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Does any mother's body odor stimulate interest in mother's face in 4-month-old infants?

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Abstract

Little is known about the effects of olfaction on visual processing during infancy. We investigated whether and how an infant's own mother's body odor or another mother's body odor affects 4-month-old infants' looking at their mother's face when it is paired with a stranger's face. In Experiment 1, infants were exposed to their mother's body odor or to a control odor, while in Experiment 2, infants were exposed to a stranger mother's body odor while their visual preferences were recorded. Results revealed that infants looked more at the stranger's female face in presence of the control odor but that they looked more at their mother's face in the context of any mother's body odors. This effect was due to a reduction of looking at the stranger's face. These findings suggest that infants react similarly to the body odor of any mother and add to the growing body of evidence indicating that olfactory stimulation represents a pervasive aspect of infant multisensory perception.

1 | INTRODUCTION

Human mothers' body odor has marked effects on infant behavior (e.g., Schaal, 2015; Schaal & Durand, 2017). For example, maternal odor can reduce infants' emotional distress and promote calm states (Doucet, Soussignan, Sagot, & Schaal, 2007; Schaal et al., 1980; Sullivan & Toubas, 1998) and the scent of a mother's breast leads 3-day-old neonates to open their eyes more than the scent of a breast without an odor (Doucet et al., 2007). In addition, maternal odor can elicit positive orientation and direct the expression of coordinated action (Rattaz, Goubet, & Bullinger, 2005; Varendi, Porter, & Winberg, 1994) via prenatal and neonatal learning processes (Delaunay-El Allam, Soussignan, Patris, Marlier, & Schaal, 2010; Doucet, Soussignan, Sagot, & Schaal, 2009; Marlier & Schaal, 2005; Schaal, Marlier, & Soussignan, 2000; Schleidt & Genzel, 1990). Overall, these findings make it clear that maternal odor contributes in significant ways to sensory awareness as well as to the emergence of social knowledge in infancy.

Importantly, maternal odors are usually accompanied by experience in other sensory modalities. Indeed, from the very onset of perceptual development, infants' knowledge about their environment derives from experience in multiple sensory modalities (Bahrick & Lickliter, 2012; Lewkowicz & Bremner, 2019; Lewkowicz, 2014). Among all other sensory inputs, such multisensory experiences include those with the mothers' face to which infants are much more frequently exposed than to other social partners' faces (e.g., Bushnell, 2001; Jayaraman, Fausey, & Smith, 2015; Sugden, Mohammed-Ali, & Moulson, 2014; Sugden & Moulson, 2019). This disproportionate exposure to the mother's face leads to a preference for her face as early as a few days after birth but, critically, this is only the case if newborns have had prior exposure to their mother's voice (Sai, 2005). With development, however, this preference changes to one for the stranger's face by around 4–5 months of age (Bartrip, Morton, & De Schonen, 2001; Taylor, Slade, & Herbert, 2014). This developmental shift in visual preferences is explained in terms of increasing familiarization with the mother's face, with ensuing reduction in visual attention to her (at least in a paired-preference test), and at the same time with increasing attraction to novel social figures (Barerra & Maurer, 1981; Gredebäck, Fikke, & Melinder, 2010).

Although it is now clear that unimodally presented faces or social odors are special to infants (for faces, cf. Bushnell, Sai, & Mullin, 1989; Field, Cohen, Garcia, & Greenberg, 1984; Pascalis, Schonen, Morton, Deruelle, & Fabre-Grenet, 1995; Pascalis & Slater, 2003; for social odors, cf. above references), it is not known whether infants associate the faces and odors that are specific to particular individuals. Previous studies have considered face-related odors as a potential confound during tests of visual preferences for the mother's face and, as a result, experimenters blocked the odors by placing a Plexiglass window between newborns and the visual stimuli with which they were tested (i.e., Bushnell, Sai & Mullin, 1989). These studies acknowledged a contrario that the mother's odor might influence the infant's processing of the visual scene. Given this possibility, the purpose of the present study was to investigate the effects of maternal odor on the processing individual faces.

Even though no studies to date have examined the effects of maternal odor on response to individual faces, several studies have investigated infant responsiveness to concurrent odors and visual stimuli (see Schaal & Durand, 2012, for a review). These studies have yielded some relevant findings. For example, it has been found that 3-month-old infants look longer at an adult face expressing an emotion that matches the hedonic value of a simultaneously presented odor (Godard, Baudouin, Schaal, & Durand, 2016) and that 4-month-olds rapidly acquire the ability to associate an arbitrary object with a distinctive odor and that they tend to look more at this object in the presence of this odor than in its absence (Fernandez & Bahrick, 1994). Similarly, it has been found that maternal odors influence sucking patterns when the infant has open eyes (Doucet et al., 2007) or is looking at the mother's face (Zimmerman & DeSousa, 2018).

