



Brain responses differ to faces of mothers and fathers

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ABSTRACT

We encounter many faces each day but relatively few are personally familiar. Once faces are familiar, they evoke semantic and social information known about the person. Neuroimaging studies demonstrate differential brain activity to familiar and non-familiar faces; however, brain responses related to personally familiar faces have been more rarely studied. We examined brain activity with fMRI in adults in response to faces of their mothers and fathers compared to faces of celebrities and strangers. Overall, faces of mothers elicited more activity in core and extended brain regions associated with face processing, compared to fathers, celebrity or stranger faces. Fathers' faces elicited activity in the caudate, a deep brain structure associated with feelings of love. These new findings of differential brain responses elicited by faces of mothers and fathers are consistent with psychological research on attachment, evident even during adulthood.

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1. Introduction

Information associated with people we know usually comes from personal experience and memories of 'person knowledge' are created and linked to the known face. To understand the brain correlates of 'person knowledge', photographs of faces have been used as stimuli in neuroimaging studies (Gobbini & Haxby, 2007). For instance, faces of celebrities (Leveroni et al., 2000; Platek, Keenan, Gallup, & Mohamed, 2004), friends (Gobbini, Leibenluft, Santiago, & Haxby, 2004; Platek et al., 2006), romantic partners (Bartels & Zeki, 2000, 2004; Fisher, Aron, & Brown, 2005, 2006) or even one's own face (Devue et al., 2007; Kircher et al., 2001; Platek et al., 2006; Sugiura et al., 2005) were used to identify the neural networks involved in the processing of familiar and personally familiar faces. In an earlier report we examined the areas that underlie processing of personally familiar faces, including parent's faces (Taylor et al., 2009). In contrast to other faces, parents' faces are typically known from birth, and are part of a close relationship spanning decades into adulthood; parent's faces are two of the most important faces throughout our lives. Research shows that from infancy humans are psychologically attached to their parents, an attachment that continues and is usually stable during adulthood (Doherty & Feeney, 2004; Fraley, 2002), although there is a tendency to be more attached to one's mother than father, even

as adults (Doherty & Feeney, 2004). Evolutionary theorists also suggest that kin relatedness is more prominent for mothers than fathers (Platek, Keenan, & Mohamed, 2005). Would this difference in attachment be expressed in differential brain activity associated with faces of mothers and fathers?

Faces are unique stimuli and recruit a specialized network of brain areas. The fusiform gyri, on the inferior surface of the temporal lobes, are key areas associated with face processing (Haxby, Hoffman, & Gobbini, 2000; Kanwisher, McDermott, & Chun, 1997; McCarthy, Puce, Gore, & Allison, 1997; Platek et al., 2006; Puce, Allison, Asgari, Gore, & McCarthy, 1996). Although the fusiform gyri also activate when processing other visuospatial features such as colour, shape (Allison, Puce, Spencer, & McCarthy, 1999; Allison et al., 1994; Ungerleider & Mishkin, 1982; Zeki & Marini, 1998) or objects (Martin, 2007), they have become the signature area for processing core visual characteristics of faces (Haxby et al., 2000; Puce et al., 1996). When we look at a familiar face, however, the visible features are only a small part of what we extract from the face; face recognition is not limited to core visual characteristics (Gobbini & Haxby, 2007; Ishai, Haxby, & Ungerleider, 2002; Ishai, Schmidt, & Boesiger, 2005). Familiar (Gobbini & Haxby, 2007) and personally familiar faces (Platek et al., 2006; Taylor et al., 2009) also elicit activity in an extended, spatially distributed network of areas in the brain that underlie cognitive and emotional information processing about a known face. Gobbini and Haxby (2007) proposed a model that differentiates between core visual processing of familiar faces that takes place in regions such as the fusiform gyrus, and extended processing that occurs in regions such as the anterior cingulate and temporal cortices. Specifically, in this report

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we asked how brain processing in the core and extended networks of the most familiar of faces – mothers' and fathers' faces – differed from each other and from other known and unknown faces.

