Mother and child in synchrony: Thermal facial imprints of autonomic contagion

Sjoerd J. Ebisch, Tiziana Aureli, Daniela Bafunno, Daniela Cardone, Gian Luca Romani, Arcangelo Merla

A R T I C L E   I N F O

Article history:
Received 5 May 2011
Accepted 28 September 2011
Available online 11 October 2011

Keywords:
Emotion
Empathy
Infrared imaging
Autonomic nervous system
Parent–child intersubjectivity

A B S T R A C T

Mothers’ ability to empathically share offspring’s emotional feelings is considered integral to primary affective bonds and a healthy socio-emotional development. What neurobiological mechanism is responsible for this ability in humans? It has been proposed that the psychological and neural components of affective experiences are strictly associated with autonomic-visceral changes. Hence, the vicarious response of empathy may also embody a sharing of changes in body physiology. The present study aimed at investigating whether maternal empathy is accompanied by a synchrony in autonomic responses. We simultaneously recorded, in an ecological context with contact free methodology, the facial thermal imprints of mother and child, while the former observed the latter when involved in a distressing situation. The results showed a situation-specific parallelism between mothers’ and children’s facial temperature variations, providing preliminary evidence for a direct affective sharing involving autonomic responding. These findings support a multidimensional approach for the comprehension of emotional parent–child relationships.

© 2011 Elsevier B.V. All rights reserved.

1. Introduction

Seeing one’s own offspring in distressing situations is a rather ordinary occurrence in everyday life. Bringing a child for the first time to nursery school or witnessing a vaccination are some vivid examples. It naturally evokes a sense of empathy with the child’s feelings, which helps parents to understand the child’s needs and to provide congruent responses. In fact, a mother’s ability to empathically share offspring’s emotional feelings in distressing situations is considered integral to the creation of primary affective bonds and a healthy socio-emotional development (Lenzi et al., 2009; Noriuchi et al., 2008; Psychogiou et al., 2007; Swain et al., 2007; Saarni et al., 1998; Eisenberg and Strayer, 1987; Bowby, 1958). What neurobiological mechanism is responsible for maternal empathy in humans? In particular, is a mother’s affective sharing of her offspring’s distress accompanied by sharing of autonomic arousal?

Whereas the psychological side of emotional parent–child relationships has been studied quite extensively, the physiological side has been largely ignored. Despite the extensive interest in neuroscience on empathy (Adolphs, 2009; Singer and Lamm, 2009; Gallese et al., 2004; Gallese, 2003; Preston and de Waal, 2002) and its relevance to infant development, previous studies investigated maternal empathy mainly by using verbal reports (Soenens et al., 2007; Strayer and Roberts, 2004; Oppenheim et al., 2001; Gondoli and Silverberg, 1997; Strayer and Roberts, 1989) and, in a few cases, by functional neuroimaging (Lenzi et al., 2009; Noriuchi et al., 2008; Ranote et al., 2004). Few studies reported also on the possible involvement of physiological responses such as heart rate and skin-conductance during emotional interactions with the child (Frodj et al., 1978; Donovan et al., 1978; see also Hatfield et al., 1994). However, autonomically mediated visceral responses are proposed to be strictly related to the experience of emotional feelings (Harrison et al., 2010; Kreibig, 2010; Stephens et al., 2010; Critchley, 2009; Damasio, 1999, 1994; James, 1894; Lange, 1885). The sympathetic and parasympathetic divisions of the autonomic nervous system represent the principal channels of interaction between the brain and bodily organs, and have complementary roles in the achievement of homeostasis and the regulation of physiological responses to emotional stimuli (Critchley, 2009; Janig, 2008; Brading, 1999). It is therefore plausible that the vicarious response of empathy, generally referred to as a common neural coding of the perception of one’s own and the other individual’s feelings underpinning a sharing of affective experiences (Adolphs, 2009; Singer and Lamm, 2009; Gallese et al., 2004; Gallese, 2003; Preston and de Waal, 2002), also embodies a direct sharing of...
changes in body physiology between the involved individuals (Critchley, 2009; Preston and de Waal, 2002; Damasio, 1999, 1994).

