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RESEARCH ARTICLE

Under the skin: Exploring 2-month-olds' thermal reactions in different social interactions with mother and stranger

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Abstract

Physiological adaptations to external stressors can reveal socio-cognitive health in infancy. With the use of thermal imaging and behavioural analyses, the current study examined the arousal markers accompanying infants' interactions with a familiar and an unfamiliar person. To address the current research question, the mother and a complete stranger interacted with 2 to 3 month-old infants (N= 10, 2 boys)in three different conditions: *Neutral*, *Play,* and *Compliment*. Behavioral analyses showed that overall gaze was longer to the *Stranger* compared to the *Mother* independent of condition. Physiological findings showed that *skin* temperature was significantly higher with the stranger independent of condition. The regions of the face that passed the significance threshold included the maxillary area, the nose, and the forehead. Both behavioral and physiological findings emphasize the ability of the infant to distinguish between a familiar and an unfamiliar person. Most importantly, however thermal imaging has proven to be a promising tool in physiologically differentiating between variable social conditions in very young infants opening up a new experimental portal for identifying healthy physiological development.

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KEYWORDS

development, emotions, infants, physiology, social, thermal imaging

1 | INTRODUCTION

Emotions have a high communicative value, from early on in human life. Behavioral expressions of emotions do not function in isolation of the central nervous system. Reactivity and recovery of the autonomic nervous system are unarguably at the heart of emotion regulation. The inability of infants to physiologically self-regulate in response to social stressors has been associated with an increased risk for later development of psychopathology (Suurland et al., 2017). Thus understanding physiological regulation in various socio-emotional settings in infancy remains of primary importance not only for psychopathology but also for atypical development. Physiological studies of very young infants present considerable difficulties both due to experimental limitations but also because of the anatomical constitution of infants. Nevertheless, thermal imaging could yield the ability to overcome a variety of the caveats faced by conventional physiological recording methods.

Experimental recordings through the attachment of electrodes sometimes seem impossible as the infant's movements render collected data with mainstream tools such as heart rate and skin conductance unusable due to noise artifacts (Ham & Tronick, 2009; Suurland et al, 2017). Attachment of electrodes poses a serious risk for an infant's health not only due to the occurrence of allergic reactions but also because adhesive use on an immature skin could lead to pain, trauma, and potentially infection (Afsar, 2009; Connoly & Buckley, 2004; Lund et al., 1997). Unlike adults in whom between 50% to 60% of the total body weight is water infants have approximately 80%. Moreover, whereas adults have 20% of total body weight in extracellular water and much more in intracellular, infants have 45% distributed extracellular and 35% intracellular (Meyers, 2009). Moreover, human babies have approximately 15%–17% fat deposits at birth, a physiological phenomenon that keeps rising leading them to a fat deposition of approximately 22%–31% in the first year of life (Ramos et al., 2015). Human infants have the highest percentage of fat in the animal kingdom, and one of the reasons for this is their large energy demanding brain (Hoke, 2018). Both fat and water retention translate to higher body surface area to weight ratio potentially inhibiting erythrocyte displays. Thus, the biological constitution of infants may be inhibiting them from exhibiting a blush. The inability of infants to display a blush in a social setting leads Buss (2014) to postulate that the inability of infants to exhibit a blush stems from a lack of identifying “themselves as social objects.” This is in contrast to behavioural data showing that infants of 2–4 months show coy smiles in response to positive attention (Reddy, 2000).

Very young infants do in fact have the capacity to redden following effortful actions. The valsalva maneuver is a physiological phenomenon present in many functions of everyday life, among others bowel movements. This cardiovascular maneuver is associated with increased abdominal pressure due to the forced expiratory rate against a closed airway. Rise in intra-thoracic pressure leads to significant arterial and heart rate increase, jugular vein distension and thus blushing (Pstras et al., (2015). Along the same lines, crying has also been associated with reddening of the face. Crying is an event driven by the sympathetic nervous system leading to an increase in heart rate as well as temperature (Kraemer and Hastrup, 1988). Crying holds the highest temperature rise ever recorded in adults (Ioannou et al., 2016). Both crying and the valsalva maneuver have a heavy physiological output. Blushing on the other hand is a much more subtle biological phenomenon (Ioannou et al., 2017).

Thermal imaging shows a route for overcoming the problem of acquiring data about blushing in infants. Unlike any other physiological modality, thermal imaging is unique in that it can reveal a multitude of physiological changes by monitoring the thermal print of the face (Ioannou et al., 2014).

Changes in the temperature of the face could be the result of heart rate output (Garbey et al., 2007), peripheral vascular constriction (Ioannou et al., 2013), perspiration (Pavlidis,, et al., 2012), and even prolonged muscular activity (Pavlidis et al., 2001). Thus, by monitoring the human face with thermal imaging from a distance, one can extract a multitude of physiological indicators regarding emotional arousal without wires intervening with the experimental procedure (Ioannou, Gallese, et al., 2014). and particularly useful for infants (Nakanishi & Matsumura, 2008).

