-step instructions. Parents kept the instructions for the duration of their participation. 2) The researcher supervised the parent following the same instructions, to ensure they were able to operate the camera. 3) If the baby was available, the researcher would place the camera on the baby's head and record a small sample of video during which they would place their face directly in front of the baby's face and say 'The baby is looking at me.' The researcher also highlighted, for the parent, where the camera should be placed, referring to a printed exemplar photograph. (The parents also kept this exemplar during the week of recording.) After the researcher had recorded, they removed the memory card and showed the video to the parent. This step also served to ensure accurate placement of the camera because the researcher could determine, from the section of video during which they indicated that the baby was looking at their face, whether the camera placement needed to be adjusted. If it did need to be adjusted, the researcher would place small sponges on the back of the camera to change the camera angle. The researcher would then repeat step 3 to check the adjustment. Theoretically, this would repeat until the researcher assessed that the camera was capturing the infant's field of view. In practice, this was repeated a maximum of twice for any child. If, however, during this step the child was not available, the researcher would demonstrate on themselves; camera angle adjustments were not made in this case. 4) The researcher had the parent place the camera on the baby or, if the baby was unavailable, the researcher's, their own, or a plush toy's head to demonstrate camera placement. If the baby was available, the researcher and parent would check this video as well. Throughout camera training, the researcher provided guidance and feedback to the parent.

Parents were instructed to charge the cameras overnight every night and, if possible, to plug them in to charge after each recording session (e.g., while the child was napping). They were asked to record as much as possible, with an encouraged minimum of twice per day. To facilitate participation with an infant population, parents were not given a schedule for recording. Parents were asked to record at any time of the day, provided the infant was awake. If the infant fell asleep during a recording session, parents were asked to end recording. They were told to record during any of the infant's activities, with the goal of best representing their typical, daily experiences. With respect to out-of-the-home recording, they were told they could record in public places, with the proviso that they not record in locations where there is a reasonable expectation of privacy (e.g., doctor's office, restroom). If they wished to record in semi-public locations (e.g., baby yoga, church) or in another person's private home or office (e.g., aunt's home), they were asked to ask the person in charge (e.g., instructor, pastor, aunt) whether they could record.

One to 2 days after receiving the camera, parents were contacted by the researcher to ensure recording was going well. If the parent identified any issues, the researcher would troubleshoot with the parent over the telephone. If the parent filled the SD card, a piece of equipment was broken (e.g., dropped in a bath, gummed by an infant, act of dog), a

piece of equipment was lost or the parent had an issue that could not be resolved over the telephone, a researcher would return to visit the parent to replace the equipment and/or resolve the issue. One to 2 days after this second visit, a researcher would again contact the parents to inquire about recording. The day before the family was scheduled to visit the lab, they were again contacted to ensure that recording had gone well and that the appointment was still convenient for them.

The family returned to the lab to return the camera. At this appointment, the infant participated in a series of tasks that are part of a larger longitudinal study and not reported here. The parents completed a final questionnaire, documenting their time recording and experience with the camera. To thank them for their participation, the family received a \$25 honorarium, a copy of all of the videos recorded from their infant's perspective, a 'baby scientist award', and, for the infant, a toy.

1.4. Data coding

Infant looking was coded frame-by-frame using Datavyu 1.3 (Datavyu Team, 2014). All coders completed an extensive training with a senior coder. They then coded 3 videos independently. On the last video, coding reliability was assessed, as measured against a highly-experienced senior coder. All coders achieved a minimum of 85% reliability. Coders were assigned to infants, so that the same coder coded all of the videos for each infant. In the cases of male coders, a senior female coder first viewed all of the videos to ensure the family's privacy was respected and to be sensitive to parents' possible concerns about a male coder (e.g., breast-feeding videos). If the videos contained any materials that the researcher deemed of concern, the male coder was assigned to a different infant.

1.5. Face identification

All parents identified primary and other caregivers, relatives, and other frequently-experienced people during the initial interview, prior to recording. These parent-reports were used to classify faces as Primary Caregivers, Other Caregivers, and Relatives. Any face that was not identified and was not the infant's own face was classified as a Stranger. These groupings and methods of categorizing individuals as caregivers were chosen to best reflect the diversity of the families who participated in the study and the previous literature that highlights the likely importance of primary caregivers in shaping infants' early face preferences (e.g., Quinn et al., 2002). We acknowledge that a different way of grouping the data could produce different insights about infants' face experience, although this would be beyond the scope of the current research question.

All infants had a female primary caregiver, and in all cases, this was their mother. All but two infants had a secondary caregiver. For 36 infants this was dad, for one it was an aunt, and for one it was a second mom. In addition, five infants had more than two caregivers (two had 5, two had 3, and one had 4). These caregivers were siblings ($n = 4$), grandparents ($n = 5$), and one uncle). Infants with no secondary caregiver experience were excluded from the analysis of secondary caregiver. Analyses including all caregivers include all persons identified by parent-report as caregivers.

During video coding, faces were identified at the individual level when this was possible. In no particular order, coders identified faces by utilizing any of a combination of: 1) the questionnaire completed at the home visit, which included a list and description of frequently-experienced people; 2) the daily diary, which included a list and description of people experienced each day; 3) the questionnaire completed at the lab visit, which included a list and description of the people the infant experienced during the week; 4) the knowledge of research assistants who had met the family; 5) videos recorded from tasks completed as part of the larger study in which the family participated on the second visit, which typically included the parent's and always included the infant's face; 6) other infant-perspective videos recorded by the infant

at 3 months of age; 7) infant-perspective video recorded from the perspective of the infant when they were 6- and 9-months-old; 8) self- or other-person- identification that occurred in videos (e.g., 'Put your brother down.');

9) the camera itself (diagnostic of whether an infant was the participant); and 10), where possible, the person coding the video met the family in-person when the family visited the lab. For every infant, a minimum of one other researcher who had met the family reviewed all of the faces coded as relatives to ensure accuracy within the relatives the researcher had met (two to six relatives' faces per infants). They then used the participant video to assess the relationship of the other faces coded as relatives. Inter-rater reliability for both measures was 100%.

