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# Brain Processes in Mothers and Nulliparous Women in Response to Cry in Different Situational Contexts: A Default Mode Network Study

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## SYNOPSIS

**Objective:** In everyday life, parents must respond to and interact with children while in different situational contexts. How situational contexts influence parents' responses has not been systematically studied. Here we investigated mothers' versus nonmothers' neural responses to infant vocalizations in different situations with different task demands. **Design:** Using fMRI in 21 women (10 mothers), we explored the effects of being distracted by self-oriented (self-referential decisions about personality adjectives) versus goal-oriented (syllabic counting of personality adjectives) tasks while listening to infant cry in comparison with other emotional sounds (infant laughing, adult crying) on the activity of two medial nodes of the Default Mode Network (DMN): the medial prefrontal cortex (MPFC) and posterior cingulate cortex (PCC). **Results:** In the self-oriented task while listening to infant cry, both mothers and nulliparas showed (weak) activation of the DMN; this response likely reflects a shift of attention from the task to the cry. In the goal-oriented task, mothers, not nulliparas, showed (weak) activation of the DMN; this result is compatible with interference of emotional sounds while attending to a goal-oriented task, an activity that deactivates the DMN. **Conclusions:** Mothers are prone to process infant cry and emotional sounds and are less distracted from doing so by situational contexts, demonstrating their greater sensitivity to emotional sounds such as cry. By contrast, situational context influenced brain responses to infant sounds in nulliparas.

## INTRODUCTION

Crying is one of the first signals that allow infants to communicate their needs (Newman, 2007). Parental care is critical in helping to meet primary needs related to infant survival and in promoting the acquisition of cognitive, social, and instrumental skills necessary for the development of adaptive behaviors in children (Bowlby, 1969). Parental care encompasses complex procedural functions that evolved over time and are shaped by characteristics of parent, child, and the wider social context (Belsky, 1984; Bornstein, 2016).

Sensitivity to infant crying is influenced by several factors. Caregivers' and children's characteristics influence adults' responsiveness to infant crying, including, for example, temperament (Montoya et al., 2012), mood (Ablow, Measelle, & Laurent, 2011; Laurent & Ablow, 2012), parental role (mothers vs. fathers; Atzil, Hendler, Zagoory-Sharon, Winetraub, & Feldman, 2012), and attachment style to own parental figures (Barrett et al., 2012; Fleming, Corter, Stallings, & Steiner, 2002; Newman, Harris, & Allen, 2011). Here, we

focused on two neglected factors that might affect responsiveness to cry: caregiver mental state and situation.

Mental state, specifically internally or externally oriented cognitions, likely influences caregiver brain responses to infant cry (De Pisapia et al., 2013). An infant who is crying will not necessarily find adults waiting to accede to the infant's requests. Rather, adults tend to be occupied by other activities or even simply immersed in their own thoughts (spontaneous cognition), a form of self-relevant mentalizing or mind wandering. A consistent pattern of activation in a cerebral network that underlies spontaneous cognition (called the Default Mode Network; DMN) has been reported (Buckner, Andrews-Hanna, & Schacter, 2008). Activity in DMN has been attributed to self-centered mental state not related to the environment, such as retrieval of autobiographical memories, mental imagery, and even social cognitive processes like understanding others' mental states (Buckner et al., 2008; Greicius, Krasnow, Reiss, & Menon, 2003; Gusnard, Akbudak, Shulman, & Raichle, 2001; Raichle, et al., 2001). The DMN tends to deactivate during activities requiring externally oriented attention and positive activation of executive function networks (Anticevic et al., 2012; De Pisapia, Turatto, Lin, Jovicich, & Caramazza, 2012; Fox, Snyder, Zacks, & Raichle, 2006). In a previous study (De Pisapia et al., 2013), mothers and nulliparous women showed greater deactivation than men in two midline nodes of the DMN – the medial prefrontal cortex (MPFC) and posterior cingulate cortex (PCC) – while resting and simultaneously listening to infant cries. The sudden onset of infant cry appeared to elicit in women promptness to disengage cognitive resources from internally focused thoughts. DMN activity reveals whether listeners activate self-relevant or externally oriented processes in the presence of infant cry while engaged in infant-unrelated mental states.

Adults are presented daily with challenges to meet infants' needs in various environmental conditions, and the "here and now" situational contexts in which children express distress likely also influence the caregiving they receive (Bornstein, 2016; Murray, 1985). Context as well as the cognitive and affective evaluation of the emotional value and intensity of infant distress stimulate parental brain and behavioral responses to infant cues (Belsky & Jaffee, 2006; Swain, 2011). Context is a dynamic multidimensional construct that includes situational, social, and cultural aspects that affect individual development and social interactions (Bronfenbrenner, 1999; Croke, Winner, & Olswang, 2016; Matsumoto, 2007). Bornstein (2016) reviewed the significance of context as a determinant of parenting, distinguishing proximal, social, and distal contexts. Proximal contexts include, for example, family structure and social support, employment status, and situation (e.g., infant-unrelated tasks parents must accomplish that are present during interactions of parents with their infants versus infant-related tasks). Situational contexts span household management to out-of-home employment. There is increasing knowledge about how individual characteristics of parents and children shape parental care (Atzil, Hendler, & Feldman, 2011; Feldman, 2007; Newman et al., 2011; Saunders et al., 2015; Smith, 2010), but much less is known about the challenges faced by parents when they have to attend to daily activities (infant-unrelated tasks) while engaging in parenting (infant-related tasks). To better understand mechanisms underlying adults' brain responses to infant vocalizations, especially infant distress, it is essential to elucidate how situational contexts, that is simultaneous infant-unrelated tasks, moderate adult responsiveness. The evaluation of situational context effects (daily activities that occupy adults) while exposed to salient infant stimuli (such as infant crying) enriches the literature about potential factors,

external to the adult-child dyad, that influence caregiver responsiveness to important infant signals.