Very few studies have used thermal imaging to experimentally examine emotional variations in infants and particularly positive emotions. Nakanishi and Matsumura (2008) have observed that during joyful expressions and laughter the overall temperature of infants from 2 to 10 months of age decreased on the forehead, cheeks and nose with the nose having the most profound temperature decrease. Furthermore, Aureli et al. (2015), by employing the still face paradigm in infants of 3–4 months of age, observed that compared to play conditions the overall temperature of the face during the still face increased in the absence of upset behavioral reactions. In the view of these findings, it was concluded that the parasympathetic nervous system was more engaged rather than the sympathetic indicating arousal rather than distress.

The present exploratory study aimed to examine facial temperature changes in infants during positive social interactions with both the mother and a stranger, respectively. The ability of an infant to be aware of a stranger and engage in a behavioral repertoire of social reciprocity represents an essential milestone for understanding human development and social cognition (Rheingold & Eckerman, 1973; Sroufe, 1977). The inability of infants to physiologically self-regulate in response to social stressors has been associated with behavioral problems that stem back to maladaptive "attachment" models of caregiver–infant interaction (Hagekull, et al., 1993). Yet infants of 2–3 months old have not been seen to blush even if they exhibit the rich behavioral cues associated with coyness (Reddy, 2000).

To explore potential physiological markers of infants of 2–3 months of age in interactions with their mothers and with a stranger, experimental conditions with three levels of interaction intimacy were chosen with increasing degrees of emotional intensity: a) Neutral contact, b) Play, and c) Compliment condition. This experimental model with a buildup of intimacy was chosen since it was likely to enable shy or coy displays without being too abrupt or intrusive (Hobson et al., 2006; Ioannou et al., 2017). As an exploratory study, it was important to sequence these conditions up in the most psychologically sensitive and non-disruptive manner possible. Infants were always presented with the mother first and the conditions in an ascending order of intensity followed by the interaction with the stranger in a descending order. Thus, rather than starting up the stranger contact with a sadden drop from the warm intimate maternal interaction to unemotional neutral interaction the stranger continued with warm intimate contact and then dropped to the more moderate playful condition ending up with a neutral condition. Thus, during interactions with the strangers, facial temperature of the children will potentially rise, indicating vagal engagement as a result of sympathetic arousal. Overall, since the complimenting condition as in adults has been observed in to be a situation of increased physiological arousal, it is highly likely that the highest temperature increase during interactions with both the mother and the stranger will be observable during the complimenting situation (Ioannou et al., 2017).

2 | METHOD

2.1 | Ethics statement

The present study was conducted according to guidelines laid down in the Declaration of Helsinki, with written informed consent obtained from a parent or guardian for each child before any assessment or data collection. All procedures involving human subjects in this study were approved by the Science Faculty Ethics Committee at the University of Portsmouth.

2.2 | Participants

Recruited participants were 10 young infants (M_{age} = 12.3 weeks, SD_{age} = 1.7) of which 8 were females and 2 were males. They had no history of complications during birth and no neurological disorders. Parents reported that all children were healthy and had achieved the expected developmental milestones for their age.

2.3 | Procedure

Participants were recruited through personal contacts as well as from the Facebook group South Sea Mummies and Toddlers. Upon arrival at the laboratory, mothers were given full details about the nature of the research questions that the experiment was trying to address and if any question arose during the debriefing session they were answered. Each family was informed that the study was partially supported by the LEGO bricks group and they were given the opportunity to choose from four different LEGO sets for their children as a thank you. Once all questions were answered and the informed consent forms were completed, mothers were asked about any complications at birth, their age, the age of the child, and any history of neurological problems. The debriefing and interview procedure took approximately 10 min and was conducted by one of the research assistants of the study. Prior to the experimental recordings, a 10-min acclimatization period occurred for the infants during which the male experimenter explained to the mother how each condition was supposed to be performed using a plastic doll. During this time, the experimenter could potentially be seen by the infant; however, there was no eye contact or engagement. On the occasion that an infant was sleeping or was upset, an effort was made to put them in a playful and awakened state. Caressing and feeding the child was usually enough to achieve an agreed-upon calm awake state which usually ranged from 10 to 20 min. Nevertheless, since this significantly prolonged each experimental session and on the occasion that these attempts to lighten the mood of the infant were unsuccessful, another visit was scheduled. All equipment was set up for both behavioral and physiological recordings 30 min–1 h before the experimental session, and when the mothers understood the experimental procedure, the experimental protocol was followed. It was made clear to the mother that during the experimental protocol that for whatever reason she should abstain from touching the face of the child during the thermal recordings as this would contaminate the infrared reading. In extent, mothers were instructed to limit their facial expressions in particular direct gaze and smiles during the neutral as well as the play conditions. On the contrary, during the complimenting condition they were asked to be particularly explicit with their facial expressions and smiles. Firstly, mothers engaged with their child by performing a familiar daily activity such as removing some clothing (the neutral condition). Next, they were asked to play with the child using a familiar toy (the play condition) and, finally, were asked to praise the child about some personal physical attributes using an elevated pitch to their voice (the compliment condition). Following the mother, the experimenter performed the same series of events, in the reverse order of experimentation (i.e., compliments, playing, and then neutral). The whole experiment took approximately 6 min during which the mother was always present in the room (Hagekull, et al., 1993).