2. Methods

2.1. Participants

The experimental design has been described in detail in another paper (Taylor et al., 2009). Briefly, we studied 10 adult participants (4 males, mean age 35.4 ± 7.7 years; eight right handed), who reported no history of neurological or psychiatric disorders. All participants grew up living with both parents (parents were not divorced), were still in regular contact with them (both parents were alive) and provided recent photographs of their parents. Participants provided lists of names of celebrities they would readily recognize. All procedures were approved by the Research Ethics Board at the Hospital for Sick Children, and participants gave written consent.

2.2. Stimuli and experimental design

Individualized protocols of digitized photographs were compiled for each participant. Grayscale photographs were controlled for neutrality (no smile or frown), light conditions and gaze direction. Photographs included faces of participant's parents (mother and father), as well as pictures of two celebrities (male and female) and strangers (male and female). There were no significant differences among luminance ($F_{(7,72)} = 0.76$, $p = 0.62$) or contrast ($F_{(7,72)} = 1.04$, $p = 0.41$) values in these images. In a rapid functional magnetic resonance imaging (fMRI) event-related design, faces were presented in a pseudo-random order. The same face repeated only after at least four intervening faces; there were a minimum 40 trials of each condition. Stimuli were presented for 500 ms interleaved with a jittered 1700–2000 ms interstimulus interval, during which a fixation cross was presented. By superimposing all photographs, including the participant's face, and adjusting levels of transparencies, a composite face image was constructed for each participant, which served as a target. Participants were asked to focus on photographs, and pressed a button to the composite picture to ensure attention was maintained.

2.3. Image acquisition

MR images were collected on a 1.5T Signa Twin EXCITE3 scanner (GE Medical Systems, WI; software rev.12M4) with a standard quadrature head coil. High resolution T1-weighted 3D SPGR images covering the whole brain were acquired (TE/TR/alpha = 9 ms/4.2 ms/15°, 116 slices, voxels = $1 \times 1 \times 1.5$ mm, 2 NEX, 7 min) as an anatomical reference. Functional images were acquired with a standard gradient-recalled echo-planar imaging sequence (TE/TR/alpha = 40 ms/2000 ms/90°, voxels = $3.75 \times 3.75 \times 5$ mm) over 27 contiguous non-tilted axial slices with interleaved acquisition.

Face stimuli were controlled using *Presentation* (Neurobehavioral Systems Inc., CA) on a personal computer, and displayed to the participants on MR compatible goggles (CinemaVision, Resonance Technology Inc., CA). Participants responded using an MR compatible keypad (Lumitouch, Photonics Control, CA) to the composite face, occurring with a 0.08 probability.

2.4. Data analysis

Imaging data were processed and analyzed using AFNI (Cox, 1996). The fMRI data pipeline included motion correction, spatial blurring (8 mm RMSD), signal intensity normalization for percent

signal change and deconvolution using a fixed haemodynamic response function. Images from each participant were then spatially normalised to the MNI N27 brain in Talairach stereotaxic space and resampled to 3 mm cubic voxels.

Group images were analyzed using a random effects ANOVA. Each face condition was first compared to baseline, which was a fixation cross, to examine recruitment of core visual regions. To display these regions (Fig. 1), region of interest (ROI) masks over the fusiform gyrus and the inferior and middle occipital gyri were anatomically defined based on the Talairach structural template provided in AFNI (MNI N27 brain in TLRC space; Eickhoff et al., 2007). The masks were applied on the thresholded group dataset.

In addition, results of whole-brain voxel-wise contrasts were performed among faces (mother, father, celebrity female, celebrity male, stranger female, stranger male) while controlling for gender. Activation differences between mothers' and fathers' faces were contrasted; as well, activation related to mothers' faces and fathers' faces was contrasted to celebrity and stranger faces. Mothers' faces were compared only to female celebrity and female stranger faces and fathers' faces were only compared to male celebrity and male stranger faces. All results were thresholded at $p < 0.01$, uncorrected with minimum volume 270 μ l (10 voxels). Talairach coordinates of group analyses are reported using neurological convention. Multi-subject directionality analyses were used to test for concordance across participants in the contrasts among face types.