In a previous fMRI study, we found a significant interaction between brain responses to an infant-unrelated task and to emotional sounds in nulliparous women; self- and goal-oriented tasks represented situational contexts during which participants listened to infant cries (Rigo et al., 2017). Daily activities requiring goal- or self-oriented processes that recruit different brain resources to address infant-unrelated and infant-related care activities were simulated in the laboratory (Bornstein, 2016). Goal-oriented tasks require external orienting of attention, which deactivates the DMN; subsequently, interference of this task has been shown to lead to an increase of cerebral activation in the DMN. By contrast, self-oriented tasks involve an internal orienting of attention, which is associated with an activation of the DMN. Interference of self-oriented tasks therefore leads to a decrease in activation of the DMN. In women, infant crying reduced activation of the DMN in a self-oriented task, which normally requires DMN activation, but no effect of infant cry (or other emotional sounds) was found in a goal-oriented task (Rigo et al., 2017). These findings led to the hypothesis that, in women, processing of emotional sounds might compete for the same brain resources required during self-oriented tasks. Compatible with this line of thinking, the situational context effect was not found in the goal-oriented task, likely because the goal-oriented task recruited different cognitive sources that did not compete with processing of emotional sounds in nulliparous women. Such evidence also suggests that activation or deactivation of the DMN, in response to infant cry, may indicate whether the sound of infant distress elicits self-relevant versus externally oriented processes in listeners.

The present study aimed to extend previous findings in Rigo et al. (2017) and examine potential interactions between the situational context and brain responses to infant cry versus other control sounds. Here, situational context (infant-unrelated care activities) was operationalized in self-oriented and goal-oriented tasks, which co-occurred with the presentation of infant cry and other emotional sounds. De Pisapia et al. (2013) and Rigo et al. (2017) reported that both mothers and nonmothers showed DMN deactivation to infant cry, pointing to the disengagement of cognitive resources from internally focused thoughts (a mental state that activates the DMN). Therefore, in response to infant cry during a self-oriented task that is known to activate the DMN, we expected to observe the same deactivation (or weak activation) of the DMN in both mothers and nulliparas. However, relative to nulliparous women, mothers are more accustomed to attending to infant cry while being occupied with infant-unrelated activities, which can require either self- or goal-oriented processes (Green, Jones, & Gustafson, 1987; Out, Pieper, Bakermans-Kranenburg, Zeskind, & van IJzendoorn, 2010). It is possible that such care experiences in mothers will be reflected in their greater promptness than nulliparous women to attend to infant cry despite their being involved simultaneously in infant-unrelated activities. This result would be a deviation from the expected activation and deactivation of the DMN in self- and goal-oriented tasks, respectively, in response to salient emotional sounds and especially to infant distress.

## METHOD

We compared previously collected fMRI data from nulliparous women (Rigo et al., 2017) with new data collected from mothers. To ensure consistency for data comparison, the tasks, stimuli, fMRI scanning parameters, and analyses were the same as used previously and focused on involvement of the DMN in nulliparous women listening to crying and

other emotional sounds. Here, ROI analysis was conducted on the two main nodes of the DMN (MPFC and PCC) and focused on the effect of infant cries versus control sounds during concurrent tasks requiring either DMN activation (self-oriented task; for meta-analysis see van der Meer, Costafreda, Aleman, & David, 2010) or deactivation (goal-oriented task; Debbanè et al., 2014; Maguire & Mummery, 1999).

## Participants

Twenty-one women participated in the study: 10 healthy mothers (with children aged 18–60 months) and 11 nulliparous women (from a previous fMRI study). Demographic information of mothers (M), nonmothers (NM), and children (C) and percentages of participants (%<sub>rep</sub>) who reported this information are as follows: (M) *M* age = 33.4 ± 5.50 years (80%<sub>rep</sub>), educational level range = 13–18 years (60%<sub>rep</sub>); (NM) *M* age = 20.5 ± 4.04 years (100%<sub>rep</sub>), educational level range = 13–16 years (64%<sub>rep</sub>); and (C) *M* age = 25 ± 8.8 months (64%<sub>rep</sub>). Age data were missing for 2 mothers and 4 children. Mothers were recruited through social networks advertising or leafletting at University of Trento and at kindergartens in Rovereto, Italy. Inclusion criteria were mothers and non-mothers having no personal or family history of neurological or mental disorders and mothers having their youngest child aged 2–4 years. All participants gave informed consent to participate, and the study was approved by the ethical committee for experiments involving humans at the University of Trento.

## Auditory and Visual Stimuli

The auditory stimuli included four categories of sounds: baby cries (BC; hunger cries from 1-year-olds), baby laughs (BL; from 1- to 2-year-olds), female adult cries (AC), and control noise sounds (CS). Each category consisted of 20 sounds for a total of 80 sounds. Human vocalizations (BC, BL, and AC) were extracted from files of sounds in public online databases (Ljung & Wahlforss, 2008; Nokes, 1997). CSs were derived from BCs: We generated white noise sounds and then, to preserve the morphological features of the temporal pattern expressed by BCs, the shape and the form of the noise signal were modulated using BCs as a reference.

Visual stimuli consisted of 80 personality adjectives selected as follows. An initial larger list of 242 adjectives was evaluated by 12 judges (Italian young adults, not otherwise informed about the experiment, and not participants to the MRI sessions) using a 7-point scale ranging from -3 (*extremely negative*) to 0 (*neutral*) to 3 (*extremely positive*). To extract values close to neutral and avoid possible confusion between positive or negative valence, we selected adjectives that were evaluated between -1 and 1. A limitation of this procedure is that each selected adjective might be perceived as slightly positive by some or slightly negative by others; nonetheless, the procedure allowed us to avoid possible emotional reactions to attributes more consistently evaluated as very negative or positive. For the syllabic counting task (see the experimental procedures for details), we used adjectives consisting of 3 (20 items) and 4 (20 items) syllables. In the self-referential decision task, the number of syllables in the adjectives (40 items) ranged from 2 to 5.