2.4 | Materials and data acquisition

To record fluctuation in skin temperature, the TP8 (ThermoPro®) Digital Guide Infrared Camera was used. The TP8 infrared camera has an uncooled FPA microbolometer with the potential of producing an image of 384 pixels × 288 pixels, a temperature sensitivity of 0.08 Ñ at 30 Ñ, and accuracy of ±1°C. To ensure that enough frames would be collected for data analyses due to the potentially excessive movements of the infants, sampling rate was set at one frame per second (1 Hz). To acquire both thermal and behavioral data (JVC-Everio), both cameras were placed 50 cm away from the child and were manually fixated and calibrated to ensure a clear image. The child was situated comfortably during the experiment in the baby stroller. Both the mother and the experimenter engaged with the child from one side of the baby so as to not obstruct the view of the camera. Meanwhile, the baby was placed in the baby stroller directly facing the camera to ensure the clearest possible view and camera angle.

2.5 | Data analyses

2.5.1 | Infrared imaging

To analyze the thermal footage, the Launch GuideIR Analyser software by Wuhan Infrared Technology was used. Data analyses were carried out by three different thermal imaging raters, each of whom was unaware of the experimental rationale. Temperature values were extracted every 5 s from six different regions of the face: the forehead, the chin, cheeks, nose, periorbital region, and the upper lip (see Figure 1) (Ioannou, Gallese, et al., 2014, p. 955). After the placement of circular or rectangular extraction points, the pixel matrix for each region of interest was examined using the Launch GuideIR Analyser software ensuring that all regions of interest had over 9 pixels. Overall, the smallest region was usually the rectangular region placed on the upper lip which had on average 64 pixels followed by the periorbital region with 85. This practice was followed for all infants and was applied only on the first frame of each infant as distance, and the size of each extraction point did not vary across frames. In the event that the infant obstructed the region of interest, then the next available frame was recorded. All extracted frames were homogeneous in angle. Once all data were extracted, data for each child

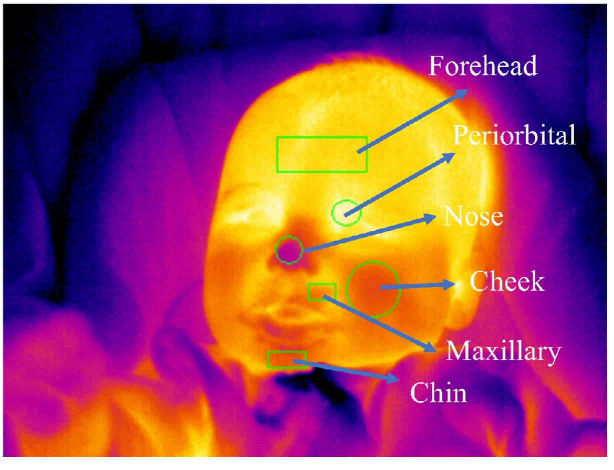

FIGURE 1 Visual representation of the regions of interest used to extract infant temperature

underwent a stem and leaf plot for each of the six regions of interest (10 × 6). This was performed to determine whether any of the data points collected were out of the normal frequency distribution. In the event that certain data points did not fit with the rest of the data set, the frame was revisited and temperature was extracted again. If the spurious value was affected by the angle of the infant, then the next available frame (which was homogeneous in angle with the previous one) was taken. Once all data were collected and cleaned for noise, the mean value was calculated for each of the regions of interest for each of the children. Next, a 2 × 3 repeated measures ANOVA within and between interactions was conducted. To eliminate the possibility that room temperature may have affected our physiological recordings, a circular region of interest was placed in the background of the room away from heat or ventilation sources and temperature was extracted every 20 s over the 6-min period of each experimental condition. To examine whether there was a difference in the temperature of the room across the six conditions, a non-parametric Friedman test was conducted. Prior to calculating the scores, values were combined to represent the mean value for each phase. The results of the non-parametric Friedman test indicated that room temperature did not fluctuate across the 6 different experimental condition χ^2 (5, n = 10) =3.94, $p < .005$. Inspection of the median values did not show a major temperature decrease however, the highest value was obtained during the mother neutral condition $Md = 23.90$ followed by the stranger play phase $Md = 23.85$. The mother's playi condition, stranger neutral as well as compliment conditions had the forth lowest value $Md = 23.80$. Finally, the lowest room temperature value was noted during the mother compliment condition $Md = 23.75$.

2.5.2 | Behavioral data

Behavioral videos were analyzed using the software Elan 5.1 (https://tla.mpi.nl/tools/tla-tools/elan/). For the current study, the same coding system was used as was used by Asendorpf, (1990) and adapted by Reddy, (2000). Training for all research assistants was provided by a specialist in Facial Action Coding System from the University of Portsmouth, and all behavioral coding took place by individuals blind to the theoretical interests and hypotheses of the experimental protocol. Prior to any form of data extraction, the duration of the six different phases was documented for each child (Neutral/Mother, Play/Mother, Compliment/Mother, Neutral/Stranger, Play/Stranger, and Compliment/Stranger) (see Figure 2).

Data were screened for parametric analyses, and reliability analyses were conducted using Kappa measure of agreement on 20% of the video data by raters naïve to the experimental protocol. Prior to the reliability analyses, values were rounded from two to one decimal place. Kappas’ alpha ($p < 0.05$) was very good (see Table 1).

