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Baby cry recognition is independent of motherhood but improved by experience and exposure

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Neurobiological changes affecting new mothers are known to support the development of the mother–infant relationship (the 'maternal brain'). However, which aspects of parenting are actually mother-specific and which rely on general cognitive abilities remains debated. For example, refuting earlier findings, a recent study demonstrated that fathers identify their own baby from their cries just as well as mothers. Here we show that this performance is independent not only of sex, but also of parenthood status. We found that mothers' ability to recognize their newborn from their cries increased rapidly within few days postpartum, with highly multiparous mothers performing better. However, both male and female non-parents could similarly recognize an assigned baby, even after a very short exposure. As in mothers, both the initial amount of experimental exposure to the baby's cries (learning opportunity) and prior experience of caring for infants (auditory expertise) affected participants' performance. We thus suggest that, rather than being female-specific or motherhood-dependent, the ability to recognize a baby from their cries derives from general auditory and learning skills. By being available to non-parents of both sexes, it may contribute to the caregiving flexibility required for efficient cooperative breeding in humans.

1. Introduction

In mammals and birds, the onset and the accuracy of parent–young recognition depend on social and ecological factors [1–3], with vocal identification being more reliable in species living in dense colonies (e.g. cliff swallows [3], penguins [1], seals [4,5] and walruses [6]), and in synchronized seasonal breeders who give birth to many infants within a short period of time (e.g. Barbary macaques [7], Japanese macaques [8], squirrel monkeys [9] and sheep [10]). Moreover, vocal recognition is characterized by a very rapid onset in species where offspring recognition becomes essential shortly after birth (e.g. ewes are able to recognize the bleats of their own lamb just 24 h postpartum [10], while Australian sea lion mothers vocally identify their offspring within 48 h postpartum before they leave to forage at sea [11]).

While in humans, the recognition of offspring from cries may be less relevant for localization or resource attribution, the ability to familiarize with the idiosyncrasies of a baby's cry is likely to support attachment as well as carers' ability to assess babies' needs from intra-individual variation in their cries [12–14]. Indeed, the knowledge of the individual characteristics of cries is likely to facilitate carers' ability to extract information on condition, emotional state and urgency to intervene, thus helping them to provide adapted care [15].

Although studies of mother–young recognition in humans have shown that mothers are able to recognize their baby's cries [16–20], the dynamics of this ability's onset remain poorly understood, with early studies either reporting no

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variation in performance during the first week of life [18,19] or an irregular evolution of performance [20,21]. Moreover, which immediate factors modulate performance has not yet been untangled. The few studies that considered not only mothers but also fathers or non-parent individuals found that the latter performed poorly compared with the former [22,23], giving support to the then predominant 'maternal instinct' theory [24,25]. However, a recent study investigating sex differences in cry recognition while controlling for the amount of time spent by each parent with their own baby [17] has challenged this view, as it has revealed that mothers and fathers are equally successful at recognizing their baby's voice provided that they have had comparable levels of exposure to their baby. This emphasizes the importance of taking into account factors such as experience or specific exposure when investigating the processes underlying individual recognition from baby cries. Given that humans have evolved as a cooperative breeding species [26], with not only high rates of paternal [27] but also alloparental care (i.e. care by grandparents, siblings and non-kin) [28], we hypothesized that cry recognition abilities may extend to non-parents of both sexes and may be dependent on experience and exposure rather than sex or parenthood status.

More specifically, we contrasted the dynamics of vocal recognition of human newborns by their mothers in natural settings, with that of non-parent young adults of both sexes using a controlled learning-testing paradigm. Including non-parents in our research allowed us to assess whether cry recognition abilities are affected by the biological and/or psychological changes induced by pregnancy. Mothers were naturally exposed to their baby's cries from birth until testing (Experiment 1), while non-parents were experimentally exposed to crying samples from a given unknown baby before testing (Experiments 2 and 3). Testing consisted of recognizing one's own (or experimentally assigned) baby among crying series from several other 'stranger' babies. We predicted that recognition abilities should not only be present in mothers but also in non-parents of both sexes, yet modulated by previous parenting experience as well as by the amount of exposure to the own (or assigned) baby's cries. General parenting experience was approximated by parity status in mothers (Experiment 1) and by experience of caring for babies in non-parents (Experiment 2). Specific exposure to own (or assigned) baby was either approximated as the baby's age at the time of testing their mother (Experiment 1), or experimentally set by presenting a variable number of reference crying samples before testing non-parents (Experiment 3). Specifically, we predicted that performance would be higher in subjects with expertise acquired during past parenting experience (Experiments 1 and 2) or with increased learning opportunities provided by extended exposure (Experiments 1 and 3).

