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RESEARCH ARTICLE

Infants scan static and dynamic facial expressions differently

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Abstract

Despite being inherently dynamic phenomena, much of our understanding of how infants attend and scan facial expressions is based on static face stimuli. Here we investigate how six-, nine-, and twelve-month infants allocate their visual attention toward dynamic-interactive videos of the six basic emotional expressions, and compare their responses with static images of the same stimuli. We find infants show clear differences in how they attend and scan dynamic and static expressions, looking longer toward the dynamic-face and lower-face regions. Infants across all age groups show differential interest in expressions, and show precise scanning of regions “diagnostic” for emotion recognition. These data also indicate that infants' attention toward dynamic expressions develops over the first year of life, including relative increases in interest and scanning precision toward some negative facial expressions (e.g., anger, fear, and disgust).

1 | INTRODUCTION

How humans perceive facial expressions is an enduring question (see Darwin, 1873; Wundt, 1909). Using static stimuli such as the now-classic “Ekman faces” (Ekman & Friesen, 1976), much has been learned about its developmental trajectory. Infants can discriminate between certain static facial expressions from birth (Farroni et al., 2007; Field et al., 1982), and by seven months can identify many of the six “core” expressions (Ekman, 1993; Ekman et al., 1987) within discreet emotion categories (Kotsoni et al., 2001; Nelson et al., 1979; Ruba et al., 2017). Yet despite this advancement of knowledge, even the earliest studies have identified limitations of using static stimuli to investigate inherently dynamic phenomena (Caron et al., 1985; Wilcox & Clayton, 1968). Communicative facial gestures necessarily occur in the context of dynamic social interactions. Outside of the lab infants rarely encounter silent, still, unresponsive faces in their natural social environments, and can find them unnatural or distressing (for instance see the still-face phenomenon; e.g., Adamson & Frick, 2003). Presenting infants with dynamic, interactive stimuli are likely to be more representative of the social cues infants encounter in their everyday environments (see Walker-Andrews & Bahrick, 2001).

Consequently, recent studies in both adults (Richoz et al., 2018; see Krumhuber et al., 2013 for a review) and infants (Addabbo et al., 2018; Godard et al., 2016; Heck et al., 2016; Libertus et al., 2017; Soussignan et al., 2017) are increasingly using dynamic stimuli, and are discovering that dynamic social cues are processed and encoded in a fundamentally different way. For instance, Bahrick et al., (2002) demonstrated that when using dynamic stimuli, infants' encoding of facial information was disrupted, as infants' instead focused their attention on the actors' behaviors. Nevertheless, other work has shown that static stimuli might underestimate infant's abilities, with infants demonstrating sensitivity to facial emotions at earlier ages when realistic, dynamic displays are used (Addabbo et al., 2018; Heck et al., 2016; Montague & Walker-Andrews, 2001; Soussignan et al., 2017). Dynamic faces are also scanned differently by infants across the first year (Hunnius & Geuze, 2004; Soussignan et al., 2017; Xiao et al., 2015), and older infants show increased attention toward “diagnostic” regions most useful for decoding expressions (e.g., the mouth region for happy and surprise, eye region for fear, anger and sadness, mouth/nose region for disgust; see Hanawalt, 1944; Jack et al., 2014; Smith et al., 2005) when expressions are dynamic (Segal & Moulson, 2020; Soussignan et al., 2017).

Yet realistic interactions are not only dynamic, but also *contingent*. Infants are not merely passive “absorbers” within interactions, but are instead active participants (Murray & Trevarthen, 1986; Tomasello et al., 2005). Facial expressions are not triggered according to a rigid experimental clock, but are guided by the infant's own behavior and attempts to engage with the adult (Murray & Trevarthen, 1986). Infants are highly sensitive to contingency, and quickly develop expectations about the content and timing of social interactions over the first six months of life (Bigelow & Birch, 1999; Nadel et al., 1999; Striano et al., 2005, 2006). Reciprocity (i.e., bi-directional responsivity) is thus a defining characteristic of social exchanges (see Bronfenbrenner, 1977), and could therefore be a critical element to conserve when attempting to simulate social cues in a lab setting.

The primary aim of the current study is to determine if infants attend to and scan static and interactive-dynamic facial expressions differently (interactive-dynamic displays will be henceforth referred to as just “dynamic”). If infants do not show substantial differences in how they attend static and dynamic displays of emotion, then a move toward methodologically complex, naturalistic paradigms may be unnecessary. We will compare scanning differences between static and dynamic facial expression stimuli for all six basic expressions (happy, sad, surprise, fear, anger, and disgust). This will be a substantial contribution to the literature given that no previous infant study has considered all six of the basic expressions, and whilst some researchers have begun to implement dynamic stimuli (e.gAddabbo et al., 2018; Heck et al., 2016), contingency has thus far been overlooked. This is critical given the universality and biological salience of all six of these expressions (Ekman, 1992, 1993; Izard, 1994, but see Jack et al., 2016), which are dynamically, but also contingently, communicated in natural environments. We predict that infants will scan dynamic and static facial expressions differently. More specifically, we predict that infants will show greater interest, and therefore look longer toward, dynamic stimuli (cf. Wilcox & Clayton, 1968) and that for dynamic stimuli there will be more precise and coordinated looking toward diagnostic regions (Segal & Moulson, 2020; Soussignan et al., 2017). As facial expressions are inherently dynamic phenomena, if clear differences between static and dynamic do emerge, then it suggests that a transition toward dynamic stimuli is warranted if we are to make meaningful and generalizable claims about how infants' perception of facial expressions develop within real-world environments.

A secondary aim of this study will be to explore how infants' scanning of dynamic expressions develops from six to twelve months. Previous work using real, dynamic-face videos has compared developmental differences in general face scanning (Hunnius & Geuze, 2004), but not facial *expression* scanning. However, research using static stimuli has identified seven months of age as a key developmental threshold in facial expression perception (Nelson et al., 1979). At this age infants are thought to not only show greater precision discriminating and categorizing emotional expressions (Soussignan et al., 2017), which in adults is associated with scanning diagnostic regions (Gosselin & Schyns, 2001), but also to show greater interest in negative-valence expressions such as fear or anger. In this study, we will examine whether this is also true when infants are presented with dynamic, interactive expression stimuli.

1.1 | The gaze-contingent eye-tracking paradigm

To present ecologically relevant dynamic expression stimuli to infants, we will use gaze-contingent eye-tracking to simulate brief social exchanges in the lab. Gaze-contingency allows infants to actively manipulate stimuli presented on the screen, increasing realism and empowering infants with a novel form of agency (see Duchowski et al., 2004; Wang et al., 2012). Gaze-contingently activated videos also allow a standardization across trials and participants, as it ensures all infants are fixating the same location (eye-region) before the expression response begins, and guarantees their attentiveness. Similar paradigms have been used previously to simulate infant-adult social exchanges (Keemink et al., 2019; Vernetti et al., 2018), and recently to investigate infants' behavioral responses to facial expressions (Keemink et al., 2021). In this paradigm, real dynamic human faces (c.f. Ruba et al., 2017; Soussignan et al., 2017) are presented on a two-dimensional display screen. Outside of facial expression research, head-mounted eye-tracking technology has been used to study infants' viewing of natural environments (e.g., Franchak et al., 2010, 2011). This approach offers a substantial increase in naturalism, and differing results have raised questions about the ecological validity of flat-screen displays (Kretch & Adolph, 2015). Yet there is also evidence that infants' reciprocal behaviors are conserved when presented with live video feeds (e.g., Meltzoff, 1988; Nielsen et al., 2008), or non-live contingent videos (Keemink et al., 2019; Vernetti et al., 2018), rather than pre-recorded videos (e.g., Barr & Hayne, 1999; Hayne et al., 2003). This instead suggests that it is a lack of contingent reciprocity that reduces realism, not the use of video stimuli *per se*. The methodology used in the current study endeavors to provide a stimulus that is more familiar to infants (i.e., a moving face) with the aim of producing results that have greater ecologically validity. From a theoretical perspective, differences in eye movements between static and dynamic stimuli potentially limit the extent to which findings from stimuli using static stimuli can be generalized to behavior outside the lab-setting as our theories need to be built on behaviors which actually take place in a real-world setting.

Even when stimuli are confined to a display screen, defining precisely where a subject is looking can be challenging (Caldara & Miellet, 2011; Hessels et al., 2018). Here we have developed a tool that automatically generates areas of interest (AOIs) using information inherent within each frame of a video stimulus (Figure 3; see Supplementary Information (SI) for details[1]). Using these "dynamic AOIs" alongside other existing tools that are useful for analyzing eye-tracking data without collapsing across time (mixed-effects modeling, cluster permutation analysis) or space (statistical heatmap

[1]Supplementary materials can be accessed online using the following link: https://osf.io/p7dqb.

