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Brain processes in women and men in response to emotive sounds

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ABSTRACT

Adult appropriate responding to salient infant signals is vital to child healthy
psychological development. Here we investigated how infant crying, relative to
other emotive sounds of infant laughing or adult crying, captures adults' brain
resources. In a sample of nulliparous women and men, we investigated the
effects of different sounds on cerebral activation of the default mode network
(DMN) and reaction times (RTs) while listeners engaged in self-referential
decision and syllabic counting tasks, which, respectively, require the activation
or deactivation of the DMN. Sounds affect women and men differently. In
women, infant crying deactivated the DMN during the self-referential decision
task; in men, female adult crying interfered with the DMN during the syllabic
counting task. These findings point to different brain processes underlying
responsiveness to crying in women and men and show that cerebral activation
is modulated by situational contexts in which crying occurs.

Keywords
Default Mode network, Emotive Sounds, Cry

Introduction

Crying is one of the first signals that infants use to communicate their needs, and crying constitutes an important cue to which caregivers readily respond (Cecchini, Lai, & Langher, 2007; Esposito & Venuti, 2008, 2010; Newman, 2007; Soltis, 2004). Infant crying augments physiological responses in listeners, and aversiveness ratings of infant cries are similarly high in mothers and fathers and in non parent women and men (Frodi & Lamb, 1978; Frodi, Lamb, Leavitt, & Donovan, 1978; Green, Jones, & Gustafson, 1987). Neuroimaging studies, mostly focused on parents, have revealed patterns of cerebral activity in response to infant negative vocalizations that are connected with approach behaviors and motivations for caregiving (Barrett & Fleming, 2011; Pechtel, Murray, Brumariu, & Lyons-Ruth, 2013; Swain, Kim, & Ho, 2011; Swain et al., 2008).

In the normal ecology of everyday life, a baby who begins to cry does not find adults waiting to assist him/ her, but crying erupts more probably while adults are otherwise engaged or simply immersed in their own thoughts. However, caregivers need to ensure they respond appropriately to infant cries regardless of the situation. To date, no studies have systematically investigated
the effects of infant crying on adult listeners who are busy in other self-oriented or externally oriented tasks and what repercussions being focused on cry-unrelated activities have for adult sensitivity.

Normally, spontaneous cognition and self-referential mental states involve consistent patterns of activation in the medial prefrontal cortex (MPFC) and posterior cingulate cortex (PCC), two midline nodes of the default mode network (DMN). Activation of the DMN occurs
during self-referential activity, thinking about some- thing not related to the environment (i.e., mind wandering), thinking about the self, retrieving autobiographical memories, mental imagery, envisioning the future, or taking another person's perspective (Buckner, Andrews-Hanna, & Schacter, 2008; Fox & Raichle, 2007; Greicius, Krasnow, Reiss, & Menon, 2003; Gusnard, Akbudak, Shulman, & Raichle, 2001; Gusnard & Raichle, 2001; Raichle et al., 2001; Raichle & Snyder, 2007). Reciprocally, the DMN is deactivated during goal-directed activities that call for externally oriented attention.

In a recent study (De Pisapia et al., 2013), we investigated cerebral responses associated with exposure to infant crying in a sample of healthy adults (with and without children) who were awake, at rest, and engaged in their own (mind-wandering) thoughts. People spend a great part of the day engaged in such self-related mental states. When we probed with baby cries (BC), we found that women exhibited greater deactivation of the DMN than men. This gender difference emerged regardless of parental status. One interpretation of the findings from this study is that the sudden onset of a baby's cry elicits in women a greater readiness to disengage cognitive resources from internally focused thoughts in order to refocus on the salient external sound. To further investigate this male/female difference in a separate study (Messina et al., 2015), we recorded motor-evoked responses (MERs) from arm muscles as

produced by transcranial magnetic stimulation (TMS) in young adults while listening to infant
cries. We found an excitatory modulation of☐ MERs at 100 ms from the onset of infant cry specific to females, who thus appear to be tuned to respond to infant cries with automatic motor excitation.

In the present study we followed on those results. In the first fMRI study, we directly compared infant crying to other salient human sounds while participants simultaneously engaged in two contrasting cry-unrelated activities that required, respectively, activation or deactivation of the DMN. One was a self-referential task to decide if an adjective described the participant's own personality (self-oriented task = SOT), and the other was a syllabic counting task to decide if an adjective had three or four syllables (goal-oriented task = GOT) (Debbané et al., 2014; Maguire & Mummery, 1999; van der Meer, Costafreda, Aleman, & David, 2010). As there
is evidence that performance in goal-oriented tasks is associated with efficient DMN deactivation, combined with greater involvement of executive functions (Anticevic et al., 2012; De Pisapia, Turatto, Lin, Jovicich, & Caramazza, 2012; Fox, Snyder, Zacks, & Raichle, 2006; Mennes et al., 2011), in a second behavioral study, we tested reaction times (RTs) in the same two tasks tested in the fMRI study.

We expected to find women more distracted by infant crying than men in both tasks, resulting in greater deactivation of the DMN in the self-oriented task and lesser deactivation of the DMN in the goal oriented task. We also expected to find in women slower RTs related to performance on the two cry-unrelated tasks in association with the onset of infant crying. Our assumption was that women's attention would be more readily engaged by infant stimuli therefore influencing their behavior. Because De Pisapia et al. (2013) used white noise as the only control sound for infant cries, they could not discriminate whether DMN deactivation (shown by women) was specifically linked to infant cry or generalizes to other baby sounds or other emotional sounds. In the present study, control conditions included other human emotional sounds (baby laugh and adult cry) as well as non☐ human/non- ☐ emotional sounds (noise).