2. Material and methods

(a) Subjects

A total of 24 mothers took part in Experiment 1 (mean age ± s.d. = 32.6 ± 3.5 years, range = 24–38 years), at the maternity ward, within the 4 days following birth. Participants' parity ranged between 1 and 5: participants either were first-time mothers ($n = 9$), or had already one child ($n = 7$) or more ($n = 8$ with 2 to 4 children). Experiment 1 (ClinicalTrials no. NCT01732978) was conducted between February 2013 and January 2014 at the Department of Paediatrics of Saint-Etienne University Hospital. It was approved by the local ethics committee (February 2012—Comité d'Ethique du CHU de Saint-Etienne, Institutional Review Board: IORG0007394) and registered with the Commission Nationale Informatique et Libertés (CNIL no.1642195 v 0). Informed consent was obtained from all participants.

Experiments 2 and 3 were conducted with students from the Rhone-Alpes area invited by e-mail and enrolled on a voluntary basis (Experiment 2: February and March 2017 at the University of Saint-Etienne; Experiment 3: March–May 2017 at the University of Saint-Etienne and July 2018 at the University Grenoble Alpes). A total of 32 non-parents, 16 female and 16 male, took part in Experiment 2 (mean age ± s.d. = 19.0 ± 1.0 years, range = 17–22 years), while a total of another 48 non-parents, 24 female and 24 male, took part in Experiment 3 (mean age ± s.d. = 20.3 ± 1.8 years, range = 18–24 years). Both experiments were approved by the local ethics committee (March 2017—Comité d'Ethique du CHU de Saint-Etienne, Institutional Review Board: IORG0007394) and registered with the local board of the Commission Nationale Informatique et Libertés at the University of Saint-Etienne. Written informed consent was obtained from all participants.

(b) Experimental protocol

(i) Stimuli collection

The 24 babies (12 boys, 12 girls) of the mothers participating in Experiment 1, plus 30 additional newborn babies (17 boys, 13 girls), were recorded within 12 and 59 h following birth. Spontaneous baby cries were recorded in the context of bathing at the maternity ward (during undressing, bathing and dressing when babies expressed their unhappiness at being manipulated or put into water). Recording were performed using a Sennheiser MD42 microphone, connected to a Marantz PMD690 recorder, placed 30 cm away from the baby's mouth. From each bath event, several sequences of crying (without background noises such as adult voices, water flowing or door slamming) were isolated using GoldWave software to be used as stimuli in Experiment 1 (mean $n = 5.8$ sequences per baby, range = 3–19; total $n = 314$ sequences isolated; mean duration ± s.d. = 7.94 ± 1.95 s).

For use as stimuli in Experiments 2 and 3, crying sequences were extracted from recordings made in bathing context at the maternity ward during Experiment 1. For 18 babies (nine boys, nine girls) recorded between 14 and 31 h after birth, several sequences of crying (without background noises such as adult voices, water flowing or door slamming) were isolated using Audacity software (mean $n = 10.9$ sequences per baby, range = 6–17; total $n = 196$ sequences isolated; mean duration ± s.d. = 7.63 ± 2.29 s). In Experiment 2, the nine babies (five boys, four girls) for which we could extract 12 crying sequences or more were used as 'assigned babies' (i.e. baby assigned to a given participant during the training stage), while all 18 babies were used as 'stranger babies'. Each 'assigned baby' was used with three or four different non-parent subjects. In Experiment 3, eight babies (four boys, four girls) for which we could extract 12 crying sequences or more were used as 'assigned babies', while all 18 babies were used as 'stranger babies'. The same eight 'assigned babies' were used once in each of the six experimental training conditions (see below).

Crying sequences were normalized using the 'normalize' function in R tuner package (the waveform of the Wave files was centred around 0 and normalized to 100% of the maximal amplitude). 'Crying sequences' (=series of single cry sounds) are subsequently referred to as 'cries' in the text to facilitate reading (see electronic supplementary material, figure S1 and audio files S1–S4).

