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Neural correlates of empathy for babies in postpartum women: A longitudinal study

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Abstract

This study investigated the empathic response of postpartum women to babies in pain and the underlying neural mechanism. Postpartum women responded with more empathy and speed to babies over other stimuli compared to controls. Brain scans taken 3 months after birth showed more elevated activation in the Middle cingulate cortex/middle frontal gyrus (MCC/MFG) than the controls regardless of the task condition. When compared to the adult and neutral conditions, the posterior cingulate cortex (PCC) region was consistently more activated when postpartum women saw babies than controls. In addition, higher activation levels in the PCC region for the baby condition significantly correlated with faster and more empathic responses to babies. Considering that PCC is a core region for the theory of mind or mentalizing which requires cognitive reasoning to understand others, these results suggest that PCC might be a pivotal neural locus facilitating cognitive efforts to empathize with babies during the postpartum period. In a follow-up experiment at 12 months after birth, we were still able to observe higher activity in the MCC/MFG of postpartum women. However, previously observed PCC activation patterns disappeared 12 months after birth, despite the women's response patterns to babies still being maintained. These results suggest that the mentalizing process activated to empathize with babies in the early postpartum period becomes less cognitively demanding over time.

KEYWORDS
empathy, fMRI, mentalizing, middle cingulate cortex, posterior cingulate cortex, postpartum

1 | INTRODUCTION

Empathy refers to the ability to share the experience of others emotionally and cognitively. For mothers, empathy enables them to understand what their babies need and to provide adequate care (Stern, Borelli, & Smiley, 2015). This maternal empathy is also crucial for the normal development of children, as a higher level of maternal empathy facilitates secure attachment between mothers and babies (Oppenheim, Koren-Karie, & Sagi, 2001) and improves the empathic ability of children themselves and their prosocial behaviors (Farrant, Devine, Maybery, & Fletcher, 2012; Stern et al., 2015). Previous studies showed that new mothers had greater empathy than pregnant

women and nonmothers (Hodges, Kiel, Kramer, Veach, & Villanueva, 2010), increased affective empathy (Gómez-Carvajal et al., 2020), and elevated maternal sensitivity (Pearson, Lightman, & Evans, 2009) during the postpartum period. However, there have been few investigations on the neural mechanism of maternal empathy. Moreover, most of these few studies monitored the neural activities of mothers while they just watched or listened to their babies' pictures or cries, respectively, without evaluating the degree of each mother's empathy to those stimuli (Bembich et al., 2016; Noriuchi, Kikuchi, & Senoo, 2008; Swain et al., 2008). Thus, neural substrates reflecting the empathic behavioral response of mothers to babies have not been well examined.

Empathy is composed of affective and cognitive components. While affective empathy is associated with the spontaneous sharing of another's emotional state, cognitive empathy, also called mentalizing, requires the ability to infer another's the mental or emotional state (Frith & Frith, 2006; Shamay-Tsoory, 2011). Affective empathy recruits the empathy network which includes the middle cingulate cortex/middle frontal gyrus (MCC/MFG), inferior frontal gyrus, amygdala, and anterior insula, along with mirror neuron areas (Lamm, Decety, & Singer, 2011; Shamay-Tsoory, Aharon-Peretz, & Perry, 2009). On the other hand, the mentalizing network includes the posterior cingulate cortex (PCC), medial prefrontal cortex (MPFC), and bilateral temporal–parietal junctions (TPJ) which largely overlap with the default mode network (DMN) (Frith & Frith, 2006; Mitchell, 2009; Saxe & Powell, 2006).

Although a biological environment such as an increased level of oxytocin is thought to naturally foster the maternal empathic response to babies, parenting still requires considerable cognitive efforts to reflect infant states and sensitively differentiate baby signals based on past episodes (Atzil, Hendler, & Feldman, 2011). In line with this hypothesis, PCC, the main region of the theory of mind and mentalizing process (Bzdok et al., 2012; Lamm et al., 2011), was more activated when mothers showed emotional responses to their own babies than to other infants (Noriuchi et al., 2008). In addition, new mothers suffering from postpartum depression showed disrupted PCC connectivity, and researchers suggested that this neural alteration might underpin impaired abilities to represent their babies' needs and sensitively respond to their babies during postpartum depression (Chase, Moses-Kolko, Zevallos, Wisner, & Phillips, 2014). Considering that maternal empathic responses not only involve affective components but also require considerable cognitive effort, we hypothesized that the mentalizing network might play an important role in the empathy that new mothers show to their babies.

Therefore, in the present study, we tried to investigate underlying neural substrates for the empathic response of mothers using task-based functional MRI (fMRI). To do this, we implemented an empathy task for which the controls and postpartum women showed different empathic responses while watching babies or adults in pain compared with neutral stimuli. We analyzed whether the postpartum group showed distinct empathic behavioral or neural responses, particularly to babies compared with other conditions.

