Facial Imprints of Autonomic Contagion in Mother and Child: A Thermal Imaging Study

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SUMMARY

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. Thermal infrared imaging offers the possibility of recording non-verbal interactions among individuals, thus paving the way to new studies and methodologies in neuropsychology.

1. INTRODUCTION

Seeing one's own offspring in distressing situations is a rather ordinary occurrence in everyday life. A sense of empathy with the child's feelings 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 (4, 17, 32, 37, 41, 42, 48). What neurobiological mechanism subtends maternal empathy in humans? In particular, does sharing of autonomic arousal accompany a mother's affective sharing of her offspring's distress?

Autonomically-mediated visceral responses are proposed to be strictly related to the experience of emotional feelings (10, 11, 12, 22, 23, 29, 31, 47). The sympathetic and parasympathetic divisions of the au-tonomic 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 (5, 10, 24). 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 af-fective experiences (1, 13, 18, 19, 40, 44), also embodies a direct sharing of changes in body physiology between the involved individuals (10, 11, 12, 13, 40).

The present study is an extension of a previous one aimed at investigating whether a mother's empathic sharing of her offspring's distress is accompanied by physiological sharing of autonomic responses (16). 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 which esti-mates variations in autonomic activity reflected by cutaneous temperature modulations by means of recording the thermal infrared signals spontaneously released by the human body (20, 34, 38, 39, 43). Facial temperature is mediated and regulated by sympathetic and parasympathetic activity, which works to preserve the body homeostasis in the human physical and psychological functioning (2), and therefore is especially active when emotional stimuli are present in the proximal environment (29).

2. METHODS

2.1 Participants

Thirteen mothers (age 31-46 years) and their typically developing biological children (5 male, age 38-42 months) participated in the experiment. Two out of 13 mother-child dyads were excluded from further data analysis, since the toy was not broken during the experiment (see Procedure section). Inclusion criterion for both mothers and children was the ab-sence of any overt physical, psychiatric or psychological disease. All participants observed standard preparation rules for thermal imaging.
The study was approved by the local Ethics Committee. Written informed consent was obtained from all participants after full explanation of the pro-cedure of the study.

2.2 Procedure

Prior to testing, each subject was left to acclima-tize for 10 to 20 minutes 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 psy-chological habituation to the setting and the experi-menter, 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" (7). 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 demon-strated the toy);
2) “playing” (the child played with the toy, while the experimenter left the room for 1 minute);
3) “mishap” (child “broke” the toy);
4) “re-entrance” of the experimenter (the experimenter did not say anything for 30 seconds 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 x 240 QWIP detectors, capable of collecting the thermal ra-diation in the 8-9 μm band, with a 0.02 second time resolution, and 0.02 K temperature sensitivity. The thermal camera response was blackbody-calibrated to null noise-effects related to the sensor drift/shift dy-namics 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 10 frame/sec.
Behavioral recordings of the children took place through two remote-controlled cameras (Canon Vc-C50iR). 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 video reading lab by specialized software (Interact Plus, Mangold) that allows to code behavior in synchrony with the ongoing mov-ies of the children during the experiment.
The toy presented to the children in the “mishap paradigm” was a black and white colored robot with a height of approximately 20 cm. When turning on the robot with a switch on its back it started to walk and play music. Both hands of the robot could be opened and closed by means of pressing/relieving a button. The hands of the robot were prepared to break when manipulated by the child. The robot could be repaired only by the experimenter. During neutral interaction between the experimenter and the child, other toys were presented, such as a puzzle, a magic wand, 3-D book.

2.4 Behavioral data analysis

Behavioral and verbal signs of children's distress during the experiment were observed according to a reliable coding system used in previous research and in the same context (7, 27, 28). According to this scheme, the child's behavior is coded according to 5 main categories (gaze direction, facial expression, bodily tension, actions and verbalizations) and various parameters (frequency, duration, latency) by two independent raters. Following from the notion that different combinations of signs may be indicative of distress, in previous studies of guilt and shame reactions to mishap paradigm and task failure (28, 33) distress has been scored categorically by restricting the number of criterion signs to five (eye/face, head/body, arms/hands, action and verbal). Thus, in the mishap and entrance phase, distress in response to mishap was defined "absent" if the child was not affected by the mishap in any way, "low" if the child showed behaviors included in one of the five codified signs, "medium" if the child showed behaviors included in two or three 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 ther-mal 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 quantita-tive estimation of temperature variations in relevant facial regions of interest in 11 mother-child dyads.