One study is especially interesting from the standpoint of the present study. In this study, Durand, Baudouin, Lewkowicz, Goubet, and Schaal (2013) found that olfaction modulates the way 4-month-old infants look at a social versus a non-social visual stimulus. Using eye tracking, Durand et al. (2013) measured attention to a picture of a stranger female face paired with the picture of a car in the presence of a maternal odor. Results indicated that infants looked longer than expected at faces than at cars and that they looked longer than expected at the eyes than at any other facial region. These results raised two alternative interpretations. On the one hand, the maternal odor may have conveyed social affordances that increased infants' visual attention to social stimuli (face over car) and to the specific attributes of social stimuli that are instrumental in active social communication (eyes vs. other facial components). On the other hand, infants may have learned that female faces are usually associated with female odors and, thus, when they were exposed to a woman's face in the context of a female's odor, it was easier for them to recognize the woman's face and distinguish it from a non-social object. Regardless of which specific mechanism best explains the results obtained by Durand et al. (2013), this study suggests that young infants associate maternal odor with visual stimulation. This, in turn, raises the following question: is the visual expectation elicited by a maternal odor specific to a given individual or does it generalize to any individual?

In the present study, we took advantage of the developmental shift observed in the mother/stranger face preference to investigate whether infants link their mother's odor with her face. Thus, in Experiment 1, we presented infants with pairs of faces consisting of their own mother's face and a stranger female's face either in the context of the mother's odor (a T-shirt infused with the mother's odor) or in the context of a control odor (a clean, unworn T-shirt). We expected one of two possible outcomes. If infants can learn to associate a specific olfactory cue (i.e., their mother's odor) with a specific face then they should look longer at their mother's face when exposed to her body odor. Alternatively, if maternal odors convey a social affordance which increases infants' attention to socially relevant visual stimuli, then maternal odors may lead infants to look longer at the stranger's face given that 4-month-old infants engage preferentially with strangers' female faces (Bartrip et al., 2001).

In Experiment 2, we aimed to determine whether the potential influence of maternal odor on infants' response to their mother's face could be observed with the body odor of any mother. As in Experiment 1, infants were presented with their mother's face paired with a stranger's face but, this time, in the context of either another mother's odor or a control odor. Again, we expected one of two possible outcomes. If infants make specific face–odor associations between the olfactory signature of their mother and her face, then they should not look more at their mother's face. Alternatively, if the odor of any postparturient woman conveys olfactory cues that are not specific to the mother but typical of human mothers in general, then infants may look more at their mother's face.

2 | EXPERIMENT 1

2.1 | Methods

2.1.1 | Participants

Infants were recruited through the local birth registry. Parents were contacted by letter and received explanations by phone about the goals and methods of the study. If they agreed to let their infant participate, we sent an informed consent sheet and the material for sampling their body odor (see below) to their home. Full details about the experiment were given when they then visited the laboratory. 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 local Committee for Protection of Persons (CPP EST-I)—University of Burgundy.

We recruited a total of 39 Caucasian infants. Fifteen of these infants were excluded from further analyses because of non-compliance (fussing, discomfort) ($n = 4$), experimenter or technical errors (inadequate eye capture by the eye-movement tracker) ($n = 8$), or failure to satisfy inclusion criteria for appropriate visual behavior ($n = 3$) (see below). The final sample comprised 24 typically developing 4-month-old infants (10 females; mean age = 122, $SD = 2.8$ days; range = 117–128 days). Of the infants tested in this experiment, 16 were breastfed (range of breastfeeding duration: 3 days–4 months) and, at the time of testing, eight were still breastfeeding (four exclusively). All infants and their mothers were healthy for several days prior to and on the day of testing (during maternal body odor sampling).

2.1.2 | Visual stimuli

For each infant, the visual stimuli consisted of a color photograph of their own mother's face paired with a stranger female's face. A digital photograph of each mother's face was taken just before the beginning of the experiment. For the stranger faces, 12 color photographs of Caucasian women's faces were selected from the authors' personal image database. All faces were presented frontally, with a smiling expression and with gaze directed at the perceiver. The faces differed in hair color and style. The dimensions of the photographs were 500 × 500 pixels, corresponding on the screen to a face of 17 cm in height and 10 cm in width. Each photograph subtended a visual angle of 19°. From these photographs, 24 face pairs were created, each composed of the infant's mother's face presented side-by-side with a stranger's face.