TABLE 1 Participant information for the initial and reduced cohorts

	Age (months)	Age *M* (*SD*) (days)	Condition *N*		Gender *N*	
			Dynamic	Static	Male	Female
Initial	6	191.17 (9.78)	33	10	21	22
	9	274.77 (12.69)	32	24	29	27
	12	366.76 (13.42)	36	14	25	25
Reduced	6	192.51 (15.32)	28	10	19	19
	9	273.78 (13.73)	20	17	21	16
	12	366.24 (11.62)	29	14	23	20

analyses), we will attempt to overcome some of the methodological challenges that arise when using more complex and naturalistic stimuli.

2 | METHODS

2.1 | Participants

One hundred and eighteen Caucasian infants (6, 9, and 12 months, see Table 1) were assigned to either the "dynamic" ($N = 77$) or the "static" ($N = 41$) condition. An additional 31 infants were excluded from the AOI analysis for not meeting the eligibility criteria (fixation duration data present for all expression trials), but were retained for the analyses that automatically discard missing data (heatmaps and time-course analyses). A small number of additional infants (max = 10) were lost as they did not produce any usable data. The sample size used in this experiment is comparable to or larger than other infant eye-tracking studies in this field (e.g., Hunnius & Geuze, 2004; Soussignan et al., 2017). All participants were full-term, healthy infants recruited locally and with no siblings with an ASD diagnosis. Parents received an information sheet via email and a further verbal briefing on the testing day before obtaining parental written consent. At the end of the session, infants received a certificate and age-appropriate toy as a reward. The present study was conducted according to guidelines laid down in the Declaration of Helsinki, and all procedures were approved by the School of Psychology's Ethics Committee at the University of Kent.

2.2 | Stimuli

Eighteen expression videos were recorded (Nikon D5200 digital camera) with six different actors (3 male, 3 female) such that each actor contributed three videos (1 neutral, 2 expressive), with each of the six core expressions (happy, sad, surprise, fear, anger, disgust) being recorded twice (by 1 male and 1 female) and neutral six times (1 per actor, see Figure 1). Each video (720 × 576 pixels) was edited to be 3 seconds in length; beginning with neutral affect and ending at peak expressive amplitude. All actors wore an identical black t-shirt, and were seated in front of a uniform green background and were filmed under identical lighting conditions. The images used in the static condition were stills taken from these videos, when the expression was judged to be at "peak" amplitude (i.e., the point at which the expression reaches its highest intensity; c.f. Ekman & Friesen, 1976; see Figure 1).

FIGURE 1 The six basic expressions. A selection of expressive stimuli used within the static condition that were created by taking stills from the dynamic expression videos at "peak" expressive amplitude. Similar to classic expression stimuli (see Ekman & Friesen, 1976), the six "basic" expressions are used (Ekman et al., 1987): happy, sad, surprise, fear, anger, and disgust; from left to right respectively

TABLE 2 Mean recognition accuracy and representativeness ratings for the static expression stimuli

	Neutral	Happy	Sad	Surprise	Fear	Anger	Disgust
Accuracy (%)	86.93	96.08	94.12	92.16	66.67	85.29	67.65
Rating (1–5)	3.73	3.62	3.02	3.92	3.78	3.43	3.12

Notes: N = 51 adult observers; Accuracy chance level = 14.29%

Fifty-one adult observers were asked to firstly recognize the expression displayed in the video (from the 6 basic expressions and neutral), then to rate how representative (1–5 scale) this video was for the target expression (i.e., how close do our stimuli match the facial expressions we are trying to represent?). Expressions were highly recognized (M = 84.57%, SD = 14.99%), and received mean representativeness ratings between "moderately well" and "very well" for all expressions (M = 3.62, SD = .38, see Table 2). Although substantially higher than chance level (14.29%), ratings for fear and disgust were lower than for other expressions. However, this is consistent with previous literature (Jack et al., 2009, 2016), which has shown these two expressions are harder to detect, and are often mislabeled as surprise and anger, respectively.

2.3 | Eye-tracking

Infants were fastened in a semi-upright car seat 60 cm from a Dell 20-inch display monitor (1024 × 768 pixels). Parents sat nearby, but just behind their infant to minimize distractions. Eye movements from both eyes were recorded (500 Hz) using an SR Research Desktop-Mount EyeLink 1000+ eye tracker with a 25 mm lens operating in remote mode (spatial resolution 0.01°, average gaze position error of 0.25°). A padded target sticker placed centrally on the forehead served as a reference point for recording eye movements and head distance. Prior to the start of each experiment, a five-point calibration procedure was implemented (Experiment Builder, SR Research, Ontario, CA), using custom "attention grabbers" (animated, noisy circles) to entice looking. Following Holmqvist et al., (2012), precision values were calculated as the root mean square (RMS) of sample-to-sample distances within computed fixations. Precision was calculated separately for each age group and results were as follows: 6 months = 0.69° (SD = 0.17°), 9 months = 0.69° (SD = 0.18°) and 12 months = 0.66° (SD = 0.12°).

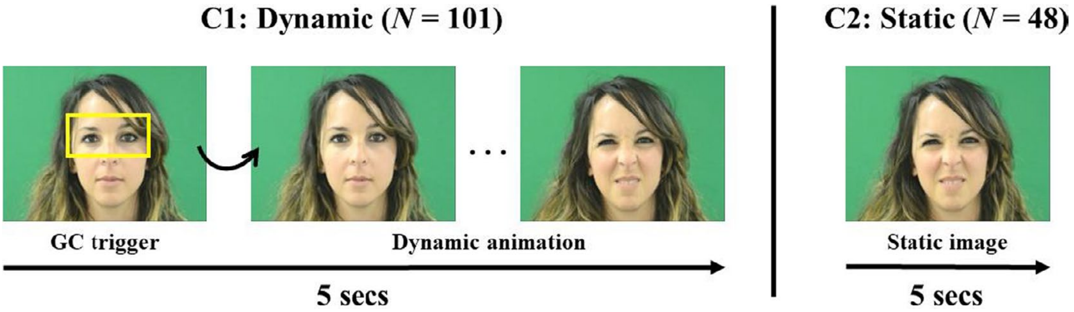

FIGURE 2 An illustration of the experimental procedure. A gaze-contingent eye-tracking paradigm was used to investigate infants' scanning of dynamic (condition 1; "C1") and static (Condition 2; "C2") facial expressions. 18 trials in both conditions lasted 5 seconds each, and were presented in a fully randomized order. In the dynamic condition, a 3-seconds expression animation was contingently triggered by infants when they fixated the actor's eye-region (yellow boundary). In the static condition, an image of the same expression was presented for the full 5-second duration

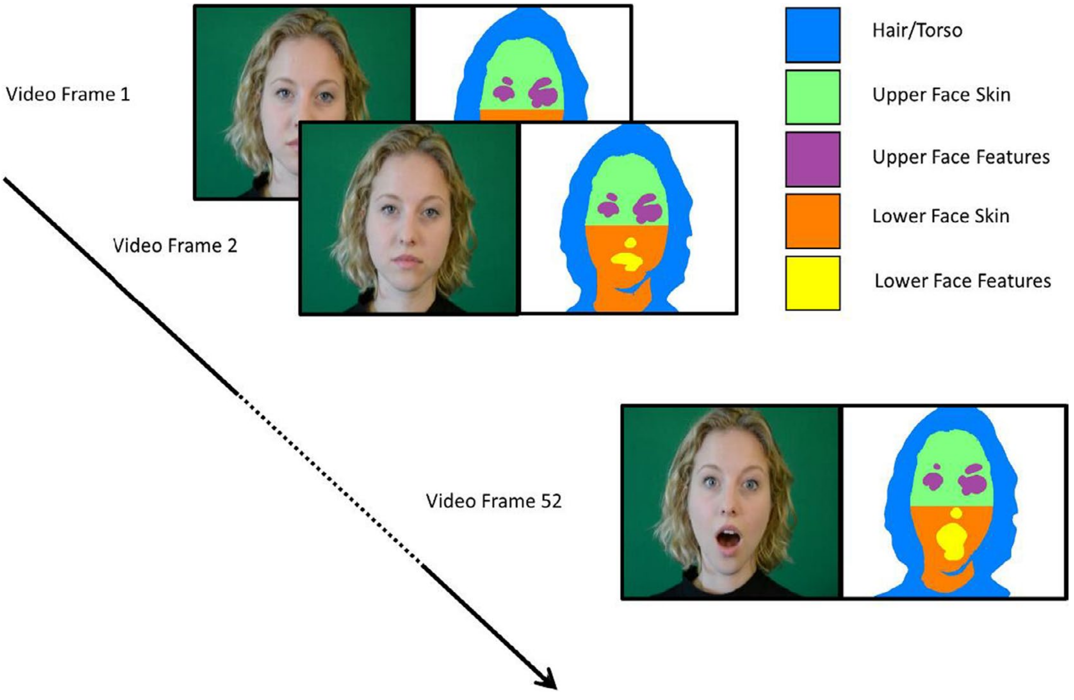

FIGURE 3 Areas of interest (AOIs) were generated for the facial expression animations using color and luminance information present within each video frame. After pre-defining a facial midpoint and skin tone range for each actor, numerical matrices defining six AOI regions were automatically computed for each video frame. These numerical matrices when combined form "dynamic AOIs", which are depicted here using color labels (background [white], hair and torso [blue], upper face skin [green] and features [purple], lower face skin [orange] and features [yellow]), alongside an image of the video frame from which they were generated