Thermal facial imprints and variations in cuta-neous temperature of facial regions of interest in chil-dren 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 landmarkers based on the subject's nose profile (15).

In order to quantify thermal variations and their correlation between children and their mothers, changes in cutaneous temperature for the nasal tip. This region was selected according to previous studies in humans as well as primates (30, 36, 43) as associated with the activation of the sympathetic nervous system by emotional or distressing stimuli (30, 34, 35, 36, 43). More precisely, thermal changes of the nasal tip may reflect sympathetic alpha-adrenergic vasomotor effects. Furthermore, sympathetic stimulation of the blood vessels can also have smaller vasodilatory effects via cholinergic and beta-adrenergic receptor action (45).

First, we assessed at the intra-individual level whether the facial skin temperature did not vary significantly or presented drifts during a 90 second 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-second pre-stimulus period (from 10 to 0 s before stimulus presentation) and each of the six 10-second 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 seconds and lasted from 20 to 30 seconds 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 representative 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 seconds after the beginning of each phase. This proce-dure also allowed to deal efficiently with the partici-pants' 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) were obtained for each participant for the analysis of the experimental phases. Similarly, 15 frames (each frame taken every about 5 seconds, and not affected by the above-mentioned short-lasting artifacts) from a neutral baseline period of 90 seconds immediately preceding the experiment were obtained.

The nasal tip temperatures of the children were manually extracted from the available thermal images. For extraction of the mothers' nasal tip temperature, 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 (baseline, mishap, entrance, soothing). The tracking algorithm is based on the 2-D cross-correlation between a template re-gion, 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. For analysis, ROI average temperatures of the mothers were extracted at the time points corresponding in time to those of the selected thermal images in the children.

In order to verify whether there was a significant modulation of skin temperature in children and their mothers during the experimental phases and the base-line period in these facial region 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 region of interest as within-subject variable.

Group correlation analyses (Pearson coefficient) analysis was performed on the thermal time courses of the determined region of interest 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. In order to verify whether correlations between au-tonomic 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. 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 participating mothers. Once the breathing signal was extracted and opportunely band-pass filtered (0.25-0.6 Hz), the duration of breathing cycles (in seconds) was evaluated 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 15 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 res-piratory 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 chil-dren varied between medium and high.

3.2 Visual analysis of facial thermal imprints

A visual inspection of the changes in facial ther-mal imprints was performed to investigate the pres-ence of appreciable signs of autonomic responses of mother and child throughout the experiment.

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 (30, 34, 35, 36, 43). This sympathetic reaction was accompanied by sudomotor response (34), which is in the maxillary area likely regulated by sympathetic postganglionic cholinergic activity, whereas 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 re-sponse in the maxillary area was initially maintained, whereas the temperature of the nasal tip soon in-creased, 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 modula-tion 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

ANOVAs with the temperature values of the faci-al region of interest (nasal tip) at the different time points as within-subject variable showed a significant modulation of temperature during the emotionally charged experimental phases (mishap, entrance, soothing) for the child [$F(14,140) = 5.605$, $p < 0.001$] as well as for the mother [$F(14,140) = 2.339$, $p < 0.01$]. No significant modulation of temperature was detected during the baseline period, neither for the child [nasal tip $p > 0.9$], nor for the mother [nasal tip $p > 0.4$].

Group analyses for the phases in which the emo-tional modulation took place (mishap, entrance, soothing) showed significant positive correlation coefficients between thermal fluctuations of mother and child for the nasal tip ($r = 0.87$, $p < 0.0001$). With respect to the neutral baseline condition, no significant correlation could be found at the group level for the nasal tip ($r = 0.13$, $p > 0.6$), 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. Example of mother-child dyad temperature variation is shown in fig. 1. Group results are graphically presented in fig. 2.