2 | METHODS

2.1 | Participants

For the initial experiment, twenty-five 20- to 40-year-old females 3 months after birth with uncomplicated pregnancies, term vaginal or Cesarean deliveries, and healthy babies were enrolled in the postpartum group. For the control group, 32 age-matched 20- to 40-year-old females who had not experienced pregnancy were recruited. All participants were native Koreans, right-handed, and had a normal or corrected-to-normal vision. Any participant who had been treated with hormonal preparations and psychotropic drugs, had experienced psychiatric, medical, or neurological comorbidities that could be related to cognitive disruption, or had head trauma that caused concussion or loss of consciousness were excluded. A follow-up experiment was also conducted with identical protocols in both the postpartum group and control group 9 months after the initial studies (12 months after birth).

The current study was approved by the Institutional Review Board of Severance Hospital, and all participants submitted written informed consent after listening to a full study explanation. The entire experiment procedure followed the latest version of the Declaration of Helsinki.

2.2 | Experiment overview

The experiment was made up of three sessions. In the pre-scan session, participants answered questionnaires for clinical and demographic characteristics, and blood samples were obtained for the estradiol assay. In the fMRI scanning session, resting-state scanning was conducted first and the remember-know encoding task, n-back task, prospective memory task, remember-know retrieval task, and empathy task were performed in the order mentioned. Then, three-dimensional (3D) T1-weighted structural images were collected. After scanning, participants answered a neuropsychological test battery to assess their cognitive function. In this present study, we reported only the empathy task data.

2.3 | Image acquisition

All scan images were obtained utilizing a 3T MR imaging unit (Discovery MR750; GE Healthcare, Milwaukee, WI) with an 8-channel head coil. We collected fMRI images with the subsequent parameters for the gradient-echo single-shot echoplanar imaging (GE-SS-EPI) sequence: TR = 2000 ms, TE = 30 ms, FOV = 240 × 240 mm^2, voxel size = 3.75 × 3.75 × 4.0 mm^3, flip angle = 90°, 33 axial slices tilted 30° from the AC–PC plane, no gap, and interleaved. During the functional sessions, experiment stimuli were projected on a screen behind the scanner, and participants watched the screen through a mirror attached to the head coil. Responses during the scan were collected using a magnet-compatible button box. For structural images, the 3D-T1-turbo field echo sequence was used with the following parameters: sagittal acquisition with TR = 8.3 ms, TE = 3.3 ms,

FOV = 198 × 220 mm^2, voxel size = 0.77 × 0.86 × 1.0 mm^3, 216 slices, flip angle = 12°, and no gap.

2.4 | Empathy task

The empathy task was implemented to measure the empathic response of participants to target stimuli while in the scanner. The stimuli included 15 neutral, 30 adults, and 30 baby pictures. In adult and baby pictures, all targets showed pain such as bleeding. Neutral pictures had no emotional objects. The whole task comprised of five blocks, and the order of the blocks was fixed as neutral-adult-baby-adult-baby in order to control for the emotional effect between blocks across participants. Each block had 15 trials, and each trial included 6 s of stimulus presentation and 2 s of fixation. During fixation, participants were required to give a response on how empathic they felt toward the target in the picture using a five-point scale. Response time was also measured in milliseconds.

2.5 | Task fMRI analysis

Preprocessing and general linear model (GLM) were performed using Statistical Parametric Mapping 8 (SPM8 with MATLAB 2014a, Wellcome Department of Cognitive Neurology, London, UK). First, EPI images were despised using the AFNI 3dDespike algorithm to mitigate the impact of outlier signals. Slice-timing correction was implemented by resampling all slices with the middle slice (i.e., 17th slice) as a criterion in the temporal order. Then, EPI images were realigned to the first volume to correct for the motion effect, and only images with ≤3 mm maximal displacement during the scan were included in the subsequent analyses. The EPI images were co-registered to the T1-weighted structural image and then spatially normalized to the Montreal Neurological Institute (MNI) template. The images were resampled into 3 × 3 × 3 mm size voxels, and spatial smoothing was executed using a Gaussian kernel which had a full width at half maximum (FWHM) of 8 mm. A 1/128 Hz high-pass filter was applied to eliminate low-frequency signal noise, and temporal autocorrelation was conducted with an AR(1) + white noise model.

The GLM included three separate task regressors for neutral, adult, and baby conditions, and these regressors were convolved with the canonical hemodynamic response function (HRF). The design matrix also included six motion parameters obtained from the realignment and a mean session regressor. Three beta images acquired from the model estimation of each condition were created for each participant, and we used these beta images for the group-level analysis. In the second-level analysis, 2 (groups) × 3 (conditions) full factorial ANOVA were implemented. The between-group factor included "Postpartum" and "Control" as groups, and the within-group factor included "Neutral," "Adult," and "Baby" as conditions. Multiple comparison correction was applied to all statistical analyses implementing the Monte Carlo simulation which corresponded to an alpha level of $p < .05$ by using the 3dClustSim algorithm from AFNI.