We also classified non-relatives' faces as strangers. By default, strangers were people that could not be certainly identified as relatives. These people ranged from family friends to passers-by on the street. We took a conservative approach in identifying relatives, omitting any person for whom the relationship could not be ascertained; consequently, these people were identified as strangers. Although we recognize that some of these faces may be relatives, we reasoned that because we wish to faithfully characterize relative face experience and that the group of potential relatives is smaller than the group of potential strangers, including non-relatives as relatives would be more problematic. From this perspective, strangers may be more likely to resemble relatives, however we can be certain that the relatives we have identified are not strangers.

1.6. Location coding

Video recording locations were classified as home, car, outdoors, and public space. Homes included any home environment, including the homes of relatives and friends, in addition to the infant's own home. We classified the location home in this way for two reasons: 1) in some videos it was unclear whose home it was, and 2) infants visiting any home are likely to be in contact only with close friends and relatives, which speaks to our research question. Car included any private vehicle, however in all cases here the car was driven by a family member. Outdoors included activities such as walks in the stroller, playing with siblings in the park, a street barbeque with neighbours, and a picnic. Public places were all non-home, indoor locations (e.g., offices, malls, recreation centres, summer camp mess hall, restaurants, and Ikea).

1.7. Context coding

Coders provided a brief summary of the each video (for summaries, please see [Supplemental Material](#)). Where possible, this included the activities of the people in the video, a clearer description of the location, and any other information that would allow a naïve person, who had not seen the video, to understand the content of the recording. The contexts varied in a multitude of different ways. For readers who wish to more fully understand the content of the videos, we provide these qualitative descriptions in a spreadsheet within the [Supplemental information](#).

2. Results

2.1. Total video

A total of 169 h, 58 min, and 8 s of video were recorded. Infants averaged 4.25 h of video each ($SD = 2.74$). Of the total video recorded, some could not be coded because the camera was occluded, there were technical issues with the camera, or other concerns that the video did not accurately represent the perspective of the infant; omitting this ruined video left a total of 157 h, 32 min, and 5 s of video ($M = 3.94$ h, $SD = 2.58$ h per infant) that could be coded. All infants included in this sample recorded a minimum of 30 min of good video.

As is typical with this type of data, the majority of measures violated

at least one assumption of parametric tests (e.g., significant non-normality, skewness, kurtosis). Therefore, we analyze the data using non-parametric tests. Below, we indicate what tests were used for each analysis.

2.2. Face duration, number of individual faces, and number of face occurrences

All infants were exposed to faces. On average, infants spent 21.1% ($SD = 12.5$, Range: 9.4%–52.4%) of their time, or 13 min per hour, exposed to faces. Previous studies with this age group have reported comparable metrics of exposure (e.g., Jayaraman et al., 2015; Sugden et al., 2014). Infants saw an average of 51 individual faces ($SD = 77.6$) during their time recording, which averaged to 37.4 individuals per hour ($SD = 54.8$). Individual faces per hour is not a straightforward division of individual faces over time recorded because faces repeat, with any number of the 51 individuals occurring within an hour (e.g., if hour 1 includes mom and dad, and hour 2 includes mom, dad, and Sachi, the infant has seen 4 individuals in 2 h and 3 individuals' faces per hour). Irrespective of the individual, duration of the current or previous occurrence, or time since last occurrence of the face, faces occurred in the field of view an average of 8.7 times per minute ($SD = 5.3$). The mean exposure length of any given face was 3.5 s ($SD = 24.9$; see Figs. 2 and 3).

2.3. Familiar faces: caregivers

The primary caregiver was the most frequently experienced single face of the majority of infants (30 of 40 infants). For the remaining 10 infants, the most frequently experienced face was another caregiver (dad $n = 3$, sister $n = 1$, grandpa $n = 1$), a relative not identified as a caregiver (uncle $n = 1$, grandma $n = 1$), the infant themselves ($n = 2$), or a stranger ($n = 1$). The single stranger occurred in a single, lengthy video, where the stranger remained in the field of view for the duration. Mom, the primary caregiver for all of the infants, represented an average of 43.9% ($SD = 24.5$) of all face exposure (see Fig. 4). On average, each experience of mom's face lasted for 2.9 s ($SD = 1.0$).

When face exposure to all non-primary caregivers was combined (excluding the 2 infants who did not have a secondary caregiver), non-primary caregiver faces represented an average of 17.5% ($SD = 14.9$) of all face exposure (see Fig. 4). On average, each experience of caregivers' faces lasted for 2.8 s ($SD = 1.7$). Altogether, primary and non-primary caregivers represented 60.4% ($SD = 24.2\%$) of infant face input. Caregivers represented more than 50% of all face input for 27 of the 40 infant participants. For only 5 infants were caregivers less than 25% of their total face input. These low-caregiver-exposure infants had high exposure to strangers' faces ($M = 59.9\%$, $SD = 31.3$; see Fig. 4; for further details on stranger face exposure, see below).

There were significant differences between infants' experience of primary as compared to non-primary caregivers' faces. Thirty of the 38 infants with more than one caregiver had more experience with their primary than their secondary caregiver's face, Related-Samples Wilcoxon Signed Rank Test $Z(37) = 4.04$, $p < .001$; Related-samples Hodges-Lehman Median difference = 25.13 [35.51–14.90]. When these faces occurred, there was no difference in duration between non-primary ($M = 2.4$, $SD = 1.6$, $Mdn = 1.9$) and primary caregiver ($M = 3.1$, $SD = 1.1$, $Mdn = 3.0$) faces, Related-Samples Wilcoxon Signed Rank Test, $Z(37) = 1.37$, $p = .171$, Related-Samples Hodges-Lehman Median Difference = 0.33 [0.84–0.20]. The primary caregiver's face duration was longer in 23 of the 38 infants.