2.4 | Procedure

The experimental stimuli were presented within a gaze-contingent eye-tracking paradigm. The experiment consisted of 18 trials, one for each expression video, presented in a fully randomized order. For the **dynamic condition,** each trial consisted of a brief social exchange. Each exchange began with an attention-grabber located to the left or right of the screen (counterbalanced across trials), and once fixated, the first frame of the expression video (the actor, facing forward with neutral affect) appeared centrally on the screen. An invisible gaze-contingent boundary was placed over the eye region, and a fixation (minimum duration 100 ms) within this region triggered the facial animation (i.e., the playing of the expression video). Infants, therefore, contingently triggered the on-screen actor to respond with one of the six basic emotional expressions (or with neutral affect in the control trials) by engaging them in eye contact. Trials ended after 5 seconds if the eye region was not fixated. If the eye region was fixated rapidly (i.e., in under 2 s), the 3-seconds expression videos paused on the last frame to ensure each trial reached its 5-seconds duration. Trials within the **static condition** were not dynamic or interactive. Each trial instead presented a static image from the expression video (at peak expression) for the full 5-seconds duration. Figure 2 provides a graphical representation of the procedure used in both conditions. The entire study duration was approximately 2 min.

2.5 | Data processing and analysis

After calculating fixation location and duration information using a custom-written MATLAB script, *x*-*y*-coordinates were coded according to facial regions using "Dynamic AOIs" which were generated automatically from the video stimuli using color and texture information (see Figure 3, Appendix A and SI for more information). To analyze these data, we first collapsed across time and space to measure general interest in the stimuli. Secondly, we investigated face scanning by comparing relative looking to upper and lower face regions. Thirdly, temporal and spatial scanning patterns were explored in greater detail using statistical heatmaps (fine-grained spatial differences) and growth-curve analyses within mixed-effects models (fine-grained temporal differences). We used this analysis plan to investigate both differences between stimulus type (static vs dynamic) and age group (six-, nine- and twelve-months). See Appendix A for further detail on data processing and analysis methodology.

3 | RESULTS

3.1 | Static vs dynamic stimuli

3.1.1 | Total looking duration toward the stimulus

In line with classic work (Wilcox & Clayton, 1968), a 2 (Condition: dynamic and static) × 6 (Expression: happiness, sadness, surprise, fear, anger, disgust) mixed ANOVA for stimulus fixation durations (FDs) yielded a main effect of Condition, $F(1,116) = 9.56$, $p = .002$, $\eta^2_p = .08$, with infants looking longer toward dynamic ($M = 4.13$ s) compared to static ($M = 3.78$ s) representations of expressions, suggesting greater interest in this type of stimuli. Pairwise comparisons indicate the effect was not uniform across expressions, however, with particularly strong effects for happiness ($p = .008$) and disgust ($p = .001$), but little difference, for instance, between dynamic and static surprise ($p = .654$; see Figure 4a). The ANOVA also yielded a main effect of Expression, $F(5,580) = 5.50$, $p < .001$, $\eta^2_p = .05$, and there was no interaction between the two factors, $F(5,580) = 1.55$, $p = .172$, $\eta^2_p = .01$.

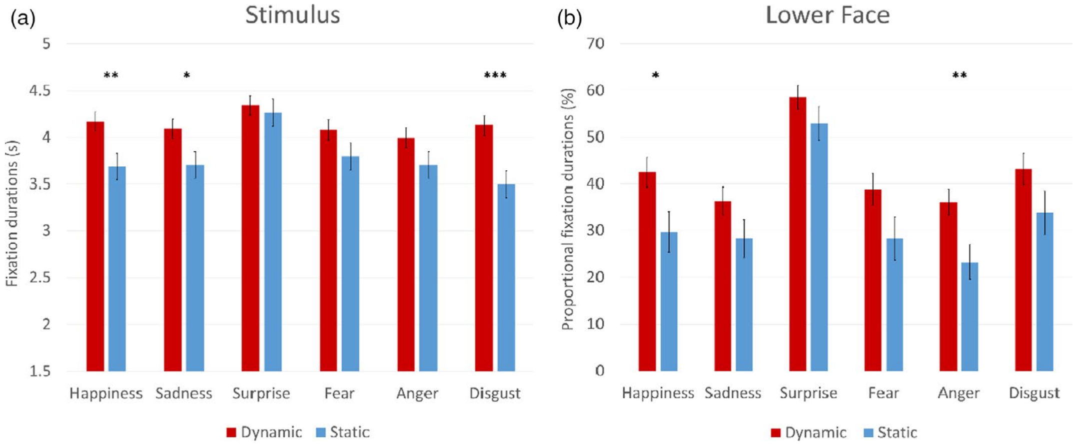

FIGURE 4 Infant visual attention toward the whole stimulus (a) and lower face region (b) divided by Condition (dynamic, red and static, blue) and Expression (happiness, sadness, surprise, fear, anger, and disgust). Mean fixation durations (seconds) toward the entire stimulus (i.e., all AOIs and background) were used to compute proportional looking time (%) to the lower face AOI. Significant pairwise comparisons between conditions are identified (*$p < .05$, **$p < .01$, ***$p < .001$, two-tailed). Error bars are standard error of the mean

3.1.2 | Proportion of looking toward dynamic AOIs

In this analysis we used dynamic AOIs to compute the proportion of looking (% of total stimulus FD) toward the upper and lower face regions (see Figure 4). A 2 (Condition) × 6 (Expression) mixed ANOVA was conducted for proportionate looking toward the lower face finding a main effect of Condition, $F(1,116) = 5.66$, $p = .019$, $\eta_p^2 = .05$, alongside a large effect of Expression, $F(5,580) = 29.54$, $p < .001$, $\eta_p^2 = .20$, but no interaction, $F(5,580) = 0.67$, $p = .646$, $\eta_p^2 < .01$. The proportion of time spent fixating the lower face was higher for dynamic stimuli (M = 42.60%), compared to static stimuli (M = 32.73%, Figure 4b). For completeness, the same analysis was conducted for upper face yielding a main effect of Condition, $F(1,116) = 4.19$, $p = .043$, $\eta_p^2 = .04$, in the opposite direction (Dynamic M = 49.26%, Static M = 57.61%). Pairwise comparisons indicate lower face looking was significantly different between conditions for happiness ($p = .019$) and anger ($p = .007$), with a marginal effect for fear ($p = .067$).

3.1.3 | Unsegmented spatial and temporal analyses

The dynamic AOI analysis highlighted differences in face scanning for dynamic compared to static happy and angry expressions. Here we further explore these differences in greater detail for one actor who performed neutral, happy, and angry expressions (Figure 5; see SI for other expressions). Specifically, we will use heatmaps to analyze pixel-wise differences between stimulus conditions and we will use growth curves and cluster permutation analyses to model the emergence of differences in lower-face looking across time. Participants that were excluded due to missing trial data (N = 31) were retained in these analyses (Dynamic N = 101, Static N = 48) as missing trials were automatically discarded.