2.6 | Region-of-interest analysis

In order to define the associations between brain activation and behavioral results, a region-of-interest (ROI) analysis was conducted. First, significant clusters where the postpartum group showed distinct activation patterns compared with the controls were extracted. Then, values of % fMRI signal change were extracted from the significant clusters using the MarsBar toolbox for SPM (http://marsbar.sourceforge.net) with six motion regressors and the session mean regressor as covariates. The extracted fMRI values for each task condition were compared between groups. Correlation analyses were also conducted between the extracted fMRI values and behavioral results (i.e., response time and empathy rating).

3 | RESULTS

3.1 | Demographic characteristics

As we performed the initial studies, some modifications were made to the empathy task paradigm, and consequently five participants of the control group who underwent the experiment before the modifications were implanted were excluded. Two participants of the postpartum group and one participant of the control group were excluded due to head movement exceeding the priori maximum criterion of 3 mm. One participant of the control group was also excluded because of a technical failure to collect behavioral responses. Therefore, 23 of 25 participants in the postpartum group and 25 of 32 participants in the control group were finally included in the initial data analyses. During the follow-up period, four participants of the postpartum group and two of the control group became pregnant; eight participants of the postpartum group and seven of the control group withdrew participation from further experiments due to time burdens from childcare or work. One participant of the control group was excluded due to a technical failure to collect behavioral responses. Therefore, the follow-up experiments (mean interval = 9.58 months, *SD* = 2.22 months) were conducted in 11 of 23 participants in the postpartum group and 15 of 25 participants in the control group. Age and years of education did not differ between the postpartum and control group at both initial experiment and follow-up (Table 1).

No significant differences were found in age and years of education between the participants who did and did not conduct the follow-up experiments in the postpartum and control group, respectively at the initial study (Table S1).

3.2 | Behavioral results

At initial studies, the postpartum group responded significantly faster ($t[46] = 2.19$, $p = .033$) and showed more empathic responses ($t[46] = -3.36$, $p = .001$) than the controls to the baby condition only (Table 1). When we only included participants who underwent follow-up experiments, the results were almost the same: the postpartum

TABLE 1 Demographic characteristics and behavioral data

	Baseline			Follow-up		
	Control group (n = 25)	Postpartum group (n = 23)	p value	Control group (n = 15)	Postpartum group (n = 11)	p value
Demographic characteristics						
Age (y)	29.3 ± 4.3	30.8 ± 3.1	.172	29 (28–32)	30 (30–33)	.134
Duration of education (y)	16.0 (16.0–18.0)	16.0 (16.0–18.0)	.348	16 (16–18)	16 (16–16)	.330
Months after delivery (m)		3.0 (3.0–3.0)			12 (12–13)	
Follow-up interval (m)				9 (8–10)	9 (9–9)	.919
Behavioral data						
RT						
Adult condition	2417 ± 487	2453 ± 395	.780	2215 (1970–2699)	2003 (1875–2243)	.217
Baby condition	2522 ± 458	2240 ± 430	.033	2296 (2040–2726)	1881 (1715–2174)	.018
Neutral condition	2980 ± 646	2786 ± 587	.283	2513 ± 536	2391 ± 495	.400
Empathy rating						
Adult condition	4.3 (3.8–4.6)	4.2 (4.1–4.6)	.584	4.5 (3.9–4.6)	4.4 (4.3–4.5)	.384
Baby condition	4.0 (3.5–4.4)	4.5 (4.2–4.6)	.001	4.1 ± 0.4	4.4 ± 0.2	.038
Neutral condition	1.6 (1.4–1.9)	1.4 (1.3–1.7)	.456	1.3 (1.2–1.8)	1.3 (1.2–1.3)	.540

Note: Normally distributed data are expressed as mean ± *SD*; otherwise, data are expressed as medians with the interquartile range in parentheses.

group showed faster (t[24] = 1.94, p = .064) and more empathic response (t[24] = −2.18, p = .018) only to the baby condition, although the results for response time did not reach statistical significance (Table S1). These faster and more empathic responses shown by postpartum women to only babies remained significant even at the 9-month follow-up (Table 1).

No significant differences were found in the initial behavioral data between participants who did and did not conduct the follow-up experiments in the postpartum and control group, respectively (Table S2).

3.3 | fMRI results

fMRI data were also analyzed by conducting a full factorial analysis with a group (Postpartum vs. Control) x task conditions (Baby vs. Adult vs. Control).

3.3.1 | Group main effect analysis

At initial studies, the postpartum group showed more activation in the left lateral prefrontal cortex, bilateral MCC/MFG, and left amygdala extending to the putamen than the control group. After a 9-month follow-up, the group main effect remained in the MCC/MFG showing greater activation. In addition, the left frontal gyrus, left temporal pole, and left sensorimotor area also showed greater activity in the postpartum group at follow-up. No regions showed decreased activation in the postpartum group than the control group at both initial and follow-up studies (Figure 1).

An ROI analysis was conducted to see if the MCC/MFG area showed more activation across each condition. We found that values of % signal change extracted from the overlapping MCC/MFG cluster were significantly greater only for the adult and baby conditions at both initial and follow-up studies in the postpartum group than in the controls. However, this difference was not observed for the neutral condition. This implies that MCC/MFG responds nonspecifically to human targets rather than responding only to the baby condition. In order to identify any associations between the activation of the MCC/MFG region with nonspecific empathic behavior, we performed a correlation analysis between % signal change and behavioral values in the empathy condition which collapsed the adult and baby conditions.