In line with this hypothesis, studies reported reduced empathic abilities in patients with primary autonomic failure (Chauhan et al., 2008) and variations in the pupil size of adults as an indicator of autonomic activity when observing others’ emotions (Harrison et al., 2007, 2006).

The present study aimed at investigating whether a mother’s empathic sharing of her offspring’s distress is accompanied by physiological sharing of autonomic responses. For this purpose, facial thermal imprints of mother and child dyads were simultaneously recorded in an ecological context while mothers observed their children when involved in a distressing situation. We used thermal infrared (IR) imaging, a contact-free methodology, which estimates variations in autonomic activity reflected by cutaneous temperature modulations by means of recording the thermal infrared signals spontaneously released by the human body (Shastri et al., 2005; Garbeoy et al., 2007; Merla and Romani, 2007; Pavlidis et al., 2007, 2002). In particular, a complex interplay of heat exchange processes involving skin tissue, inner tissue, local vasculature, and metabolic activity causes cutaneous temperature to vary. These internal processes are mediated and regulated by sympathetic and parasympathetic activity, which works to preserve the body homeostasis in the human physical and psychological functioning (Anbar, 2002), and therefore is especially active when emotional stimuli are present in the proximal environment (Kreibig, 2010).

2. Methods and materials

2.1. Participants

Twelve mothers (age 31–46 years) and their typically developing biological children (3 male, age 38–42 months) participated in the experiment. Two out of 12 mother–child dyads were excluded from further data analysis, since the toy was not broken during the experiment (see Section 2.2). Inclusion criterion for both mothers and children was the absence of any overt physical, psychiatric or psychological disease. All participants were asked to refrain from heavy physical activities and intake of vasoactive substances for 2 h prior to the measurements, and to avoid the presence of cosmetic substances on their faces at the time of the experiment.

The study was approved by the Local Ethics Committee. Written informed consent was obtained from all participants after full explanation of the procedure of the study, in line with the Declaration of Helsinki.

2.2. Procedure

Prior to testing, each subject was left to acclimatize for 10–20 min to the experimental room and to allow the baseline skin temperature to stabilize. The recording rooms were set at standardized temperature (23 °C), humidity (50–60%), and without direct ventilation. The subjects comfortably sat on a chair during both acclimatization and measurement periods, without any restriction to body movement.

Before the start of the experiment the children underwent an adequate familiarization period for psychological habituation to the setting and the experimenter, first in presence of their mothers, followed by neutral interaction with the experimenter alone.

After a neutral baseline period of interactive activities with the experimenter, children were presented with a potential stressful experience elicited by the “mishap paradigm” (Cole et al., 1992). More specifically, children were invited to play with a toy, which was previously manipulated to break on the child’s hands when playing with it, thus suggesting that the child accidentally broke the toy. The toy was introduced by the experimenter as her own favorite. Distinct phases could be distinguished in the paradigm: (1) “presentation” (the experimenter demonstrated the toy); (2) “playing” (the child played with the toy, while the experimenter left the room for 1 min); (3) “mishap” (child “broke” the toy); (4) “re-entrance” of the experimenter (the experimenter did not say anything for 30 s and merely looked at the broken toy); (5) “soothing” of the child (the experimenter cheerfully indicated that the toy could be fixed and that the breaking was not the child’s fault). Mothers were invited to observe their children in interaction with the experimenter through a one-way mirror from a separated room, while naive about the specific content of the experiment.

2.3. Materials and data acquisition

Thermal IR imaging was performed by means of two digital thermal cameras (FLIR SC3000, FlirSystems, Sweden), with a Focal Plane Array of 320 × 240 QWIP detectors, capable of collecting the thermal radiation in the 8–9 μm band, with a 0.02 s time resolution, and 0.02 K temperature sensitivity. The thermal camera exposure was black-body-calibrated to null noise-effects related to the sensor drift/shift dynamics and optical artifacts. Thermal images of the faces of the mother and the child were simultaneously acquired along the whole experimental paradigm. Sampling rate for thermal imaging was set at 1 frame/s.