## Experimental Tasks

Participants underwent two different experimental tasks (infant-unrelated activities) that determined the situational contexts in this study. In the self-oriented task (SOT), participants decided whether each personality adjective (presented at the center of the screen) described them (*yes* or *no*); in the goal-oriented task (GOT), participants decided whether each personality adjective had 3 or 4 syllables (Rigo et al., 2017).

## Experimental Design

A 2\*4\*2 repeated-measures factorial design was implemented. The first two within-subjects factors were the *task* (SOT and GOT) and the *sound* (BC, BL, AC, and CS). The between-subjects factor was *parental status* (mother and nonmother).

## Image Acquisition

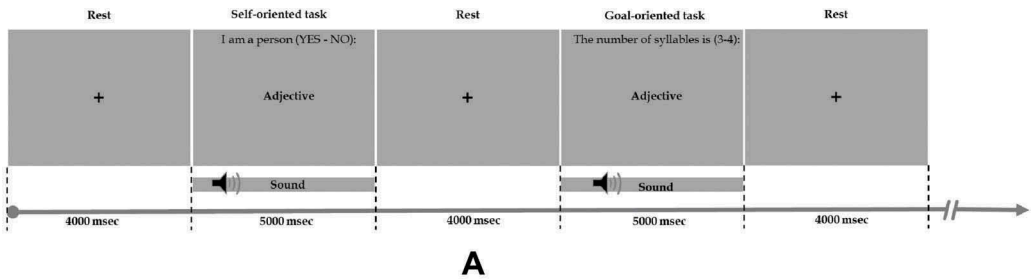
First, we acquired high-resolution T1-weighted MPRAGE structural images (176 axial slices, slice thickness = 1 mm, FOV = 256 mm, TI (inversion time) = 1020 ms, flip angle = 7°, TR = 2700 ms, TE = 4.18 ms). Second, functional images were acquired through a whole-body scanner Bruker MedSpec MRI magnet 4T equipped with a Siemens Sonata gradients of 40 mT/m, with 8-channel coils for signal reception. Functional T2\*-weighted images were obtained with a standard echo planar imaging (EPI) technique, (37 slices, slice thickness = 3 mm, field of view (FOV) = 192 mm, flip angle = 75°, TR (repetition time) = 2200 ms, TE (echo time) = 33 ms, matrix 64 × 64, voxel size 3 × 3 × 3 mm, 334 volumes). The functional session lasted about 11 min.

## Experimental Procedure

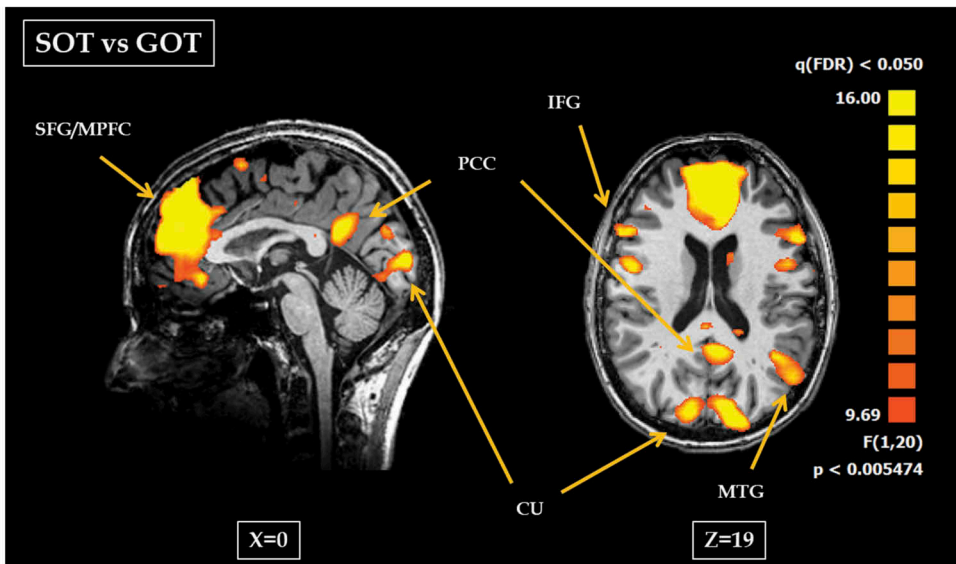
Before the experimental scan session, participants underwent a training block to familiarize them with the tasks. We implemented a block design (Figure 1A) that included two tasks (SOT and GOT), alternated in random order, one task at a time. After the presentation of a fixation point (4000 ms), one of the four sound stimuli (task unrelated) was played; the order of sounds was randomized. Simultaneously with the onset of the sound (BC, BL AC, CS), the task was presented and one personality adjective (task related) appeared at the center of the screen. Both sound and adjective were presented for 5000 ms. Participants were told about both visual and auditory stimuli prior to the trials and were asked to focus on the adjective to accomplish the task. A sentence at the top of the screen informed participants which task to perform. Participants were asked to respond by pressing a response button box as fast as possible, but reaction times were not collected.