For all initial data, the mean % signal change of the overlapping MCC/MFG cluster showed significant negative correlation with the mean response time for the adult and baby conditions (r = −0.33 [95% confidence interval (CI), −0.55 to −0.07], p = .023) and positive correlation with the mean empathy rating for the adult and baby conditions (rho = 0.24, p = .094) but the latter result did not reach statistical significance. When only participants who underwent the follow-up experiments were included in analysis, the difference was not significant despite the correlation coefficients (response time: r = −0.28, p = .162; empathy rating: rho = 0.28, p = .161) being similar to those from all participants at the initial study. The correlations were also not significant at the 9-month follow-up (Figure 2).

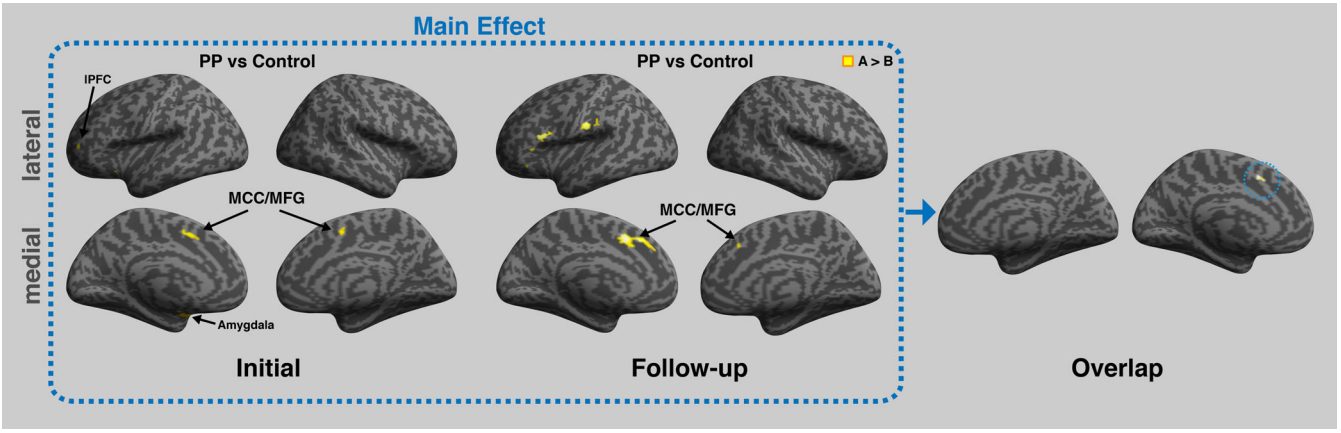

FIGURE 1 Group main effect results at initial study and follow-up. Right panel shows an overlapping MCC/MFG area between the initial and follow-up results. MCC/MFG = middle cingulate cortex/middle frontal gyrus, PP = postpartum