(ii) Playback stimuli preparation

In Experiment 1, a test consisted in a series of 15 cries, including three cries from the participant's own baby and three cries from four other babies (two boys, two girls) having similar postnatal age. For each mother, two series of 15 cries from 'own' and 'stranger babies', presented in a randomized order, were prepared. For seven participants' own infants, only four or five cries (instead of six) could be isolated from the bath events: in these cases, a same cry was used twice but in different playback series. Also, the four 'stranger babies' differed from one series to the other. In total, 48 series of cries were prepared for the 24 participants (i.e. two per participant), using 720 stimuli of 8.08 ± 1.92 s on average (range = 5.38–25.92 s).

In Experiment 2, the procedure consisted in two types of phases: training phases and testing phases. For training phases, we prepared series of three cries from a given baby (the participant's 'assigned baby'). For testing phases, we prepared series of 15 cries, including three cries from the participant's 'assigned baby' and three cries from each of four other 'stranger babies' (two boys, two girls) presented in a randomized order. For each participant, we prepared two training series and two sets of two testing series using the same 30 cries but presented in a randomized order within and across series. For the 'assigned baby', we used different cries in the training versus testing series in order to maximize the ecological validity of our results. Finally, the four 'stranger babies' were the same in the four testing series. Randomization was achieved using an R script implementing the 'sample' function. In total, 64 training and 128 testing series of cries were prepared for the 32 participants (i.e. two training and four testing series per participant), using 2112 stimuli of 7.48 ± 2.27 s on average (range = 3.40–14.62 s).

In Experiment 3, the procedure also consisted in two types of phases: one training phase whose content varied across participants, and testing phases whose architecture was identical for all participants. For the training phase, we prepared series of either one, two, three, four, five or six cries from a given baby (the participant's 'assigned baby'), designed to provide participants with varying extents of opportunity to familiarize with the baby's cry. Eight exemplars of each type (between one and six cries) were prepared. For testing phases, we prepared series of 15 cries, including three cries from the participant's 'assigned baby' and three cries from each of four other 'stranger babies' (two boys, two girls) presented in a randomized order. For each participant, we prepared one training series of between one and six cries and two sets of two testing series using the same 30 cries but presented in a randomized order within and across series. Here too, for the 'assigned baby', we used different cries in the training versus testing series, and the four 'stranger babies' were the same in the four testing series. Randomization was achieved using an R script implementing the 'sample' function. In total, 48 training and 192 testing series of cries were prepared for the 48 participants (i.e. one training and four testing series per participant), using 3048 stimuli of 7.64 ± 2.33 s on average (range = 3.40–14.62 s).

(iii) Experimental procedure for mothers

For Experiment 1, the 24 mothers were tested in their room at the maternity ward between 22 and 78 h postpartum (mean baby age ± s.d. = 44.4 ± 13.6 h), while their newborn was sleeping or quietly resting (there were no instances of babies waking up and disrupting the experiment). Mothers were tested twice at 10 min intervals: they were asked to listen to a series of 15 cries (through Sennheiser HD 25-1 headphones connected to a Marantz PMD690 recorder/player) and to determine whether each cry belonged to their own offspring or not.

Our playback series were designed to elicit 20% of 'yes' replies (three cries from 'own baby' out of 15) and 80% of 'no' replies (12 cries from 'stranger babies' out of 15). To avoid any potential influence of the experimenter, the playback tests were conducted as a double-blind experiment. Track names were coded and the mother tested knew neither how many cries originated from her own baby nor how many different babies were presented in the playback.

(iv) Experimental procedure for non-parents

For Experiments 2 and 3, the participants were tested in small groups (range = 2–9 and 1–6 at a time, for Experiments 2 and 3, respectively), in computer rooms at the university. They were guided through the general procedure by the experimenter, but completed each phase (either training or testing) autonomously as the experiment was implemented on Praat [29] using the Experiment Multiple Forced Choice tool ('ExperimentMFC 6' script). Each participant was facing a computer screen where the instructions appeared, listened to the stimuli through Sennheiser HD 205 headphones (at a volume mimicking natural level) and could proceed or answer questions by a simple mouse click.

The 32 non-parents participating in Experiment 2 were first given the following instruction: 'You will now hear several cries from the same baby that will be called YOUR baby for the rest of the study' (first training series of three cries). A couple of minutes later, they had to complete the first testing series of 15 cries and were asked to determine whether each cry had been produced by their assigned baby or not. About 10 min later, they had to go through a second training series (another series of three cries), then complete the second testing series. To assess long-term memory of their assigned baby's individual vocal signature, participants were asked to come back a few hours later (mean ± s.d. = 3.73 ± 0.44 h, range = 3–4.5) to complete another two testing series, at an interval of 10 min. At the end of the last testing session, the participants were asked to fill in an online questionnaire (built using WebQuest.fr) recording, notably, their age, their prior experience at caring for babies less than 1-year old ($n = 12$ without versus 20 with experience), and their current exposure to babies ($n = 13$ exposed versus 19 not exposed).