2.1.3 | Odor stimuli

Infants participated in two conditions, one involving the mother's odor and the other involving a control odor. The mother's odor stimulus was composed of the mother's upper-chest odor collected on a T-shirt (100% cotton) that was sent (enclosed in a paper bag itself enclosed in a zip-locked hermetic polypropylene bag) to the mother in the week preceding the testing of her infant. The T-shirt was worn by the mothers for the three consecutive nights preceding her visit to the laboratory. Over this period, the mothers were asked to wear the T-shirt on their skin and refraining from using perfume or other odorant cosmetics and from showering with odorous soap. During the day, they were asked to keep the T-shirt in the paper bag inserted in the hermetically locked plastic bag and to leave the plastic bag at ambient temperature (i.e., far away from any heating device). The control stimulus consisted of an unworn T-shirt that was conserved in both bags in the same conditions. This unsoiled T-shirt had a very slight fabric odor.

2.1.4 | Apparatus and procedure

The infants were tested at the Babylab located in the Dijon Centre des Sciences du Goût. Testing took place in an area enclosed by partitions. To limit visual distraction during the experiment, all windows were occluded and the lights were progressively switched off. The room was well aired between testing sessions, and the experimenters (two females) were instructed to refrain from using perfume or

drinking coffee before the testing. The infants were securely and comfortably seated in a baby-seat in semi-reclining position. Their face was positioned facing the screen of the eye-tracking system at a distance of about 60 cm and a video camera at a distance of about 100 cm. During the experiment, the parents sat behind and far enough (>2.5 m) from their infants so that their infants could not perceive their personal odor (the parents were asked not to use perfume on the day of the experiment) and they were instructed not to intervene in any way. Similarly, the experimenters sat at a distance of more than 2 m from the infant during the testing session.

We used a SensoMotoric Instruments RED250 eye-tracking system to record the movement of the infants' two eyes while the infants viewed the visual stimuli. The visual stimuli were presented on the SMI's system monitor against a white background and their presentation was controlled by SMI's Experiment Center software.

The experiment began with a 9-point calibration routine to calibrate each infant's point-of-gaze. During the calibration routine, we presented a cartoon figure against a white background. The cartoon figure could be seen moving while it emitted a rattle sound. When the infant looked at it for at least 1 s, the figure moved to another position on the screen and remained in that position until it was fixated again for at least 1 s. This was repeated for up to nine positions covering the different parts of the screen, including the center, the four corners, and the four intermediate positions close to the screen borders. If the eye-tracker did not find the eyes with a reliable validity (<1.5°), the calibration procedure was repeated for that position. The data for a particular infant were retained for subsequent analyses only if his/her gaze was detected with a deviation of less than 1.5° of visual angle on average. Only infants who passed the calibration phase successfully were included in the analyses.

After successful calibration, the experimental phase began. The stimulus T-shirts were affixed on the infants' upper chest, right under the chin, so that they could inhale its effluvium. The T-shirts were folded so that infants would be exposed to the axillary, breast, neck, and all the other body regions that normally produce odorous substances (Schaal & Porter, 1991).

We used an intersensory matching task during which infants saw four pairs of side-by-side visual stimuli, comprised of a mother's face and a stranger's face, while they were exposed to odors. The side of presentation of the two faces was alternated across trials and the order of odor (the mother's or the control odor) presentation was counterbalanced across infants. The particular stranger's face in each pair of faces was randomly selected for each infant from among 12 possible faces. Each of the two trials comprising the same olfactory condition were separated by a 1 s inter-trial interval while at least 30 s separated the two olfactory conditions. The screen was changed to a blue color during the inter-trial intervals.