Methods

fMRI Experiment 1

Participants

We recruited 22 healthy nulliparous adults (11 females, M age 20.5 ± 4.04 years; 11 males, M age 25.25 ± 2.77 years) through the University of Trento. Inclusion criteria were to be a non☐ parent, 18 to 30 years of age, and having no personal or family history of neurological or mental disorders. 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 stimuli

Each participant listened to 80 different sounds: 20 baby cries (BC; hunger cries from 1-year-olds), 20 baby laughs (BL; from 1- to 2-year-olds), 20 female adult cries (AC), and 20 control noise sounds (CS). Human vocalizations were excerpted from files of sounds in public online databases (Ljung & Wahlforss, 2008; Nokes, 1997). We selected 5000ms from the original cry and laugh sounds (sampling rates 44.1 kHz/32bit), and the resulting sounds were noise corrected (removing any constant background sounds) And matched for volume using Audacity 2.0.4 (http://auda city.sourceforge.net). Fundamental frequency ($\Box$ f0) showed variations among sounds ($F(2,57) = 3.71$, $p < .03$). The post hoc Tukey test showed that f(0) was higher in BL (M 549.82 ± 100.78 Hz) than BC (M 482.25 ± 73.17 Hz, $p < .023$) and AC (M 480.80 ± 98.05, $p < .020$), whereas f (0) between AC and BC did not differ. CS were built to generate noise sounds as a control condition for baby cry to take into consideration morphological features of the temporal pattern expressed by infant cries (Lorberbaum et al., 2002; Swain et al., 2008). Using Cool Edit Pro Version 1.2 Syntrillium Software (http://www.syntrillium.com), we generated white noise streams of 5000 ms, the same duration as the human sounds. To ensure the same temporal modulation as present in infant crying, white noises were perfectly matched for intensity and range of frequencies to$\Box$ BC.

Visual stimuli

Visual stimuli were 80 personality adjectives that were extracted from a set of 242 adjectives that were previously assessed by 11 adults for their positive and
negative quality using a 7-point scale ranging from −3 (extremely negative) to 0 (neutral) to 3 (extremely positive). Given our interest in testing the effect of the emotive sounds, to avoid any confound we selected only adjectives that were neutral (e.g., forgetful, impatient, careful), rather than positive (e.g., gentle, expert, good), and negative (e.g., rude, sloppy, unfair). In the SOT, the number of syllables in the adjectives (40 items) ranged between 2$\Box$ and 5. For the GOT, we used adjectives consisting of 3 (20 items) and 4 (20 items) syllables.

Experimental tasks

Participants underwent two different experimental tasks. In the SOT, participants had to decide whether the personality adjective presented at the center of the screen described their own personality (yes or no). In the GOT, participants had to decide whether the personality adjective was composed of 3 or 4 syllables.

Experimental design

We implemented a 2×☐ 4×☐ 2 repeated-measures factorial design. The first 2-level within-subjects factor was the task, the SOT and the GOT. The design provided for two tasks that alternated in random order, one task at a time in each trial. The second 4-level within-subjects factor was the sound (BC, BL, AC, and CS). Sounds were irrelevant to the task, and the order of sounds was random. Given our interest in investigating differences between men and women, the third 2-level between subjects factor was gender (Figure 1).

Experimental procedure

The investigator briefly explained what the experimental tasks required, and participants underwent a training block. Stimulation consisted of simultaneous presentation of a task-related visual adjective and a task-unrelated sound. In the training block, participants were told about the simultaneous presentation of the adjective and the sound and were asked to focus on the task. After presentation of a fixation point (4000 ms), one of the four sounds was played. Simultaneously with the onset of the sound, the task was presented, and one adjective appeared in the center of the screen. A sentence at the top of the screen informed participants which task to perform (e.g., "I am a person" or "The number of syllables is"). Participants were instructed to respond as fast as possible over a total of 80 randomized trials (40 for each task). Each trial consisted of one sound and one task lasting 5000 ms (Figure 1).

Image acquisition

Functional images were acquired through a whole-body scanner equipped with a Bruker MedSpec MRI magnet of 4 Tesla (T) and Siemens Sonata gradients of 40 mT/m, a system with 8-channel coils for signal reception. Functional T2*-weighted images were obtained with a standard echo planar imaging (EPI) technique, acquiring 37 slices of the brain volume with the following para- meters: slice thickness = 3 mm, 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. The total acquisition time was about 11 min, the number of functional volumes was 334. For each participant we also acquired high-resolution T1-weighted structural images (MPRAGE, 176 axial slices, slice thickness = 1 mm,
FOV = 256 mm, EN (inversion time) = 1020 ms, flip angle = 7 °, TR = 2700 ms, TE = 4.18 ms). Image pre☐ processing and analysis All analyses of fMRI data were carried out with BrainVoyager QX version 2.8 (http://www.brainvoyager. com/) running on a Windows OS. The experimental task session was preceded by☐ four dummy scans to eliminate the magnetic saturation effect. Pre☐ processing steps of functional images provided for 3D motion correction using trilinear interpolation and linear trend removal, realigning of each volume to the first volume of the session to correct artifacts due to movements of the head. Then, the realigned functional 2D images were co registered with the 3D anatomical image. To improve the co registration process, the 3D anatomical image was corrected for inhomogeneity (2 cycles), and brain tissue was segregated from head tissue. Functional 2D images were translated and rotated into the AC-PC plane, and

eight landmarks for the borders of the cerebrum were defined. After pre☐ processing, functional images were normalized into a Talairach space (Talairach & Tournoux, 1988), and an 8- mm full-width at half-maximum Gaussian smoothing was applied. Eight predictors, one for each sound condition (BC, BL, AC, and CS) in each task (SOT and GOT) were convolved with the hemodynamic response function (HRF). For statistical analysis of the activation blocks defined by the experimental paradigm, we defined a general linear model (GLM) with the predictors of experimental conditions (2 tasks * 4 sounds) to create a whole brain statistical map for each participant. The first whole brain analysis (random-effects GLM, p(Bonf) <. 05) aimed to probe the % signal difference of the cerebral activation

in association with the two tasks (SOT and GOT) in brain regions compatible with the DMN (namely MPFC, PCC, bilateral inferior parietal lobe [IPL]) (Buckner et al., 2008), thereby validating the experimental design. The analysis