3 | RESULTS

3.1 | Infrared imaging

We conducted six 2 (person: mother; stranger) × 3 (condition: neutral; playful; compliment) fully repeated measures ANOVAs on the facial temperatures for each of the six regions of interest separately. The results of complex ANOVA with small numbers of participants have to be treated with a degree of caution. However, a pattern of results did emerge that suggests the significant results are not random. There were no significant main effects of condition, and there were no person × condition interactions, but there were significant main effects for person on the forehead, nose, and maxillary

FIGURE 2 Illustration of the conditions (neutral, play, compliment) during the mother–infant dyad on the top and stranger–infant dyad on the bottom

regions of interest with the stranger condition having higher temperatures than the mother condition all with large effect sizes (see Table 2).

Temperature was also higher in the stranger condition for the remaining regions of interest although the differences were not significant. There was a high degree of consistency in the pattern of the increases for individual infants. The following figures illustrate this for the significant main effect of person for forehead, nose, and maxillary the effect was consistent for most infants (see Figures 3-4).

In summary, there is no indication that condition had any effect on temperature in any region of the face; however, there is evidence that facial temperatures for some regions of interest were substantially higher in the stranger condition. Although it was expected that the compliment condition would yield higher facial temperatures, the results were in the predicted direction but not significant.

3.2 | Behavioral data analyses

We analyzed the differences in the behavioural reactions of the infant to mother and stranger across the three conditions. We could not use a factorial ANOVA approach as the data were non-normally distributed and the sample size was small. We therefore conducted Friedman non-parametric ANOVAs comparing the six possible combinations of mother and stranger and compliment, neutral, and play.

TABLE 1 Coding of the infant's interactions

Gaze duration *Relative to condition duration (gaze duration in seconds/condition duration in seconds *60)*	To Person, *kappa* = 0.9	Infant's gaze focused on the face of the adult partner in the condition.
	To Object, *kappa* = 0.8	Infant's gaze focused on the object being held or used by the adult in the condition.*
Smile frequency	Smile *kappa* = 1	Either openmouthed or closemouthed extension of lips with or without cheek raise.
Shy smile* *Based on occurrence.	Shy smile *kappa* = 0.8	Defined as a smile with at least one of the following occurring before the end of the peak of the smile—GA (gaze aversion), HA (head aversion), and AR (arm raising near the face).
Distress frequency	Distress *kappa* = 0.8	The occurrence of any of the following behaviors was taken as an indicator of distress: frowns, puckered mouth, frozen looks, actual crying. If these behaviors co-occurred, they were counted as one occurrence.

TABLE 2 Results of 2 × 3 ANOVAs for all regions of interest

ROI	Source	*F (df)*	*p*	η_p^2	M_{mother} *(SD)*	$M_{stranger}$ *(SD)*
Forehead	***Person**	**6.25 (1, 9)**	**.034**	**0.41**	**35.51 (0.50)**	**35.72 (0.58)**
	Condition	0.32 (1, 18)	.73	0.034		
	Person × condition	0.182 (1, 18)	.83	0.02		
Nose	***Person**	**9.30 (1, 9)**	**.014**	**0.51**	**32.92 (2.42)**	**33.88 (1.70)**
	Condition	0.091 (2, 18)	.913	0.01		
	Person × condition	2.06 (2, 18)	.16	0.19		
Periorbital	Person	0.43 (1, 9)	.53	0.05	36.12 (0.61)	36.24 (0.68)
	Condition	0.01 (2, 18)	.99	0.01		
	Person × condition	2.85 (2, 18)	.08	0.24		
Cheek	Person	0.13 (1, 9)	.73	0.01	33.99 (0.99)	34.04 (0.85)
	Condition	0.86 (2, 18)	.44	0.09		
	Person × condition	0.33 (2, 18)	.72	0.03		
Chin	Person	2.61 (1, 9)	.14	0.22	34.26 (1.13)	34.48 (0.72)
	Condition	0.49 (2, 18)	.49	0.62		
	Person × condition	2.54 (2, 18)	.11	0.22		
Maxillary	***Person**	**5.96 (1, 9)**	**.037**	**0.40**	**34.92 (0.84)**	**35.31 (0.63)**
	Condition	0.01 (2, 18)	.997	0.01		
	Person × condition	0.27 (2, 18)	.777	0.03		

*Significant effects highlighted in bold.