The 48 non-parents participating in Experiment 3 were also first given the following instruction: 'You will now hear crying from a single baby that will be called YOUR baby for the rest of the study'. However, in the case of this protocol, this unique training series was composed of between one and six crying samples, eight participants (four female, four male) being assigned to each of the six training conditions. Participants' age (range = 18–24 years) and prior experience at caring for babies ($n = 23$ without versus 25 with experience) were balanced across conditions. A couple of minutes later, participants had to complete the first testing series of 15 cries and were asked to determine whether each cry had been produced by their assigned baby or not. About 10 min later, they had to go through a second testing series. To assess long-term memory of their assigned baby's individual vocal signature, participants were asked to come back a few hours later (mean ± s.d. = 4.08 ± 0.51 h, range = 3–5) to complete another two testing series, at an interval of 10 min.

In both Experiments 2 and 3, our playback series were designed to elicit 20% of 'yes' replies (three cries from 'assigned baby' out of 15) and 80% of 'no' replies (12 cries from 'stranger babies' out of 15). To ensure impartiality and avoid errors arising from bias, the playback tests were conducted as a double-blind experiment, track names were coded, and the participants knew neither how many cries originated from their assigned baby nor how many different babies were broadcasted. Also, participants were asked not to converse together about the experiment.

(c) Statistical analysis

All statistical analyses were performed using R Studio [30].

Experiment 1 aimed at evaluating postpartum mothers' ability to recognize their own baby from their cries. More specifically, we tested whether this ability was influenced by their baby's age at the time of testing, their baby's age at the time of recording, their own age, their parity status (i.e. 'no previous offspring', 'has already had one offspring', or 'has already had two or more offspring'), and the testing stage (i.e. first versus second testing series).

Meanwhile, Experiments 2 and 3 aimed at evaluating non-parents' ability to recognize a given 'assigned' baby from their cries. More specifically, in Experiment 2, we tested whether this ability was affected by their sex, their age, their prior experience at caring for babies ('yes' or 'never'), their current exposure to babies ('yes' or 'no') and the testing stage (i.e. first, second, third versus fourth testing series). In Experiment 3, participants' sex, age and prior experience at caring for babies were balanced across training conditions; therefore, we focused on the influence of the exposure (from one up to six cries presented during training) on participants' performance. More specifically, we tested whether non-parents' answers were affected by the status of the baby ('assigned' versus 'strangers'), the amount of exposure (input) during training, and the stage of testing.

For each experiment, a $\text{GLM}_{\text{binomial–logit}}$ model was built using the 'glmer' function (in R lme4 package), the binary response variable being the 'yes'/'no' answer participants gave when asked whether each cry belonged to their own (or assigned) baby or not (see electronic supplementary material, S2 for details). Raw values of the continuous variables were centred and scaled. Mother's identity (Experiment 1), tested participant's identity and assigned baby's identity (Experiments 2 and 3) were included in the models as random factors. To test for the significance of the fixed factors and their interactions, we applied the 'Anova' function (R car package) to each model, thus performing a type II ANOVA. Initially, all explanatory variables and the two-way interactions involving the factor 'Baby' were fitted in a maximal model. Then, nonsignificant interactions were dropped to simplify the model [31]. When appropriate, we conducted *post hoc* tests, either tests on estimated slope coefficients for continuous variables or pairwise comparisons for categorical variables (using 'testInteractions' function in R phia package), with *p*-values adjusted for multiple comparisons (Holm method). All tests were two tailed and we set the significance threshold at $p \leq 0.05$.