that followed aimed to investigate the modulation of brain activity in the☐ MPFC☐ and☐ PCC☐, the two midline nodes of the☐ DMN☐ . A priori region of interests (ROIs) were defined anatomically using the same masks used in De Pisapia et al. (2013): MPFC – x=3, y=49, z = 20 (3926 voxels) and PCC –x = −1, y = −46, z = 25 (1827 voxels). The ROI analysis was conducted as a follow-up. First, we con- ducted a whole brain contrast of all conditions > rest (random-effects GLM, q(FDR) < .05) (Genovese, Lazar, & Nichols, 2002). Next, individual beta values evoked by each condition were retrieved within each ROI, and a random-effects GLM analysis was carried out to test for between-group differences in main effects and interaction effects.
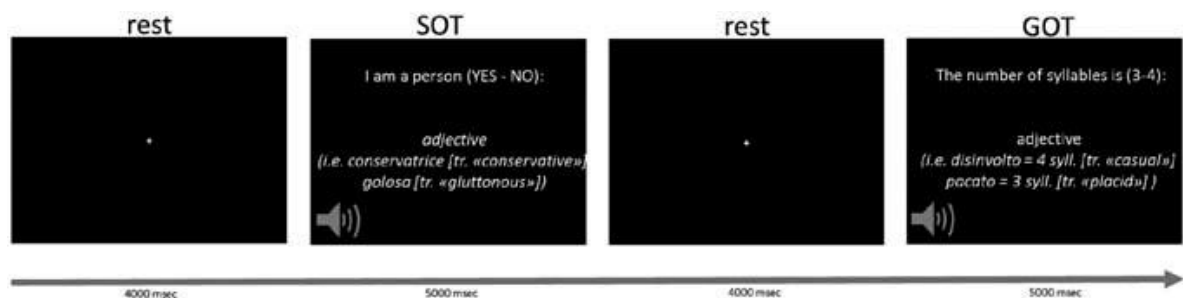

Figure 1. Experimental setup. Simultaneous with the onset of a sound, the task was presented and one personality adjective compared at the center of the screen. The experimental session provided for two tasks (SOT and GOT); one block presented one task a time. Abbreviations: SOT = self-oriented task, GOT = goal-oriented task.

Behavioral experiment 2

Participants

We recruited 23 healthy non☐ parent adults (12 females, M age 22.91 ± 2.95 years; 11 males, 23.00 ± 2.83 years). Recruitment procedures and

inclusion/exclusion criteria were the same as for the fMRI Experiment 1. Stimuli and procedure Tasks and stimuli were the same as in the fMRI Experiment 1. Response times (RTs) were collected from button response box.

Results

fMRI Experiment 1

First, we looked at differences in cerebral activity between the SOT and the GOT (Figure 2). Data fromthewhole brain analysis were submitted to two-tailed repeated-measures ANOVA. We found greater activity during the SOT than the GOT ($F(1,19) = 50.75$, $p < 0.001$, p(Bonf) < .05) inmidline structures compatible with the DMN, namely PCC (BA 31), vMPFC (BA 10),medial SFG (BA6) that included dMPFC BA 24 and 32, bilateral☐ IPL (BA 40), and left middle temporal
gyrus MTG (BA 21, 39). See Table 1 for all activated brain regions. Analyses revealed significant effects for sound ($F (3,57) = 5.80$, $p = .002$) in bilateral STG (BA22) (Table 2). No significant main effect of gender or the☐ two- or☐ three-way interactions emerged.

A main aim of Experiment 1 was to investigate gender differences with regard to whether task-unrelated infant and control sounds influence activation of the DMN associated with the execution of a task. In the following analysis, we focused on two specific ROIs, the midline nodes of the DMN identified previously (De Pisapia et al., 2013). Medial prefrontal cortex (MPFC) We observed a significant main effect of task (SOT versus GOT) in the MPFC ($F(1,19) = 75.12$, $p < .001$, $\eta p 2 = .790$). This anterior medial node of the DMN activated in the SOT and deactivated in the GOT. Gender and sound main effects and all☐ two- and☐ three way interactions were not significant. Because there was a strong effect of task, the following two-tailed
repeated-measures ANOVAs aimed to disaggregate the main effects of sound and gender and the☐ two-way interaction in each task separately. Analyses revealed a significant☐ two-way interaction of sound and gender in the GOT, but not in SOT. No significant main effects in both SOT and GOT emerged.

