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

Sjoerd J. Ebisch[a,b,*,1], Tiziana Aureli[b,c,1], Daniela Bafunno[c], Daniela Cardone[a,b], Gian Luca Romani[a,b], Arcangelo Merla[a,b]

[a] Institute of Advanced Biomedical Technologies (ITAB), G. d'Annunzio Foundation, Chieti, Italy
[b] Department of Neuroscience and Imaging, G. d'Annunzio University, Chieti-Pescara, Italy
[c] Faculty of Psychology, G. d'Annunzio University, Chieti-Pescara, Italy

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ABSTRACT

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.

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; Bowlby, 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 (Frodi 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

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* Corresponding author at: Department of Neuroscience and Imaging, G. d'Annunzio University, Via dei Vestini 33, 66013 Chieti (CH), Italy.
Tel.: +39 08713556949x01; fax: +39 08713556930.
E-mail address: sjoerdebisch@yahoo.com (S.J. Ebisch).

[1] These authors contributed equally to this work.

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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., 2009; Garbey 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 response was blackbody-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.

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 movies 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 (Kochanska et al., 2002, 1995; Cole et al., 1992) (supplementary Table 1). 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 (e.g. Kochanska et al., 2002; Lewis et al., 1992) 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 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 behavior by the child, limiting the reliability of the thermal signal (e.g. temporarily leaving the room, touching/occluding the face).

Thermal facial 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 landmarkers 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; Nakanishi and Imai-Matsumura, 2008; Merla and Romani, 2007). 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 (Smith and Kampine, 1990).

Different 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.