2.4. Familiar faces: self

One notable feature of the videos was that infants were often exposed to their own face. This occurred when parents presented them to a mirror and, because many infant toys and accessories included mirrors (e.g., activity mat with a mirror in its peak), when babies were playing independently. In a previous study, one infant's face exposure was nearly exclusively to their own face (Sugden et al., 2014). We expected that own-face exposure would differ from adult face exposure, since infant behaviour is generally different from that of adults. In this sample, 32 of 40 infants had some exposure to their own face. Excluding the infants with no own-face exposure, 4.1% ($SD = 7.3$, Range: 0.01–32.7%) of all exposure was to their own face (see Fig. 4). On

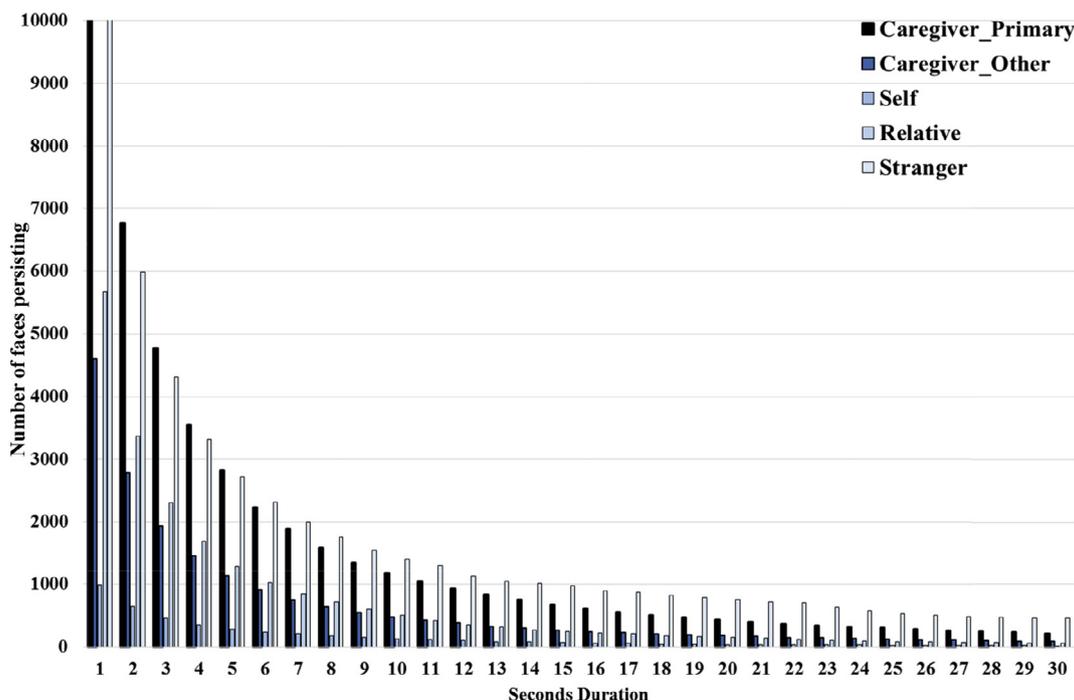


Fig. 2. Unstandardized survival curve of number of face instances persisting for face exposure durations for faces of the primary caregiver, other caregivers', the infant themselves (self), relatives, and strangers.

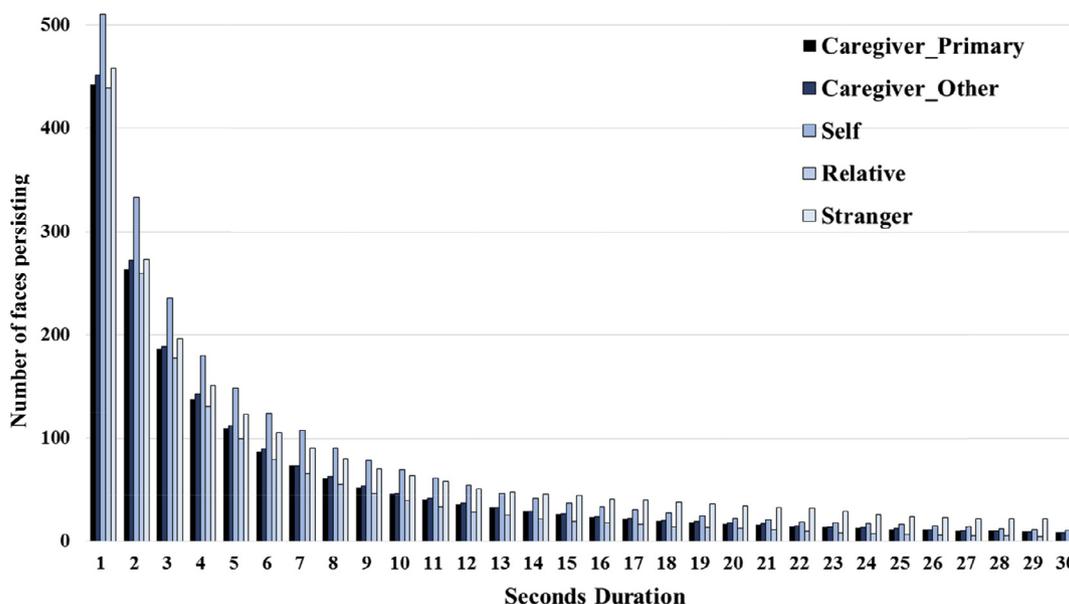


Fig. 3. Standardized survival curve of number of face instances persisting for face exposure durations for faces of the primary caregiver, other caregivers, the infant themselves (self), relatives, and strangers (Standardized to represent proportion of 1000 faces that persist up to each time interval.)

average, infants’ own faces persisted in their field of view for 2.1 s ($SD = 1.3$).