3.4 Control analysis for respiratory effects on thermal variations

Correlation analyses investigating the relationship be-tween thermal variations on the nasal tip and

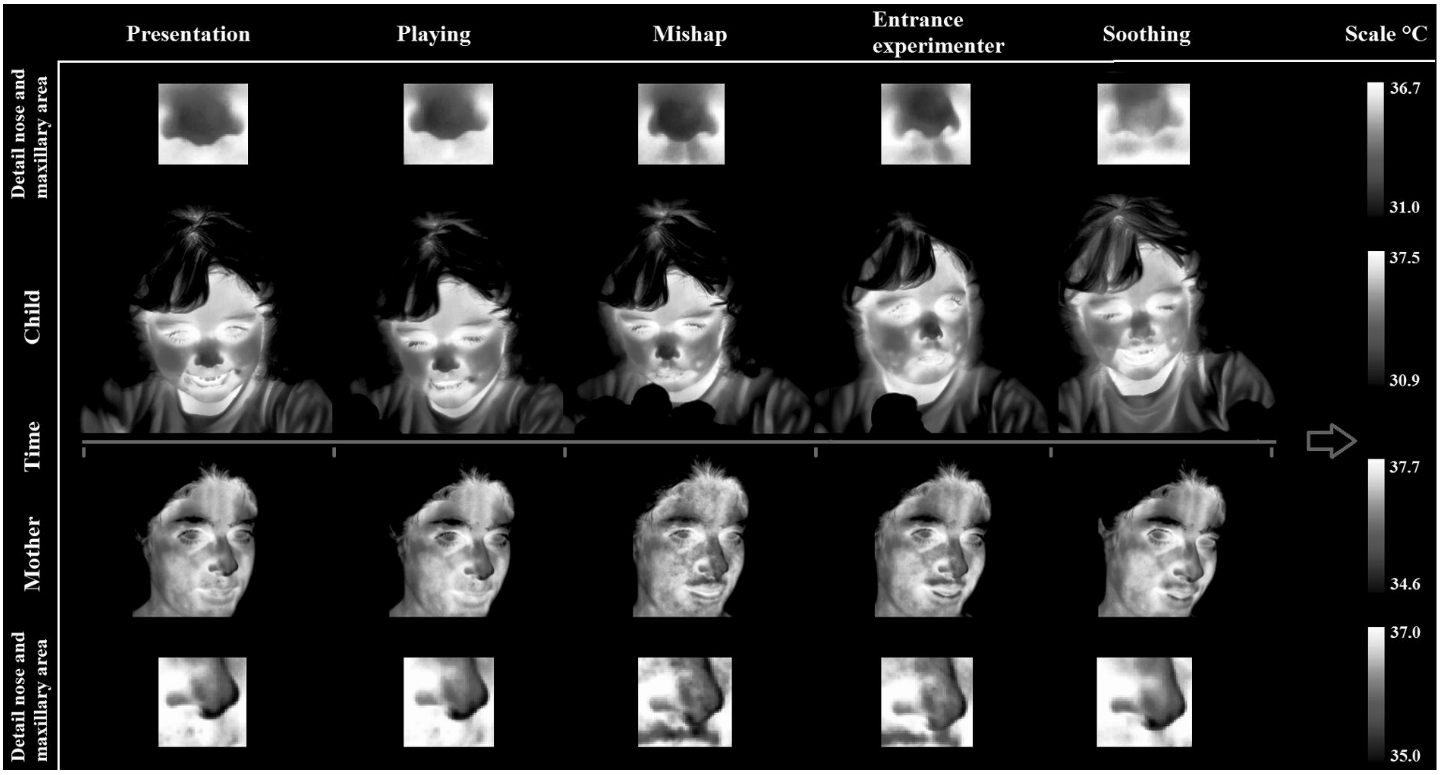
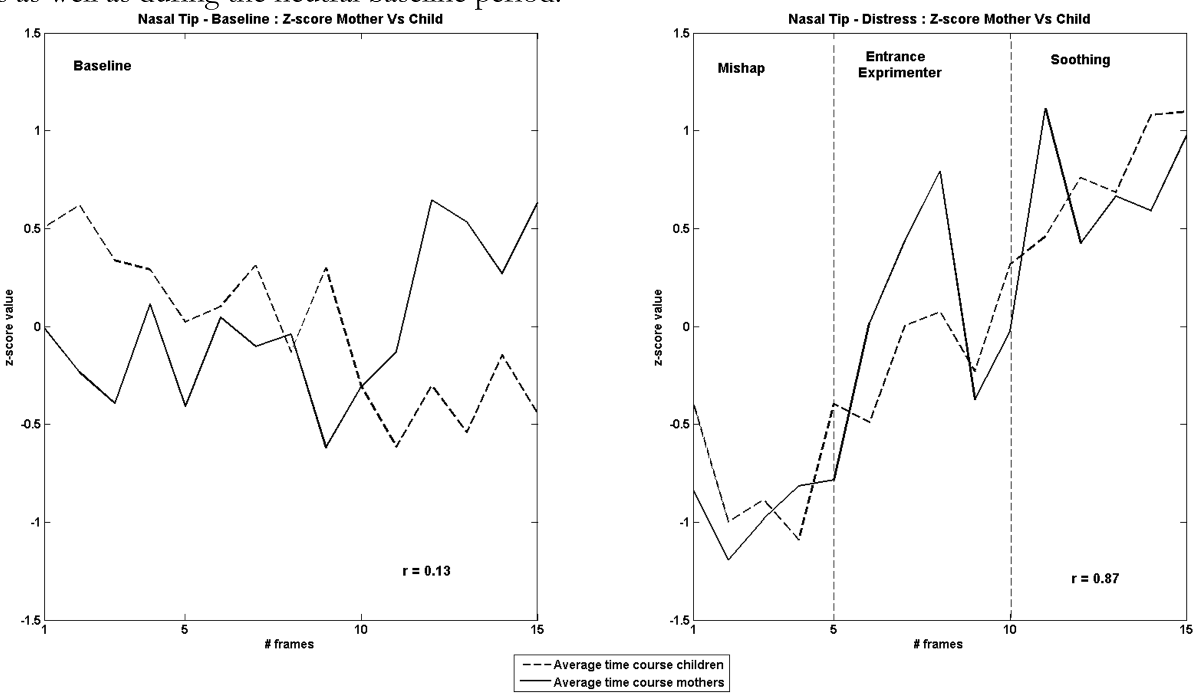