- SOT : Although women deactivated more than men the MPFC, especially at the onset of infant cry (Figure 4), the analysis revealed no gender differences in the contrasts of interest, namely pairwise comparisons between infant crying and other sounds (Figure 3a).
- GOT : Within-subject contrasts showed that the sound * gender interaction in the GOT was significant for infant crying (BC) versus adult crying (AC) ($F (1,20) = 4.58$, $p = .045$, $\eta p 2 = .186$). We found a significant gender difference in BOLD signals comparing adult cry with baby cry (female BOLD ACBC = -.063 ± .101; male BOLD AC-BC = .258 ± .110; $t(20) = 2.25$, $p = .036$) (Figure 3b). Men showed weaker deactivation of the MPFC in association with adult crying compared to infant crying).
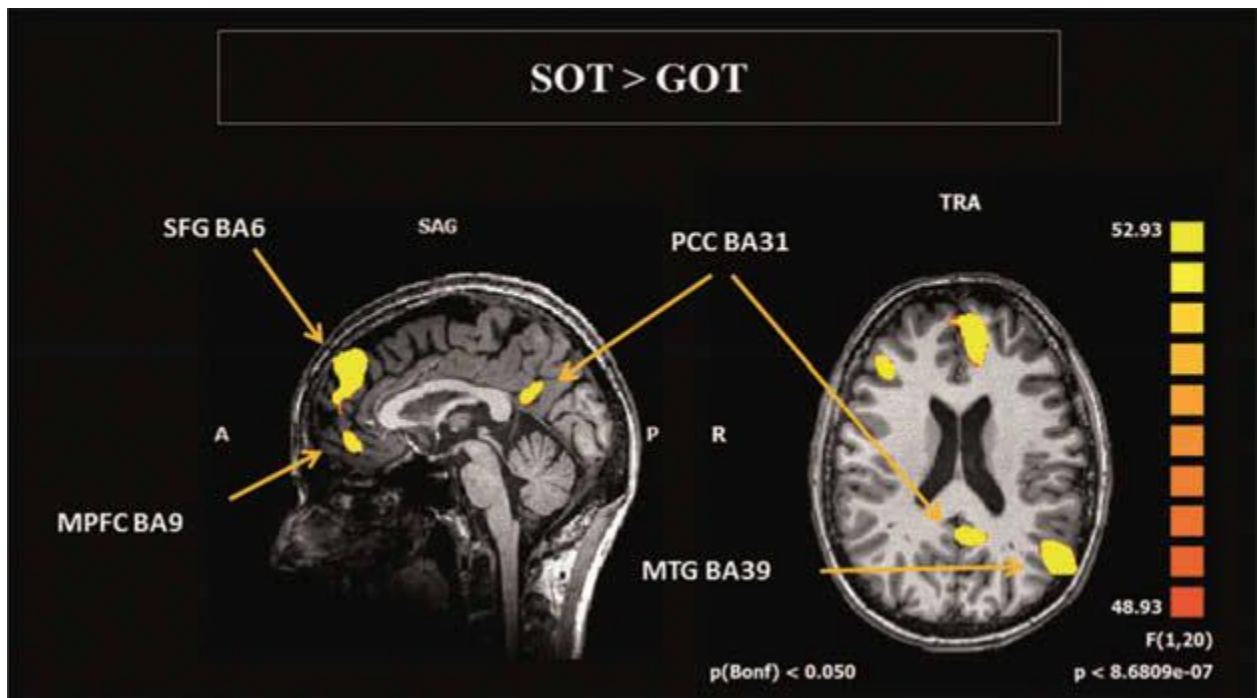
Figure 2. Cerebral activation in main effect of task. Brain regions that showed greater activation in the SOT in contrast to the GOT (p (Bonf) < .05). The self-oriented task involved a cerebral network which was compatible with the DMN. Abbreviations: SOT = selforiented task, GOT = goal-oriented task, MPFC = medial prefrontal cortex, SFG = superior frontal gyrus, PCC = posterior cingulate cortex, MTG = middle temporal gyrus.

Table 1. Main effect of *task*.

	BA	Left/right	x	y	z	Voxels at p(Bonf) < .05	F
Superior frontal gyrus	6	L	−13	19	57	18,748	207,251
Middle temporal gyrus	39	L	−49	−62	21	2930	164,357
Inferior parietal lobule	40	R	47	−35	42	3456	135,766
Inferior frontal gyrus	47	L	−46	25	−9	3532	122,766
Middle frontal gyrus	9	R	35	31	21	1702	122,180
Inferior parietal lobule	40	L	−34	−47	39	2870	108,429
Posterior cingulate	31	L	−7	−50	24	1989	94,064
Precentral gyrus	6	L	−46	1	27	431	92,451
Middle temporal gyrus	21	L	−52	−14	−18	3088	88,619
Precuneus	7	R	26	−65	33	1002	87,901
Lingual gyrus	18	L	−10	−71	−3	1555	86,482
Middle frontal gyrus	6	L	−40	13	48	955	83,403
Medial frontal gyrus	10	L	−1	46	−6	783	79,355
Declive	*	R	11	−74	−12	562	73,428
Cuneus	17	R	14	−89	6	766	72,879

Self-referential decision (SOT) *versus* syllable counting (GOT). Brain regions compatible with the default mode network are highlighted in italics. BA = Brodmann area. Left/right = left or right hemisphere. x, y, and z coordinates are in Talairach space. Voxels = cluster size in voxels.

Table 2. Main effect of *sound*.

	BA	Left/right	x	y	z	Voxels at p(Bonf) < .05	F
Superior temporal gyrus	22	R	53.0	−8.0	0.0	13,980	105,452
Superior temporal gyrus	22	L	−52.0	−11.0	3.0	11,949	89,594

BA = Brodmann area. Left/right = left or right hemisphere. x, y, and z coordinates are in Talairach space. Voxels = cluster size in voxels.

Posterior cingulate cortex (PCC)

We observed a significant main effect of task (SOT versus GOT) in the PCC ($F_{(1,19)} = 45.912$, $p < .001$, $\eta p\ 2 = .697$) and a trend in the interaction of task * sound * gender ($F_{(1,19)} = 2.164$, $p = .101$, $\eta p\ 2 = .098$). We did not observe any significant main effects of sound or gender or □ two-way interactions. Given the strong main effect of the task and the trend in the □ three-way interaction, the following two-tailed repeated-measures ANOVAs focused on the main effects of sound and gender and the □ two-way interaction in each task separately. Analyses showed a significant □ two-way interaction of sound and gender in the GOT, and a trend in the SOT. Main effects of sound and gender in SOT and GOT were not significant.