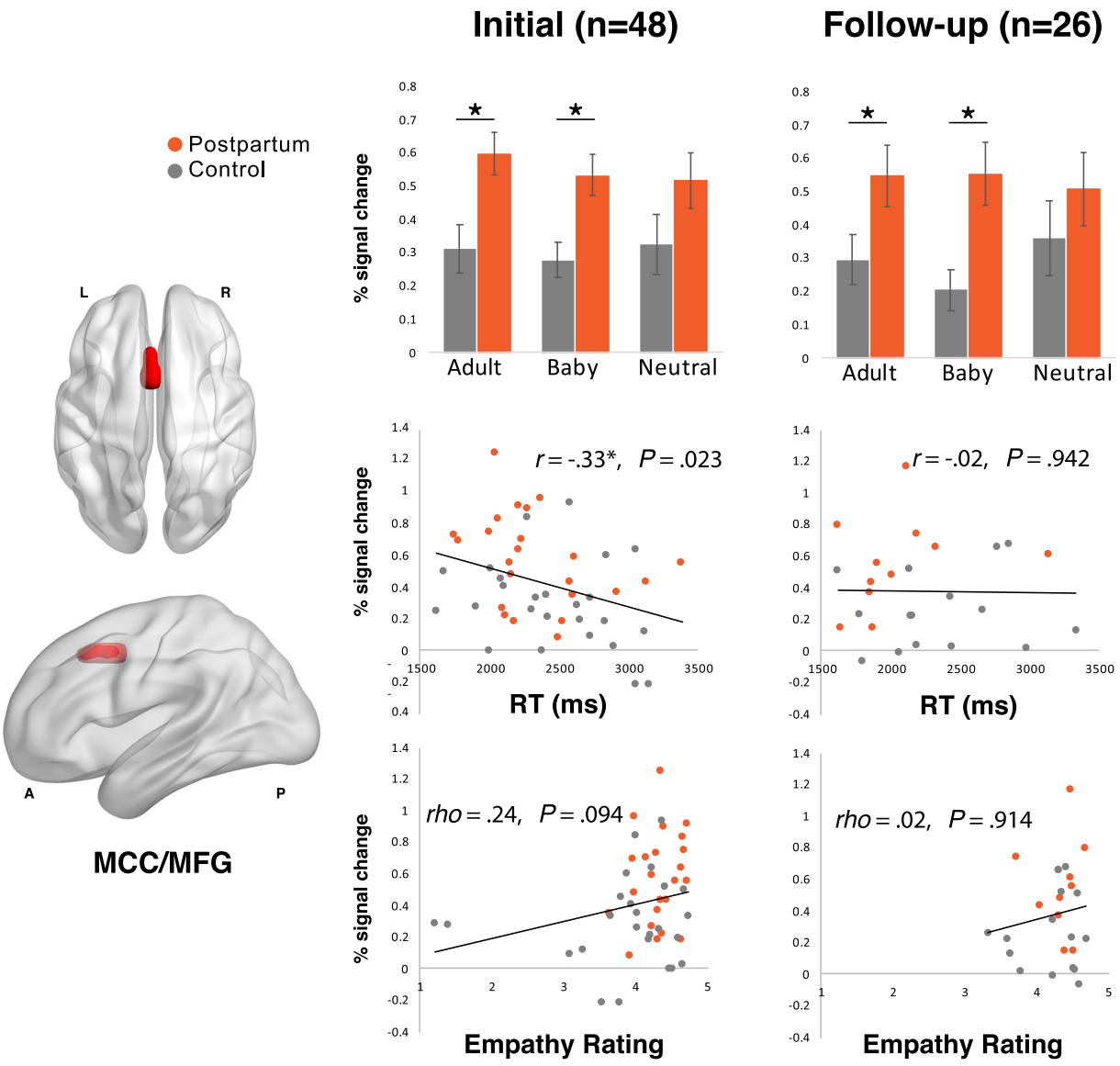

FIGURE 2 ROI analysis for MCC/MFG and correlation results. Correlation was analyzed between percent signal changes of MCC/MFG in (Adult and Baby) and behavior results for RT and rating in (Adult and Baby). The MCC/MFG cluster is the overlapping area where the postpartum group showed more activity than the controls both in initial and follow-up studies. The first column shows the results of all participants for the initial studies, and the second column shows the results of the follow-up data. MCC/MFG, middle cingulate cortex/middle frontal gyrus; RT, response time

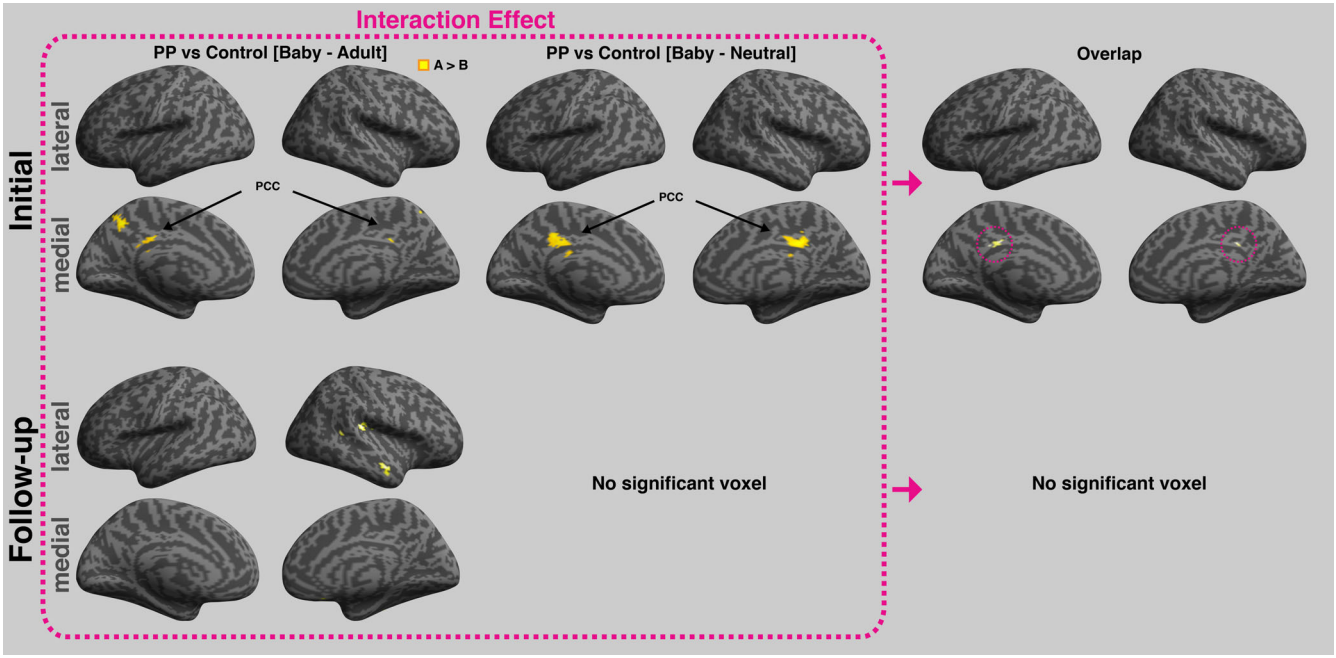

FIGURE 3 Interaction effect between group and task conditions in the initial and follow-up studies. Right panel shows an overlapping area between the first and second interaction results. PCC, posterior cingulate cortex; PP, postpartum

We also compared the two time points to assess if the areas where the postpartum group showed more activation than the controls differed between the initial and follow-up experiments in participants who had both initial and follow-up data available. We did not find any significant clusters with this comparison.