3. Results

Each face condition was compared to baseline to examine recruitment of occipital regions and the fusiform gyrus (Table 1; Fig. 1). Whole-brain comparisons of mother's face to fixation showed more activity in bilateral fusiform gyri, inferior frontal gyri and thalamus; right superior temporal gyrus, right lingual gyrus, right angular gyrus, right inferior parietal lobule and right middle frontal gyrus as well as left cuneus. Father's faces activated the left middle occipital gyrus and the right fusiform gyrus more than baseline. Similarly, male celebrity faces activated more in bilateral fusiform and lingual gyri than baseline. Female celebrity faces activated these regions as well as the left inferior and right middle frontal gyri. Fig. 1 shows that all familiar faces activated these core visual areas, albeit to different degrees. Faces of mothers elicited the most extensive activity, primarily in the right hemisphere, and also showed the highest overlap with activity elicited by other faces. In contrast, fathers' faces elicited activity in the left hemisphere. Faces of male and female celebrities activated adjacent posterior regions in both hemispheres (Fig. 1).

Whole-brain contrasts were also performed among the different faces (Table 2). The right superior temporal gyrus was more active to mothers' faces than fathers' faces. Mothers' faces also elicited more activity compared to unknown females in left supramarginal gyrus, left insula, and left middle frontal gyrus, right middle temporal gyrus and right superior and inferior frontal gyri. Bilateral middle temporal gyri, right inferior frontal gyrus and left cingulate gyrus activity was observed for mother faces compared to celebrity females. Fathers' faces elicited more activity in the left caudate than celebrity males. In addition, as shown in Table 2, multi-subject conjunction analyses on the directionality of signal change indicated that most regions were concordant for at least 9 out of 10 of our participants.

Overall, mothers' faces elicited more activation than either fathers' faces or other female faces in brain regions implicated in face and familiarity processing (Table 2; Fig. 2). Notice that observed regions such as the superior temporal and the inferior frontal

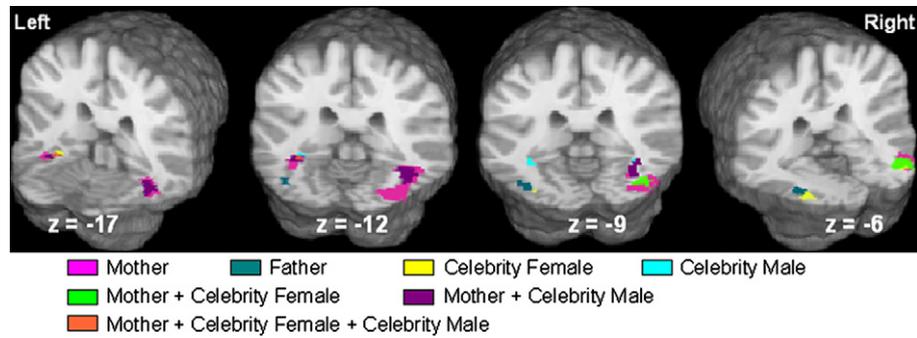


Fig. 1. Rendered group activation maps of core visual regions active during processing of familiar faces. Different colours represent significantly more activity related to familiar faces (mother, father, celebrity male and celebrity female) compared to baseline, as well as regions where resulting activity for the different faces overlap. To display only core regions, the thresholded group results ($p < 0.01$, uncorrected with minimum volume $270 \mu\text{l}$) were applied on anatomical ROI masks over the fusiform gyri and the inferior and middle occipital gyri.

Table 1
Familiar faces compared to baseline.