2.5. Familiar faces: relatives

Infants also had experience with non-caregiver relatives, such as siblings, grandparents, aunts, uncles, and cousins. Although ‘relatives’ is a heterogeneous group, we consider them together because of the diversity of experiences infants receive; not all infants saw the same relatives (e.g., not all infants saw grandma). Moreover, we also reasoned that there would be consistency in how infants experience relatives’ faces that would differentiate them from how infants likely experience strangers. For example, we expected relatives to be more likely than strangers to engage with the infant. Infants who had no

exposure to non-caregiver relatives are omitted from this section of analysis. Of the 40 infants, 30 were exposed to relatives’ faces. On average, infants experienced 4.3 individual ($SD = 7.0$) relatives. When they occurred, non-caregiver relatives represented an average of 18.8% ($SD = 16.0$) of all face exposure (see Fig. 4). On average, each experience of a relative’s face lasted for 2.4 s ($SD = 1.2$).

2.6. Unfamiliar faces: strangers

Thirty-seven infants were exposed to strangers’ faces. The three infants without stranger face exposure were excluded from this analysis. As a group, strangers represented an average of 24.0% ($SD = 24.4$) of all face exposure (see Fig. 3). On average, infants experienced 48 strangers, however this varied widely ($SD = 79.0$,

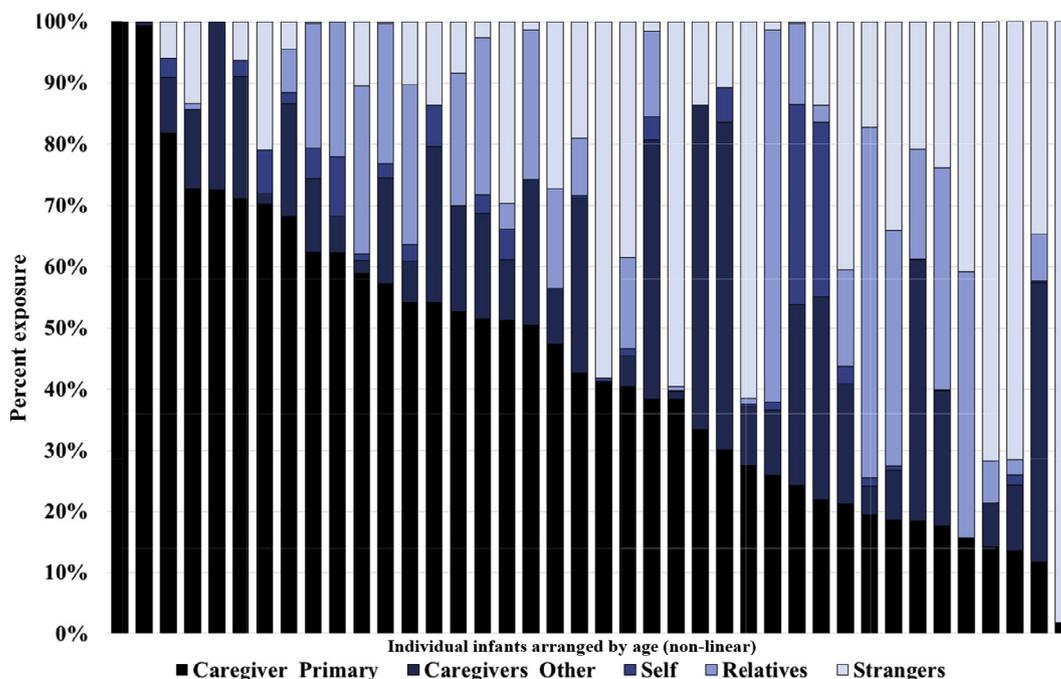


Fig. 4. Each individual infant’s percent exposure to primary caregiver, other caregivers, the infant’s own (self), relatives’, and strangers’ face(s).

Table 1
Cox regressions of face duration comparing primary caregiver to other face types.

Face type	B (SE)	Wald (p)	Hazard Ratio [95% CI]
Primary Caregiver (reference category)		156.62 (< 0.001)	
Other caregivers	−0.03 (0.01)	5.64 (0.018)	0.97 [0.95–1.00]
Infant themselves (self)	−0.15 (0.02)	42.33 (< 0.001)	0.86 [0.82–0.90]
Relatives	0.13 (0.01)	1.48 (0.224)	1.01 [0.99–1.04]
Strangers	−0.09 (0.01)	97.59 (< 0.001)	0.91 [0.90–0.93]

$Mdn = 14$, Range: 1–422). More than half of strangers occurred only once or twice (52.8% of all strangers' faces) and 80.8% occurred fewer than a dozen times. By comparison, primary caregiver faces occurred an average of 610 times ($SD = 538.6$).