- SOT: We found a trend in within-subject sound * gender interaction in the contrast of infant crying (BC) versus adult crying (AC) ($F_{(1,,20)} = 2.89$, $p = .104$, $\eta p\ 2 = .126$). Between-group comparisons revealed that women deactivated the PCC more than men when listening to infant crying in contrast to adult crying (female $BOLD_{AC-BC} = -.165 \pm .053$; male $BOLD_{ACBC} = .008 \pm .075$; $t_{(20)} = 1.78$, $p = .090$) and infant 360 laughing (female $BOLD_{BC-BL} = -.170 \pm .091$; male $BOLD_{BC-BL} = .039 \pm .088$; $t_{(20)} = 1.73$, $p = .099$) (Figure 3c). This deactivation in response to infant cries (Figure 4) occurred in women while engaged in a SOT, which positively activates the DMN. Looking at this contrast in women and men independently, the follow-up LSD (least significant difference) pairwise comparisons showed greater deactivation of the posterior node of the DMN in association with the onset of infant crying in women compared with adult crying ($t_{(10)} = 3.10$, $p = .011$), but not in men ($t10 = 0.11$, $p = .917$).
- GOT : As in the MPFC, within-subject contrasts showed a significant sound * gender interaction in the contrast of infant crying (BC) versus adult crying (AC) ($F_{(1,20)} = 4.696$, $p = .042$, $\eta p\ 2 = .190$). From between-group comparisons, we found lesser cerebral deactivation of the PCC in men than in women with the onset of adult crying (female $BOLD_{AC-BC} = -.081 \pm .091$; male $BOLD_{AC-\ BC} = .248 \pm .122$; $t_{(20)} = 2.27$, $p = .034$) Figure 3d). No other significant effects emerged.
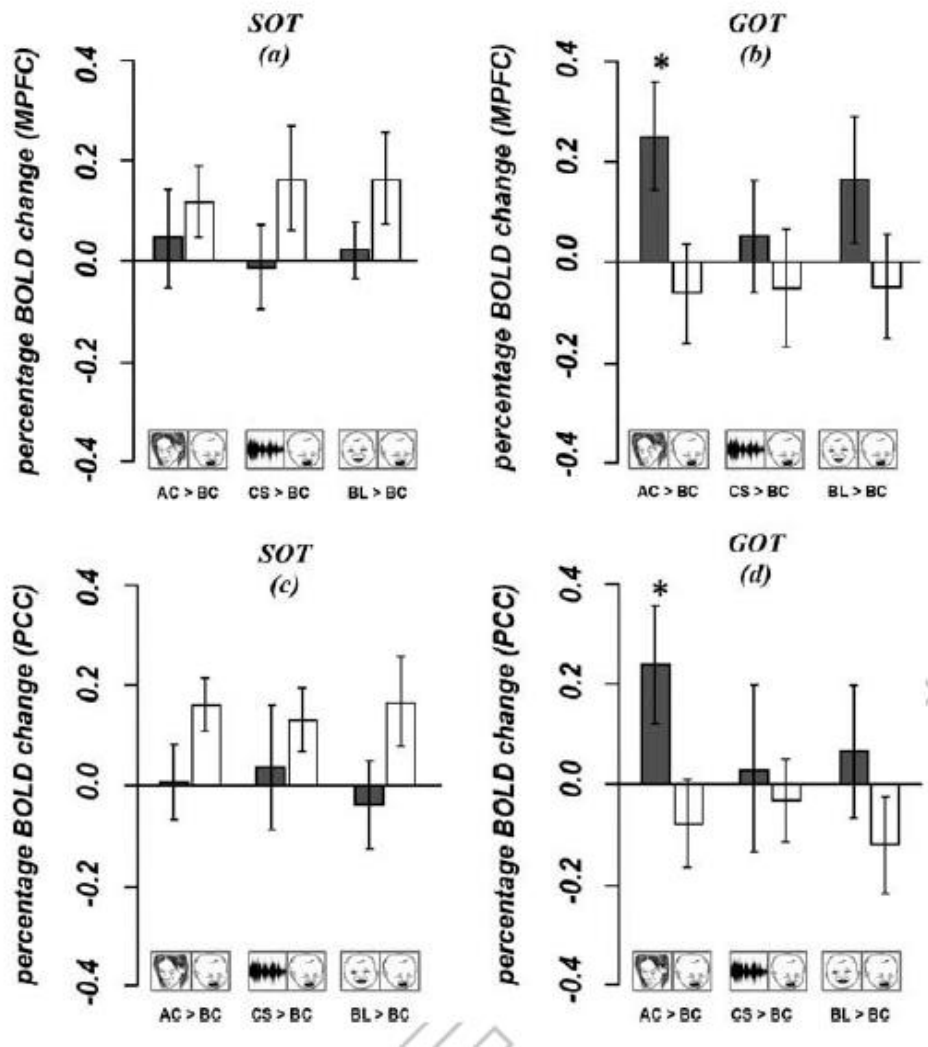
Figure 3. ROI analysis focused on MPFC and PCC in the SOT and the GOT. Gray and white bars represent, respectively, men and women. Panels (a) and (b) represent the BOLD signals change in the MPFC during the SOT and GOT in the following contrasts: AC > BC, CS > BC, and BL > BC. Panels (c) and (d) represent the BOLD signals change in the PCC during the SOT and GOT with the same contrasts: AC > BC, CS > BC, and BL > BC. Abbreviations: SOT = self-oriented task, GOT = goal-oriented task, ROI = region of interest, MPFC = medial prefrontal cortex, PCC = posterior cingulate cortex, BC = baby crying, AC = adult crying, CS = control sound, and BL = baby laughing.
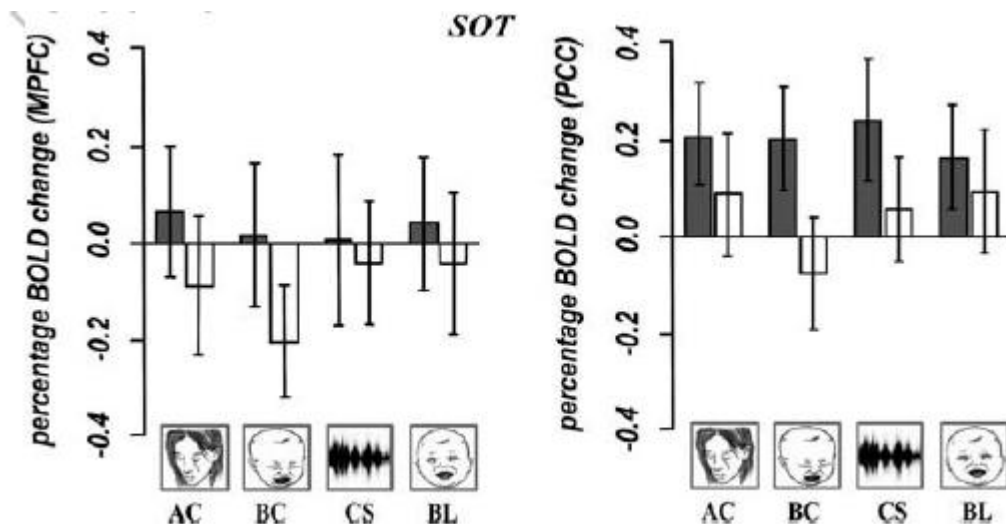(*) $p < .05$.