3. Results

(a) Experiment 1: individual recognition of newborns from their cries in postpartum mothers

To investigate the dynamics of vocal recognition of newborns in natural settings, mothers ($n = 24$) were tested at the maternity ward during the first 4 days after giving birth with two series of 15 cries including only three from their 'own baby'. While neither the mother's age nor her baby's age at the time of cry recording had an effect on correct recognition of offspring or rejection of other babies, both her parity and her baby's age at the time of the experiment significantly affected her performance (table 1): the older her baby was at the time of the playback experiment, the more successful the mother was at identifying her own baby, with success rate rising roughly from 40 to 80% between day 1 and day 3 postpartum (chance level = 20%. *Post hoc* tests on adjusted slope for z-AgeTest, following significant interaction between Baby and z-AgeTest factors, see table 1. Test on slope for 'own baby': $\chi^2 = 8.92$, $p = 0.003$), but not at rejecting other babies (test on slope for 'stranger babies': $\chi^2 = 1.00$, $p = 0.317$) (figure 1*a*). Besides, mothers who already had two older children (or more) were better at identifying their newborn baby's cries compared with first- or second-time mothers (*post hoc* tests following significant interaction between Baby and Parity factors, see table 1. Pairwise comparisons for 'own baby': 'P1 versus P2', $\chi^2 = 0.32$, $p = 0.569$; 'P1 versus P3', $\chi^2 = 5.55$, $p = 0.055$; 'P2 versus P3', $\chi^2 = 4.71$, $p = 0.060$), but no such differences were found for the rejection of other babies' cries (pairwise comparisons for 'stranger babies': $\chi^2 < 0.18$, $p = 1$ for all dyads) (figure 1*b*). The rate of 'false-positive errors' (i.e. cries from strangers considered as originating from own baby by mothers) was comparable across participants (mean ± s.d. = 18% ± 13) (figure 1).

Table 1. Factors influencing mothers' ability to identify their own baby's cries ($\text{GLM}_{\text{binomial–logit}}$: analysis of variance table). Baby = baby's category (i.e. 'own baby' versus 'stranger baby'), AgeTest = own baby's age at the time of the experiment (in decimal hrs), AgeRec = own baby's age at the time of stimuli recording (in decimal hrs), AgeMum = participant's age at the time of the experiment (in years), Parity = participant's number of offspring at the time of the experiment ('P1' = no previous offspring, 'P2' = has already had one offspring, 'P3' = has already had two or more offspring), Test = test number (i.e. first versus second series of 15 cries). AgeTest, AgeRec, and AgeMum raw values were centred and scaled (i.e. transformed into *z*-scores: z-AgeTest, z-AgeRec, and z-AgeMum). Mother's identity was included in the model as a random factor.

Experiment 1	χ^2 (type II Wald χ^2 tests)	d.f.	*p*
Baby	56.88	1	**<0.001**
z-AgeTest	2.57	1	0.109
z-AgeRec	2.23	1	0.135
z-AgeMum	0.18	1	0.672
Parity	0.74	2	0.690
Test	3.28	1	0.070
Baby : z-AgeTest	8.02	1	**0.005**
Baby : Parity	8.54	2	**0.014**

(b) Experiment 2: individual recognition of newborns from their cries in non-parents

To investigate the dynamics of vocal recognition of newborns by non-parents, we tested young adults ($n = 32$) in a controlled learning-testing paradigm. Following a training phase (presentation of three cries from their 'assigned baby'), participants were presented with a testing series (15 cries, including only three from their 'assigned baby', all different from those presented during the training). They completed this procedure (training then testing) twice in a row, followed a few hours later by another session comprising two testing series. While neither the participants' age, their sex, nor their current exposure to infants had any effect on correct recognition or rejection, their prior experience of caring for babies significantly affected their performance at discriminating between their assigned baby and other babies (table 2): participants who had previously cared for babies less than 1-year old were more successful at identifying their assigned baby (average success rate of 63% ± 22 for experienced participants versus 42% ± 19 for inexperienced participants; chance level = 20%. *Post hoc* tests following significant interaction between Baby and Experience factors, see table 2. Pairwise comparison for 'assigned baby': $\chi^2 = 8.65$, $p = 0.003$), but there were no differences in performance for rejecting other babies (pairwise comparison for 'stranger babies': $\chi^2 = 0.01$, $p = 0.917$) (figure 2*a*). Indeed, the rate of 'false-positive errors' (i.e. cries