The heatmaps (Figure 5a–c), depict spatial differences in face scanning between conditions as z-scores (Dynamic = red and Static = blue), with significant regions ($p < .05$) outlined in black. Natural blinking was present in the dynamic neutral stimuli, but not static, which showed clusters of increased

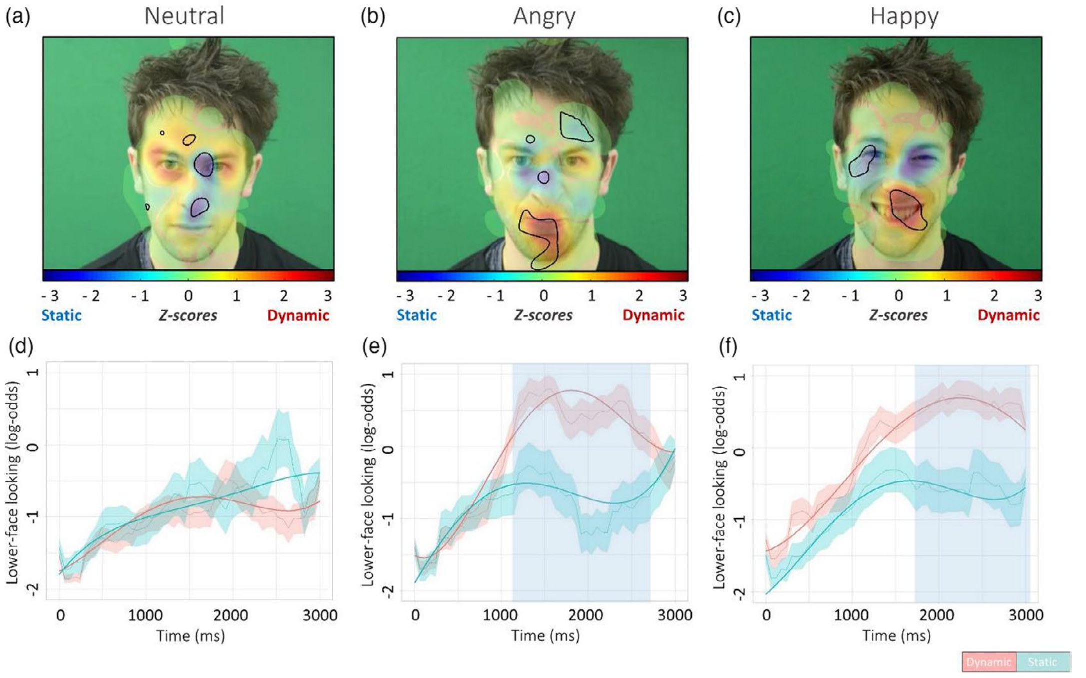

FIGURE 5 Statistical heatmap and time-course analyses for neutral (a, d), angry (b, e), and happy (c, f) trials for one actor. The heatmaps (a-c) depict spatial differences in face scanning between conditions as z-scores, with positive values denoting greater looking for the dynamic condition (orange/red) and negative values denoting greater looking for the static condition (blue). Regions of significant difference between conditions ($p < .05$, two-tailed) are outlined in black. Differences in lower-face looking between dynamic (red) and static (blue) conditions across the expression animation time-window (3 s) were modeled using polynomial growth curves and analyzed using multilevel logistic regression (d-f). For each trial, the log-likelihood of fixating the lower face was computed across 60 ms time-bins, plotted here (faint line) with the standard error of the mean (colored border). These data were then modeled using linear, quadratic, cubic, and quartic polynomial time terms (solid line). Cluster permutation analysis was used to identify time-windows of significant differences between conditions (blue/grey shaded region)

looking to central regions (Figure 5a). For the dynamic happy and angry expressions, however, the heatmaps show a lower-face bias (Figure 5b,c). For both expressions, significance clusters for the dynamic condition emerge around the mouth, chin, and nose regions, and in the upper face and eye region for the static condition.

To capture temporal differences in face scanning between conditions, we model the log-likelihood of lower-face looking across time (60 ms time bins) using growth curves (Mirman et al., 2008) and multilevel logistic regression (Barr, 2008). The curves generated from the polynomials overlay the fixation data in Figure 5d–f (see Table 3 for model parameters). In these models the empirical log-likelihood of fixating the lower-face AOI was our dependent variable (LowerFace), with Condition (Dynamic = .5, Static = −.5) and Time as predictors. Time was defined by four polynomial terms. We also included between participant random effects within our models, for the intercept and all four polynomial time slopes. The change in deviance (ΔD) based on the deviance statistic (−2LL; minus two times the log-likelihood) was used to assess whether each additional parameter significantly improved model fit, using an intercept-only model as a baseline.

Similar to the heatmap and AOI analyses, there were significant main effects of Condition, indicating increased lower-face looking for dynamic happy ($p = .001$) and angry ($p = .005$) expressions

TABLE 3 Lower face looking within neutral, angry, and happy trials

	Model fit			Parameter estimates			
Fixed effect	**−2LL**	**ΔD**	***p***	***β***	***SE***	***t***	***p***
Neutral							
Intercept	16,393	–	–	−.974	.101	−9.654	<.0001
Condition	16,393	0	.5264	−.063	.213	−.296	.7677
Linear	16,064	329	<.0001	2.041	.386	5.285	<.0001
Quadratic	15,962	102	<.0001	−.985	.290	−3.393	.0009
Cubic	15,955	7	.0090	.260	.295	.884	.3784
Quartic	15,952	3	.0729	.133	.196	.678	.4988
Condition: Linear	15,938	14	.0002	−.277	.808	−.342	.7328
Condition: Quadratic	15,923	15	.0001	−.838	.614	−1.365	.1747
Condition: Cubic	15,923	0	.9303	−.269	.621	−.433	.6659
Condition: Quartic	15,917	6	.0126	.044	.413	.107	.9151
Angry							
Intercept	20,786	–	–	−.345	.103	−3.332	.0011
Condition	20,780	6	.0096	.629	.219	2.878	.0047
Linear	20,070	710	<.0001	2.935	.379	7.752	<.0001
Quadratic	19,546	524	<.0001	−2.927	.364	−8.035	<.0001
Cubic	19,546	0	.6387	−.125	.285	−.439	.6611
Quartic	19,502	44	<.0001	.734	.256	2.869	.0048
Condition: Linear	19,416	86	<.0001	1.945	.801	2.428	.0166
Condition: Quadratic	19,335	81	<.0001	−2.744	.775	−3.543	.0005
Condition: Cubic	19,260	75	<.0001	−1.890	.605	−3.121	.0022
Condition: Quartic	19,254	6	.0117	.766	.544	1.409	.1612
Happy							
Intercept	21,728	–	–	−.320	.109	−2.946	.0038
Condition	21,717	11	.0008	.770	.232	3.325	.0011
Linear	20,538	1179	<.0001	3.883	.388	10.015	<.0001
Quadratic	20,199	339	<.0001	−2.042	.293	−6.967	<.0001
Cubic	20,184	15	.0002	−.320	.289	−1.106	.2706
Quartic	20,179	5	.0219	.311	.222	1.403	.1628
Condition: Linear	20,091	88	<.0001	1.981	.831	2.384	.0185
Condition: Quadratic	20,091	0	.9515	−.327	.629	−.520	.6040
Condition: Cubic	20,062	29	<.0001	−1.117	.618	−1.808	.0728
Condition: Quartic	20,060	2	.1771	−.393	.477	−.823	.4119

compared to static, but not for dynamic neutral ($p = .768$). Condition interacted with the linear term for happiness ($p = .019$), and the linear, quadratic, and cubic terms for anger (all $p < .02$). The interactions with linear indicate a greater increase in lower-face looking across time for dynamic compared to static. For anger, the interactions with higher temporal terms suggest that compared to static, dynamic lower-face looking followed a stronger inverted-U pattern (quadratic), with its peak shifted more toward the latter half of the trial (cubic). Using cluster permutation analysis (Wendt et al., 2014) we identified time windows in which the groups diverged (highlighted in grey in Figure 5d–f). At approximately the midpoint of dynamic expression trials (happy: 1680–3000 ms, $p = .01$; angry: 1080–2760 ms, $p < .001$), infants begin to show greater looking toward lower facial regions.