Standard thermal recordings of the children took place through two remote-controlled cameras (Canon Vc-C50Rk). Video-signals were sent to two video-recorders (BR-JVC) and the resulting movies were subsequently mixed by a Pinnacle system (Liquid 6) to have a two- or three-split image. Subsequently, the movies were processed in a vanilla Coder/MPEG-2 codec. Unrelated noise-related data were excluded. (the 5 codified signs, “medium” if the child showed behaviors included in one of the five codified signs, and “high” if the child showed behaviors included in at least four of the five codified signs. 2.5. Thermal data analysis

A visual inspection of the changes in facial thermal imprints in 10 mother–child dyads was performed to qualitatively investigate the autonomic responses of mother and child throughout the experiment.

This visual analysis was followed by a quantitative estimation of temperature variations in relevant facial regions of interest in 6 mother–child dyads. Four out of 10 mother–child dyads were excluded from quantitative data analysis, because of interfering behaviors by the child, limiting the reliability of the thermal signal (e.g. temporarily leaving the room, touching/occluding the face).

Facial thermal imprints and variations in cutaneous temperature of facial regions of interest in children and their mothers were analyzed using custom-made Matlab programs (http://www.mathworks.com). To chase a cluster of pixels corresponding to the same region on the face, we corrected, whenever possible, for translation of the face in the thermograms, which arose from body movements before analyzing changes in facial skin temperature. In case of marked rotation of the head, we skipped to the next frame in which the subjects restored their initial position. We corrected for the displacement between images frame by frame using anatomical landmarks based on the subject’s nose profile (Dowdall et al., 2007).

In order to quantify thermal variations and their correlation between children and their mothers, changes in cutaneous temperature for specific facial regions of interest were calculated. Such regions were selected according to previous studies in humans as well as primates (Kuraoka and Nakamura, 2011; Nhan and Chau, 2010; Shastri et al., 2009; (1) the nasal tip and (2) the maxillary area. Both regions are associated with the activation of the sympathetic nervous system by emotional or distressing stimuli (Kuraoka and Nakamura, 2011; Nhan and Chau, 2010; Shastri et al., 2009; Nakamshi and Inai-Matsuuma, 2008; Merla and Romani, 2007). More precisely, thermal changes on the nasal tip may reflect sympathetic α-adrenergic vasomotor effects. Furthermore, sympathetic stimulation of the blood vessels can also have smaller vasodilatory effects via cholinergic and beta-adrenergic receptor action (Smith and Kampine, 1990).

Differed from the nasal tip, the maxillary thermal signal depends on a combination of blood perfusion and sweat gland activity, the latter being regulated by sympathetic postganglionic cholinergic activity. Thus, different receptor mechanisms may underlie thermal variations of the nasal tip and maxillary area.
First, we assessed at the intra-individual level whether the facial skin temperature did not vary significantly or presented drifts during a 90 s baseline period immediately preceding the experiment, thus providing evidence for proper acclimatization of subjects. Second, in order to investigate the presence and timing for the change in skin temperatures following stimulus presentation (i.e. the onset of the experimental phases), we carried out multiple comparison tests between the 10 s pre-stimulus period (from 10 to 0 s before stimulus presentation) and each of the six 10 s post-stimulus periods. Analysis of variance (ANOVA) results rejected the hypothesis of equality of the means of the distributions. Dunnett’s t-test showed that stimulus-related skin temperature variations occurred within the first 10 s and lasted from 20–30 s for the mishap, entrance and soothing phase. Therefore, for further analysis of the individual mother–child dyads as well as of the group data, we decided to take into account 5 frames for each experimental phase in which emotional modulation took place (mishap, entrance, soothing), as closest in time as possible to 6, 12, 18, 24, 30 s after the beginning of each phase. This procedure also allowed to deal efficiently with the motion and vocalizations in the ecological experimental setting by excluding frames affected by short-lasting motion or vocalization artifacts. Thus, a total of 15 frames (data points) was obtained for each participant for the analyses of the experimental phases. Similarly, 15 frames (each frame taken every about 5 s, and not affected by the above-mentioned short-lasting artifacts) from a neutral baseline period of 90 s immediately preceding the experiment were obtained.