Figure 4. ROI analysis focused on MPFC and PCC in the SOT. Bars represent the BOLD signal change in association with each sound: AC, BC, CS, and BL.☐ Gray and white bars represent, respectively, men and women. Abbreviations: SOT = self-oriented task, MPFC = medial prefrontal cortex, PCC = posterior cingulate cortex, BC = baby crying, AC = adult crying, CS = control sound, and BL = baby laughing.

Behavioral experiment 2

Because☐ RT☐ was not normally distributed, raw RT data in ms were transformed using a natural logarithm and submitted to repeated-measures ANOVA. We found a significant main effect of task ($F(1,21) = 33.24$, $p = .001$, Hp 2 = .613). Sound and gender factors and☐ two-way interactions did not reach significance. Furthermore, we found a trend to significance in the☐ three-way interaction task * sound * gender ($F(3,63) = 2.19$, $p = .098$, ηp 2 = .094). Given the significant main effect of task, data were submitted to further two-tailed repeated measures ANOVAs to explore the main effects of sound and gender and their interactions in each task separately. Analyses showed a significant ☐ two-way sound * gender interaction in GOT. No significant main effects of sound and gender in SOT and GOT or the☐ two way interaction in SOT emerged. To be consistent with the fMRI results, the significant contrasts of the behavioral data are reported for each task separately.

- SOT: The analysis revealed no significant main effects or interactions.
- GOT: The interaction between sound and gender was significant ($F(1,63) = 2.80$, $p = .047$, ηp 2 = .117). Within-subject contrasts revealed that the sound * gender interaction was significant in the contrast infant crying (BC) versus adult crying (AC) ($F(1,21) = 4.69$, $p = .042$, ηp 2 = .183). Between-group comparisons showed that men were slower in association with AC than BC, whereas women showed the opposite pattern (femaleACBC = −86.041 ± 82.797 ms; male AC −BC = 198.416 ± 96.626 ms; $t(21) = −2.15$, $p = .042$) (Figure 5).
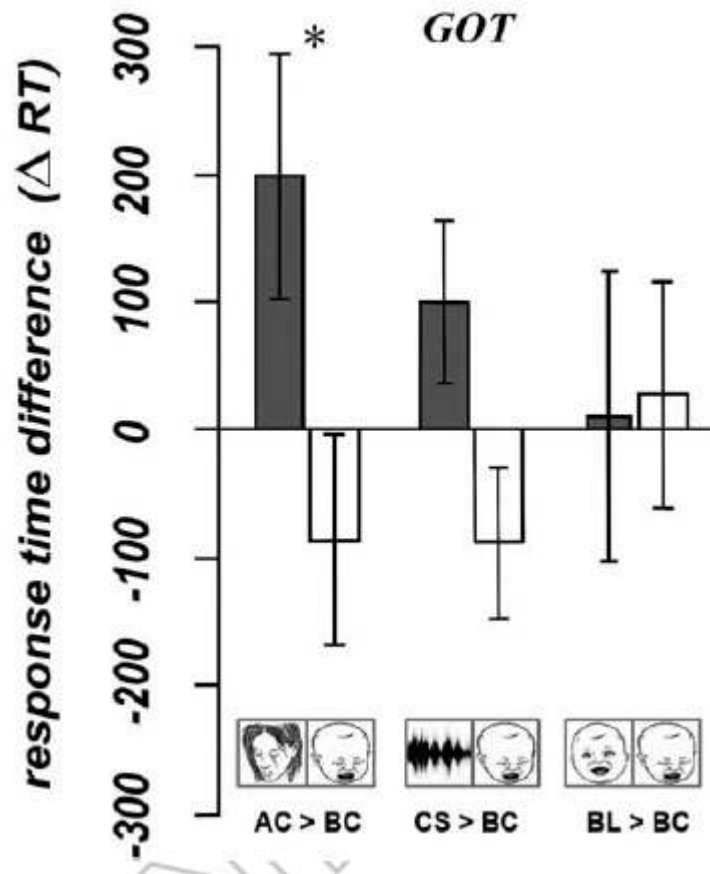
Figure 5. Reaction time (ms). Plots represent participants' performances in the GOT, while they were listening to adult cry (AC), baby cry (BC), baby laugh (BL), and the noise control sound (CS). Gender differences were found in AC > BC contrast. ⬚ Gray and white bars represent, respectively, men and women. Abbreviations: GOT = goal-oriented task, BC = baby crying, AC = adult crying, CS = control sound, and BL = baby laughing. (*) $p < .05$.

Discussion

Our general purpose was to better understand how brain processes during listening to infant crying differ between women and men. We investigated the effect of the onset of infant crying versus control sounds on brain processes activated during concurrent self- and externally oriented activities (self-oriented task [SOT] = self-referential decision; goal-oriented task [GOT] = syllabic counting), two tasks that engage the ⬚ DMN⬚ in contrasting ways (Fox, Zhang, Snyder, & Raichle, 2009; Spreng, Stevens, Chamberlain, Gilmore, & Schacter, 2010; van der Meer et al., 2010). We focused on activation of the⬚ MPFC⬚ and⬚ PCC , the two main nodes of the DMN, previously identified in listeners' responsiveness to infant crying (De Pisapia et al., 2013).