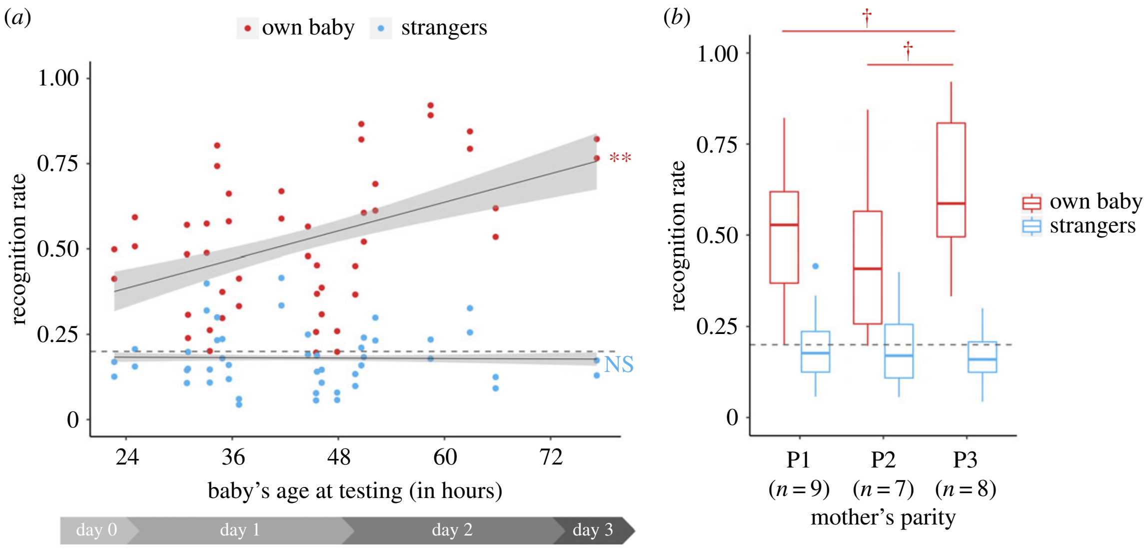

Figure 1. Maternal vocal recognition of their crying newborns. (*a*) Dynamics of recognition onset by mothers (in red: correct recognition rate of the participant's own baby; in blue: false-positive recognition rate of stranger babies, i.e. mistakenly recognizing other babies' cries as belonging to their own baby; model estimates with 95% confidence). (*b*) Influence of mother's previous experience with babies on recognition ability (red and blue: same as in (*a*); box-and-whisker plot: median, 25th and 75th percentiles; whiskers indicate the values within 1.5 times the interquartile range). Baby's age at the time of testing as well as mother's parity influence mothers' ability to identify their own baby's cries (correct recognition rate in red), but not to reject other babies' cries (false-positive recognition rate in blue). *Post hoc* tests following significant factor interactions (with Holm adjustment): for each category of Baby ('own' versus 'strangers'), test on adjusted slope for z-AgeTest (*a*), and pairwise comparisons between Parity categories (*b*). $^{**}p \leq 0.01$, $\dagger p \leq 0.10$. Dashed line: chance level. (Online version in colour.)

Table 2. Factors influencing non-parents' ability to identify their assigned baby's cries ($\text{GLM}_{\text{binomial–logit}}$: analysis of variance table). Baby = baby's category (i.e. 'assigned baby' versus 'stranger baby'), Sex = participant's sex ('female' versus 'male'), Age = participant's age (in years), Experience = participant's experience at caring for baby less than 1-year old ('yes' = already cared for babies, 'no' = never cared for babies), Exposure = participant's current exposure to babies aged less than 1-year old ('yes' = have a baby in their family circle, their circle of friends or their neighbourhood, 'no' = have not spent time with any baby recently), Test = test number (i.e. first, second, third or fourth series of 15 cries), Input = participant's input during the training phase (between one and six crying samples). Age raw values were centred and scaled (i.e. transformed into *z*-scores: z-Age). Participant identity and assigned baby identity were included in the models as random factors.

	χ^2 (type II Wald χ^2 tests)	d.f.	*p*
Experiment 2			
Baby	144.10	1	**<0.001**
Sex	1.22	1	0.270
z-Age	0.14	1	0.708
Experience	0.74	1	0.389
Exposure	0.13	1	0.722
Test	3.56	3	0.313
Baby : Experience	13.68	1	**<0.001**
Experiment 3			
Baby	83.50	1	**<0.001**
Input	0.25	1	0.620
Test	4.32	3	0.229
Baby : Input	11.54	1	**<0.001**
Baby : Test	8.15	3	**0.043**

from strangers considered as originating from assigned baby by the participants) was comparable across participants (mean ± s.d. = 23% ± 14) (figure 2*a*). Remarkably, participants could still recognize their assigned baby's cries among stranger babies' cries several hours after the training phases (table 2).