Voxels	x	y	z	t-Value	Hem.	Area
<i>Mother > baseline</i>						
398	37	-60	-13	4.15	R	Fusiform gyrus
287	48	23	13	3.82	R	Inferior frontal gyrus
210	51	-54	12	3.93	R	Superior temporal gyrus
117	19	-88	5	3.86	R	Lingual gyrus
73	-15	-90	3	3.55	L	Cuneus
63	-43	14	14	3.87	L	Inferior frontal gyrus
52	33	-58	34	3.46	R	Angular gyrus
50	-35	-47	-16	4.03	L	Fusiform gyrus
27	16	-12	10	3.68	R	Thalamus
19	48	-61	47	3.60	R	Inferior parietal lobule
13	-14	-33	4	3.69	L	Thalamus
12	34	-6	48	3.56	R	Middle frontal gyrus
<i>Father > baseline</i>						
20	-39	-73	-9	3.47	L	Middle occipital gyrus
10	39	-53	-10	3.40	R	Fusiform gyrus
<i>Celebrity male > baseline</i>						
151	38	-51	-15	3.89	R	Fusiform gyrus
31	-34	-44	-14	3.76	L	Fusiform gyrus
11	30	-68	-4	3.74	R	Lingual gyrus
11	-18	-72	-2	3.36	L	Lingual gyrus
<i>Celebrity female > baseline</i>						
332	20	-71	-7	3.67	R	Lingual gyrus
41	-30	-43	-18	3.90	L	Fusiform gyrus
20	-43	29	13	3.88	L	Inferior frontal gyrus
19	25	-45	-23	3.71	R	Fusiform gyrus
16	-37	-81	-5	3.75	L	Inferior occipital gyrus
11	41	13	32	3.38	R	Middle frontal gyrus

Note. Talairach coordinates represent the center of the cluster at $p < 0.01$ uncorrected with minimum cluster size of 10 voxels. Hem = hemisphere.

gyri are not part of the visual core system; they are part of the extended network for processing familiar faces. Activity in the caudate was significantly different for fathers' faces when compared to celebrity males, whereas no significant difference in activity was found between fathers' faces and faces of unknown males.

4. Discussion

This study explored the differences in brain responses to faces of participants' mothers and fathers. These faces elicited activity in a network of face-responsive regions, which included the fusiform, superior temporal, middle temporal, inferior frontal and superior frontal gyri. It is well known that faces are processed by a visual as well as a non-visual extended system (Gobbini & Haxby, 2007). Our discussion concentrates on the extent to which these

Table 2
Contrasts of brain activity related to faces of mothers and fathers.

Voxels	x	y	z	t-Value	Hem.	Area
<i>Mother > father</i>						
16	43	-56	19	3.10	R	Superior temporal gyrus ^a
<i>Mother > unknown female</i>						
145	-54	-48	23	3.49	L	Supramarginal gyrus ^a
97	8	22	54	3.24	R	Superior frontal gyrus ^a
79	-43	14	13	3.21	L	Insula ^a
57	50	32	3	3.30	R	Inferior frontal gyrus ^a
28	61	-54	-1	3.05	R	Middle temporal gyrus ^a
14	55	-23	-9	3.04	R	Middle temporal gyrus
10	-46	39	15	3.38	L	Middle frontal gyrus
<i>Mother > celebrity female</i>						
85	55	-57	10	3.36	R	Middle temporal gyrus ^a
54	-53	-53	2	3.21	L	Middle temporal gyrus ^a
49	54	15	15	3.20	R	Inferior frontal gyrus ^a
18	49	32	4	3.30	R	Inferior frontal gyrus ^a
15	-24	-39	41	3.29	L	Posterior cingulate gyrus ^a
<i>Father > celebrity male</i>						
22	-8	7	1	3.21	L	Caudate ^a
<i>Celebrity female > unknown female</i>						
14	-48	30	13	3.00	L	Inferior frontal gyrus ^a
13	-15	36	32	3.10	L	Superior frontal gyrus ^a

Note. Talairach coordinates represent the center of the cluster at $p < 0.01$ uncorrected with minimum cluster size of 10 voxels. Hem = hemisphere.

^a Signifies the regions showing at least 9 out of 10 participant concordance in directionality.

systems are involved in the processing of mothers' and fathers' faces.