3.2 | Developmental differences

3.2.1 | Expression interest: Proportion of looking to the face

To investigate developmental differences in dynamic expression interest, a 6 (Expression) × 3 (Age) ANOVA for proportional looking durations toward the face AOI was conducted. This analysis yielded main effects for Expression, $F(4.1,303.7) = 7.13$, $p < .001$, $\eta_p^2 = .09$, Age, $F(2,74) = 5.05$, $p = .009$, $\eta_p^2 = .12$, and an Age × Expression interaction, $F(8.2,303.7) = 2.06$, $p = .038$, $\eta_p^2 = .05$. Pairwise comparisons (Bonferroni) indicate greater face-looking for surprise ($M = 96.54\%$) in comparison to all other expressions (Combined $M = 91.01\%$, all $p < .03$), but also for fear ($M = 93.10\%$) compared to anger ($M = 88.99\%$, $p = .045$). Overall, six-month-olds spent proportionally less time on the face ($M = 88.89\%$) compared to nine ($M = 93.39\%$, $p = .046$) and 12-month-olds ($M = 93.65\%$, $p = .015$). Planned contrasts indicate that age differences emerged for the angry expression, $F(2,74) = 8.36$, $p = .001$, $\eta_p^2 = .18$, with higher looking for nine ($p = .004$) and twelve-month-olds ($p = .001$) compared to six-month-olds. An Age effect also emerged for sadness, $F(2,74) = 3.39$, $p = .039$, $\eta_p^2 = .08$, and a marginal effect for disgust, $F(2,74) = 2.97$, $p = .058$, $\eta_p^2 = .07$, again following the trend of reduced face-looking in six-month-olds.

3.2.2 | Expression interest: Temporal differences

To explore the development of dynamic expression interest unsegmented across time, we modeled the empirical log-odds of proportional looking toward the face AOI, using Age, Expression, and Time as fixed effects. Each expression was compared against neutral, while two contrasts were created for Age; the first comparing the average of nine and twelve-month-olds against six-month-olds (C1: 6 M = −.66, 9 M = .33, 12 M = .33), and the second comparing twelve-month-olds against nine-month-olds (C2: 6 M = 0, 9 M = −.5, 12 M = .5). Time was defined by three slope terms: linear, quadratic, and cubic. A maximal random effects structure was attempted, however including Expression as a parameter lead to non-convergence in all models and it was therefore removed (see Baayen et al., 2008; Barr et al., 2013).

All parameters significantly improved model fit except for Age, though Age interactions with Expression and Time polynomials did improve fit (Table 4). Figure 6a illustrates the pattern of face-looking to expressions across time, and the substantial negative linear effect of Time ($\beta = -3.418$) can be perceived as infants' interest in the face declined over time. Face-looking at the start and end of trials was comparatively flatter (cubic effect). There were also positive effects of all expressions compared to neutral (all $p < .02$), though expressions varied in the size of their effect. Heightened interest in the face was strongest for surprise ($\beta = .445$), and weakest for anger ($\beta = .188$). Relative

TABLE 4 Developmental differences in face looking

	Model fit			Parameter estimates			
Fixed effect	**−2LL**	**ΔD**	***p***	***β***	***SE***	***t***	***p***
Intercept	300,360	–	–	.961	.055	17.563	<.0001
Time							
Linear	295,668	4692	<.0001	−3.418	.219	−15.614	<.0001
Quadratic	295,559	109	<.0001	.022	.137	.159	.8740
Cubic	295,519	40	<.0001	.635	.114	5.577	<.0001
Age	295,519	0	.8068				
C1: (9 + 12 M) vs 6 M				.072	.118	.611	.5421
C2: 12 M vs 9 M				−.063	.134	−.473	.6365
Expression	294,347	1172	<.0001				
Happy				.295	.072	4.090	<.0001
Sad				.334	.074	4.488	<.0001
Surprise				.445	.075	5.942	<.0001
Fear				.301	.074	4.043	<.0001
Anger				.188	.073	2.571	.0102
Disgust				.361	.074	4.861	<.0001
Age: Time	294,227	120	<.0001				
Expression: Time	293,423	804	<.0001				
Age: Expression	292,895	528	<.0001				
Age C1: Happy				.002	.155	.012	.9906
Age C1: Sad				.043	.159	.268	.7889
Age C1: Surprise				−.413	.162	−2.554	.0108
Age C1: Fear				.044	.160	.277	.7821
Age C1: Anger				.398	.157	2.537	.0113
Age C1: Disgust				−.122	.161	−.760	.4473
Age C2: Happy				−.084	.176	−.476	.6340
Age C2: Sad				.177	.183	.966	.3340
Age C2: Surprise				.047	.182	.258	.7961
Age C2: Fear				.247	.182	1.360	.1741
Age C2: Anger				.001	.179	.008	.9939
Age C2: Disgust				.332	.179	1.853	.0641
Age: Expression: Time	292,499	396	<.0001				

(Continues)

TABLE 4 (Continued)

Fixed effect	Model fit −2LL	ΔD	p	Parameter estimates β	SE	t	p
Age C1: Surprise: Linear				−.729	.690	−1.056	.2909
Age C1: Surprise: Quadratic				.769	.563	1.366	.1720
Age C1: Surprise: Cubic				.222	.449	.493	.6221
Age C1: Anger: Linear				2.510	.670	3.754	.0002
Age C1: Anger: Quadratic				.596	.546	1.092	.2752
Age C1: Anger: Cubic				−.643	.436	−1.475	.1404

Notes: N: Participants = 101, Trials = 1659, Observations = 84,609.

to older infants, six-month-olds showed greater interest in the surprised face compared to neutral ($\beta = -.413$, $p = .011$), and less interest in the angry face compared to neutral, both overall ($\beta = .398$, $p = .011$) and linearly across time ($\beta = 2.510$, $p < .001$, Figure 6b). A marginal interaction also suggests twelve-month-olds showed greater interest in the disgusted face compared to nine-month-olds ($\beta = .332$, $p = .064$).

3.2.3 | Expression scanning: Proportion of looking to the lower face

To analyze dynamic expression scanning, 6 (Expression) × 3 (Age) ANOVAs were conducted separately for proportional looking toward the lower face and lower-face features. A main effect of Expression was found for both lower face, $F(5,370) = 16.47$, $p < .001$, $\eta_p^2 = .18$, and feature, $F(5,370) = 12.73$, $p < .001$, $\eta_p^2 = .15$, though no main effects of Age (both $p > 23$) or interactions with Age were found (both $p > 23$). Performing the same analyses for upper face and features also found no main effects of Age (both $p > .47$) or any interactions with Age (both $p > .52$). Nevertheless, post-hoc tests reveal infants' clear looking toward diagnostic regions. Surprise attracted greater lower-face looking ($M = 57.87\%$) than other expressions (Combined $M = 38.98\%$, all $p < .001$), and greater lower-feature looking ($M = 29.88\%$) compared to all other expressions (Combined $M = 17.09\%$) except happiness ($p = .159$, all other $p < .01$). Fear also attracted less lower-feature looking ($M = 12.13\%$) in comparison to disgust ($M = 19.97\%$, $p = .024$) and happiness ($M = 22.71\%$, $p = .002$).

3.2.4 | Expression scanning: Temporal differences

We further investigated developmental differences in scanning, by modelling infants' looking toward the lower facial features (Table 5; see SI for lower face; four polynomial terms). The pattern depicted