## fMRI Data Analysis

All analyses of fMRI data were performed with BrainVoyager QX version 2.8 (Brain Innovation, Maastricht, the Netherlands) running on a Windows operating system. To eliminate the magnetic saturation effect, four dummy scans preceded the scan session. We carried out a standard preprocessing analysis which consisted of correction of motion artifacts using 3D motion correction with trilinear interpolation and linear trend removal,



A



B

FIGURE 1

(A) Block design. The instruction for the task (top of the screen), the task-related adjective (centered on the screen) and the task-unrelated sound were presented simultaneously for a duration of 5 s. The recovery period lasted 4 s. (B) Main effect of task. Abbreviations: SOT = self-oriented task, GOT = goal-oriented task, MPFC = medial prefrontal cortex, SFG = superior frontal gyrus, IFG = inferior frontal gyrus, PCC = posterior cingulate cortex, MTG = middle temporal gyrus; CU = Cuneus.

realignment of functional volume to the first volume of the session, correction for inhomogeneity of 3D anatomical image (two cycles), and segregation of brain tissue from head tissue. Functional 2D images were coregistered with the 3D anatomical image, before they were translated and rotated into a cuboid in AC-PC space with specified eight landmarks to define the borders of the cerebrum. Images were normalized into a Talairach space (Talairach & Tournoux, 1988), and an 8-mm full-width at half-maximum Gaussian smoothing was applied. A total of eight predictors – one for each sound (BC, BL, AC, and CS) in each task (SOT and GOT) – were convolved with the hemodynamic response function (HRF). To calculate a whole brain statistical map for each participant, a general linear model (GLM), fitted in with all predictors (2 tasks\*4 sounds) was defined. First, we conducted a whole brain analysis (random-effects GLM,  $q(\text{FDR}) < .05$ ) to ascertain the differential involvement of the DMN in the two tasks, before performing a region of interest (ROI) analysis focused on two

nodes of the DMN: MPFC and PCC. To define the anatomical ROI, we used the same masks used in the previous studies of non-parents' responsiveness to infant and adult emotional sounds (De Pisapia et al., 2013; Rigo et al., 2017). Mask coordinates ( $x, y, z$ ) and voxel sizes were the following: MPFC  $x = 3, y = 49, z = 20$  (3926 voxels) and PCC  $x = -1, y = -46, z = 25$  (1827 voxels). For ROI analysis, we conducted a whole brain contrast of *all conditions > rest* (random-effects GLM,  $q(\text{FDR}) < .05$ ; Genovese, Lazar, & Nichols, 2002) to retrieve the individual beta values evoked by each condition within each ROI, after which a random-effects GLM analysis was carried out.

## RESULTS

### Whole Brain Analysis

As in the previous study (Rigo et al., 2017), we conducted a whole brain analysis aimed to validate the paradigm and show differential involvement of the DMN in self-oriented and goal-oriented tasks in all participants (Table 1; Figure 1B). The effect of type of *task* ( $p < 0.005, q(\text{FDR}) < .05$ ) was significant; we found activated clusters in several brain regions among which were those ascribable to the DMN (see *F* statistics and *p* values in Table 1): bilateral ACC/MPFC (BA 32, 9,12), bilateral PCC and precuneus (BA 23,30), and right inferior parietal lobe IPL (BA 40) (see Table 1 for details about all activated brain regions).

### ROI Analysis

**Preliminary Analysis.** The difference in ages between mothers and nonmothers could confound the study comparison. To investigate the effect of participants' age on involvement of the DMN, we calculated correlations between the age of participants and BOLD signals from the two ROIs, the MPFC and the PCC. Based on the experimental design, we included eight dependent variables of the BOLD signal (two-level *task*\* four-level sound conditions) from each ROI (Table 2). Only one positive correlation emerged: the control sound for the ROI MPFC and the GOT,  $r = .50, p = .031$ . Thus, the likely confounding effect of age would be marginal because age correlated with only 1 of 16 dependent variables and that was with non-human control sounds in only a single condition. Age was not added as a covariate in ROI analyses. No significant correlations were found between child age and the BOLD signal from MPFC and PCC in each sound condition.

**Medial Prefrontal Cortex (MPFC).** Analysis revealed a main effect of *task*,  $F(1,19) = 27.60, p < .001, \eta_p^2 = .592$ , and a marginal two-way interaction *Task\*Parental status*,  $F(1,20) = 4.05, p < .059, \eta_p^2 = .176$ . No other main effects or two- or three-way interactions were found (Figure 2). Consistent with the different involvement of the DMN in self-oriented and goal-oriented tasks, pairwise comparisons revealed that the SOT activated the MPFC to a greater extent than the GOT ( $\text{BOLD}_{\text{GOT-SOT}} = .273 \pm .052, p < .001$ , Least Significant Difference). No difference between mothers and nonmothers was found in the self-oriented task. In the GOT, greater activation of the MPFC appeared in mothers than nonmothers ( $\text{BOLD}_{\text{GOT}}_{\text{NM-M}} = -.391 \pm .158; t(19) = -2.47, p = .023$ ).



TABLE 1

The Main Effect of *Task*. Peaks of Cerebral Activity with Brodmann Areas (BA), Coordinates in Talairach Space (X, Y, Z), Cluster Sizes and *F*-Values. Brain Regions that can be Attributed to the DMN are in *Italics*