(c) Experiment 3: effect of exposure on non-parents' ability to recognize a newborn from their cries

To further investigate the dynamics of vocal recognition of newborns by non-parents, we tested young adults ($n = 48$) using a second controlled learning-testing paradigm (Experiment 3). During the training phase, participants listened to between one and six cries from their 'assigned baby'. During the testing phases, they were presented with two testing series (15 cries each, including only three from their 'assigned baby', all different from those presented during the training). Testing phases took place immediately after the training phase, as well as a few hours later. Sex, age and prior experience at caring for babies was balanced across training conditions. The amount of exposure (input) during the training phase significantly affected participants' performance at discriminating between their assigned baby and other babies (table 2): the more crying samples the participants were exposed to during training, the more successful they were at identifying their assigned baby (for *post hoc* tests following significant interaction between Baby and Input factors, see table 2). Test on slope for 'assigned baby': $\chi^2 = 7.47$, $p = 0.006$), but no differences were found in their ability to reject other babies (test on slope for 'stranger babies': $\chi^2 = 0.22$, $p = 0.642$) (figure 2*b*). Indeed, the rate of 'false-positive errors' (i.e. cries from strangers considered as originating from assigned baby by the participants) is comparable across participants (mean ± s.d. = 29% ± 12) (figure 2*b*). Remarkably, participants whose training consisted in only one crying sample had a success rate at identifying their assigned baby of 33% ± 21 ($n = 8$), well above chance level (20%). However, the

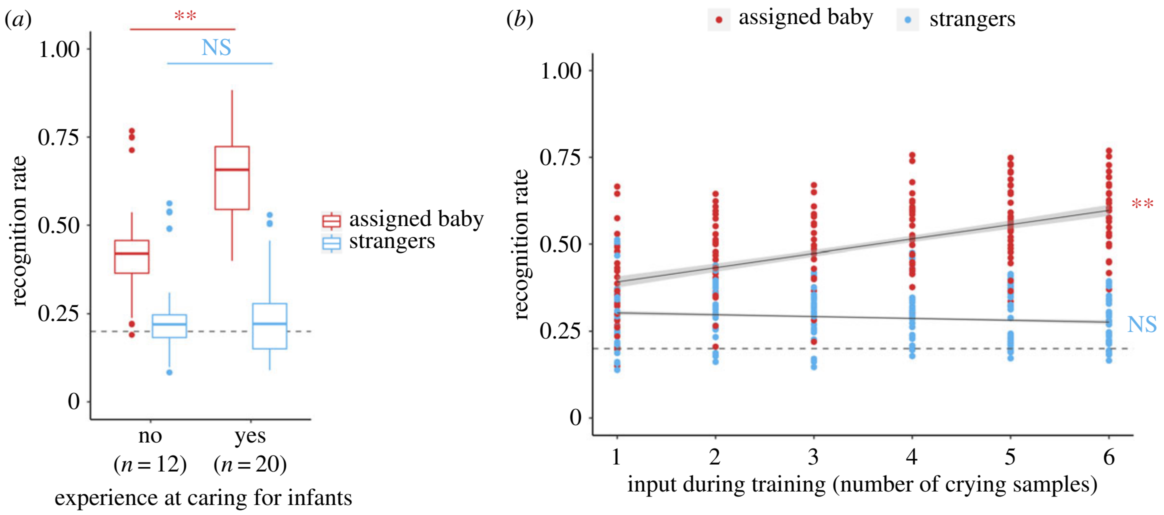

Figure 2. Non-parents' ability to recognize an assigned newborn from their cries. (*a*) Effect of baby-caring experience (Experiment 2). Box-and-whisker plot: the boxes show the median, the 25th and the 75th percentiles; whiskers indicate the values within 1.5 times the interquartile range. On the *x*-axis, *n* is the number of participants belonging to each category. (*b*) Effect of training (Experiment 3). Data points and model estimates with 95% confidence interval plot, $n = 48$ participants (8 per condition). Not only participant's prior experience at caring for infants, but also the number of cry samples they have heard during training influence non-parents' ability to identify their assigned baby's cries (in red: correct recognition rate of the participant's assigned baby), but not to reject other babies' cries (in blue: false-positive recognition rate of stranger babies, i.e. mistakenly recognizing other babies' cries as belonging to their assigned baby). *Post hoc* tests following significant factor interactions (with Holm adjustment): for each category of Baby ('assigned' versus 'strangers'), pairwise comparisons regarding Experience (*a*), and test on adjusted slope for Input (*b*). $^{**}p \leq 0.01$. Dashed line: chance level. (Online version in colour.)