In the fMRI study, looking at the cerebral activation of the MPFC and PCC during the SOT, the sound effect was observed during infant crying (in contrast with adult crying) in women (not in men). Women showed greater deactivation in the PCC. The DMN is activated when the attentional focus of

individuals is on self monitoring processes about their own feelings, thoughts, episodic memories, and body perception, but also during unfocused attention states (Gusnard et al., 2001; Shulman et al., 1997). The DMN is also activated in self-related mental states, like deciding about one's own personality in the SOT (van der Meer et al., 2010; Whitfield-Gabrieli et al., 2011), and the deactivation we observed in women suggests a shift of attention from the SOT to the sudden infant cry sound (Di & Biswal, 2014; Sridharan, Levitin, & Menon, 2008). In general, auditory perception tasks deactivate the DMN (Abbott, Kim, Sponheim, Bustillo, & Calhoun, 2010; Binder et al., 1999; McKiernan, Kaufman, Kucera- Thompson, & Binder, 2003). However, it has been reported that several factors influence the degree of the deactivation in this network, including the load of the task, the discriminability and presentation rate of stimuli, and the emotive valence and salience of the stimuli (Antrobus, 1968; Antrobus, Singer, & Greenberg, 1966; Binder et al., 1999; Giambra, 1995; McGuire, Paulesu, Frackowiak, & Frith, 1996; McKiernan et al., 2003; Nummenmaa et al., 2014; Pope & Singer, 1976; Shulman et al., 1997; Teasdale, Proctor, Lloyd, & Baddeley, 1993). In our study, infant crying exerted more interference than other sounds in women, capturing attentional resources from the SOT, and deactivation of the PCC reflected the disengagement from the task.

In the GOT, which requires shifting attention toward an external orientation, DMN deactivated in all participants (Gusnard et al., 2001; Raichle et al., 2001). Contrary to our expectations, men but not women were significantly distracted by sounds in this task. Men showed lesser deactivation than women in the MPFC and PCC to female adult crying when contrasted with infant crying. In other words, the GOT deactivated the MPFC and PCC, but female adult crying elicited positive activation of the same regions. The observed weak deactivations in men might reflect a resource competition to process female adult crying and simultaneously count syllables. In fact, the DMN is partially activated in response to exogenous stimuli that have self-relevance (Li, Mai, & Liu, 2014; Nummenmaa et al., 2014; Vessel, Starr, & Rubin, 2013). The DMN is also positively activated when individuals evaluate their own (and others') beliefs, perspectives, and mental states (Li et al., 2014). Internal thoughts can coexist with individuals performing externally oriented tasks (Greicius & Menon, 2004; Shulman et al., 1997; Wilson, Molnar-Szakacs, & Iacoboni, 2008). In the GOT in the present study, the weak deactivation in men in association with female adult crying might indicate that this specific sound, more than the other sounds, elicits self- relevant processes which can contribute to mentally understanding others. Consequently, self-relevant processes, associated with the partial activation of the DMN, elicited by female adult crying, might explain
the reduced deactivation of the MPFC and PCC in men in the GOT (Li et al., 2014; Nummenmaa et al., 2014).

The findings of the behavioral study, tightly tied to the fMRI study, partially supported the neurobiological data. Contrary to our initial expectations, but consonant with the fMRI findings, we did not observe any effect of sound on participants' performance in the SOT. Deciding whether an adjective describes one's own personality requires different processes from those

underlying syllable counting. Having or not having a specific personality trait is never entirely true or false. There is a variable margin of uncertainty between individuals, which could have further interfered with☐ RTs, masking the interference of concurrent sounds. Coherent with the fMRI results, in the GOT men were slower while listening to female adult crying in contrast to infant crying. These data accord with studies that report that the best performance in tasks is linked to the optimal deactivation of the DMN during externally oriented tasks (Anticevic et al., 2012; Bartova et al., 2015; De Pisapia et al., 2012; Fox et al., 2006; Mennes et al., 2011). In the fMRI study and in the behavioral study, men showed weak deactivation in the DMN and long RTs in the GOT while listening to female adult crying.

An intriguing aspect that emerged from the present findings is that, whereas the saliency of adult crying affected both the MPFC and the PCC in men, the effect of infant crying in women was observed only in the PCC. To our knowledge, only a few studies have reported gender differences in the activity of the DMN. For example, mind wandering without the presence of irrelevant sounds elicits higher activity in DMN regions, and stronger functional connectivity between the anterior and the posterior medial regions of the DMN in women than men (Bluhm et al., 2008). Furthermore, men show higher deactivation in the anterior cingulate cortex (ACC) and PCC during a mental rotation task than do women (Jiménez, Mancini Marïe, Lakis, Rinaldi, & Mendrek, 2010). In tasks that activate the DMN, women tend to have higher activation in the DMN than men. This difference might facilitate men in externally cognitive tasks (Gusnard et al., 2001; Raichle et al., 2001), and women in introspective tasks (Jiménez et al., 2010). A possible interpretation of the different involvement of MPFC and PCC in women than in men might be that greater activation of DMN in women (Bluhm et al., 2008) could promote greater expertise in self-referential tasks, which could manifest itself through the capacity in women to only partially engage the DMN in the SOT, thereby freeing brain resources for elaboration of the concurrent salient infant sound.

Sound sensitivity differs in women and men. Infant crying affected women, and female adult crying affected men. In the present study we used infant sounds, which are known to trigger attuned responses in parents (Pechtel et al., 2013). In addition, as control sounds we used female adult crying and baby laughing, which convey emotive meanings like infant crying. Infant crying distracted women while their attention focused on the SOT. The DMN deactivation we found inmwomen while listening to infant crying is convergent with a recent study of mind wandering (resting state) and passive listening to sounds, which reported greater deactivation of the DMN with infant crying in women than in men (De Pisapia et al., 2013). While not designed to investigate the DMN, another study reported that, in response to infant vocalizations (crying and laughing), women had strong deactivation in an anterior medial cluster, including the☐ ACC☐ and anterior ☐ MPFC, which overlap the medial anterior node of the DMN (Seifritz et al., 2003). Passively listening to sounds deactivates the DMN and, based on the saliency of the ongoing stimulation, the deactivation of the DMN increases with the saliency of sounds (Di & Biswal, 2014; Menon & Uddin, 2010; Sridharan et al., 2008).