TABLE 1 Mean looking time (in seconds) and standard deviations (*SD*) according to olfactory context, type of face, and trials in Experiment 1 (mother's body odor) and Experiment 2 (stranger's body odor)

Olfactory context	**Mother/stranger**				**Control**			
Trial	**Trial 1**		**Trial 2**		**Trial 1**		**Trial 2**	
Face	**Mother**	**Stranger**	**Mother**	**Stranger**	**Mother**	**Stranger**	**Mother**	**Stranger**
Experiment 1 (mother's odor)								
Mean (*SD*)	9.2 (5.9)	9.0 (5.8)	6.3 (5.4)	11.3 (7.2)	7.2 (4.7)	11.3 (5.3)	5.2 (4.4)	10.7 (6.1)
Experiment 2 (stranger's odor)								
Mean (*SD*)	9.0 (5.0)	8.2 (6.0)	7.7 (6.1)	9.4 (6.5)	9.3 (7.5)	7.7 (5.7)	5.1 (3.6)	9.9 (6.9)

2.1.5 | Dependent variables

Each infant's total looking time at the mother's and stranger's face was computed from the oculometric data across the four trials (see Table 1 for means and *SD* in each condition). Prior studies have found that 4-month-old infants prefer a stranger's face to their own mother's face (Bartrip et al., 2001; Taylor et al., 2014). As a result, we computed a stranger's face preference for each infant by dividing the total looking time to the stranger's face by the total looking time to the mother's and the stranger's face and converted this ratio to a percentage by multiplying by 100.

2.2 | Results

2.2.1 | Looking at the stranger's versus the mother's face

Overall, infants looked longer at the stranger's than the mother's face ($M = 10.6$, $SD = 4.4$ vs. $M = 7.0$, $SD = 3.5$ s; $t(23) = 3.86$, $p = .0008$, $d = 0.79$). This preference for the stranger's face was significantly higher than chance ($M = 60.4\%$, $SD = 10\%$; $t(23) = 5.07$, $p < .0001$, $d = 1.04$).

2.2.2 | Effect of mother's odor

To assess whether the mother's odor influenced the infants' looking time at the stranger's face, we ran a $2 \times 2 \times 2$ mixed, repeated-measures analysis of variance (ANOVA) on the percentage of looking at the stranger's face, with Olfactory context (mother's odor vs. control odor) and Trial (trial 1 vs. trial 2) as within-subject factors, and Olfactory context order (mother's odor first vs. control odor first) as a between-subjects factor. The main effect of the Olfactory context was statistically significant, $F(1, 22) = 9.81$, $p = .005$, $\eta_p^2 = 0.31$; this difference was due to a lower percentage of looking at the stranger's face in the presence of the mother's odor than in the presence of the control odor (56.2% vs. 64.5%). At the same time, paired *t* tests (two-tailed) indicated that infants' preference for the stranger's face (i.e., percentage to the stranger's face above 50%) was significantly higher than chance in the presence of the mother's odor ($M = 56.2\%$, $SD = 11.8\%$; $t(23) = 2.57$, $p = .017$, $d = 0.52$) as well as in the presence of the control odor ($M = 64.5\%$, $SD = 12.5\%$; $t(23) = 5.70$, $p < .0001$, $d = 1.16$). Figure 1 shows the average percentages of looking to the stranger's face in both the mother's odor and the control odor conditions. It is noteworthy that the decrease in percentage of looking time to the stranger's face in presence of the mother's odor is due to an increase in looking at the mother's face [7.8 ± 4.3 s in the maternal odor condition vs. 6.2 ± 3.6 s in the control odor condition; difference = +1.6 s; $t(23) = 2.20$, $p = .038$, $d = 0.45$]. By contrast, there was no effect of the odor condition on looking time at the stranger's face [10.1 ± 4.5 s in the maternal odor condition vs. 11.0 ± 4.9 s in the control odor condition; difference = −0.8 s, $t(23) = 1.20$, $p = .24$]. Complementary analyses yielded no other significant main effects nor interactions with the infants' feeding experience (breast-, bottle- or mixed feeding).

3 | EXPERIMENT 2

The results from Experiment 1 indicated that infants engage more their attention to their mother's face in the context of maternal odor than they do in the context of the control odor. These results suggest