rate of false-positive errors was close to chance level independently of the amount of exposure during the training phase. Also, participants could still recall their assigned baby's vocal signature and distinguish between their cries versus strangers' cries several hours after the training phase, though a slight drop in performance was observed during the third testing series regarding the identification of the assigned baby (*post hoc* tests following significant interaction between Baby and Test factors, see table 2. Pairwise comparisons for 'assigned baby': 'Test 1 versus Test 3', $\chi^2 = 6.53$, $p = 0.053$; 'Test 2 versus Test 3', $\chi^2 = 8.50$, $p = 0.021$; $\chi^2 < 2.52$, $p > 0.452$ for all the other dyads), but not the rejection of stranger babies (pairwise comparisons for 'stranger babies': $\chi^2 < 1.78$, $p = 1$ for all dyads).

4. Discussion

Our investigation of the dynamics of recognition performance shows that mothers learn to recognize their baby's cries very quickly, and that non-parents achieve similar levels of performance in an experimental setting, on the basis of very limited exposure. Conversely, the rate of false-positive answers (erroneously attributing a stranger's cry to one's own baby) remains independent of listener type and experience, and is comparable across our experiments and previous studies: 18% in mothers of less than 3-day-old babies (this study), 23–29% in non-parents (this study), 21% in mothers of one-week-old babies [20], 16% in mothers and 20% in fathers of two- to five-month-old babies [17], 25% in mothers of four- to six-month-old babies [23]. Whether these high rates of mis-recognition of stranger babies constitute a 'safety margin' helping carers to avoid rejecting their own baby, or are due to an inherent limited reliability of cries' cues to identity remains to be investigated. Indeed, while cries contain sufficient acoustic cues to identity to constitute a functional 'individual signature' [17], they are also characterized by strong intra-individual variability, hence the importance of exposure to multiple exemplars on listener's performance.

Overall, we show that neither the sex nor the parenthood status of participants impacts their performance at recognizing their baby's voice. Instead our study emphasizes the key influence of the time spent with the baby (the length of natural exposure since birth in mothers or the amount of initial experimental exposure in non-parents). Our results are consistent with previous work showing that listeners can readily learn to identify adult voices experimentally [32], as well as with studies of newborn face recognition showing that mothers, fathers and other relatives (aunts and grandmothers) achieve similar levels of performance [33,34]. Besides, while previous studies produced contrasted results regarding the influence of multiparity on mothers' performance, reporting either a beneficial effect (e.g. baby's face recognition [35]) or no effect at all (e.g. baby's voice [19] or face recognition [36]), our observations emphasize the influence of prior experience in infant caring for all participants: both multiparous mothers and experienced non-parents performed better at the recognition task. Together these observations suggest that baby recognition relies on perceptual and cognitive abilities shared by all human adults rather than specific to motherhood [37,38].

While it is accepted that pregnancy can have long-lasting organizing effects on the neural circuits underlying maternal behaviour (the 'maternal brain'), the specific nature and extent of these effects remain poorly understood [39–42]. Moreover, the fact that mothers are the primary caretakers in most mammal species (and obviously in most rodent laboratory models) has biased most investigations towards motherhood rather than fatherhood or other types of allo-maternal investment [43,44]. Here we found that the ability to recognize a baby from their cries, which may support familiarization and attachment, is independent of sex and parenthood and thus likely to be part of an array of universal cognitive skills that facilitate cooperative breeding in our species [45,46]. We suggest that a more systematic and comprehensive examination of these abilities has the potential to improve our understanding of the cognitive transition accompanying parenthood, thereby informing infant care policies.

Ethics. Experiments were approved by relevant ethics committees, as specified in 'Material and methods', and written informed consent was obtained from all participants.

Data accessibility. Data available from the Dryad Digital Repository: https://doi.org/10.5061/dryad.83bk3j9n2 [47].

Authors' contributions. All authors conceived and designed the experiments. A.P. collected the stimuli and conducted Experiment 1; H.B. conducted Experiments 2 and 3. H.B. analysed the data. All authors interpreted the data. H.B. drafted the manuscript with the help of N.M. and D.R. and F.L., H.P. and A.P. critically revised the manuscript. All authors gave final approval for publication and agree to be held accountable for the work performed therein. H.B. and A.P. contributed equally to this work.

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