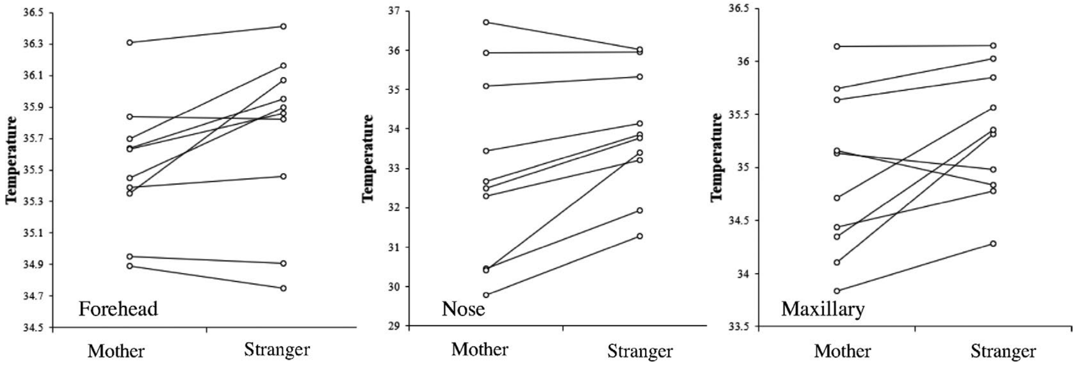

FIGURE 3 Changes in temperature across conditions for individual infants

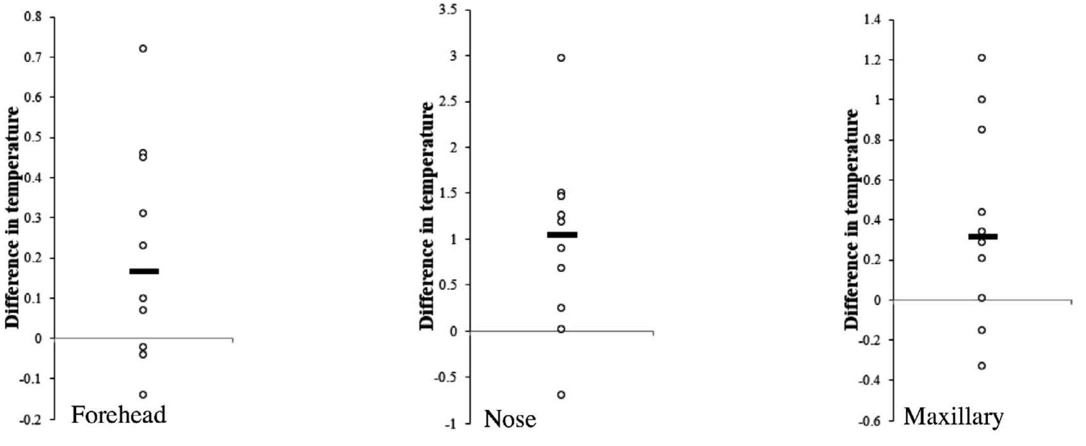

FIGURE 4 Difference in temperature between conditions for individual infants

We analyzed each behaviour separately (see Table 3). There was a significant result for gaze to person (scaled for length of duration of the interaction) where all the values in the stranger condition were higher than the comparable values in the mother condition. The differences between stranger and mother were significant ($p < .05$) for the neutral and compliment conditions but not the play condition. There was no clear pattern for gaze to object and shy smiles although the overall results were significant. There was no significant effect for smiles.

The influence of person and condition on gaze direction and duration.

We conducted a fully repeated measures 2 × 3 × 2 factorial ANOVA on the gaze duration data. The independent variables were person (mother vs. stranger), condition (neutral, play, compliment), and focus (person vs. object). We found a significant main effect of person with gaze being significantly longer in the stranger condition (M = 22.97, SD = 14.50) than the mother condition (M = 17.57, SD = 13.19), F (1, 9) = 9.67, p = .013, $\eta_p^2 = 0.52$ with a large effect size. There was also a significant main effect of condition, F (2, 18) = 12.71, p = .00036, $\eta_p^2 = 0.58$ with a large effect size. Post hoc comparison with Bonferroni adjustment revealed that play had significantly longer gaze (M = 26.42, SD = 11.27) than the neutral condition M = 16.25, SD = 13.21), p = .001, and the compliment condition (M = 22.97, SD = 17.05), p = .03. There was no significant difference between the neutral and

TABLE 3 Mean ranks as a function of mother/stranger and situation

	M N	M P	M C	S C	S P	S N	Chi square
Gaze person	3.00	2.05	3.40	5.40	2.75	4.40	**χ^2 = (5) 21.41 p = .001**
Gaze object	3.50	5.30	2.40	2.00	5.30	2.50	**χ^2 = (5) 32.27 p < .001**
Smiles	2.38	2.88	2.88	5.13	3.63	4.13	χ^2 = (5) 7.76 p = .17
Shy smiles	2.78	3.17	3.61	5.00	3.11	3.33	**χ^2 = (5) 12.58 p = .028**

Abbreviations: C, compliment; M, mother; N, neutral; P, playing; S, stranger.

*Significant effects highlighted in bold.

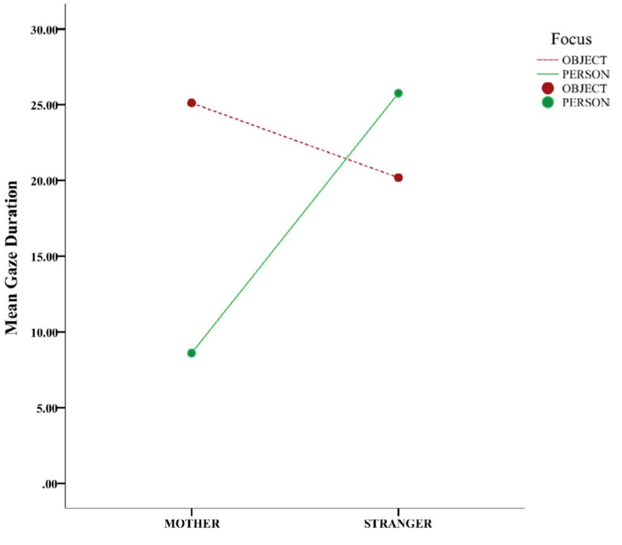

FIGURE 5 Gaze duration as a function of person and direction

compliment conditions. There was no significant main effect of gaze direction. However, the significant main effects are qualified by two interactions (Figure 5.)