Consistent with previous studies, all face conditions elicited activity in core visual regions (Fig. 1). Our results demonstrated the mothers' faces evoke more extensive activity in these regions, an effect that may be explained by the extent of familiarity. Using recognition of famous faces (Eger, Schweinberger, Dolan, & Henson, 2005; Leveroni et al., 2000), previous research determined that brain responses are greatly increased by familiarity and this is reflected by more activity in core visual regions. This augmented activity in core visual regions may be due to increased salience of familiar faces, or result from a sustained interaction between core and extended regions, possibly in a feedback loop, to process cognitive or social information about the person. Research also suggests that face resemblance has an evolutionary purpose which is related to kin recognition (Platak et al., 2005). Our data suggest that mothers' faces are more salient than fathers' faces and/or evoke richer cognitive, emotional and/or social memories shared between participants and their mothers.

Mothers' faces elicited more activation than either fathers' faces or other female faces in brain regions implicated in face and famil-

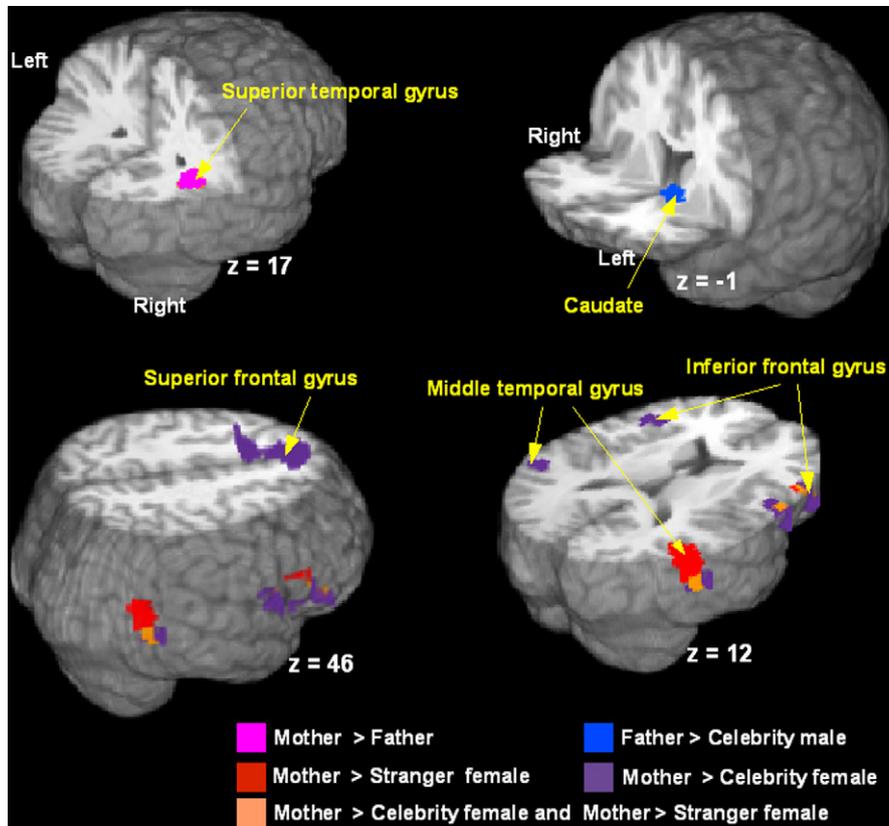


Fig. 2. Rendered group activation maps of brain regions more active during processing of mother and father faces.

ilarity processing (Table 2; Fig. 2). When looking at their mothers' faces participants showed significantly more activity in the right superior temporal gyrus compared to their fathers' face. Compared to stranger or celebrity faces, mothers' faces elicited activity in an extended network of areas, including the inferior frontal and middle temporal gyri (Table 2; Fig. 2). This finding is in agreement with previous reports showing that frontal and temporal regions play a key role in processing previous knowledge associated with a face (Gobbini & Haxby, 2007; Platek, Krill, & Kemp, 2008). Brain activity in areas such as the insula and parts of the striatum (e.g., caudate) are known for their involvement in emotional processing, part of the extended network associated with emotional aspects of faces (Bayle & Taylor, 2010; Gobbini & Haxby, 2007). Of these areas, fathers' faces elicited above threshold activity only in the caudate when compared to famous faces (Fig. 2), but not when compared to stranger faces, except if a more relaxed threshold was used ($p = 0.07$, uncorrected with minimum cluster size of 10 voxels).