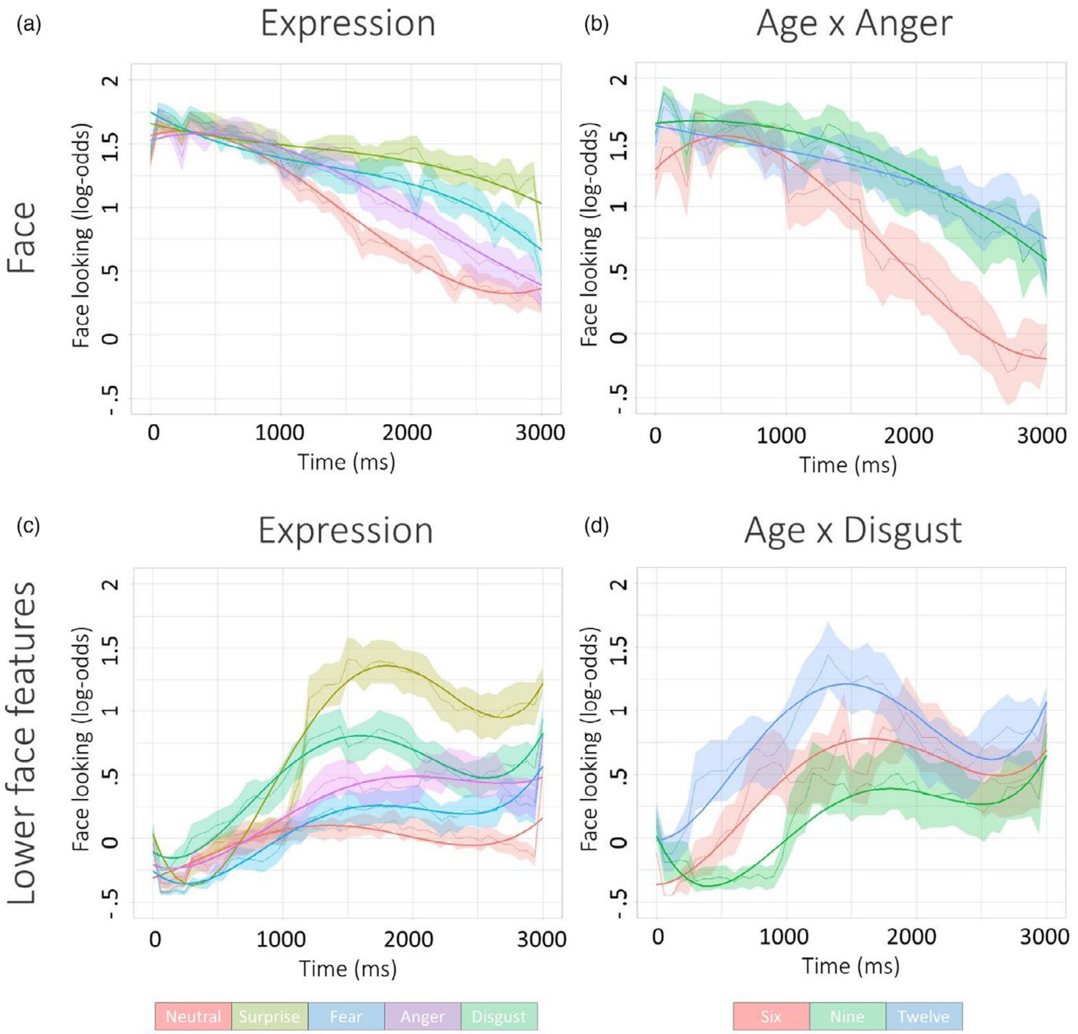

FIGURE 6 Temporal differences in face and lower feature looking across Age and Expression. The log-likelihood of fixating the lower face was computed across 60 ms time-bins, plotted here (faint line) with the standard error of the mean (colored border). Three polynomial terms were used to model face-looking across time (linear, quadratic, and cubic), and four for lower-feature looking (linear, quadratic, cubic, and quartic). The log-likelihood of fixating face (a and b) and lower-features (c and d) is plotted divided by Age: six (red), nine (green), and twelve (blue) months, and Expression: neutral (red), surprise (yellow/green), fear (blue), anger (purple), and disgust (green). For clarity, disgust has been omitted from (a). In (b and d), data from two significant Age × Expression interaction effects are plotted, displaying developmental differences in face looking for the angry expression (b) and lower feature looking for the disgusted expression (d)

in Figure 6c broadly reflects an increase in lower-feature looking across time (Linear: $\beta = .440$), with an "inverted U" shape (Quadratic: $\beta = -.467$) and asymptotic tails (see Mirman et al., 2008). Lower-feature looking was also not predicted by Age (all $p > .37$), or any Age × Time interactions (all $p > .26$). Expressions with diagnostic lower features, such as surprise, happy and disgust, showed strong positive effects compared to neutral (Surprise: $\beta = .731$, Happiness: $\beta = .485$, Disgust: $\beta = .469$; all $p < .001$), while expressions with diagnostic upper-face features showed much weaker effects

TABLE 5 Developmental differences in lower-feature looking

	Model fit			Parameter estimates			
Fixed effect	**−2LL**	**ΔD**	***p***	***β***	***SE***	***t***	***p***
Intercept	250,123	–	–	−1.511	.056	−27.002	<.0001
Time							
Linear	247,991	2132	<.0001	.440	.183	2.400	.0168
Quadratic	247,340	651	<.0001	−.467	.155	−3.016	.0027
Cubic	247,339	1	.3340	.471	.130	3.614	.0003
Quartic	247,085	254	<.0001	.248	.110	2.265	.0241
Age	247,083	2	.3038				
C1: (9 + 12 M) vs 6 M				.035	.121	.288	.7734
C2: 12 M vs 9 M				.123	.137	.898	.3704
Expression	244684	2399	<.0001				
Happy				.485	.074	6.520	<.0001
Sad				.305	.076	4.002	<.0001
Surprise				.731	.077	9.494	<.0001
Fear				.091	.077	1.182	.2375
Anger				.264	.075	3.500	.0005
Disgust				.469	.076	6.172	<.0001
Age: Time	244,618	66	<.0001				
Expression: Time	243,212	1406	<.0001				
Age: Expression	242,811	401	<.0001				
Age C1: Happy				.012	.160	.074	.9408
Age C1: Sad				−.059	.163	−.364	.7161
Age C1: Surprise				−.341	.165	−2.061	.0394
Age C1: Fear				−.268	.165	−1.623	.1049
Age C1: Anger				−.011	.162	−.066	.9471
Age C1: Disgust				.030	.164	.184	.8539
Age C2: Happy				.024	.181	.132	.8951
Age C2: Sad				−.191	.187	−1.018	.3089
Age C2: Surprise				.065	.188	.345	.7305
Age C2: Fear				.137	.188	.730	.4656
Age C2: Anger				.144	.184	.780	.4358
Age C2: Disgust				.576	.185	3.122	.0018
Age: Expression: Time	242,488	323	<.0001				
Age C1: Surprise: Linear				−1.815	.704	−2.578	.0100

(Continues)

TABLE 5 (Continued)

	Model fit			Parameter estimates			
Fixed effect	**−2LL**	**ΔD**	***p***	***β***	***SE***	***t***	***p***
Age C1: Surprise: Quadratic				−.632	.573	−1.104	.2700
Age C1: Surprise: Cubic				−.083	.507	−.164	.8700
Age C1: Surprise: Quartic				.896	.408	2.198	.0281
Age C2: Disgust: Linear				−.554	.797	−.696	.4866
Age C2: Disgust: Quadratic				−1.504	.644	−2.337	.0196
Age C2: Disgust: Cubic				.942	.569	1.656	.0980
Age C2: Disgust: Quartic				.054	.457	.118	.9060

Notes: N: Participants = 101, Trials = 1659, Observations = 72,641.

compared to neutral (Fear: $\beta = .091$, $p = .238$; Anger: $\beta = .264$, $p < .001$). Interactions with Age also indicate developmental differences in face scanning. Compared to older infants, six-month-olds showed greater interest in the lower features of surprise, both overall ($\beta = -.341$, $p = .039$) and across time (Age Linear: $\beta = -1.815$, $p = .010$; Quartic: $\beta = .896$, $p = .028$). While twelve-month-olds showed greater looking toward the lower features of the disgusted expression compared to nine-month-olds ($\beta = .576$, $p = .002$), and a more pronounced curve across time (Quadratic: $\beta = -1.504$, $p = .020$; see Figure 6d). Six-month-olds also showed reduced looking to the lower-face in general, for both angry ($\beta = .429$, $p = .021$) and disgusted ($\beta = .692$, $p < .001$) expressions (See SI for more information).

3.2.5 | Expression scanning: Spatial differences

Developmental differences in face scanning were analyzed unsegmented across space using heatmaps. Figure 7 displays the heatmap analyses for angry, fearful, disgusted, and happy trials (see Figure S3 in SI for sadness and surprise). For each expression, the left panel displays standardized fixation data plotted for each age, the larger image displays the results from a matrix ANOVA across time (p values), and the lower panel depicts post-hoc t-maps representing mean differences between age groups, with regions of significant differences outlined in black (Bonferroni-corrected alpha = .016). For **anger,** only small, scattered regions emerged as significantly different across Age, though twelve-month-olds showed much cleaner looking toward the eyes and mouth compared to six-month-olds, who fixated a more central region. Similarly, for **fear**, older infants showed greater looking toward diagnostic facial features such as the whites of the eyes and open mouth, while six-month-olds fixated