Although some physiological studies that tested reactions to baby crying showed inconsistent findings on gender differences (Boukydis & Burgess, 1982; Brewster, Nelson, McCanne, Lucas, & Milner, 1998; Frodi et al., 1978; Out, Pieper, Bakermans-Kranenburg, & Van IJzendoorn, 2010), other recent investigations focused on more adaptive reactions to distressed sounds highlight clearer differences between genders (Byrd-Craven, Auer, & Kennison, 2014; Tkaczyszyn et al., 2012). For example, a study aimed to test physiological reactions to negative sounds, such as□ BC and sounds of violence, in non□ parents, reported that women showed a substantial decrease of heart rate variability–high frequency (HRV-HF) while listening to baby crying compared to men (Tkaczyszyn et al., 2012). The HRV-HF is associated with vagal activity and the parasympathetic system; the authors hypothesized that the HRV-HF decrease suggests reduced activation of the parasympathetic system in favor of greater involvement of the sympathetic system, a change that predisposes the body to react. Furthermore, women show lower HR than do men also when exposed to prolonged infant crying (Out et al., 2010). Other researchers have reported that infant crying represents a stressor that increases the cortisol response more than other stressor sounds (such as hate speech) in childless women and not in childless men (Byrd-Craven et al., 2014). In childless adults, women are more likely than men to prefer infant faces and display care behaviors and feelings when exposed to infant cues (Blakemore, 1981; Charles, Alexander, & Saenz, 2013; Lockard, Daley, & Gunderson, 1979; Maestripieri & Pelka, 2002).

Conversely, adult crying affected brain responses and performance in GOT in men. To our knowledge, our study is the first to show the effect of adult crying on DMN cerebral activity, and thus there is no other evidence with which to make direct comparisons. However, two closely related lines of research can be considered in interpreting our results. First, recent physiological studies suggest that nulliparous men show higher physiological reactions to violent sounds (i.e., cries of pain or impact sound of slaps on the skin) and hate speech coming from the environment (Byrd- Craven et al., 2014; Tkaczyszyn et al., 2012) than infant crying. Because of greater responsiveness in men to threat sounds, adult crying more than infant crying may be a stressor that potentially communicates environmental danger. Second, in the present study adult crying sounds came from women. Female stimuli might exert stronger attraction than infant cues in nulliparous men for their relevance to the formation of close relationships. For example, men prefer female faces over male faces (Alexander & Charles, 2009). Other researchers have found that, during simultaneous presentation of infant and adult faces, men prefer to fixate on an
infant face only if the concurrent adult face is a male, but not when the counterpart is a female (Cárdenas, Harris, & Becker, 2013). Other evidence shows that in mammals, and in humans, social attachment and bonding, including mating and parenting, are mediated by hormones (Feldman, 2012; Hines, 2011; Lee, Macbeth, Pagani, & Young, 2009; Rilling & Young, 2014). For example, oxytocin (OT) is a hormone that is involved in the sympathetic response to infant stimuli in mothers and fathers (Apter-Levi, Zagoory-Sharon, & Feldman, 2014; Bales, 2014; Feldman, 2012; Swain et al., 2008). Childless men show lower plasma OT than fathers. Childless men show

higher activation in reward regions when exposed to sexual stimuli, whereas fathers show the opposite pattern (Mascaro, Hackett, & Rilling, 2014). The effect of female adult crying that we observed in this experiment in young and childless men could be

interpreted in light of evolutionary perspectives. An 640 important future direction of this study is to extend investigations to parents as well as to vary the gender of□ AC.

There is evidence that men and women process negative affective experiences through different cerebral mechanisms. For example, men show stronger causal connectivity than women between the amygdala, a limbic structure which elaborates negative emotions, and the dorsal□ MPFC, connected with cognitive processes and reasoning (Lungu, Potvin, Tikàsz, & Mendrek, 2015). Other findings suggest that the intensity of emotional experience in women correlates with the activation of the anterior insula, which is connected with self-focused perceptions (e.g., bodily sensations), where as in men the same affective experience correlates with the activation of visual areas, suggesting an external world-connected way to process affective stimulation (Moriguchi, Touroutoglou, Dickerson, & Barrett, 2014). Following this line of thought, in men the increase of emotional load activates brain structures compatible with cognitive processing, whereas women show greater involvement of limbic circuits (Hall, Witelson, Szechtman, & Nahmias, 2004). In addition to the different sound sensitivity observed in women and men, gender difference in processing negative emotive experience further support our findings. In women affective and self-focused processes activated by negative emotional sounds might be entered in competition with cerebral processes that underlie the SOT, and the increase in emotive load stimulated by the greater saliency of infant crying might have augmented this competition, thus affecting the execution of SOT. By contrast, in men cognitive processes underlying the elaboration of negative emotive stimuli might have had stronger interference with brain cognitive mechanisms activated in GOT, emerging to the most salient

sound, the adult crying.

Our study has a number of limitations. One is thesmall sample sizes in both fMRI and behavioral studies. Sample size reduces statistical power and increases the likelihood of type II error, the failure to reject a false null hypothesis. Thus, the low-significant difference between men and women in the SOT might be a consequence of the low statistical power in this study. Future research should extend the main findings of the present study using larger samples. Moreover, we did not collect behavioral measures during the fMRI session; consequently, it was not possible to investigate interactions between BOLD signals and behavioral measures. fMRI and behavioral measures came from independent samples. Nor did we control for individual differences in the amount of participants' previous experience with children. Typically, women are more involved in direct child care, whereas men are involved in more indirect child care (Bornstein, 2015). Further investigations should address this association.

Infant crying elicits automatic attention shifts in women who are engaged in self-referential thoughts, resulting in greater deactivation of the DMN, whereas

female adult crying elicits in men less efficient deactivation of the DMN in self-unrelated cognitive tasks. The present study extended previous findings (De Pisapia et al., 2013) and used a more ecological experimental design than a passive listening task to investigate how
sensitivity to salient sounds is influenced by what listeners are doing. Future studies should investigate adult responsiveness to infant crying in more ecologically valid settings that are representative of situations in which caregivers are called on to respond to infant signals.

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