The current data complement the models proposing that face processing is expressed by a distributed network of brain areas (Gobbini & Haxby, 2007; Ishai et al., 2005; Platek et al., 2008). Two regions that stand out in processing mothers' faces were the inferior frontal and the middle temporal gyri. In a meta-analysis Platek et al. (2008) reported that the inferior frontal gyri were implicated in a network associated with processing one's own face; own face processing is also reflected by activity in middle temporal and superior frontal gyri (Platek et al., 2006). As these areas were activated more to faces of mothers, it appears that similar brain regions are implicated in mother and self-related processing (Goldberg, Harel, & Malach, 2006; Platek et al., 2006), likely related to significant overlap in personal experiences with one's mother and self-related memories.

Only fathers' faces produced activation in the caudate, which has been associated with feelings of maternal and romantic love

(Bartels & Zeki, 2004; Fisher et al., 2005). The caudate is an area of deep, central grey matter, known to play a role in motor control (Menon, Glover, & Pfefferbaum, 1998), although more recently, caudate activity was also elicited by learning visual categories (Nomura & Reber, 2008) and processing reward-related information (Tricomi & Fiez, 2008). Studies using face stimuli show caudate activation related to maternal (Bartels & Zeki, 2004; Leibenluft, Gobbini, Harrison, & Haxby, 2004) and romantic love (Fisher et al., 2005; Taylor et al., 2009). One may expect that because of a closer attachment, faces of mothers should also elicit activity in the caudate. At a lower threshold, using a minimum cluster of 10 voxels, activity in the caudate was present for the comparisons fathers' versus unknown male faces ($p = 0.07$), mothers' versus celebrity female faces ($p = 0.08$), and mothers' versus unknown female faces ($p = 0.03$). It may be the case that while viewing mothers' faces activity in the caudate is obscured by activity in other cortical areas and thus only appears at a more lenient threshold. Together with the distinct caudate activity associated with fathers' faces, these findings support the idea that this region is associated with a global sensation of love or reward which mothers' and fathers' faces engender.

Although face recognition has been extensively studied and numerous reports show that faces elicit the classic pattern of activity that includes the fusiform gyri (Haxby et al., 2000; McCarthy et al., 1997; Puce et al., 1996), neuroimaging studies have mostly examined recently learned and celebrity faces (Elfgrén et al., 2006; Ishai et al., 2002, 2005; Ishai & Yago, 2006). Neuroimaging data suggest that personally familiar faces elicit a distinct signature in the brain (Platek et al., 2006) implicating activity in an extended network including the prefrontal and temporal lobes. We examined the areas in the extended network involved in the complex processing related to the mother and father faces of adult participants. This is the first report of brain activity related

significantly and specifically to mothers' and fathers' faces, as only a few studies have investigated personally familiar faces (Bartels & Zeki, 2000; Platak et al., 2006). We believe that the results from this study are important, as they present evidence of brain correlates or indices of relationships formed over many years of personal experience with another person.

The highlights of our findings are twofold. First, mothers' faces elicited more overall activity in core and extended brain areas associated with familiar face processing than faces of fathers and other female faces. Neonates and young infants readily respond to faces of their mothers (Pascalis, De Schonen, Morton, Deruelle, & Fabre-Grenet, 1995; Walton, Bower, & Bower, 1992) and look differentially at mother's expressions compared to expressions by fathers and strangers (Montague & Walker-Andrews, 2002). In agreement with previous findings, differential activity to mothers' faces may be attributable to greater exposure to one's mother's face during critical childhood years. Second, deep brain structures such as the caudate, contribute to a global feeling of affection we feel for our parents. Caudate activity was most evident for faces of fathers, but also detectable for mothers' faces. Overall, these results are in agreement with psychological models showing that even as adults we remain attached to our parents, particularly our mothers, who in adulthood hold second place as attachment figures after partners (Doherty & Feeney, 2004). In light of our findings, faces of mothers and fathers appear to be effective stimuli for selectively and differentially activating brain regions associated social emotional processing and provide a means for further research into understanding the neural basis of personally familiar faces that carry affective importance.

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