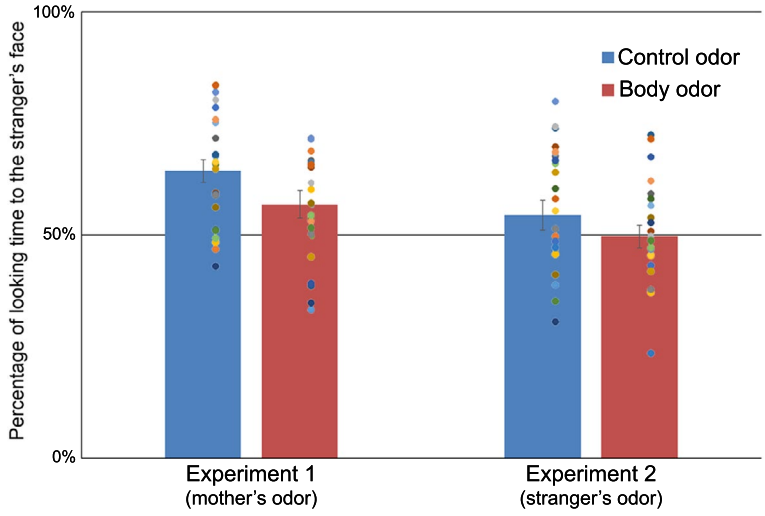

FIGURE 1 Percentage of time the infants looked to the stranger's face as a function of odor condition in experiments 1 (control odor vs. mother's odor) and 2 (control odor vs. stranger's odor). Error bars indicate the standard error of the mean. Points indicate the percentage of each infant

that infants' prior exposure to their mother's face in the context of her body odor led to the formation of an individual-specific face–odor association. Despite this, however, these results do not indicate whether this face–odor association is individual-specific (i.e., limited to the olfactory signature of their mother) or category-specific (whether it generalizes to the 'maternal odor' of any postparturient woman). To distinguish between these two alternative interpretations, we conducted a second experiment in which we once again exposed infants to the mother's and stranger's faces but, this time, we contrasted their visual preferences in the context of another mother's body odor and a control odor.

3.1 | Methods

3.1.1 | Participants

Forty-one Caucasian participants were recruited for this experiment. The data of 17 participants were excluded due to non-compliance ($n = 5$), experimenter or technical complications due to inadequate eye capture by the eye-movement tracker ($n = 10$), or the failure to satisfy the inclusion criteria for appropriate visual behavior ($n = 2$). The final sample was composed of 24 healthy participants (13 females) aged 4 months (mean age = 124, $SD = 2.06$ days; range = 121–127 days). Among the infants tested, 20 were breastfed (range of breastfeeding duration: 1–4 months) and, at the time of testing, 10 were still breastfeeding (seven exclusively). All infants were healthy 3 days prior to and on the day of testing.

3.1.2 | Visual and odor stimuli

As in Experiment 1, the visual stimuli were color photographs of the infant's mother paired with colored photographs of a stranger's face. For the stranger's face, we selected the color photographs of

12 other mothers who came to the laboratory two days before the testing session. For the odor condition in this experiment, we presented the odor of the T-shirt worn by the 12 Caucasian postparturient donors who served as subjects for the stranger face pictures (here referred to as the "stranger's odor"). Their odors were collected following the same procedure as in Experiment 1. For the control odor condition, we exposed infants to an unworn T-shirt.

3.1.3 | Experimental setting and procedure

The experimental setting and procedure were identical to those of Experiment 1.

3.1.4 | Dependent variables

The dependent variables were identical to those defined in Experiment 1.

3.2 | Results

Contrary to Experiment 1, and despite a slight preference for the stranger's face, the infants did not look longer at the stranger's face than at the mother's face (8.8 ± 4.9 s vs. 7.8 ± 3.7 s; $t(23) = 0.99$, $p = .33$). The mean percentage of looking at the stranger's face was not significantly higher than chance [$M = 52.9\%$, $SD = 10.8\%$; $t(23) = 1.30$, $p = .21$].

3.2.1 | Influence of the stranger's odor

The percentages of looking time at the stranger's face were submitted to a 2 × 2 × 2 repeated-measures ANOVA, with Olfactory context (stranger's odor vs. control odor) and Trial (trial 1 vs. trial 2) as within-subject factors, and Olfactory context order (stranger's odor first vs. control odor first) as a between-subject factor. As in Experiment 1, only the main effect of the Olfactory context was significant [$F(1, 22) = 5.35$, $p < .05$, $\eta_p^2 = 0.20$]. As can be seen in Figure 1, this effect was due to a decrease of the percentage of looking time at the stranger's face in the context of the stranger's odor (49.7%) than in the control odor context (56.0%). Follow-up t tests showed that preference for the stranger's face was not significantly higher than chance in the context of the stranger's odor [$M = 49.7\%$, $SD = 11.5\%$; $t(23) = -0.13$, $p = .90$], but that it was in the control odor context [$M = 56.0\%$, $SD = 13.8\%$; $t(23) = 2.14$, $p = .043$, $d = 0.44$] (see Figure 1). As in Experiment 1, the significant decrease in preference for the stranger's face in the stranger's odor context was not due to decreased looking at the stranger's face in this context relative to the control-odor context; this difference was positive [+0.2 s; $t(23) = 0.03$, $p = .98$]. Rather, it was due to greater looking at the mother's face. Nonetheless, despite the fact that looking at the mother's face tended to increase in the presence of the stranger's odor, the difference was not significant [8.4 ± 3.8 in the stranger's odor condition vs. 7.2 ± 4.4 s in the control odor condition; difference = +1.1 s; $t(23) = 1.60$, $p = .12$]. No other main effects or interactions were significant, and complementary analyses indicated no effect of the mode of infant feeding.