In order to verify whether there was a significant modulation of skin temperature in children and their mothers during the experimental phases and the baseline period in these facial regions of interest, group ANOVAs were performed with the thermal values at the 15 selected time points according to the procedure described above in the facial regions of interest as within-subject variable.

Pearson correlation analyses of the thermal time courses of the determined regions of interest were performed for the experimental phases in which the emotional modulation took place (mishap, entrance, soothing) investigating quantitatively whether the individual mother–child dyads showed a synchronicity in autonomic activity. To verify whether correlations between autonomic parameters were specific for the experimental phases, that is, situation specific, the same procedure was applied to a baseline period of neutral interaction between the experimenter and child immediately preceding the experiment.

Finally, a group analysis was performed on the thermal time courses of the determined regions of interest. In order to standardize the individual time courses, the thermal value of each selected data point in the time course was converted to a z-score. Subsequently, the standardized individual thermal time courses were averaged separately for the children and the mothers. Correlation analysis was performed between the averaged time courses of the children and the mothers.

### 2.6. Control analysis

In order to account for the possibility that the observed thermal variations in an empathic situation could reflect respiratory alterations, the mothers’ temperature dynamics of the nasal tip were correlated with respiratory alterations.

For the extraction of the breathing signal, a tracking algorithm was applied to the thermal videos to ensure the proper localization of the defined facial ROI (nasal vestibule area) on each of the processed frames of the experimental phases (mishap, entrance, soothing). The tracking algorithm is based on the 2-D cross-correlation between a template region, chosen by the user on the initial frame, and a similar ROI in a wider searching region, expected to contain the desired template in each of the following frames. ROI average temperature distributions were computed in order to extract the time courses of the nasal breathing signal of the participant. Once the breathing signal was extracted and opportunely band-pass filtered (0.25–0.6 Hz), the duration of breathing cycles (in seconds) was estimated using an algorithm based on zero-crossing detection of the de-trended breathing signals. The obtained breathing cycle series were smoothed using a moving average (span of 8 signal samples). Data extraction and following analysis were developed by homemade Matlab algorithms (the Matworks Inc.).

Prior to the computation of Pearson correlation coefficients, we followed the same procedure as described above for calculating the correlation between facial temperature dynamics of mothers and their children. Thus, for every mother we took into account the respiratory cycle duration at 5 equally distributed time points for each of the experimental phases (mishap, entrance, soothing). Then, correlations between the resulting data points representing the duration of breathing cycles and the 15 data points representing the nasal tip temperature were computed for the individual mothers.

A group analysis was also performed. In order to standardize the individual respiratory series, the value of each of the 15 data points was converted to a z-score. Subsequently, the standardized individual respiratory time series were averaged for the group of mothers. Correlations were calculated between the average nasal tip temperatures and average respiratory cycle durations. Furthermore, multiple regression analysis was performed with both nasal tip thermal signal of the children and mothers’ respiratory activity as independent variables, and nasal tip thermal signal of the mothers as dependent variable.

In order to verify whether there were significant respiratory alterations in the mothers during the experimental phases, a group ANOVA was performed with the 15 respiratory cycle duration values as within-subject variable.

### 3. Results

#### 3.1. Behavioral results

As expected, behavioral data confirmed a significant increase of children’s distress during the experimental phases, that is, after the mishap. According to the categorical scores, distress levels across the children varied between medium and high. Behavioral indicators of distress and their categorical scores (i.e. levels) during the experimental phases in the individual children included in quantitative data analysis are presented in Table 1.