| Brain regions  | BA      | Left/Right | x   | y   | z   | Voxels at $q(\text{FDR})$<br><.05 | <i>F</i> |
|--|---------|------------|-----|-----|-----|-----------------------------------|----------|
| Cuneus   |         | R          | 18  | -91 | 4   | 32288                             | 54.92    |
| <i>Anterior Cingulate/Medial Frontal Gyrus</i>         | 32/9/12 | L/R        | -6  | 38  | 19  | 54378                             | 50.80    |
| Middle Temporal Gyrus                                  | 21      | R          | 63  | -7  | -14 | 2424                              | 41.74    |
| Inferior Frontal Gyrus                                 | 47      | L          | -42 | 17  | -5  | 11763                             | 32.76    |
| Inferior Frontal Gyrus                                 | 47      | R          | 36  | 17  | -11 | 5391                              | 30.26    |
| Middle Frontal Gyrus                                   | 6       | L          | -36 | 8   | 53  | 1717                              | 28.87    |
| Inferior Temporal Gyrus                                | 22      | L          | -54 | -16 | -17 | 9122                              | 25.07    |
| <i>Inferior Parietal Lobule</i>                        | 40      | R          | 51  | -31 | 46  | 9512                              | 24.44    |
| <i>Posterior Cingulate</i>                             | 23/30   | L          | -3  | -49 | 22  | 4581                              | 19.92    |
| Inferior Frontal Gyrus                                 | 45      | R          | 48  | 23  | 16  | 1139                              | 19.65    |
| <i>Posterior Cingulate</i>                             | 23      | R          | 6   | -34 | 22  | 460                               | 19.47    |
| Inferior Semi-Lunar Lobule                             |         | L          | -36 | -73 | -35 | 502                               | 19.31    |
| Uvula  |         | R          | 12  | -70 | -29 | 1696                              | 19.19    |
| Inferior Frontal Gyrus                                 | 44      | L          | -45 | 2   | 25  | 2143                              | 18.67    |
| Inferior Parietal Lobule                               | 40      | L          | -42 | -34 | 34  | 7043                              | 18.55    |
| Cuneus   | 19      | R          | 27  | -83 | 40  | 3354                              | 17.65    |
| Inferior Frontal Gyrus                                 | 6       | R          | 48  | 2   | 19  | 1261                              | 17.50    |
| Middle Temporal Gyrus                                  | 39      | L          | -45 | -58 | 25  | 4342                              | 17.34    |
| Declive  |         | L          | -58 | -61 | -14 | 301                               | 17.07    |
| Anterior Superior Temporal Gyrus                       | 38      | L          | -30 | 14  | -38 | 351                               | 15.46    |
| Middle Frontal Gyrus                                   | 9       | R          | 39  | 44  | 38  | 147                               | 14.97    |
| Precentral Gyrus                                       | 4       | L          | -51 | -1  | 44  | 547                               | 14.93    |
| Inferior Frontal Gyrus                                 | 47      | R          | 54  | 23  | 1   | 373                               | 14.78    |
| Middle Frontal Gyrus                                   | 9       | L          | -36 | 32  | 34  | 1198                              | 14.68    |
| Middle Temporal Gyrus                                  | 39      | R          | 45  | -58 | 25  | 407                               | 14.63    |
| Paracentral Lobule                                     | 31      | L          | -3  | -22 | 40  | 160                               | 13.34    |
| Insula   | 13      | L          | -39 | -4  | 7   | 254                               | 13.18    |
| Medial Frontal Gyrus/ <i>Anterior Cingulate Cortex</i> | 6/24    | L          | -6  | -4  | 52  | 270                               | 12.92    |

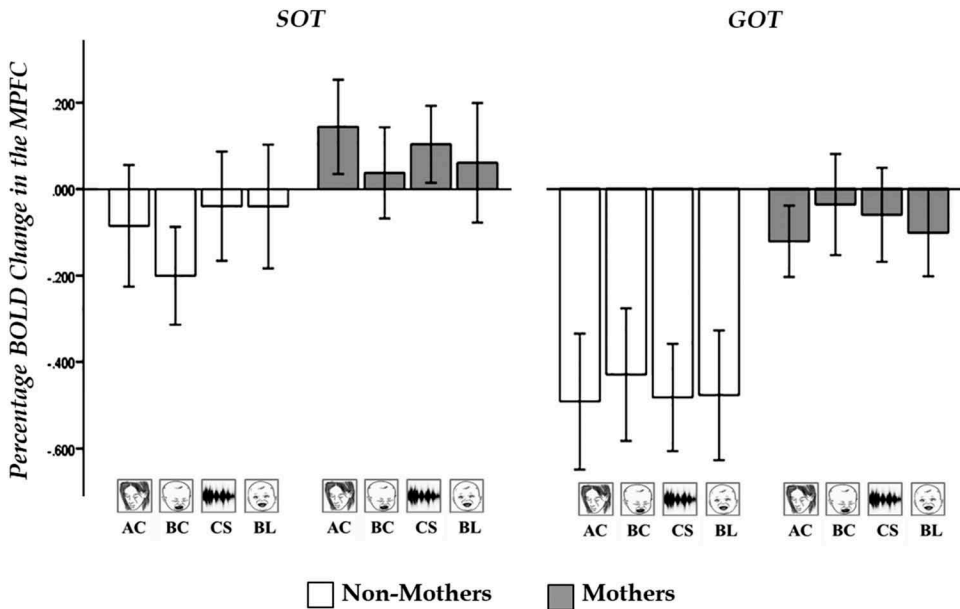
Given a strong effect of task, the next two-tailed repeated-measures ANOVAs were aimed to disaggregate the main effects of sound and parental status and the two-way interaction in each task separately, but no significant main effects or two-way interactions in SOT or GOT were found.

**Posterior Cingulate Cortex (PCC).** Analysis revealed a main effect of *task*,  $F(1,19) = 19.11$ ,  $p < .001$ ,  $\eta_p^2 = .501$ , and two significant two-way interactions, namely *Task\*Parental status*,  $F(1,19) = 4.52$ ,  $p < .047$ ,  $\eta_p^2 = .176$ , and *Task\*Sound*,  $F(3,57) = 3.28$ ,  $p < .03$ ,  $\eta_p^2 = .147$  (Figure 3). The GOT activated PCC more than the SOT did ( $\text{BOLD GOT-SOT} = .216 \pm .049$ ,  $p < .001$ , Least Significant Difference). In SOT, and in accord with findings of the MPFC, no significant difference between mothers and nonmothers was found. In the GOT, that should have deactivated the DMN, mothers did not show a deactivation of DMN. Instead, mothers exhibited a trend to activate the PCC more than nonmothers ( $\text{BOLD GOT}_{\text{NM-M}} = -.260 \pm .135$ ;  $t(19) = -1.93$ ,  $p = .065$ ). Additional paired comparisons revealed that mothers did not show different activation of the