2.7. Strangers versus relatives

Comparing strangers to relatives (i.e., family members who are not caregivers or the infant themselves) for the 29 infants who had exposure to both, 16 infants received nearly proportionally equal exposure to relatives as to strangers. Fifteen infants had more relative and 14 infants had more stranger exposure, Related-Samples Wilcoxon Signed Rank Test, $Z(28) = 0.62$, $p = .538$, Related-samples Hodges-Lehman Median difference = 3.88 [−7.96 to 20.94]. The number of strangers experienced was significantly greater than the number of relatives experienced, Related-Samples Wilcoxon Signed Rank Test $Z(28) = 3.99$, $p < .001$, Related-samples Hodges-Lehman Median difference = 39.00 [9.00–53.50]. Only four infants saw more individual relatives than strangers and one infant saw equal numbers of each type of individual. When they did occur, strangers' faces did not dwell for a significantly different length of time ($M = 2.9$ s, $SD = 4.7$) than did relatives' faces ($M = 2.4$ s, $SD = 1.2$), Related-Samples Wilcoxon Signed Rank Test $Z(38) = 0.83$, $p = .405$; Related-samples Hodges-Lehman Median difference = −0.19 [−0.58 to 0.25].

2.8. Consistency in duration, context, and location

Since infants are sensitive to statistical probabilities, we considered that measures of central tendency may not fully capture face exposure. To capture metrics of consistency within and across contexts, we took a corpus approach and analyzed the full dataset, irrespective of the individual participants. We consider consistency in duration - how likely was it that the face would persist in the field of view. Considered across several face experiences, average persistence is therefore the average duration that each face is experienced. We also consider the context in which the face occurs. Although there are many different ways to capture, operationalize, and define context, we operationalized context by in two ways. First, we considered discrete events as defined by video; since each video represents different events (e.g., playing, meal-time, shopping), we reasoned that they would likely differ in their opportunities for face experience. Second, we considered discrete locations, since we reasoned that face experience likely also differs by location.

2.9. Consistency in duration

Consequently, we tested the survival functions of face duration over time of each type of face. Survival curves have typically been used to examine survival rates of species (e.g., factors influencing the survival rate of giraffe calves after 3, 6, and 12 months) or after interventions (e.g., 1-, 3-, and 5-year survival rates of cancer patients after different types of chemotherapy). We have conducted a similar analysis where

we consider the survival (i.e., duration in the field of view) of faces by face type (i.e., primary caregiver, other caregivers, the infant themselves, relatives, and strangers). Although we consider all face experiences in our analyses, up to the maximum face duration that occurred in our dataset (2400 s), we include only up to 30 s in the figures (see Figs. 2 and 3), beyond the 10 s which represents $> 99.9\%$ of face experiences. We considered the survival function of faces in two different ways. First, we considered the median face duration. Second, we conducted a cox regression, modeling face duration factored by face identity.

2.9.1. Survival curve medians

As illustrated in Figs. 2 and 3 there were significant differences in the probability that faces of different types would remain in the infant's field of view. Both the median (Independent samples median test ($73,042, 5$) = 341.84, $p < .001$) and distribution (Independent-samples kruskal-Wallis test ($73,042, 5$) = 875.39, $p < .001$) were significantly different by category. At the 25th percentile and median only the infant's own face (25th percentile = 0.50 s, Median = 1.13 s) differed from the other face types (25th percentile = 0.38 s, Median = 0.88 s). By the 75th percentile, the infant's own face still differed (2.88 s) from that of strangers (2.25 s), relatives (2.13 s), non-primary caregivers (2.25 s) and primary caregivers (2.18 s).

2.9.2. Survival curve regression model

Within the video data, we had no censored values and a total of 72,737 face instances. We entered the face identities in the first step of the model. The model was significant ($X^2(4) = 156.77$, $p < .001$) and a significant improvement over the model without face identity ($X^2(4) = 158.40$, $p < .001$). With the primary caregiver as the reference group, there was no significant difference between primary caregiver and relative faces. The difference was significant for all other face types: the probability of disappearing from the field of view was significantly reduced by 3% for other caregivers, 14% for the infant themselves, and 10% for strangers (see Table 1 and Fig. 5).

2.10. Consistency in context

We considered probability of exposure in a second way, by examining the number of videos in which faces of a given type would occur. Since videos were taken on different days and at different times throughout the day, we consider them to be snapshots of various periods within the infant's week with the camera. (For full descriptions of what's occurring in each video, please see the 'What's Happening' column in the full dataset published in Sugden and Moulson (submitted).) Consequently, this measure represents the probability, across time, activities, and days, that any given face would recur.

Of the 542 videos containing faces, mom's face was the most likely to occur in any given video, present in 87.8% of videos and most frequent in 55.9% of videos (see Table 2). Put another way, the odds of mom occurring in any given video were 7.2–1. The secondary caregiver was the second-most frequent face, occurring overall in 39.3% and most frequent in 15.5% of videos; the odds of the secondary caregiver appearing were only 0.65–1. Combined, all non-primary caregivers occurred overall in 42.4% of videos and were most frequent in 17.0% of videos, with the odds of occurring of 0.74–1. The odds were higher than the infant themselves would appear in any given video, 0.24–1, appearing in 24.2% of all videos and most frequent in only 2.2% of videos. The odds of a stranger appearing in a video were 0.33–1, occurring in 24.9% of videos but being the most frequent face in only 10.7% of videos.

2.11. Consistency in location

Lastly, we considered consistency across locations. As with different videos, different locations were taken to represent different types of