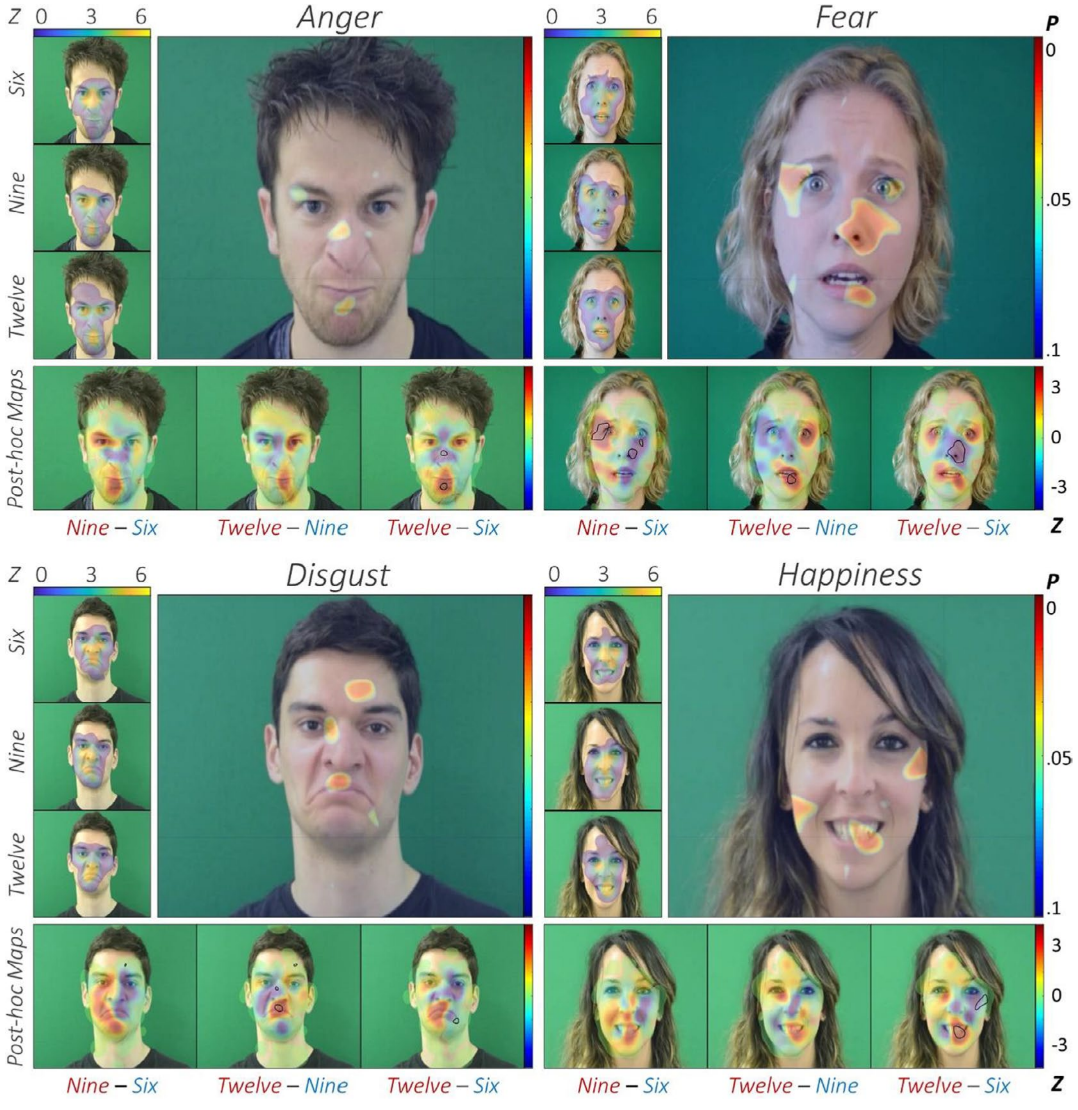

FIGURE 7 Developmental differences in facial expression scanning are depicted via heatmap analyses for **angry, fearful, disgusted, and happy** expression trials. For each of the four quadrants, fixation location and duration data are plotted as z-scores for each age group (six, nine, and twelve months) in the left-side panel, with highly fixated regions appearing orange/yellow. The *p* values (two-tailed) from 0 (red) to .1 (blue) from a one-way matrix ANOVA across Age are presented in each of the large "ANOVA map" images. In the lower panel of each quadrant, *t*-maps display the mean differences between post-hoc Age map comparisons (9–6 months, 12–9 months, and 12–6 months) as *z*-scores ('Post-hoc maps'), with positive (red) values denoting regions of increased looking in older infants, and negative (blue) values denoting regions of increased looking in younger infants. Clusters of significant differences between Age maps are outlined in black using a Bonferroni-corrected alpha (.016)

centrally. For **disgust**, twelve-month-olds showed greater looking toward the mouth-nose diagnostic region compared to nine-month-olds (see also Figure 6d), and for **happiness** a section of the diagnostic mouth-region was fixated more in twelve-month-olds compared to six-month-olds. There were few developmental differences in face scanning for **sadness** and **surprise** (see Figure S3).

4 | DISCUSSION

How infants direct their visual attention toward emotional facial expressions is highly dependent on whether it is presented as static or dynamic. Replicating classic work (Wilcox & Clayton, 1968), we found dynamic (i.e., dynamic-contingent) stimuli hold infants' attention longer than static stimuli. Further, we found dynamic expressions are scanned differently by infants, as they attract greater looking toward lower facial regions. The temporal profiles of infants' scanning also indicated that they allocated visual attention in a qualitatively different way for dynamic expressions. When expressions were dynamic, infant scanning was reactive, with their responses coordinated to temporal changes in the stimuli, while face scanning for static expressions was much less varied across time (see Figure 5; see Võ et al., 2012). Infants showed clear diagnostic scanning of dynamic expressions, but our data also highlight that infants demonstrate considerable inter-stimulus variability, showing sensitivity to individual differences in an actor's facial morphology and expression performance (e.g., compare Figure 5b and Figure S1b). While these results may present a more complex picture of infant face scanning, we believe that conserving critical components of naturalistic expressions (i.e., dynamism and contingency) provides us with a closer representation of the real-world phenomena.

Converging with recent work (Addabbo et al., 2018; Heck et al., 2016; Richoz et al., 2018; Soussignan et al., 2017) we have established here that infants scan static and dynamic facial expressions differently. Yet the underlying reasons for these differences are difficult to determine given that informative facial signals are not distinct from facial motion (see Xiao et al., 2014). For instance, infants direct their attention to the mouth region during speech (Lewkowicz & Hansen-Tift, 2012; Võ et al., 2012), which is simultaneously the most informative region for language learning, and the most mobile. Interestingly, dynamic-face stimuli provide additional diagnostic motion cues which are disproportionately communicated through the lower facial features (Jack et al., 2014; Krumhuber et al., 2013; Smith et al., 2005), which provides one possible explanation for the lower face bias infants demonstrated here for dynamic expressions. What is clear however is that infant expression scanning is not random, but it also does not follow any "default" scan pattern. Recent work with adults has also shown that the traditionally held view of a default "triangular" scanning pattern between the eyes and mouth is not accurate, but is an artifact of averaging across participants who instead show stable but idiosyncratic and task-specific face-scanning strategies (Arizpe et al., 2017; Kanan et al., 2015; Mehoudar et al., 2014). Likewise, infants also show "bespoke" expression scanning by spontaneously directing their attention to informative facial regions (Võ et al., 2012).

For facial expressions, information-seeking scanning would lead to greater interest in biologically salient emotions (e.g., threat-related signals such as fear; see Leppänen & Nelson, 2009; Peltola et al., 2013), and a larger proportion of fixations targeting the features most useful for decoding the expression. For expression interest, we found clear differences between expressions, and found infants looked longest toward surprised faces, and aside from neutral, showed the least interest in angry faces; a pattern which was most pronounced in the six-month age group. Few studies have investigated surprise, but existing research with static stimuli has noted that it can be discriminated, but is not preferred relative to other expressions (Ludemann & Nelson, 1988; Serrano et al., 1992; Young-Browne et al., 1977). It is possible that surprise is much more salient when dynamic, as motion may disproportionately enhance its perceived intensity relative to other expressions (Biele & Grabowska, 2006; Weyers et al., 2006). The reduced interest in anger is consistent with literature examples of infants showing a marked tendency to disengage from angry faces (La Barbera et al., 1976; Schwartz et al., 1985). While our results do not support a generic "negativity bias" at seven months (c.f. Vaish et al., 2008), we did find evidence of heightened interest in fearful faces (Peltola et al., 2009, 2015), and older infants did show a relative increase in interest toward negative expressions; first anger by nine months, then disgust by twelve months (see Ruba et al., 2017).