There was a significant interaction between person and gaze direction, F (1, 9) =6.63, p = .03, η_p^2 = 0.42 with a large effect size. As can be seen from Figure 6, the interaction is due to gaze to person being shorter than gaze to object in the mother condition but there was no difference in the stranger condition.

This interpretation was confirmed by a simple main effects analysis, which revealed a significant difference between gaze to person and object in the mother condition (p = .005) but no difference between gaze to person and object in the stranger condition (p = .31).

We also found a significant condition × gaze direction interaction, F(2, 18) = 25.87, p < .001., η_p^2 = 0.74, with a large effect size. As can be seen from Figure 7, the interaction is due to there being no difference in duration between gaze to person and to object in the neutral condition; however, simple main effects analysis revealed that gaze was significantly longer to object than to person in the play condition (p < .001) but the reverse in the compliment condition where gaze to person was significantly longer than to object (p = .013).

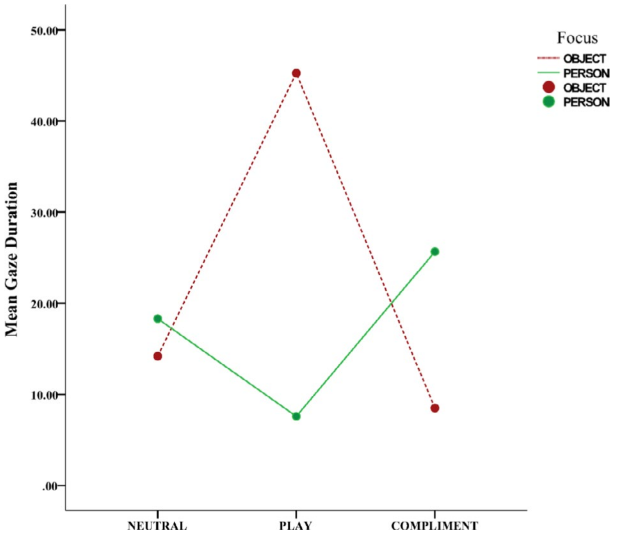

FIGURE 6 Gaze duration as a function of condition and direction

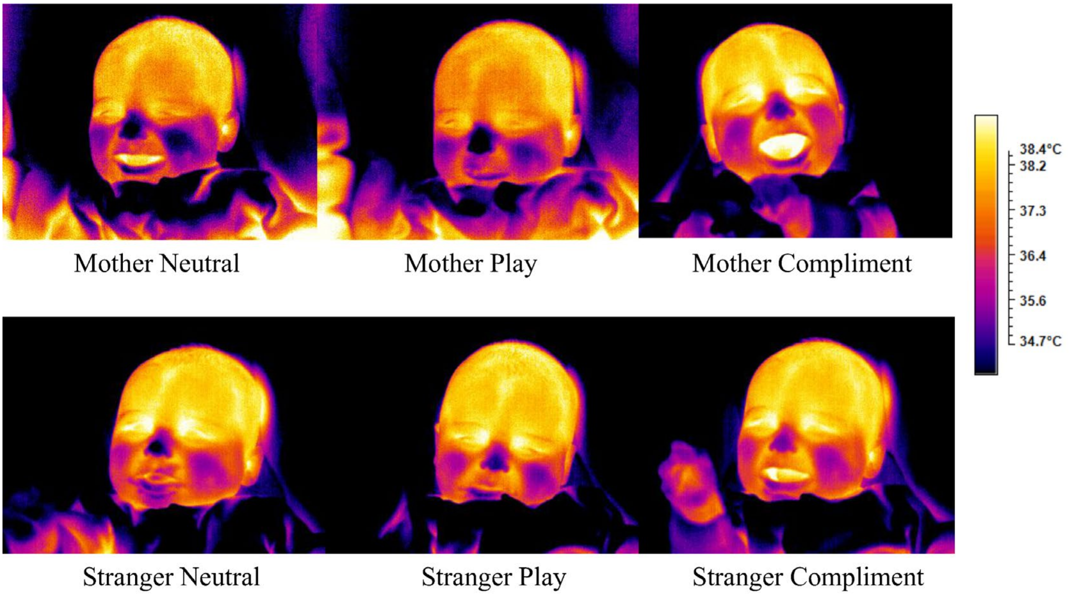

FIGURE 7 Infrared images illustrating the temperature change during the neutral play and compliment condition for the mother–infant dyad on the top and stranger–infant dyad on the bottom

3.3 | Qualitative description of the thermogram

Images represent the general tendency of the population sample (see Figure 8). All images that are illustrated in the thermogram have been taken 20 s after the initiation of each condition with an emissivity of .98 (as listed in the operational manual), 40% humidity, and room temperature of 23.4°C. To prepare the thermogram for presentation, the temperature range was decreased so that the images depict only the relevant information that was analyzed, in this case the child's face. As can be seen from the thermogram, the upper row depicts the mother's interaction with the child where the color tones, particularly of the forehead, lean more toward red to orange tones. During the stranger interaction, the forehead of the child becomes hotter and this difference can be seen in the fact that orange tones now move toward lighter shades of yellow. Although it is hard to distinguish color changes on the maxillary area if the two rows are compared, there is a minor shift in the color of the upper row compared to the lower row. In particular, shades of dark become more purple. Finally, the nose shows more fair tones during the stranger interaction compared to the mother and this effect takes place in most phases of the experiment. Specifically, there is a shift from blue to purple.