3.3.2 | Group x task condition interaction analysis

At initial studies, the postpartum group showed more activation in the precuneus and PCC compared to the control group in the (Baby–Adult) contrast. In addition, in the (Baby–Neutral) contrast, the PCC region also showed greater activity in the postpartum group, and this region partly overlapped with a significant cluster in the (Baby–Adult) contrast (Figure 3). There was no significant region for other interaction contrasts in the initial data. At 9-month follow-up, the significant cluster in PCC disappeared, but activation increased in the right superior temporal gyrus, right temporal pole, and right middle temporal gyrus for the (Baby-Adult) contrast in the postpartum group.

To explore whether the disappearance of the PCC cluster in the follow-up data were due to differences in the participants included in the initial and follow-up experiments, we performed an identical analysis on participants who underwent both initial and follow-up experiments. On voxel-wise analysis, no significant clusters were found. However, ROI analysis with the overlapping PCC cluster, which was extracted from the results of all participants with available initial data, revealed that % signal change was significantly greater in the postpartum group than in controls only for the baby condition in all participants (t[46] = −2.67, p = .010) as well as participants who underwent the follow-up experiments (t[24] = −2.95, p = .004) at initial studies, while the significance of the difference disappeared at follow-up (Figure 4). Furthermore, the initial % signal change of the overlapping PCC cluster was not significantly different between participants who did and did not undergo the follow-up experiments for all three task conditions.

In addition, we also examined the transient effect of PCC by conducting a regression analysis with dummy variables. The design matrix included six dummy variables (three task conditions; baby, adult, and neutral x two-time variables; initial and follow-up). We again found the impact of the baby condition to be significant for PCC activity at the initial experiment, but this significance disappeared at follow-up (t[60] = 3.052, p = .003, and t[60] = 1.301, p = .198, respectively).

On correlation analysis, the mean % signal change of the overlapping PCC cluster showed significant negative correlation with response time (r = −0.39 [95% CI, −0.59 to −0.16], p = .006) and positive correlation with empathy rating (rho = 0.31 [95% CI, 0.01 to 0.55], p = .035) only for the baby condition. However, these correlations were no longer significant at follow-up (Figure 4).

4 | DISCUSSION

In this study, we investigated the underlying neural substrates engaged in the maternal empathic responses of postpartum women. Postpartum women showed distinct empathic behavioral and neural responses to signs of babies suffering. Behaviorally, they showed faster and more empathic responses only to babies in pain. Considering that participants were not instructed to respond as quickly as