**TABLE 2**  
 Correlations (Spearman's Rho) between the BOLD Signal of the Regions of Interest (The Medial Prefrontal Cortex [MPFC] and the Posterior Cingulate Cortex [PCC] for Each of the Total 8 Conditions (Two-Level *Task* \* Four-Level *Sound*) and the Age of Participants (Mothers and Nonmothers; N = 19)

|                      | 1      | 2      | 3      | 4      | 5      | 6      | 7      | 8      | 9      | 10     | 11     | 12    | 13     | 14     | 15     | 16   | 17 |
|----------------------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|-------|--------|--------|--------|------|----|
| 1. (MPFC) SOT BC     | -      |        |        |        |        |        |        |        |        |        |        |       |        |        |        |      |    |
| 2. (MPFC) SOT BL     | .669** | -      |        |        |        |        |        |        |        |        |        |       |        |        |        |      |    |
| 3. (MPFC) SOT AC     | .665** | .660** | -      |        |        |        |        |        |        |        |        |       |        |        |        |      |    |
| 4. (MPFC) SOT CS     | .682** | .757** | .565** | -      |        |        |        |        |        |        |        |       |        |        |        |      |    |
| 5. (MPFC) GOT BC     | .626** | .615** | .639** | .535*  | -      |        |        |        |        |        |        |       |        |        |        |      |    |
| 6. (MPFC) GOT BL     | .569** | .445*  | .692** | .578** | .704** | -      |        |        |        |        |        |       |        |        |        |      |    |
| 7. (MPFC) GOT AC     | .688** | .722** | .803** | .440*  | .802** | .531*  | -      |        |        |        |        |       |        |        |        |      |    |
| 8. (MPFC) GOT CS     | .657** | .411   | .768** | .372   | .703** | .826** | .666** | -      |        |        |        |       |        |        |        |      |    |
| 9. (PCC) SOT BC      | .408   | .036   | .256   | .270   | -.144  | .148   | -.122  | .304   | -      |        |        |       |        |        |        |      |    |
| 10. (PCC) SOT BL     | .154   | .459*  | .255   | .317   | .130   | .185   | .108   | .203   | .382   | -      |        |       |        |        |        |      |    |
| 11. (PCC) SOT AC     | .149   | .256   | .527*  | .199   | .108   | .182   | .205   | .355   | .578** | .681** | -      |       |        |        |        |      |    |
| 12. (PCC) SOT CS     | .104   | .203   | .282   | .504*  | .001   | .223   | -.151  | .141   | .510*  | .449*  | .560** | -     |        |        |        |      |    |
| 13. (PCC) GOT BC     | .077   | -.008  | .275   | -.010  | .368   | .173   | .210   | .377   | .223   | .433   | .627** | .413  | -      |        |        |      |    |
| 14. (PCC) GOT BL     | .178   | -.014  | .351   | .114   | .200   | .487*  | .021   | .573** | .599** | .533*  | .684** | .518* | .584** | -      |        |      |    |
| 15. (PCC) GOT AC     | .197   | -.066  | .473*  | -.073  | .318   | .374   | .361   | .620** | .351   | .173   | .497*  | .175  | .578** | .588** | -      |      |    |
| 16. (PCC) GOT CS     | .300   | -.066  | .356   | .056   | .201   | .318   | .130   | .614** | .635** | .277   | .539*  | .400  | .606** | .639** | .777** | -    |    |
| 17. Participants Age | .139   | .026   | .278   | -.013  | .433   | .391   | .376   | .495*  | .013   | -.253  | .168   | -.049 | .276   | .294   | .309   | .327 | -  |

\*p < .05. \*\*p < .01



**FIGURE 2**

Change BOLD signals in the MPFC during the self-oriented task (SOT) and self-oriented task (GOT). White and gray bars represent, respectively, nonmothers and mothers; vertical lines represent standard error of mean. Abbreviations: SOT = self-oriented task, GOT = goal-oriented task, MPFC = medial prefrontal cortex, AC = adult cry, BC = baby cry, CS = control sound, BL = baby laugh. Activation of the medial prefrontal cortex was greater in SOT than GOT in all participants ( $p < .001$ ) and in GOT in mothers than nonmothers ( $p < .023$ ).

DMN across the two tasks (SOT-GOT =  $.111 \pm .225$ ;  $t(9) = 1.56$ ,  $p = .152$ ), but nonmothers did (SOT-GOT =  $.321 \pm .228$ ;  $t(10) = 4.68$ ,  $p = .001$ ). Nonmothers showed greater deactivation of the DMN in the GOT than in the SOT.

Paired  $t$  test analyses were conducted to compare betas for each sound between the SOT and GOT. We found higher activation in the SOT than GOT for AC and BL (BOLD:  $AC_{(SOT-GOT)} = 0.381 \pm .074$ ,  $t(21) = 5.16$ ,  $p < .001$ ;  $BL_{(SOT-GOT)} = 0.224 \pm .086$ ,  $t(21) = 2.61$ ,  $p = .016$ ). Given that the SOT activates the DMN more than the GOT, the higher activation found in AC and BL during the SOT revealed that the responsiveness to AC and BL was affected by the simultaneous task in which the listener was engaged. Response to BC was not affected by the type of tasks and maintained a stable activation.

As in the MPFC, the PCC showed a main effect of *task*, and the next analysis disaggregated the main effects of sound, parental status, and the two-way interaction in each task. The SOT: Within-subject contrasts revealed a *sound* interaction for BC versus AC (BC-AC:  $F(1,19) = 13.60$ ,  $p = .002$ ,  $\eta_p^2 = .417$ ) and, as trends interactions of BC with CS (BC-CS:  $F(1,19) = 4.15$ ,  $p = .056$ ,  $\eta_p^2 = .179$ ) and BL (BC-BL:  $F(1,19) = 3.90$ ,  $p = .063$ ,  $\eta_p^2 = .170$ ) were also found. The SOT (that should have activated the DMN): Pairwise comparisons showed a trend of BC to deactivate more than other sounds: BC-AC =  $-.236 \pm .064$ ,  $p = .002$ , BC-CS =  $-.104 \pm .056$ ,  $p = .082$ , and BC-BL =  $-.111 \pm .070$ ,  $p = .131$  (Least Significant Difference). The GOT: The main effects of sound and parental status and the two-way interaction were not significant.