Fig. 1 - Facial thermal imprint of one of the mother-child dyad (adapted from 16).

Fig. 2 - Graphical representation of group temperature variations of the nasal tip area during the experimental phases as well as during the neutral baseline period.



nasal respiratory variations in the individual mothers did not yield significant correlations ($p > 0.05$). Group analysis confirmed the lack of a correlation between nasal temperature dynamics and respiratory activity in the mothers ($p > 0.7$). Furthermore, a multiple re-gression analysis showed that nasal tip temperature variations in the mothers were statistically independ-ent from the mothers' respiratory activity (Beta = 0.02, $t = -0.17$, $p > 0.8$), whereas the relationship between nasal tip temperature variations in the mothers and those in the children remained signifi-cant (Beta = 0.91, $t = 7.963$, $p < 0.001$). 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 ($p > 0.1$).

4. CONCLUSIONS

The present study provides two main results. First, facial thermal imprints of the mothers suggest that observation of their child's experience of distress in-duced significant emotional arousal mediated by the autonomic nervous system. The facial thermal modu-lations 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 in-dividual 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 artefacts 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 artefacts 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.

These results, showing a synchronism between mothers' and children's autonomic responses, offer ra-ther 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 (8, 9, 10, 11, 12, 22, 23, 29, 31, 47).

The present study provides reliable measures of autonomic responses recorded simultaneously for both distressed children 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 meas-urement 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 behaviour and without age restrictions (30, 36, 43). This ecological context has the advantage of obtaining more valid and generalizable data than those collected in fake laboratory settings. This also suggests important applications of the thermal IR imaging technique for providing data that add to developmental, comparative and evolutionary research on emotion in humans as well as non-human individuals (3, 13).

Some other issues should be noted. 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 sup-port the "maternal" nature of this emotional sharing. Differences both in intensity and in synchrony of au-tonomic responses could be expected between moth-ers and other groups. Differences should also be ex-pected 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.

Furthermore, mimicry of facial muscular responses have been found predictive for self-reported empathic experiences and are related with variations in facial temperature as well (21, 25, 46). 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 re-sponses at different levels, like motor, autonomic and experiential (26).

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 au-tonomic 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 (14), the present results provide reasonable evidence for a crucial and still poorly explored aspect of the phenomenon under scrutiny.

Finally, because of the contact-free nature of thermal infrared (IR) imaging, its successful application in the context of psychological research suggests that it could be particularly useful in investigating the neuro-biological basis of behavior, especially in populations difficult to involve in controlled and artificial experi-mental settings, like children. It also allows to study people in ecological settings without interfering with spontaneous behavior, providing more valid and gen-eralizable results.

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