In sum, we found that the pattern of visual exploration obtained in Experiment 2 in the context of the stranger's odor was similar to the one found in Experiment 1 in the context of the familiar mother's odor.

3.2.2 | Comparison of the influence of mother's and stranger's odors

Overall, the infants appeared to respond in similar ways in both experiments. Specifically, despite a general decrease in the preference for the stranger's face, the size of the odor effect seemed quite similar. Specifically, we found a similar decrease in the percentage of looking at the stranger's face in the presence of either odor than in the presence of a neutral odor [8.4% (SD = 13.8%) in Experiment 1; 6.3% (SD = 13.6%) in Experiment 2; $t(46) = 0.51$, $p = .61$].

When the results of both experiment are considered together, they raise an interesting question: is the maternal odor effect the result of a reduction of interest in the stranger's face or an increase in attention to the mother's face in the context of any maternal odor, be it familiar (in Experiment 1) or unfamiliar (in Experiment 2). Comparisons of looking time across the two experiments indicated that it was the latter. To assess this question further, we computed the percentage of additional time each individual infant looked at their mother's face in the context of a maternal odor (time to the mother's face in a maternal odor condition minus time to the mother's face in the control condition divided by the time to the mother's face in the control condition). The same analysis was done for the stranger's face. These percentages of additional time looking to the faces in the context of any maternal odor were then submitted to a 2 × 2 repeated-measures ANOVA, with Face (mother vs. stranger) as a within-subjects factor, and Type of maternal odor/experiment (mother's odor/Experiment 1 vs. stranger's odor/Experiment 2) as a between-subjects factor. The main effect of Face was significant, $F(1,46) = 7.07$, $p = .011$, $\eta_p^2 = 0.13$, the percentage of additional looking at the face in the presence of any maternal odor was larger for the mother's face than for the stranger's face (41.6% vs. 6.4%). The type of maternal odor evinced no main or interaction effects (Fs < 1). One sample t tests further indicated that the percentage of additional looking at the mother's face in the context of maternal odor was significantly higher than chance in presence of either mother's odor (M = 47.9%, SD = 78.2%; $t(23) = 3.00$, $p = .006$, $d = 0.61$), or the stranger's odor (M = *35.4%*, SD = 72.5%; $t(23) = 2.39$, $p = .025$, $d = 0.49$), with no significant difference between the two ($t(46) = 0.58$, $p = .57$). There was no significant additional looking time to the stranger's face in either the mother's or stranger's odor condition (M = 4.9%, SD = 68.6%; $t(23) = 0.35$, $p = .731$ and M = 8.0%, SD = 65.5%; $t(23) = 0.60$, $p = .555$, respectively). Figure 2 shows the average percentages of additional looking to the mother's and the stranger's face in both maternal odor conditions and the control odor conditions.

4 | DISCUSSION

The present study investigated whether 4-month-old infants' responsiveness to their mother's face versus a stranger's face is altered by the presence of their mother's or another mother's body odor. Past studies of visual preferences in the absence of specific odors have found that 4-month-old infants prefer a stranger's face to a familiar face (Bartrip et al., 2001; Taylor et al., 2014). We replicated this previously reported preference for the stranger's face in the control odor condition. In addition, and most importantly, we found that a mother's body odor—regardless of whether it is the infant's own mother's odor or another mother's odor—affects 4-month-old infants' looking at their mother's versus another female's face.