#### 3.2. Visual analysis of facial thermal imprints

A visual inspection of the changes in facial thermal imprints was performed to investigate the presence of appreciable signs of autonomic responses of mother and child throughout the experiment. As an example, the facial thermal imprints of one of the mother–child dyads is shown in Fig. 1.

As to the child, no appreciable modulations were detected regarding facial skin temperature distribution during the presentation and playing phase. However, after the mishap (i.e., after the breaking of the toy), a sympathetic reaction could be observed, reflected by a sudden and wide-spread decrease of face temperature, especially in the maxillary area and nasal tip as previously found in human as well as macaques (Kuraoka and Nakamura, 2011; Nhan and Chau, 2010; Shastri et al., 2009; Nakanishi and Imai-Matsumura, 2008; Merla and Romani, 2007). This sympathetic reaction was accompanied by sudomotor response (Merla and Romani, 2007), which is in the maxillary area likely regulated by sympathetic postganglionic cholinergic activity, whereas

---

Table 1

<table>
<thead>
<tr>
<th>Child</th>
<th>Baseline behavior: presentation phase</th>
<th>Mishap phase</th>
<th>Entrance phase</th>
<th>Level of distress</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Fingers in mouth arms across body, bodily avoidance.</td>
<td>Gaze aversion, lip prolled-in, motionless, repairing.</td>
<td>Lip prolled-in, head lowered.</td>
<td>Medium</td>
</tr>
<tr>
<td>2</td>
<td>Fingers in mouth.</td>
<td>Gaze aversion, lip prolled-in.</td>
<td>Motionless, hunched shoulders, head lowered, repairing.</td>
<td>High</td>
</tr>
<tr>
<td>3</td>
<td>Head lowered.</td>
<td>Lip prolled-in, motionless, repairing.</td>
<td>Gaze aversion, lip prolled-in, motionless, hunched shoulders, head lowered, fingers in mouth.</td>
<td>High</td>
</tr>
<tr>
<td>4</td>
<td>No distress.</td>
<td>Gaze aversion, lip prolled-in, repairing.</td>
<td>Lip prolled-in, motionless, hunched shoulders, bodily avoidance.</td>
<td>Medium</td>
</tr>
<tr>
<td>6</td>
<td>No distress.</td>
<td>Gaze aversion, lip prolled-in, bodily avoidance, repairing.</td>
<td>Gaze aversion, lip prolled-in, hunched shoulders, head lowered, repairing, negative self-evaluation</td>
<td>High</td>
</tr>
</tbody>
</table>
the decreased skin temperature in the nasal tip could reflect peripheral vasoconstriction due to alpha-adrenergic activity. These sympathetic responses were maintained after the entrance of the experimenter. During the soothing phase, the sudomotor response in the maxillary area was initially maintained, whereas the temperature of the nasal tip soon increased, likely reflecting a withdrawal of the sympathetic alpha-adrenergic vasoconstrictor effect. This initial response was followed by a more generalized face temperature increase and the extinction of the sudomotor response, up to re-establishing the baseline state. Moreover, an over-response of nasal tip temperature was observed, compared to the start of the experiment.

Concerning the mother, no appreciable modulation of skin temperature distribution was detected during the presentation and playing phase. After the mishap as well as after the entrance of the experimenter, the same thermal variations observed in the child were detected in the mother, although more intensely in both cases. During the soothing phase, the mother showed a gradual and generalized increase of facial temperature with extinction of the sudomotor response in the maxillary area, re-establishing the baseline state. Moreover, like the child, she showed an over response of nasal tip temperature, compared to the start of the experiment.