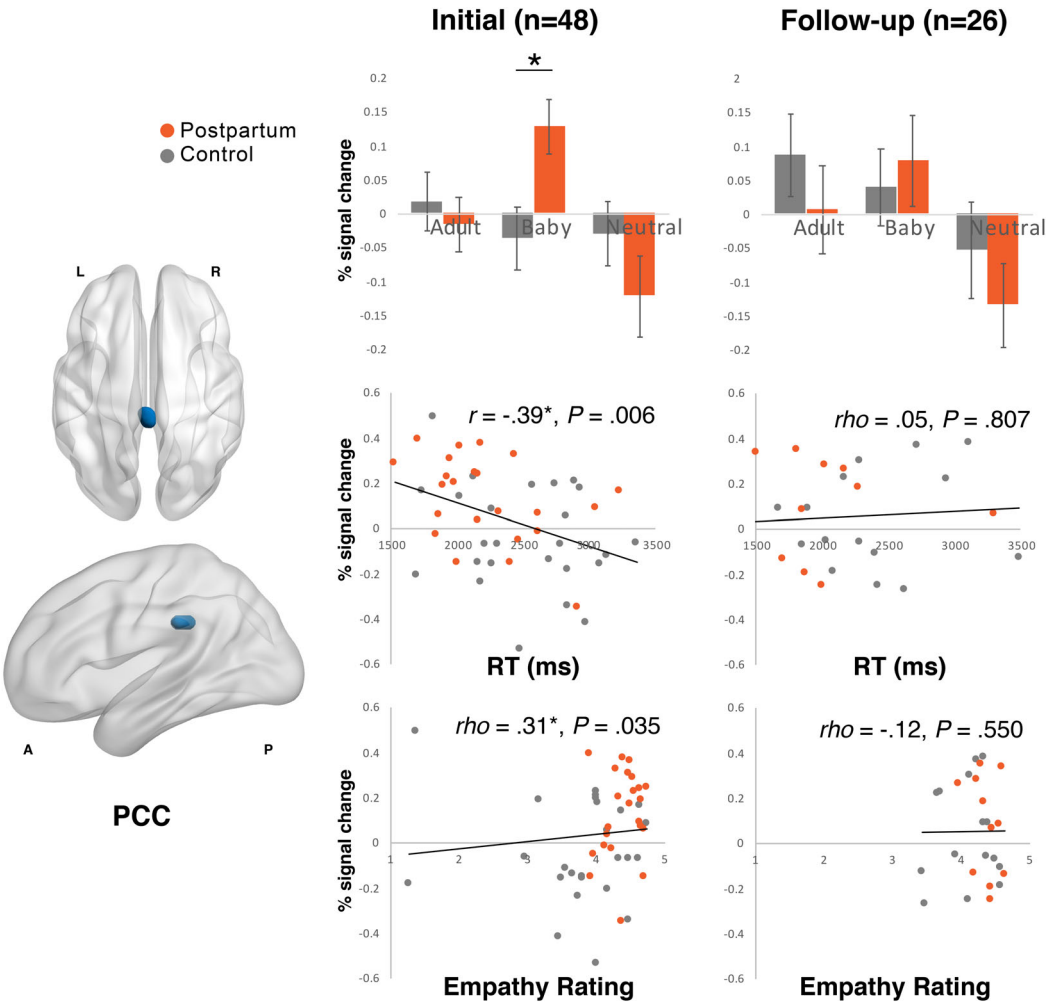

FIGURE 4 ROI analysis in the overlapping PCC and correlation results. Correlation was analyzed between percent signal changes of PCC in (Baby) and behavior results for RT and rating in (Baby). The PCC cluster is an overlapping area between significant clusters showing the interaction effect of PP versus Control (Baby–Adult) and PP versus Control (Baby–Neutral) in the initial data analysis with the initial data being available for all participants. The first column shows the results of all participants at the initial studies, and the second column shows the results of the follow-up data. PCC, posterior cingulate cortex; PP, postpartum; RT, response time

possible, this distinct behavioral pattern indicates a robust and spontaneous response unique to postpartum women. At the initial study, fMRI results showed that while MCC/MFG was more activated for both adults and babies in pain, PCC was selectively more activated for babies in distress in postpartum women 3 months after birth compared to the controls. Additionally, greater MCC/MFG activity was correlated with faster responses to the collapsed adult and baby condition, and PCC activation significantly correlated with more empathic and faster responses only to babies in distress. The follow-up results suggest that while nonspecific MCC/MFG activation for both adults and babies in pain lasted up to 1 year after birth, selective PCC activation for babies only was transient during the early postpartum period.

Postpartum women have shown impaired performance in general cognitive processing as well as in more specific cognitive functions such as working memory, delayed free recall, and prospective memory. (Anderson & Rutherford, 2012; Nah, Shin, Yi, Lee, & Han, 2018; Shin et al., 2018). Meanwhile, similar to our results, fast and strong empathic responses to babies during motherhood have been consistently reported (Hodges et al., 2010). Given that empathy might impose high loads on cognitive processing (Cameron et al., 2019), we can postulate that baby-related processing might be enhanced at the expense of the general cognitive process.

Previous studies investigating maternal empathy mostly compared the reactions of postpartum women to their own babies and others and found that mothers empathized more with their own babies than the controls (Bembich et al., 2016; Noriuchi et al., 2008; Swain et al., 2008). Unlike these previous studies, we did not use pictures of babies that belonged to any of the study participants. However, we could still observe strong and fast empathic responses by postpartum women to babies compared to adults or neutral things in pictures. This suggests that the distinct empathic response of a mother to her own baby might be generalized to other babies as well.

When postpartum women performed the empathy task, their MCC/MFC areas were hyperactivated across conditions compared

with the controls for initial studies performed 3 months after birth. The increased activation of MCC/MFC was maintained in the follow-up study performed 12 months after birth. MCC/MFC hyperactivation was associated with faster empathic responses to pain regardless of whether an adult or baby was being observed at the initial study. MCC/MFG has been considered as a core region for pain empathy in multiple studies (Bernhardt & Singer, 2012; Lamm et al., 2011; Morrison, Peelen, & Downing, 2007). A meta-analysis study reported that MCC/MFG is the most consistently activated region along with the anterior insula in studies on pain empathy (Lamm et al., 2011). Since MCC/MFG is mainly involved in interoceptive awareness and emotional processing (Fan, Duncan, de Greck, & Northoff, 2011; Kurth, Zilles, Fox, Laird, & Eickhoff, 2010), it might pass the processed emotional responses evoked by feeling pain onto the anterior insula. Anterior insula plays a role in the integration of information, which might be used for higher cognitive processing. This interplay of MCC/MFG and anterior insula might enable individual pain experience to be used as a model in order to understand others. All other regions (i.e., lateral prefrontal cortex, amygdala, bilateral inferior frontal gyrus, temporal pole, and sensorimotor area) showing more activation in postpartum women at initial or follow-up scans in our study have also been associated with pain empathy (Lamm et al., 2011). The higher activation of these regions in postpartum women to a nonspecific target might be related to nonselective social potentiation after delivery, which is supported by previous studies showing that affective empathy was enhanced in new mothers compared with pregnant women and non-mothers (Hodges et al., 2010; Santamaría-garcía & García, 2020). Moreover, our study also found that neural changes can last as long as 12 months after birth.