In Experiment 1, the maternal odor increased looking at the mother's face and reduced, without abolishing it, the typical bias that 4-month-olds exhibit for a stranger's face. That is, even though looking at the mother's face increased in the context of the mother's odor relative to the control odor, the mother's body odor did not reverse the bias that 4-month-olds usually show toward a stranger's face. These results suggest that infants' greater looking at their mother's face involves cross-modal matching

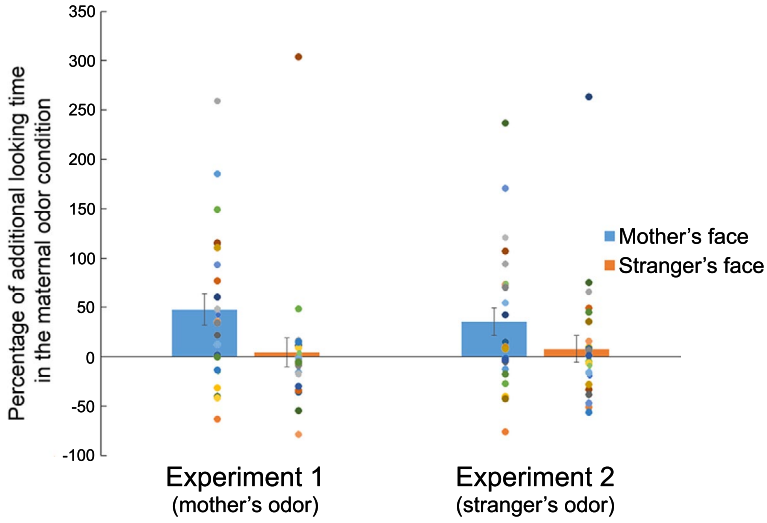

FIGURE 2 Percentage of additional looking time to the mother's and the stranger's face in the mother's (Experiment 1) and stranger's (Experiments 2) odor condition. The percentage was computed, for each type of face, by subtracting the time in the control odor condition to the time in the maternal odor condition, divided by the time in the control odor condition. Error bars indicate the standard error of the mean. Points indicate the percentage of each infant

of a surrounding body odor with the associated face and, thus, leads to a reduction of the bias for the stranger's face. Experiment 2 yielded results similar to those from Experiment 1. They indicated that the context of the body odor of another mother led to decreased preference for the stranger's face due to an increase in looking at the mother's face.

An unexpected result is that the strength of the original stranger face preference in the absence of odor is inconsistent between Experiments 1 and 2 (64.5% vs. 56%, respectively). One suggestion to explain the lower strength of the stranger's face to attract infants' gaze in Experiment 2 (as compared to Experiment 1) is that the strangers' faces in Experiment 1 were selected from the authors' image database (a set of prototypical feminine faces regularly used in our studies; e.g., Durand, Gallay, Seigneuric, Robichon, & Baudouin, 2007; Gallay, Baudouin, Durand, Lemoine, & Lécuyer, 2006; Godard et al., 2016). In Experiment 2, the strangers' faces were those of the postparturient mothers who were also the odor donors. These latter stimulus-faces may have been less prototypical of female faces than those used in Experiment 1, indicating that they were less attractive for infants. Postparturient faces may also have shared some visual cues of similarity with the infants' own postparturient mother's face, inducing more difficulty for discrimination and therefore for the expression of preference. Such physiology-related facial signatures were described to occur in women across the menstrual cycle and cannot be excluded in the postpartum conditions (e.g., Farage, Neill, & MacLean, 2009). Thus, while the physiologically imprinted faces of the strangers' faces are contrasted in Experiment 1, they may not be in Experiment 2, potentially leading to a reduction in discriminative responses of infants. But most importantly, the maternal odor effect was consistent across studies, with similar differences between maternal and control odor conditions.

The current results raise the question of why the body odor of their own mother as well as the one of another mother have a similar effect on 4-month-old infants' visual attention to mother's versus stranger's faces. One possibility is that postparturient mothers impregnate their T-shirts with partly similar odor components that reflect physiological commonalities in the early stages of mothering (e.g., Vaglio, 2009; Vaglio, Minicozzi, Bonometti, Mello, & Chiarelli, 2009). The fact that infants