4 | DISCUSSION

These exploratory data show that thermal infrared imaging provides a promising tool for discriminating between different live social interactions in infants aged 2 to 3 months. Infants, display arousal markers that indicate an ability to differentiate between their mother and a stranger. Temperature analyses showed that the nose, the maxillary area, and the forehead were significantly higher during interaction with the stranger compared to the mother. Although behavioral analyses showed a rather similar tendency with the physiological results not all examined behavioral parameters showed a clear pattern (despite reaching significance for shy smiles and gaze to object). Non-parametric analyses showed that the duration of gaze to the stranger person was higher than the mother an observation that was evident during the compliment and neutral condition. Parametric, analysis showed that overall gaze duration was longer during the stranger interactions compared to the mother. Nevertheless, despite the fact that gaze duration toward the object or the person did not mark a significant difference during the stranger phase, the infant–mother dyad showed significantly longer gaze durations toward the object rather than the person. In effect, independent of person the play condition showed the longest gaze durations. Furthermore, examining the results in regard to condition it was observed that gaze duration was longer toward the object compared to the person during the play condition an effect that was reversed during the compliment phase with gaze duration toward a person being greater than the object.

Consensus is yet to be reached with respect to *infant shyness* of 2 months old with little agreement about what constitutes displays of shyness and its role in what it says about early infancy and self-conscious emotions. There is, however, ample research on infant shyness between 4 and 16 months (Colonnesi, Bögels et al., 2013; Amsterdam, 1972; Amsterdam & Greenberb, 1977; Lewis & Brooks-Gunn, 1979; Reddy, 2000). However, as Izard & Hyson (1986) conceded as many as three decades ago, infants of this age may be able to express shyness as a discrete emotion. Behavioral findings from the present study point to the ability of the child to identify the familiar person and in effect behave differently. In effect, the child chooses stronger and less subtle behavioral cues of engagement with the stranger rather than the mother, which points to the functional effort by the child as suggested by (Colonnesi, Wissink et al., 2013) to improve trust, liking as well as minimize threat (Keltner & Anderson, 2000). This "social challenge" of interpersonal wariness with its plethora of behavioral displays is "a phenomenon that may reflect the infant's emerging identity as a separate individual" (Batter & Davidson, 1979, pp. 106). Wariness of strangers seems to be an unrefined form of social awareness, and it is possibly where the infant for the first time identifies the physical vulnerability of the "self" away from the comfort and watchful eye of the caregiver. Interactions of the infant with others seem be at the core of the emergence of self-representation (Montirosso & McGlone, 2020). Infants seem to start acquiring a sense of self-specificity through sensory signals received initially through the touch of the mother learning very early on in life and differentiating between self and non-self. This comes as an outcome of the synchronous decoding of visual–proprioceptive and visual–tactile stimulation. These somatic sensations seem to be embedded in a social brain network including the insula that form a healthy sense of self-identity which seems to be impaired in atypical models of self-identity (Lombardo et al., 2010). Thus, social reciprocity in its variety of forms seems crucial for the emergence of self-identity.

Physiological manifestations in studies such as Ioannou et al. (2017), Ioannou, Morris, et al. (2014), Ioannou et al. (2016); Ioannou, Gallese, et al. (2014) resemble the results of the current study since overall an increase in temperature on the infants' faces was observed by varying the degrees of the social challenge. Looking at the results, one could speculate a rather positive social interaction at least at the first phylogenetic phase of autonomic arousal of vagal withdrawal (Porges, 2001), if not positive then definitely not negative or threatening (Aureli et al., 2015; Waters et al., 1975) as no signs of sympathetic arousal have been observed associated usually with a vasoconstriction of arteriovenous anastomoses and a decrease in the temperature of the nose (Chotard et al., 2018; Ioannou et al., 2013, 2015). Current findings suggest that infants of 2 to 3months old of age show physiological signs of sociality with the autonomic nervous system adapting to accompany behavioral displays of positive shyness. In support of this argument, Damasio and Carvalho (2013) have postulated that feelings have a physiological bodily representation and these feelings or mental states provide an additional level of behavioral regulation. Thus, the physiological component must be linked with a behavioral output and it is through these somatic markers that higher-order cognitive function is formed shaping social decision-making. The claim that babies cannot blush may well be untrue in a social context. Perhaps infants do blush. However, erythrocyte displays are not visible to the eye due to the infants' high body surface area that could occlude subcutaneous blood vessel dilatation.