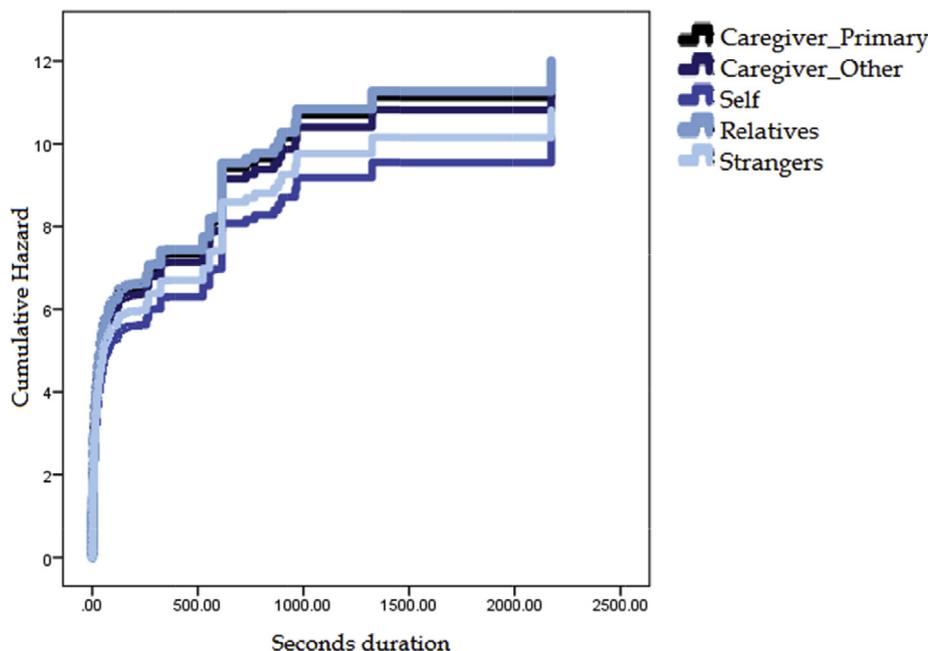


Fig. 5. Cumulative hazard for face extinction for faces of different types.

activities and qualitatively different opportunities for face exposure. We considered four separate locations: Homes (private residences), Outside (not in a building, e.g., on the street, in a park), Car (in a vehicle), and Public (in an indoor, non-home environment). Omitting instances where the location was not clear (e.g., the infant could only see the ceiling, the infant was in a carrier with the top down) or where no faces were present, the majority of recordings (74.9%) and faces (58.9% of instances and 39.7% of time) occurred in the home. Similarly, 12.2% of recordings and 15.6% instances of (11.4% of exposure time to) faces occurred outside (e.g., walks in the stroller). Indoor public places (e.g., malls, restaurants) represented 9.6% of all recordings, but 24.5% of instances of face exposure (47.8% of exposure time). Car rides were infrequent (3.3% of videos) and there were nearly no faces experienced in car rides (1.4% of instances and 1.1% of exposure).

With these baseline metrics in mind, we then considered the way in which faces of different types were distributed across these different environments. Infants are sensitive to contextual cues, with context aiding memory (e.g., Jones, Pascalis, Eacott, & Herbert, 2011). We anticipated that mom would be consistent throughout, expected secondary caregivers to occur at home but were agnostic as to their presence in other venues, anticipated relatives would occur inside and outside of the home equally, and expected strangers to be primarily an outside-of-the-home phenomenon.

Primary and non-primary caregivers were ubiquitous, appearing in all location types considered. To explore both whether the faces dominated in a particular location as well as whether they occurred at all across locations, we considered two metrics: 1) the faces experienced

for the longest overall duration (“top face”) in each instance of recording within a particular location, and 2) whether faces occurred at all within a given location (regardless of the proportion of time during which they appeared). The primary caregiver was the top face most often (see Table 3) in three of the four locations (home: 57.5%, car: 72.2% and outside: 54.5%) and second most frequent in public places (38.5%), after strangers (40.4%). Other caregivers were the second-most frequent top face at home (19.0%) whereas relatives and the infant themselves were second-most-frequent top faces outside (21.2%) and in the car (11.1%), respectively. The observed frequencies were significantly different from the expected frequencies, particularly for Caregivers at home (see Table 4).

When considering the instances of each face (or face type) occurring in each location, the primary caregiver was the face most likely to occur at home (47.3%) and in the car (47.2%) and second-most-likely in public (12.0%; see Table 3). Other caregivers were second-most-likely to occur in the car (18.9%) and nowhere else. Relatives were most likely to occur outside (31.6%) and at home (18.5%) whereas strangers were second-most-likely to occur outside (27.7%) and most likely to occur in public (74.0%). The infant themselves was never most or second-most-likely to occur in any location.

3. Discussion

The primary caregiver (mother for all of the infants in the current study) was the most frequent and consistent face within infants’ environments. She was the most frequent face for 30 of 40 infants,

Table 2
Proportional instances of occurrence of faces by event (video) context.

Metrics by context (video)		Percent experience and odds ratios of occurrences per face type (n°)				
		Caregiver(s)		Self	Relatives	Strangers
		Primary	Others			
Contexts where face(s) was (were) most frequent	Percent (n)	55.90% (30/3)	16.97% (92)	2.21% (12)	14.21% (77)	10.70% (58)
	Odds of being most frequent (X^2)	1.27:1 (349.4)	0.20:1 (2.48)	0.02:1 (85.7)	0.17:1 (9.1)	0.12:1 (23.4)
Contexts where face(s) occurred at all	Percent (n)	87.82% (47/6)	47.05% (2/5)	24.17% (1/3)	32.10% (1/7)	24.91% (1/3)
	Odds of occurring at all (X^2)	7.21:1 (249.65)	0.89:1 (1.85)	0.32:1 (45.5)	0.47:1 (15.5)	0.33:1 (42.2)

* n observed is reported in the Table. X^2 n expected for most frequent = 108.4. X^2 n expected for face occurred at all = 234.2.

Table 3
Proportional duration of faces by location.