react similarly to the body odors of their mother and of any other mother has, in fact, been noted in several studies. For example, the odor-induced soothing effect is not specific to an infant's own mother's odor, but can also be elicited by any other mother's odor (e.g., Sullivan & Toubas, 1998). Also, 2-week-old bottle-fed infants are not only attracted to the odors of their mother but to the odors of any nursing woman (Porter, Makin, Davis, & Christensen, 1991). Such results do not mean, however, that infants are unable to differentiate their mother's odor from that of another mother. Several studies have shown that infants can, in face, differentiate between their mother's odor and that of another woman when the two odors are paired in the same test (cf., e.g., Cernoch & Porter, 1985; Delaunay-El Allam, Marlier, & Schaal, 2006; Macfarlane, 1975). Overall, such results suggest that several cues (e.g., individuality, gender, age, kin, physiological stage, health, psychological state, immunogenetic type, and diet) can be nested in the complex body odor of a particular person and that the perception of these different cues can be assessed under specific test conditions (cf. de Groot, Smeets, Kaldewaij, Duijndam, & Semin, 2012; Havlíček, Fialová, & Roberts, 2017; Miller & Maner, 2010; Penn et al., 2006; Schaal, 1988; Schaal & Porter, 1991). Thus, in the present case, it is possible that the physiological/psychological state of postpartum women similarly affected their body odors in a way that rendered them olfactorily similar to the infants. The present results suggest that infants may have associated such a supra individual, categorical odor characteristic of the early mothering stage with the mother's individual-specific face. If that is the case, then future studies should examine 4-month-olds' visual responsiveness to their mother's versus a stranger woman's face in the context of an odor sampled in a woman who has not recently become a mother. This visual preference procedure could also assess odor context effects with odorant mixtures sampled in overlapping categories of donors (females of different ages or life stages) or in dissimilar categories of donors (i.e., a male, the father) or with arbitrary odorants (perfumes associated or not with the mother). Specifically, exposing infants to a readily controllable artificial scent in the presence of their mothers and then testing their visual preferences for two or more faces in the familiar scent context and an unfamiliar scent context would permit a further delineation of the factors contributing to early olfacto-visual processes in early infancy. At a more global level, such an experimental approach provides an interesting way of further unpacking the development of infant's social cognition based on the experimental match or mismatch of faces and odors.

Overall, the current results provide evidence that olfaction can influence the visual behavior of 4-month-old infants. They show that maternal odors in general, regardless of whether they are an infant's own mother's odors or another infant's mother's odors, can modulate infants' visual attention to familiar and stranger faces. These results are consistent with the earlier findings reported by Durand et al.'s (2013) showing that maternal odors promote greater attention to social versus non-social visual objects and extend them examining infant selective attention to different types of social stimuli. Together with Durand et al.'s (2013) findings, the present results highlight the often-overlooked fact that maternal odors can affect infant visual behavior. This is actually not surprising given that by 4 months of age infants have already had more experience with maternal chemostimulations than with any other type of stimulation. This is due to the fact that the chemical senses (together with somesthesis) are the earliest of all the sensory systems to emerge during prenatal development (e.g., Lecanuet & Schaal, 1996). Accordingly, early odor experience outweighs early experience with other forms of stimulation and, thus, is likely to have an effect on responsiveness to inputs in other later-emerging sensory modalities such as vision. Given this developmental scenario, our results demonstrate that the olfactory system continues to influence the visual system over the first months of life even though the latter is quickly becoming the predominant sensory system. Future studies should examine the role of olfaction at older ages. Given that a stranger face elicits more attention in older infants, it will be interesting in a developmental perspective to determine whether maternal odors as a category

act in the same manner as they do in the present study. What we know is that the odor of the breast stimulates eye opening in the first postnatal days (Doucet et al., 2007). At age 4 months, the mother's odor stimulates infants to look more to a female face than to a car pictured side-by-side (Durand et al., 2013). And the present study indicates that cues conveyed in the body odor of women who have recently become mothers are associated with the mother's face. Beyond 4 months, our knowledge is even patchier regarding olfacto-visual interactions in face processing. One study (Godard et al., 2016) shows a matching between expressions of emotion from an adult facial display and hedonically contrasted odorants at age 3 months, but not 5 and 7 months. It may not be excluded that olfaction has a stronger perceptual impact in the early months, when visual processing is relatively less efficient in information intake. Even though vision becomes the dominant sensory modality as development progresses, findings have also shown that olfaction keeps on subtly influencing visual processes into adulthood (e.g., Leppänen & Hietanen, 2003).

In conclusion, the present results indicate that olfaction plays an important role in young infants' perception of their social partners and they are consistent with findings showing that the mother's body odor can also shape face categorization by enhancing a face-selective electro-encephalographic response in the infant brain (Leleu et al., 2019). Findings such as these add to a growing body of evidence indicating that multisensory interaction has a pervasive influence on behavior in early human development (Lewkowicz, 2014).

See Supporting Information section for more details on analyses of looking time toward the eye region. Raw Data are available on Open Science Framework, see Supporting Information section for the link.

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CONFLICTS OF INTEREST

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SUPPORTING INFORMATION

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

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