To our knowledge, the nasal tip has usually been one of the most reliable regions in inferring stressful states manifested in the form of a temperature decrease (Kuraoka & Nakamura, 2011; Nakayama et al., 2005). However, significant results obtained on the maxillary area should be approached with caution due to the fact that the item of measurement was rather small, and potentially in the same angle as respiration flow. However, more importantly since the camera used was of a lesser resolution than 640 × 512 pixels as the one used by Shastri et al., (2102) this may have led to some false conclusion as perspiration pores which could have been present have not been picked up. At least the fact that a rise in temperature was observed "reluctantly," this phenomenon ensures that we do not have a sympathetic activation which ensures that the child is in a state of eustress or was experiencing a positive social context. The forehead as a region of interest has been one of the most widely implicated regions in understanding psychophysiological activation due to accessibility issues as it is a wide exposed area of the face. Overall, an increase in cardiac output would lead to an increase in supraorbital blood volume circulation thus raising the temperature of the forehead (Hahn et al., 2102; Ioannou et al., 2016; Puri et al., 2005; Zhu et al., 2007). On the other hand, sympathetic activation in considerable amounts of distress would lead to the activation of perspiration pores which would have the opposite effect and a decrease the overall temperature of the forehead (Pavlidis et al., 2012). Moreover, more of a mechanical lead temperature increase could be driven by the increased use of the corrugator muscle used for frowning as observed in (Levine et al., 2009; Zhu et al., 2007). Nonetheless, due to the fact that during our behavioral analyses no muscular elements of frowning were observed by the infants the phenomenon of observed temperature rise would be the derivative of a cardiac output increase (Porges, 2001).

As previously mentioned, one of the clear limitations of this study was the sample size. Because of the primacy that age plays in an experiment of this nature, collecting enough willing participants who fit the desired metrics poses quite a challenge in addition to the challenges of sustaining infants through controlled studies. Keeping infants interested for over a minute poses a major experimental challenge especially when the approach consists of 6 interaction conditions as well as running the risk of a "physiological spillover" effect (Ioannou, Morris, et al., 2014). These obstacles aside, the overwhelming consistency in arousal indicators as perceptible through thermal imaging should serve as a basis for further investigation into the physiological responses to various stimuli in infants. Despite the fact that this study provides the first step for a study of a bigger scale, it would be important in the future to look for markers of abnormal social development. These could include infants that already exhibit signs of developmental abnormalities, children of parents with mental health problems or misattuned attachment models between the mother and the infant. In this way, a better understanding will be attained on the mosaic of different emotional states as well as the biomarkers that point out to developmental social anomalies. Moreover, studies show that children respond differently to gender, size, and facial characteristics; however, the main scope of our study was to pilot how children react to strangers compared to their mothers and utilize thermal imaging to document this phenomenon physiologically (Brooks & Lewis, 1976; Clarke-Stewart, 1978; Langlois et al., 1990; Lewis & Brooks, 1974). Future studies with greater numbers of infants would be nice to consider additional variations in regard to social interactions. Moreover, although we have ensured that the room temperature did not fluctuate throughout the experimental recordings it would be better for future studies to install a room thermometer for this purpose rather than relying on post-infrared analyses methods. Due to the nature of our study, a manual tracking system was employed to avoid noise being introduced by rapid head motor movements of the infant. One of the main benefits of manual tracking is the fact that an absolute measure of control exists in terms of temperature extraction but on the other hand this technique relies heavily on the experimenter's discrepancy to properly place anatomically regions of interest to derive infrared readings. Although automatic extraction methods in the past used to have considerable deficits due to the employment of "appearance modeling," new methods based on particle filtering have managed to overcome problems of abrupt head turning and are not so highly computationally demanding (Zhou et al., 2013). Particle filtering developed by Zhou et al. (2013) overcomes large positional and physiological changes that often disrupt temperature extraction due to the spatial and temporal smoothness components of the applied mask template which in addition constantly recognizes pixel values that need thermal updating and as a result does not lose the focal cite of interest. Although this technique is far superior, provides more data for analyses and it is significantly more time efficient, unfortunately it was not at our disposal. Overall, previous thermal imaging studies at least in the domain of emotions have mainly used manual extraction for temperature processing (Ioannou, Gallese, et al., 2014).

The purpose of the study was to explore the physiological markers that underpin signs of healthy socio-cognitive development while grounding autonomic arousal on mainstream behavioral techniques for interpreting social awareness and coy displays. Findings collected with infrared imaging lead to the conclusion that infants of 2–3 months of age have the cognitive machinery not only to distinguish between a mother and a stranger but also to adopt behavioral strategies that function at the broader level as an early indication of socio-physiological adaptability and potentially healthy self-conscious development. Behavioral strategies adopted by the child during the interaction of the child with the mother but most importantly with the stranger show an effort by the peripheral nervous system to provide physiological support for the adaptive social displays of the child. The increased physiological arousal observed during the interaction with the stranger aims to firstly tackle the novel and socially challenging stimulus but also prepare the peripheral nervous system to even accept social rejection and regress to a more primitive physiological model. The importance of the peripheral nervous system in supporting behavior is pivotal to the understanding of emotions as the color and the vigor of the social display would not be within the social norm if physiological arousal was not there to support it. Collecting physiological data from the face through ecological experimental designs aims to act as an easily accessible method for better understanding infant cognition and development, as the face is the vessel through which both behavior and physiology are manifested for the effectiveness of communication.

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