For expression scanning, infants, like adults (Eisenbarth & Alpers, 2011; Jack et al., 2014; Scheller et al., 2012; Smith et al., 2005), showed clear expression-specific diagnostic face scanning. Temporal analyses revealed a pronounced peak in lower-feature looking as the mouth widened in surprise, but looking fell on the eye region when eyes widened in fear. Large peaks in lower-feature looking were also found for other expressions with highly diagnostic and dynamic lower-features (e.g., happiness and disgust), and smaller peaks for expressions with less salient lower features (e.g., sadness and anger). This pattern was consistent across age groups, but subtle developmental differences did emerge. For surprise, the mouth region held six-month-olds attention longer than older infants, but as looking was spatially precise in all age groups, this likely reflects six-month-olds' increased interest in surprise in general. Consistent with the expression interest results and previous literature (Addabbo et al., 2018; Ruba et al., 2017), we also found distinct developmental trajectories in scanning for certain negative expressions. For anger, twelve-month-olds demonstrated greater overall lower-face looking, and more precise scanning of the eyes and mouth compared to six-month-olds; and for disgust, twelve-month-olds showed enhanced looking toward the diagnostic mouth/nose region compared to nine-month-olds. In contrast, developmental differences in scanning for happy and sad were negligible, suggesting that face scanning for these facial expressions may be stable by six months of age. Similarly, infants also did not show AOI-based developmental differences in fearful face scanning. However, the heatmaps did indicate more precise diagnostic looking to the whites of the eyes and open mouth in twelve-month-olds, while six-month looking clustered much more around the nose and central regions of the face. Particularly when dynamic, both upper and lower features are considered diagnostic for fearful faces (Eisenbarth & Alpers, 2011; Jack et al., 2014), as such, these developmental differences were likely to be missed in the AOI analysis as they cannot be described according to asymmetries in looking along the vertical axis (i.e., upper or lower face bias). Nevertheless, these heatmap findings complement previous literature that note a developmental change in fearful face processing across the first year of life (see Leppänen & Nelson, 2009).

Given these results, we believe that gaze-contingently triggered exchanges can provide a useful framework through which we can embed social phenomena of interest, such as facial expressions, and investigate them in a lab setting. However, here we contrast non-contingent static images with stimuli that are both dynamic and contingent, making it difficult to distinguish between the relative contributions of each. Differences in how infants attend dynamic social stimuli are beginning to be investigated (e.g., Libertus et al., 2017), yet contingency has received little attention, and comparing contingent and non-contingent expressions would be a useful next step. In this paradigm, the expression was also triggered by an eye-region fixation. Given what we understand about infant-adult social exchanges (e.g., Batki et al., 2000; Murray & Trevarthen, 1986), this decision was ecologically (not just practically) motivated. This does however limit our method to expressions both initiated by and directed toward the infant, rather than those triggered by other internal or external events. Alongside this paradigm, we also introduced “Dynamic AOIs”, a new methodological tool that can automatically assign interest regions for dynamic stimuli (see SI for a detailed description). We believe this tool might be useful for future eye-tracking research using naturalistic facial expression stimuli, but also could be applied to the investigation of other facial cues that emerge in dynamic social contexts (e.g., eye gaze, speech). While our focus here is on infant behavior and development, Dynamic AOIs might also be useful for researchers interested in how humans attend naturalistic social stimuli at different developmental stages.

Theoretically, our work contributes to a growing interest in addressing whether the infant behaviors recorded in response to experimental stimuli and procedures in a lab setting are representative of the real-world phenomena we are trying to explain (e.g., Adolph, 2020). This is not a trivial matter and one that must be addressed if our scientific aim is to generalize findings from the lab to a real-world setting. In this paper by taking a step towards improved ecological validity, we have shown not only that infants display different eye movements when viewing static and dynamic stimuli, but that the patterns of eye movements shown for dynamic stimuli are systematic. Faces are inherently dynamic and if eye movements when viewing dynamic faces do differ from static faces, as we have shown here, then it is important to consider what functional role these eye movement patterns play in the processes of expression learning and recognition.

In this paper, we have provided the first demonstration of expression-specific eye movements to facial expressions representing each of Ekman's six basic emotions (Ekman & Friesen, 1976). Moreover, these eye movements clearly map on to the previously reported "diagnostic" face regions for identifying facial expressions (Gosselin & Schyns, 2001). The refinement of expression-specific eye movement patterns that we report are suggestive of learning and could help to explain the varied categorical abilities for facial expressions reported in past studies with infants younger than 6 months of age (e.g., Farroni et al., 2007; White et al., 2019). While these studies tell us *that* infants discriminate some expression face pairings but not others, exploring eye movement patterns might help to tell us *why* this pattern of results is reported. The refinement of eye movements seen here would suggest even less refined patterns of eye movements in infants younger than 6 months of age that might account for the results reported. It would be interesting for future studies to explore this directly in order to better understand how eye movements facilitate learning in the first months of life.

There has been much research seeking to understand how infants perceive facial emotion. Despite facial expressions being inherently dynamic phenomena, naturally occurring within contingent social interactions, much of our current understanding is based on paradigms presenting infants with static, unresponsive face stimuli. Here we demonstrate that infants' interest toward the face, and their scanning across facial regions, differs substantially depending on whether expressions are interactive videos or static images. Although all age groups showed clear diagnostic scanning of expressions, we found evidence of a developing sophistication in scanning for angry, disgusted, and fearful expressions from six to twelve months. We believe this description of infants' interest in and scanning of the six "basic" emotional expressions can provide a baseline for future developmental theories of dynamic expression perception.

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CONFLICT OF INTEREST

The authors declare no conflicts of interest with regard to the funding source for this study.

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section.

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APPENDIX A

Looking durations

Eye-tracking data were processed in MATLAB (Mathworks, R2017a). A custom-written velocity-based algorithm that has successfully been used in recent publications (Keemink et al., 2019; Kelly et al., 2019; Prunty et al., 2020) was used to identify saccades. Data were initially smoothed by applying a four-sample rolling window that returned a median average. Angular speed was computed based on four samples. Velocity values greater than 1000°/s were judged to be impossible and were removed from analysis. We set a velocity threshold of 40°/s, with samples falling below this value identified as potential fixation samples. Time and distance between two potential fixations were calculated. If inter-fixation values were <20 ms and < .03° then fixations were merged. All fixations <100 ms were removed. Fixations summaries containing discrete fixations were compiled along with their duration, location, and sequential number.

AOI analyses

A custom MATLAB script (see SI for more information) was written to identify areas of interest (AOIs) directly from the stimulus (see Figure 3). This method used color and luminance information within video frames to define background, hair, upper torso, face, and facial features (see Kolkur et al., 2017 for a similar skin detection method). After pre-defining a face "midpoint" and skin tone range for each actor, a numerical matrix defining six AOIs (Background, hair/torso, upper-face skin, upper-face feature, lower face skin, lower face feature) was automatically computed for each video frame (or for just the single image used for the static condition). The script identified feature regions for the mouth, nose, eyes and eyebrows, before dividing them into "upper" and "lower" categories either side of the midline (centered upon the bridge of the nose). Further, by combining feature and skin regions, we were able to analyze general upper versus lower face looking. Specific "dynamic AOIs" were therefore generated for each expression video that can accurately accommodate for variations in size and location of interest regions between actors and across time (see Hessels et al., 2018 for an alternate approach).

Heatmaps

Fixation heatmaps (see Caldara & Miellet, 2011) were produced by summing all fixation durations within a trial for each pixel "coordinate", smoothing these with a Gaussian kernel and computing a matrix of *z*-scores from the resulting values. Difference maps were created by subtracting one map from another (e.g., dynamic – static). Heatmaps were also produced for each participant individually, thus creating a sample of fixation matrices that could be concatenated into multi-dimensional arrays. Using these, clusters of significant differences between maps could be identified using matrix *t*-tests or ANOVAs (Mathworks, Statistics and Machine Learning Toolbox).

Time-course

When using dynamic stimuli, on-screen information changes over time. Time therefore becomes a relevant variable, as collapsing data across this dimension may obscure important patterns (Barr, 2008). Here we used growth-curve analysis to incorporate time as a predictor within mixed-effects regression models using the lmer function from the lme4 R package (Bates et al., 2014; Mirman et al., 2008). For these analyses, 3 s of fixation data from each trial (from the gaze-contingent onset till the end of the expression animation) were aggregated to 20 ms time slots forming a binomial dataset for each AOI (Fixating AOI = 1, Not fixating AOI = 0). Mean proportions were computed, then adjusted to the log-odds scale using an empirical logit (E-log) transformation (see Barr, 2008). Groups were also sum-coded (e.g., Condition: Dynamic = +.5, Static = −.5) so that the intercept represented mean log-odds. The curvilinear relationship of time course on AOI looking was then modeled (across 60 ms time bins) using orthogonal power polynomials (Dink & Ferguson, 2015; see Mirman et al., 2008). These can represent complex functional forms by incorporating higher order components (e.g., quadratic, cubic, quartic). Within these models the intercept represents effects irrespective of time, the slope reflects a unidirectional change over time, the 2nd order (quadratic) term represents a symmetrical double change (i.e., the rise and fall of a curve) over time, while 3rd and 4th order (cubic and quartic) terms reflect three and four changes over time respectively, capturing any steepness or asymmetry of the curve around the inflection point.