	Location	Percent experience per face (n)				
		Caregiver(s)		Self	Relatives	Strangers
		Primary	Others			
Contexts where face(s) was (were) most frequent	Home	57.53% (233)	19.01% (77)	2.47% (10)	14.32% (58)	6.67% (27)
	Outdoor	54.54% (36)	10.61% (7)	0.00% (0)	21.21% (14)	13.64% (9)
Contexts where face(s) occurred at all	Public	38.46% (20)	13.46% (7)	0.00% (0)	7.69% (4)	40.38% (21)
	Car	72.22% (13)	5.56% (1)	11.11% (2)	5.56% (1)	5.56% (1)
Contexts where face(s) occurred at all	Home	47.35% (20,139)	17.40% (7,403)	3.80% (1,615)	18.52% (7,879)	12.93% (5,500)
	Outdoor	25.79% (2,926)	13.89% (1,576)	1.05% (119)	31.58% (3,583)	27.70% (3,143)
	Public	11.97% (2,142)	5.87% (1,051)	0.29% (52)	7.91% (1,415)	73.97% (13,240)
	Car	47.22% (450)	18.89% (180)	17.42% (166)	6.61% (63)	9.86% (94)

NB: Shaded cells are the most frequent face or face type within each category

NB: Shaded cells are the most frequent face or face type within each category.

whereas other caregivers were most frequent for 5 infants. Mom represented 44% of infants’ face exposure, whereas other caregivers were 17%. When a caregiver face appeared, its persistence did not differ regardless whether it was the primary or a non-primary caregiver, however the primary caregiver was more likely to appear across locations and contexts. The odds of her occurring in any given context were 7.2 to 1. By comparison, the odds of another caregiver occurring were only 0.7 to 1. Caregivers appeared in every environment classified and were the most frequent face in the majority of these environments. Strangers and other relatives were far less consistent. If infants were exposed to relatives, relatives represented 19% of face exposure, however 10 infants had no exposure to relatives. Across contexts, exposure to relatives was spotty, with a probability of being present in any given context of 0.2–1. Strangers had a comparably low probability of occurrence across contexts, 0.3–1, but represented 24% of all face exposure. Although there was no significant difference in the total exposure time infants received to strangers as compared to relatives, infants saw more individual strangers than relatives. The length of time a face persisted in the field of view differed primarily at the longer lengths (75th percentile and beyond), with the infant themselves persisting for longer than all other face types. Contrary to expectations, other caregiver faces, the infant’s own face, and strangers’ faces all persisted for longer than the primary caregiver’s face.

Why does frequency of exposure matter? Across multiple modalities and definitions of ‘frequency’, infants demonstrate sensitivity to the statistical regularity of events. Within hours of birth, the amount of exposure infants receive to their mother’s face predicts their preference for their mother’s face (Bushnell, 2001). Similarly, infants with female primary caregivers are exposed to female faces more than male faces (Sugden et al., 2014) and, as we found, primarily their primary caregiver. Infants with female primary caregivers show a preference for female faces whereas those with male primary caregivers show a

preference for male (Quinn et al., 2002). This female preference only appears for faces that resemble the infant’s mother (i.e., own-race) but not those that do not (i.e., other-race) (Quinn et al., 2008). It is not just attention that is tuned by frequency of exposure. Infants’ ability to discriminate faces is also shaped by exposure: ability to discriminate familiar face types improves with age while ability with unfamiliar types does not (Kelly et al., 2007, 2009). Familiarity and continued ability to discriminate, however, can be maintained by minimal experimental exposure (Anzures et al., 2012; Scott & Monesson, 2009).

It was not just frequency of exposure that differentiated caregivers from other faces; it was also their consistency within and across contexts. Within context, when their faces occurred, they were less likely to persist in the infant’s field of view, as compared to strangers’ or other relatives’ faces. If infants are learning about and processing faces, providing them with a longer period of time in which to encode the face would be beneficial because it makes it more likely that they will process it sufficiently to allow them to evidence learning (Hunter et al., 1983), especially since faces are complex stimuli (Richards, 2010), and one for which infants show developmental trajectories of attention (Frank, Vul, & Johnson, 2009) and learning (Bhatt, Bertin, Hayden, & Reed, 2005; Schwarzer, Zauner, & Jovanovic, 2007; Xiao, Xiao, Quinn, Anzures, & Lee, 2013) within the first year. From this perspective, it is curious that the arguably most important faces would not be the ones that persist for the longest durations in the field of view. Other factors, such as attention may change the distribution of infant looking within a visual scene to prioritize some faces over others. Consequently, although the face diet is not providing differential face duration as a cue to perceptual import, the infant themselves may deploy their attention in such a way as to ensure experience with critical faces in their world. This is an empirical question that would best be answered with head-mounted eye-tracking in infants’ natural, lived environments.

Across a longer time-span, familiar faces were more likely to recur.

Table 4
Chi Squared of duration of faces by location.

	Location	Chi squared values per face (<i>n</i> observed; <i>n</i> expected)				
		Caregiver(s)		Self* (observed only)	Relatives	Strangers
		Primary	Others			
Contexts where face(s) was (were) most frequent ($X^2 = 61.8$, $p < .001$)	Home	0.3 (233; 225.5)	1.0 (77; 68.7)	* (10)	0.0 (58; 57.5)	6.14 (27; 43.4)
	Outdoor	0.1 (36; 37.7)	1.8 (7; 11.5)	* (0)	2.0 (14; 9.6)	0.4 (9; 7.24)
	Public	3.2 (20; 29.7)	0.5 (7; 9.0)	* (0)	1.7 (4; 7.6)	41.1 (21; 5.7)
	Car	1.6 (13; 9.1)	1.1 (1; 2.8)	* (2)	0.8 (1; 2.3)	0.3 (1; 1.8)
Contexts where face(s) occurred at all ($X^2 = 25,490.2$, $p < .001$)	Home	1757.3 (20,139; 15,004.2)	343.5 (7,403; 5,970.8)	196.4 (1,615; 1,141.53)	12.8 (7,879; 7,567.3)	4205.8 (5,500; 12,852.2)
	Outdoor	289.6 (2,926; 4,002.6)	0.2 (1,576; 1,592.8)	113.0 (119; 304.5)	1212.2 (3,583; 2,018.7)	23.8 (3,143; 3,428.5)
	Public	2756.7 (2,142; 6,314.0)	850.3 (1,051; 2,512.6)	382.0 (52; 480.4)	983.2 (1,415; 3,184.5)	11320.30 (13,240; 5,408.4)
	Car	38.6 (450; 336.2)	16.0 (180; 133.8)	771.0 (166; 25.6)	66.95 (63; 169.5)	130.6 (94; 288.0)
NB: Shaded cells are those where the observed value is higher than the expected value						
* Self omitted from this analysis due to 0 observations within 2 of the 4 locations.						