Regarding correlation, however, MCC/MFG activation was only correlated with response time but not with empathy rating at initial studies. The correlation with response speed was also not maintained in follow-up studies. In addition, the empathy network including the MCC/MFG area overlaps with the network for salience, reward, and emotional regulation (Refer to the Supplementary Material for further details). Among these networks, the salience network has been particularly reported as activating in response to stimuli which requires a state of alert for threat detection. Vigilant and harm-avoidant behaviors of mothers are crucial when protecting infants from possible threats (Barba-Müller, Craddock, Carmona, & Hoekzema, 2019). Thus, the activity pattern of MCC/MFG could also be explained by the salience mechanism. Our results are not able to confirm that the activity of MCC/MFG only reflects affective empathy. Therefore, future studies are needed in order to elucidate how MCC/MFG activation is related to empathy and salience in postpartum women.

In contrast to the long-lasting and nonspecific hyperactivation of MCC/MFG, neural changes in PCC were transient and more specific to babies like behavioral responses. In our study, PCC, a core region of the mentalizing network and cognitive empathy (Frith & Frith, 2006; Mitchell, 2009), was more activated only when postpartum women responded to babies in pain 3 months after birth, and its level of activation correlated with both empathy ratings and response times. While affective empathy occurs automatically by adopting another person's emotional state (Decety & Jackson, 2004; Singer & Lamm, 2009), mentalizing requires cognitive efforts to infer another's state based on previous personal experience (Frith & Frith, 2006). One study reported that increased PCC activation during the mentalizing process in patients with congenital insensitivity was highly correlated with higher empathy scores (Danziger, Faillenot, & Peyron, 2009). Since these patients cannot experience pain, they are unable to use their own pain experience to understand the pain of others, which is what would naturally happen in people with intact cognition. Thus, it is likely that more activation of PCC reflects more effort to imagine and simulate another's pain in patients with congenital insensitivity. Considering this, our result might suggest that increased PCC activation in postpartum women 3 months after birth is related to a higher level of cognitively controlled efforts by relatively new mothers to understand their babies.

Meanwhile, PCC hyperactivation only to the pain of babies disappeared at follow-up performed 12 months after birth. However, postpartum women 12 months after birth still showed faster and stronger empathic responses to babies' pain than the controls. This shows that the behavioral response of postpartum women to babies does not recruit significant PCC engagement any longer in the follow-up experiment. Although the participation rate for the follow-up experiment was low (48%), our results suggest the possibility that the mentalizing process for babies becomes less challenging over time in postpartum women. A possible explanation for this is that new mothers adapt to mentalizing babies' situations during the first year after birth. The disappearance of the PCC activity pattern at follow-up is in contrast to the hyperactivation of MCC/MFG in postpartum women, which persists to follow-up. Accordingly, we might assume that as a mother gains experience with childcare, cognitive processes for understanding babies might become more efficient, while an automatic affective empathic response remains. Future studies are warranted on the neural adaptation of empathy-related networks with behavioral responses to babies.

Several limitations of this study need to be considered. Maternal empathy might be closely related to hormonal change after delivery, but we could not examine the relationship of neural and behavioral empathic responses with the serum levels of hormones. Oxytocin might play an important role in the empathy that mothers have for infants (Rocchetti et al., 2014) and other prosocial behaviors. Future investigations need to be done on how hormonal changes such as those for oxytocin affect empathy networks and behavioral responses. The rate of loss to follow-up might be another limitation of this study. Since only 11 of 23 postpartum women participated in the follow-up experiment, our results are hardly free from selection bias due to the small number of participants followed. Thus, caution is needed when interpreting and generalizing the results derived from our follow-up data. In addition, the higher loss rate to follow-up in this population should be considered when constructing future studies.

Another thing to consider is possible differences between first-time mothers and experienced mothers. It is possible that women who have prior experience with pregnancy and baby care might be able to engage the cognitive empathy process more effectively and

easily. In our study, 17 of 23 postpartum women were first-time mothers, and we could not compare these first-time mothers with the experienced mothers because of insufficient sample size. If future studies could perform comparisons on a larger scale, they might be able to find neural results that imply that empathy for babies is less cognitively demanding for experienced mothers than first-time mothers, which could possibly corroborate our hypothesis.

In conclusion, the hyperactivation of PCC might be the neural underpinning for maternal empathy during the early postpartum period. The neural alteration disappeared 1 year after birth without changes to more empathic and faster responses to babies in pain, suggesting that the cognitive understanding required to empathize with babies in the early postpartum period might become more efficient over time.

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CONFLICT OF INTERESTS

The authors declare no potential conflicts of interest.

DATA AVAILABILITY STATEMENT

Data supporting the findings of this study are available on request from the corresponding author but are not publicly available due to privacy or ethical restrictions.

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of this article.

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