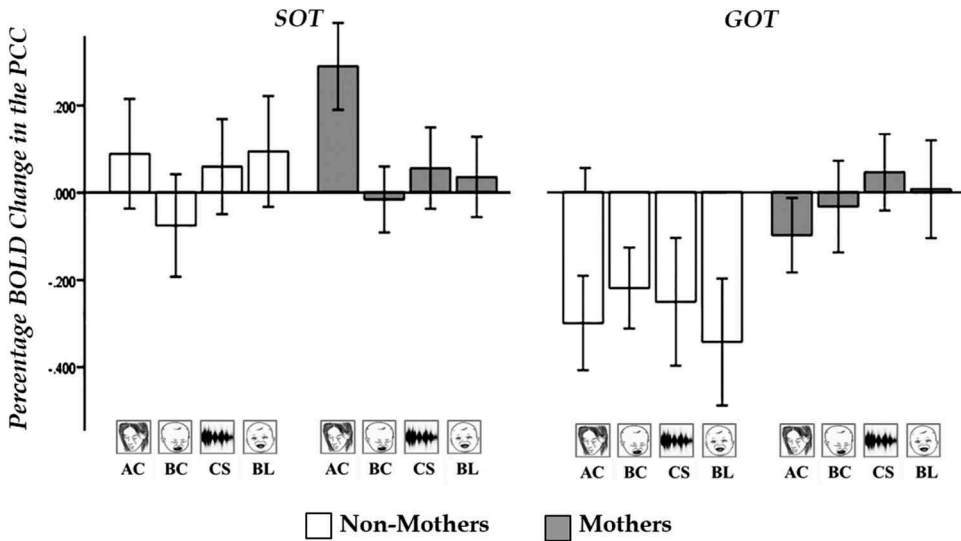


FIGURE 3

Change BOLD signals in the PCC during the SOT and GOT. White and gray bars represent, respectively, nonmothers and mothers; vertical lines represent standard error of mean. Abbreviations: SOT = self-oriented task, GOT = goal-oriented task, PCC = posterior cingulate cortex, AC = adult cry, BC = baby cry, CS = control sound, BL = baby laugh. The posterior cingulate cortex activation was greater in SOT than GOT in non-mothers ( $p < .001$ ), in the adult cry ( $p < .001$ ), and the baby laugh conditions ( $p < .016$ ). In SOT, baby cry resulted in greater deactivation of the posterior cingulate cortex than adult cry ( $p < .002$ ), control sound ( $p < .056$ ), and baby laugh ( $p < .063$ ) in all participants.

## DISCUSSION

The present study aimed to uncover and compare potential interactions between situational contexts, given by simultaneous infant-unrelated activities, and response to infant cry and other emotional sounds in mothers and nulliparous women. Infant-unrelated activities were defined by tasks that required internally or externally oriented attention. We focused on the involvement of the Default Mode Network (DMN) that is well known to be activated by self-related states of mind, requiring internally oriented attention. The task that activated the DMN was a self-oriented task, thinking about one's own personality, whereas the DMN was deactivated by a goal-oriented task that assumes an external focus of the attention (Davey, Pujol, & Harrison, 2016; van der Meer et al., 2010).

In the self-oriented task (requiring activation of the DMN), we found that infant cry deactivated the DMN more than comparison sounds. This effect was found in mothers and nulliparous women alike. In this task, our expectation was partially met because we found an effect of infant cry but no significant difference between mothers and nulliparous women. In accord with previous studies (Rigo et al., 2017), these results suggest that women (mothers and nulliparous women) show lower activation of the DMN in the presence of an infant cry as compared to the other sounds. Deactivation of the DMN to the abrupt onset of infant cry reflects a shift of attention away from self-orientation (Di & Biswal, 2014; Sridharan, Levitin, & Menon, 2008). Involvement of the

DMN can be modified by auditory stimulation (Abbott, Kim, Sponheim, Bustillo, & Calhoun, 2010; Binder et al., 1999; McKiernan, Kaufman, Kucera-Thompson, & Binder, 2003) and changes in the presence of meaningful environmental information (i.e., intelligible vs. unintelligible sounds; Simony et al., 2016). In the present study, alteration of expected activity of the DMN in a self-oriented task likely reflects partial disengagement of cerebral resources from an infant-unrelated task (which requires internally oriented attention) to infant distress vocalization. Therefore, low activation of the DMN seems to suggest that the infant distress cry and, to a lesser extent, other sounds, are salient stimuli that increase vigilance, regardless of whether the woman is already committed to carrying out a self-referencing task that cannot be interrupted.

Few studies have investigated how context shapes responsiveness to infant sounds. The present study represents a first-order reply on this question. However, we do not contend that there is a specific type of parental DMN response to infant sounds. Our idea is that the saliency of some sounds can partially recruit cognitive brain responses (in this study the DMN) from simultaneous activities, resulting in altered involvement of the DMN. This means that, if the DMN is activated, as is the case with a self-oriented task, sounds can reduce activation or deactivate the DMN. This effect was previously reported in De Pisapia et al. (2013) and Rigo et al. (2017) in non-parental adults. Conversely, if a task strongly deactivates the DMN, as do goal-oriented tasks, sounds can reduce deactivation or activate the DMN (reported in Rigo et al., 2017). The different involvement of the DMN is more the consequence of the partial recruitment of cognitive brain resources from the task toward the sounds. As a strategy to test the interaction between listening to infant vocalizations (which promote infant-related responses) and simultaneous (infant-unrelated) activities, we implemented a design with two tasks, which predict involvement of the DMN. Any deviation of expected DMN activity can tell us if participants were distracted. The magnitude of the DMN shift predicts vigilance to the environment, which in turn prompts motor responses (Hinds et al., 2013; Uddin, Kelly, Biswal, Castellanos, & Milham, 2009). There is evidence that fast performance in behavioral tasks (short reaction time) is associated with strong deactivation of the DMN during externally oriented tasks (De Pisapia et al., 2012; Fox et al., 2006; Mennes et al., 2011). In line with this suggestion, a cross-cultural fMRI study revealed that infant vocal distress and, in different measures, infant laugh and adult distress, enhanced activity in brain regions that are linked to the intention to move and to speak in mothers (Bornstein et al., 2017).