3.3. Mother and child in synchrony

ANOVA with the temperature values of the facial regions of interest (nasal tip, maxillary area) at the different time points as within-subject variable showed a significant modulation of temperature during the emotionally charged experimental phases (mishap, entrance, soothing) in both regions for the child [nasal tip: \( F(14,70) = 8.582, p < 0.001 \); maxillary area: \( F(14,70) = 2.110, p < 0.05 \)] as well as for the mother [nasal tip: \( F(14,70) = 11.009, p < 0.001 \); maxillary area: \( F(14,70) = 2.259, p < 0.05 \)]. No significant modulation of temperature was detected during the baseline period, neither for the child [nasal tip \( p > 0.6 \); maxillary area \( p > 0.3 \)], nor for the mother [nasal tip \( p > 0.9 \); maxillary area \( p > 0.3 \)].

Correlation analyses for the experimental phases in the individual mother–child dyads showed significant positive values between thermal fluctuations of mother and child in all 6 cases for the nasal tip and in 3 out of 6 cases for the maxillary area (Table 2). In 3 cases, no significant correlation between the mother’s and child’s thermal variations of the maxillary area could be found during the experimental phases.

With respect to the baseline condition, in 4 out of 6 cases no significant correlation could be found for the nasal tip, whereas a significant correlation was absent in all cases for the maxillary area (Table 2). In only two cases, a significant correlation between the mother’s and child’s thermal variations of the nasal tip could be found during the baseline period.

Group analyses for the phases in which the emotional modulation took place (mishap, entrance, soothing) showed significant positive correlation coefficients between thermal fluctuations of mother and child for the nasal tip \( r = 0.92, p < 0.001 \) as well as for the maxillary area \( r = 0.94, p < 0.001 \). With respect to the neutral baseline condition, no significant correlation could be found at the group level, neither for the nasal tip \( r = 0.01 \) nor for the maxillary area \( r = 0.12 \), suggesting that the observed parallelism in thermal variations between mother and child also at the group level was specific for situations with an emotional valence. Group results are graphically presented in Fig. 2.

### Table 2

<table>
<thead>
<tr>
<th>Mother–child dyad</th>
<th>Distress (( r_{\text{mother–child}} ))</th>
<th>Baseline (( r_{\text{mother–child}} ))</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Nasal tip</td>
<td>Maxillary area</td>
</tr>
<tr>
<td>1</td>
<td>0.64*</td>
<td>0.56*</td>
</tr>
<tr>
<td>2</td>
<td>0.90*</td>
<td>−0.25</td>
</tr>
<tr>
<td>3</td>
<td>0.63*</td>
<td>0.43*</td>
</tr>
<tr>
<td>4</td>
<td>0.52*</td>
<td>0.55*</td>
</tr>
<tr>
<td>5</td>
<td>0.65*</td>
<td>0.60*</td>
</tr>
<tr>
<td>6</td>
<td>0.73*</td>
<td>−0.03</td>
</tr>
</tbody>
</table>

* \( p < 0.05 \).
3.4. Control analysis for respiratory effects on thermal variations

Correlation analyses investigating the relationship between thermal variations on the nasal tip and nasal respiratory variations in the individual mothers did not yield significant correlations ($p \geq 0.05$). Group analysis confirmed the lack of a correlation between nasal temperature dynamics and respiratory activity in the mothers ($p \geq 0.7$). Furthermore, a multiple regression analysis showed that nasal tip temperature variations in the mothers were statistically independent from the mothers’ respiratory activity ($\beta = 0.02$, $r = -0.17$, $p \geq 0.8$), whereas the relationship between nasal tip temperature variations in the mothers and those in the children remained significant ($\beta = 0.91$, $r = 7.963$, $p \leq 0.001$). ANOVAs with the respiratory cycle duration values as a within-subject variable failed to show a significant modulation of respiratory activity in the mothers during the experimental phases ($p \geq 0.1$).

Correlation coefficients concerning the relationship between thermal variations on the nasal tip and nasal respiratory variations in the mothers are provided in Table 3. A graphical representation of the group results is provided in supplementary Fig. 1.