NB: Shaded cells are those where the observed value is higher than the expected value.

*Self omitted from this analysis due to 0 observations within 2 of the 4 locations.

This was true across video recording occasions and familiar locations, but not across locations where strangers predominate. In our analysis, primary caregiver, other caregivers, the infant themselves, and relatives represented only one or a few people. Infants were exposed to many more individuals classified as stranger: the category of stranger represented up to 422 different individuals for any given infant. The majority did not recur more than twice and therefore the same stranger was unlikely to be seen in multiple locations despite strangers, as a group, being present in nearly all locations. Consistency across contexts can be considered as distributed learning opportunities for infants, a learning type more successful than massed learning for faces (Cornell,

1980), suggesting a qualitatively superior type of experience with familiar faces than stranger faces.

Strangely, infants' exposure to their own faces also points to a higher quality experience. More than three quarters (32/40) of infants experienced their own face. Although own-face exposure represented only 4% of their face experience, the persistence of self-faces was higher than that of all other faces, including caregivers. Infants of this age have been found to smile and look at their own image (Rochat & Striano, 2002), and to engage with the mirror as if it were another infant with whom to play (Amsterdam, 1972). From the metrics provides here, it does seem to be a potentially powerful learning experience. Does self-

face exposure facilitate face processing or potentially the understanding or use of face information? Would it result in earlier self-recognition (e.g., success at the rouge task; Bertenthal & Fischer, 1978)? Would seeing oneself moving support language or other developmental skills requiring control over orofacial muscles? The implication of this early mirror exposure on learning is an open question.

Infants' exposure to faces is dominated by exposure to one face, their primary caregiver. Exposure to that face is many times more frequent than exposure to other faces, and also distinguishes itself in other ways, primarily through its consistency across time and context. What implications does this have for early learning about faces? Perceptual narrowing—the increased specialization for familiar face types and decreased ability with unfamiliar face types—is presumed to result from an overall increase in exposure to familiar face types (e.g., own-race faces). The current results raise the interesting possibility that the increased specialization for familiar face types results not from generalized exposure to, for example, more own-race than other-race faces, but from exposure to one exemplar of the familiar face type – their primary caregiver. Whether developing ability with familiar face types is better predicted by overall exposure to familiar face types or by exposure to their primary caregiver is an empirical question.

Beyond perceptual narrowing, it is interesting to consider the implications of the current findings for infant face processing more generally. An influential model of face processing suggests that faces are represented in a multi-dimensional face space (Valentine, 1991), where each face is represented by a unique point in face space. The underlying dimensions of face space are shaped by perceptual experience, such that they maximize discrimination and recognition of faces that we encounter regularly. In adults, similarity to previously encountered faces influences recognition ability (i.e., own-race faces are better discriminated and recognized than other-race faces). One would hypothesize that infants, whose face space is dominated by exposure to a single face, might be even more sensitive to similarity, such that the likelihood of learning a newly encountered face would depend largely on its similarity to their primary caregiver's face.

Although infants' face exposure tended to be highly homogeneous, there were significant individual differences in face experience. Infants varied in their exposure to their primary caregiver's face, other caregiver faces, relatives, their own face, and strangers. This variability points to important differences in experience likely to support different types of learning. That some infants experienced exclusively or nearly exclusively the face of their primary caregiver points to a restricted face diet which likely facilitates caregiver face learning, but may make challenging infants' capacity to process non-caregiver-type faces. On the other end of the spectrum, some infants experienced a wealth of strangers' faces, a highly diverse population of many individuals; would these infants then struggle to identify their primary caregiver but show greater flexibility and capacity in processing a diversity of faces? Moreover, face duration varied between individual infants; would a steady slow diet of faces that persist for longer in the visual field provide greater learning than faces that rapidly appear and disappear? Would rapid and slow face experience lead to the development of different processing strategies? These are open empirical questions pointing to the need to link early experience with later ability.

The way in which infants are exposed to faces is, in many respects, boring. They are exposed to a highly homogenous pool of potential faces, repeatedly, and across multiple locations and contexts. Much of their experience is with a single face, their primary caregiver. This parallels the findings of other studies that found comparably low diversity in infants' face experience (Jayaraman, et al., 2015; Rennels & Simmons, 2008; Sugden et al., 2014). The implications of this are not boring. Faces are a complex stimulus that are difficult to learn, as evidenced by the long trajectory of the development of face perception (e.g., slow trajectory of configural processing, Mondloch, Le Grand, & Maurer, 2002). Additionally, infant memory and recognition are sensitive to context (Fagen et al., 1997; Haaf, Lundy, & Coldren, 1996).

Thus, providing distributed practice that recurs across contexts likely facilitates early face learning. This distributed, simplified practice with faces likely works in concert with social (Scherf & Scott, 2012), perceptual (Sugden & Moulson, 2017), and attentional (Palermo & Rhodes, 2007) mechanisms to allow very young infants to quickly and efficiently achieve the capacity to recognize important faces in their environment. Although the current study cannot speak to the question, knowing how this early exposure links to later attention and ability would provide powerful insight to disentangle the contributions of different aspects of experience to ability.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.visres.2018.09.005>.

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