In the goal-oriented task that normally deactivates the DMN, we observed no effect of sound; mothers did not show expected deactivation of the DMN, but nulliparous women did. Rather, mothers showed a partial activation of the DMN. In this task, our expectations were also partially met. We observed altered involvement of the DMN in mothers relative to nulliparous women (this effect extended to all emotional sounds). For a better interpretation of psychological mechanisms that underlie differences in brain responses in the goal-oriented task in mothers and nulliparous women, we would need to consider overall DMN involvement shown by mothers in all experimental tasks and not just in the goal-oriented task. Mothers showed partial activation of the DMN in all sound conditions and in both tasks, whereas in nulliparous women distinct differences in involvement of the DMN were reflected in the self-oriented versus goal-oriented task. Perhaps the DMN is partly recruited to respond to social stimuli. There is evidence of a partial overlap of brain regions recruited by the DMN and by social networks involved in the attribution of others' mental states (Li, Mai, & Liu, 2014; Mars et al., 2012). Deactivation of DMN

reflects promptness to respond to external stimuli, but activation is linked to self-reflection and to a range of self-related mental processes, including monitoring the external environment (Gusnard & Raichle, 2001; Mars et al., 2012).

Parental experience moderates brain responses underlying alarm and preoccupation (Purhonen et al., 2001; Seifritz et al., 2003). For example, mothers show higher levels of arousal and alert compared to nulliparous women when exposed to unexpected emotional stimuli (baby crying) as well as to neutral sounds (neutral word) (Purhonen et al., 2001). Moreover, responsiveness of women to salient stimuli could change over time with accrual of maternal experience. For example, alertness increases during the early postpartum period, and it has been suggested that high alertness in mothers facilitates prompt allocation of attentional resources to salient stimuli, most likely to promote rapid responsiveness (Purhonen, Valkonen-Korhonen, & Lehtonen, 2008). Differences in responsiveness to infant vocalizations between mothers and nulliparous women could be reflected in different involvement of the DMN. Higher levels of alertness to salient sounds in mothers contra nulliparous women possibly redistribute brain resources during experimental tasks, sparing brain resources for the benefit of cognitive processing of sounds in the environment. The similar pattern of activation of the DMN observed in mothers in both the self-oriented task and goal-oriented task might reflect the activation of social cognitive processes, which are oriented to interpreting emotional sounds.

Increasing evidence points to the involvement of the DMN in affective and cognitive tasks as well as in emotion processing (Buckner et al., 2008; Metzinger & Gallese, 2003). The magnitude of activation of this neural network during processing of external cues is associated with the level of relatedness of the stimulus to personal events and experiences and self-related emotional judgment and mood (Grimm et al., 2011). Infant cry, even if coming from an unfamiliar child, can activate mothers' thoughts and feelings reminiscent of their own experience in responding to their own infant's distress. In the present study, similar activation of the DMN in response to infant cry in both tasks can be explained by theories of social cognition as well as by self-relatedness of infant cry with mothers' own intimate experiences in taking care of their children. Understanding how the DMN is involved in responsiveness to infant cry, and how the DMN interacts with cerebral mechanisms activated by infant vocalizations and situational contexts in healthy mothers, can provide insights about cerebral mechanisms that shape maternal responsiveness.

The present study has several limitations, including a small sample size. The main aim was to uncover the potential role of situational contexts on responsiveness to infant cry. Situational context refers to the circumstances within which the adult and the child interact in the here and now and includes all parental daily activities, not just those related to infant care. To simulate situations in which participants underwent different infant-unrelated activities while listening to infant vocalizations, we used an experimental setting that provided cognitive tasks in a scanner and infant sounds from public databases. Any interpretation of findings and application to the real world should consider the artificiality of this situation. Additionally, findings in the present study are confined to a situational context with or close to neutral valence. In both the self-oriented and the goal-oriented tasks, the task-related stimuli were adjectives describing neutral personality traits. However, adjectives referring to human beings are never entirely neutral because the exact value of a neutral adjective is not an intrinsic property of the word itself, but depends on the context, the specific interpretation, and even the culture. To address this point, we implemented procedures to stay within a range of

neutrality. Interpretation of the greater sound interference observed in mothers than nulliparous women should be made with these specific situational contexts in mind. In general, the management of routines and duties tied to one's home, family, social world, and work can exert a strong impact on maternal infant caregiving (Bornstein, 2016). Future research should examine different situational contexts with different levels of stress and emotional-cognitive demands.

The present study aimed to investigate the potential role of situational contexts on mothers' and non-mothers' brain responses to infant cry versus other sounds. We found that mothers' brain responses, as compared to those of nulliparous women, were affected by emotional sounds while performing infant-unrelated tasks. Although both mothers and nulliparous women showed altered activation of the DMN when listening to emotional sounds, the involvement of the DMN in nonmothers was more impacted by task demands than by emotional sounds, whereas mothers showed similar involvement of the DMN in self-oriented and goal-oriented tasks, suggesting a redistribution of brain resources to accomplish these tasks while processing salient sounds.

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**Ethical Principles:** The authors affirm having followed professional ethical guidelines in preparing this work. These guidelines include obtaining informed consent from human participants, maintaining ethical treatment and respect for the rights of human or animal participants, and ensuring the privacy of participants and their data, such as ensuring that individual participants cannot be identified in reported results or from publicly available original or archival data.

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