4. Discussion

The present study provides two main results. First, facial thermal imprints of the mothers suggest that observation of their child’s experience of distress induced significant emotional arousal mediated by the autonomic nervous system. The facial thermal modulations observed in the mothers were surprisingly similar to those observed in the child. Second, facial thermal modulations of the mothers correlated with corresponding modulations of their children at the individual as well as at the group level. Control analyses showed that the thermal variations observed in the mothers in an empathic situation are unlikely to reflect respiratory alterations or other short-lasting artifacts throughout the experiment. Although both vasomotor and respiratory activity could be modulated by emotional stimuli, facial thermal variations were statistically independent from mothers’ respiration and no significant alterations of respiratory activity were detected in the mothers during the experimental phases. Furthermore, segments in the thermal time courses corrupted by motion or vocalization artifacts were excluded from quantitative data analysis and would not be able to explain the observed parallelism between mother and child. Thus, mother–child dyads showed a significant and situation-specific synchronicity between the autonomic reactions individually exhibited by each partner.

Previous studies investigated maternal empathy mainly by using verbal reports (Soenens et al., 2007; Strayer and Roberts, 2004, 1989; Oppenheim et al., 2001; Gondoli and Silverberg, 1997) and by neuroimaging (Lenzi et al., 2009; Noriuchi et al., 2008; Ranote et al., 2004). Some evidence for the involvement of autonomic activity in empathy already exists (Harrison et al., 2009, Table 3)
2007, 2006; Chauhan et al., 2008), but very few studies investigated physiological changes during mother–child interactions as an index of autonomic reactions in emotional parent–child relationships (Frodi et al., 1978; Donovan et al., 1978). Moreover, most studies on the neurobiological basis of empathy only evaluated the empathizing partner without directly relating physiological data of multiple partners in real time as an indicator of emotional sharing. Therefore, differently from previous studies that measured indirect or cognitive aspects of emotional sharing, the present results, showing a synchronism between mothers’ and children’s autonomic responses, offer rather direct evidence for the affective aspect of empathy as an embodied vicarious process.

The findings are also consistent with the notion that both the psychological and the neural components of emotional feelings are essentially integrated with autonomic-visceral changes (Harrison et al., 2010; Kreibig, 2010; Stephens et al., 2010; Critchley, 2009; Craig, 2009, 2002; Damasio, 1999, 1994; James, 1894; Lange, 1885). It has been proposed that a discrete network of brain regions is involved in the dynamic interaction between homeostatic information, cognitive processes, and motivational signals, supporting subjective feeling states. This network may include cortical regions, like insular cortices, anterior cingulate cortex and orbitofrontal cortex, amygdala, and low-level brainstem nuclei as well as limbic and dopaminergic midbrain regions (Critchley, 2009; Damasio, 1999). Indeed, a largely overlapping neural network has been related to parents’ affective and empathic responses to their offspring as well as to variations in pupil size reflecting empathic autonomic responses (Lenzi et al., 2009; Noriuchi et al., 2008; Swain et al., 2007; Harrison et al., 2006; Ranote et al., 2004).

The present study provides reliable measures of autonomic responses recorded simultaneously for both distress-related emotions and their empathizing mothers, without the disadvantages of most of the physiological methods when applied to psychological domain, including the poor practicability and psychologically demanding character of the measurement equipment. By means of thermal IR imaging, physiological correlates of emotional reactions were investigated in an interactive and ecological experimental context without interfering with spontaneous behavior and without age restrictions (Kuraoka and Nakamura, 2011; Nhan and Chau, 2010; Shastri et al., 2009). This suggests important applications for providing data that add to developmental, comparative and evolutionary research on emotion in humans as well as non-human individuals (de Waal and Ferrari, 2010; Bard, 2009). In particular, this approach could contribute to elucidate the bottom-up emotional processes in parent–child intersubjectivity considered at the foundation of human social interaction (Bard, 2009; Trevathan and Atikten, 2001).

Furthermore, the task used here presented children with a natural situation that is likely to occur in ordinary life. This ecological context has the advantage of obtaining more valid and generalizable data than those collected in fake laboratory settings. According to developmental literature, the task used in this study elicited feelings of guilt in the observed children, as confirmed by children’s behavioral reactions (Kochanska et al., 2002, 1995; Cole et al., 1992). Hence, maternal empathy was measured in this study for an emotion that is subtler than those usually used in empathy research, like pain, and that has never been investigated so far.

However, it must be acknowledged that the number of mother–child dyads included in the analysis of the present study was limited, suggesting that the provided evidence may be considered preliminary. Because of the use of a natural and ecological experimental context, not all collected data were suitable for reliable quantitative data processing. Nevertheless, the results, especially for the nasal tip, were surprisingly consistent across the individual dyads as well as in group analysis. The failure to find a significant correlation at the individual dyad level in 3 mother–child dyads for the maxillary area could be explained partly by inferences inherent to this facial region, causing relatively noisier data, compared to the nasal tip (respiration, mouth movements, combination of blood perfusion and sweat gland activity, movements occluding the region from view). Furthermore, the detected synchronicity between mother and child appeared specific for the experimental phases in which the mother observed the child in an emotionally charged situation, and visual analysis of the facial thermal imprints suggested similar results also in a larger group of mother–child dyads.

Some other issues should be noted. It could be argued that an alternative explanation for the observed autonomic reactions in the mothers would be that they reflect an experience of their own distress rather than reflecting the other’s distress, because of a sense of responsibility for the child breaking the toy, or a primordial physiological mechanism elicited by a threatening situation involving one’s offspring. In our opinion, the friendly climate of the lab and the poor value of the objects manipulated by the children most likely prevented mothers from really getting distressed by the child’s conduct. Furthermore, the use of an experimental context where the mother’s reaction was strongly relying on her interpretation of the child’s behavioral features, rather than on the distress-evoking stimulus per se, would suggest that the detected synchrony in autonomic arousal reflects maternal sharing of their child’s distress. We thus incline to believe that the maternal autonomic responses stemmed from the children’s emotional state. The vicarious nature of maternal emotion is also supported by the parallelism we found between mother and child responses, which has been the very result of our study rather than the responses per se, and this result is explained better by hypothesizing shared than independent feelings.

Although the present results show plausible evidence for emotional sharing between mother and child, testing whether similar patterns of physiological responses emerged in the mother if she had broken the toy herself, could properly support this evidence. Likewise, testing the mothers against other categories of people could support the “maternal” nature of this emotional sharing. According to literature on self-reported empathy, mothers may show significantly higher levels of empathy than fathers (Strayer and Roberts, 1989). Therefore, differences both in intensity and in synchrony of autonomic responses could be expected between mothers and other groups. Differences should also be expected between women who are the mothers of the observed children and women who are not, the latter supposed to be less emotionally tied to the child or to be less familiar with the child’s typical behavioral signs of distress. In sum, based on our results, further studies using relevant control groups are encouraged in order to test specific hypotheses.

Finally, mimicry of facial muscular responses have been found predictive for self-reported empathic experiences and are related with variations in facial temperature as well (Jafri et al., 2011; Harrison and Morgan, 2010; Sonnby-Borgstrom, 2002). It would be a relevant issue for future studies to integrate these different types of measurements in order to gain more insight in the interrelationship between empathic responses at different levels, like motor, autonomic and experiential (Jiang et al., 2005).

In conclusion, the present results pave the way for a more comprehensive approach to the investigation of the neurobiological basis of emotional parent–child relationships as a multidimensional phenomenon. Supporting the hypothesis that empathy embodies a direct sharing of visceral-autonomic responses, we found a close and specific parallelism between the autonomic variations of mothers observing their children in a distressing situation and those occurring in children themselves. Since this sharing is assumed to represent the most basic and direct level of empathy (Decety and Jackson, 2004), the present results provide reasonable