Toward a neuroscience of parenting : adult attachment and oxytocin affect neural and behavioral responses to infant attachment signals

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Citation

Hendricx - Riem, M. M. E. (2013, June 4). *Toward a neuroscience of parenting : adult attachment and oxytocin affect neural and behavioral responses to infant attachment signals*. Retrieved from https://hdl.handle.net/1887/20924

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Title: Toward a neuroscience of parenting : adult attachment and oxytocin affect neural and behavioral responses to infant attachment signals
Issue Date: 2013-06-04

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Attachment in the brain: Adult attachment representations predict amygdala and behavioral responses to infant crying

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Abstract

In the current study we demonstrate that adult attachment representations influence neural, emotional and behavioral responses to infant crying, thus validating the Berkeley Adult Attachment Interview with functional Magnetic Resonance Imaging. We examined amygdala activation, feelings of irritation, and the use of excessive force as indicated by grip strength using a hand-grip dynamometer during exposure to infant crying and scrambled control sounds in 21 women without children. Individuals with insecure attachment representations showed heightened amygdala activation when exposed to infant crying compared to individuals with secure attachment representations. In addition, insecure individuals experienced more irritation during infant crying and used more excessive force than individuals with a secure representation. Amygdala hyperactivity might be one of the mechanisms underlying the experience of negative emotions during exposure to infant crying in insecure individuals and might explain why insecure parents respond inconsistently to infant signals or reject their infants’ attachment behavior.

INTRODUCTION

Infant crying is a salient attachment signal that contributes to infant survival through eliciting parental proximity and care (Bowlby, 1969/1982; Soltis, 2004). Crying evokes strong emotional reactions in parents, ranging from feelings of empathy to negative emotions such as anxiety and anger (Dix, 1991). Empathic emotional reactions motivate sensitive parental behaviors such as soothing or feeding the child, whereas negative emotional reactions increase the likelihood of using harsh responses that are aimed to stop the crying by all means because it is perceived as aversive (Dix, Gershoff, Meunier, & Miller, 2004). Not all parents are always able to respond in a sensitive way to their crying infant, and excessive, high-pitched crying can trigger even child abuse or neglect in some parents (Barr, Trent, & Cross, 2006; Out, Pieper, Bakermans-Kranenburg, Zeskind, & Van IJzendoorn, 2010; Reijneveld, Van der Wal, Brugman, Sing, & Verloove-Vanhorick, 2004; Soltis, 2004). Although it has been shown that adult attachment affects parental responding to infant crying (Leerkes & Siepak, 2006), little is known about the neural mechanisms underlying attachment-related individual differences in parenting behavior. The present study was designed to shed more light on the perception and processing of infant signals in individuals with different adult attachment representations by examining neural, emotional, and behavioral responses to infant crying.

Adult attachment reflects the current state of mind with respect to attachment and refers to the mental representation of past and present attachment experiences. Adult attachment can be measured with several instruments, but the 'gold standard' for the measurement of adult attachment is the Adult Attachment Interview (Hesse, 2008; George, Kaplan, & Main, 1985; Main & Goldwyn, 1984), a semi-structured interview in which participants are required to reflect upon their attachment-related experiences (Hesse, 2008; Main, Hesse, & Goldwyn, 2008). Participants are asked to describe their relationships with attachment figures, to give specific examples to support these descriptions and to evaluate their memories of attachment-related events from their current perspective. The coding system of the AAI includes three major adult attachment classifications: secure-autonomous (F), insecure-dismissing (Ds) and insecure-preoccupied (E) (see methods for descriptions of these classifications). The AAI has been administered to more than 10.000 respondents since its development (Bakermans-Kranenburg & Van IJzendoorn, 2009), and numerous studies support its validity and reliability (e.g., Bakermans-Kranenburg & Van IJzendoorn, 1993; Benoit & Parker, 1994; Crowell et al., 1996; Sagi et al., 1994).

Several studies have shown that individual differences in adult attachment, measured with the AAI, are related to different patterns of responding to infant signals and therefore affect infant attachment and developmental outcomes (see Van IJzendoorn, 1995). More specifically related to infant crying, secure-autonomous adults are suggested to be able to respond adequately to their crying infants since they are free of distorted perceptions of their infants' needs (Blehar, Waters, & Wall, 1978; see also Mesman, Oster, & Camras, 2012), whereas individuals with an insecure attachment representation may respond inconsistently or reject their infants' attachment behavior. As a consequence, secure parents more often have infants who are securely attached, whereas parents with an insecure attachment representation tend to have insecurely attached infants (Main, 2000). Leerkes and Siepak (2006) examined attachment-related predictors of emotional and cognitive responses to infant distress. They found that adult attachment as measured with self-report questionnaires influenced how individuals perceived infant crying. Individuals with insecure attachment styles were more likely to make negative, internal attributions to the nature of the cry (e.g., spoiled or difficult temperament). In addition, they were less accurate at identifying infant emotions and more likely to be amused or neutral in response to infant distress. Other studies support the notion that insecure parents tend to process infant crying or other attachment-related information in a defensive and negatively biased manner, and that this kind of information processing contributes to insensitive interactions that increase the risk of insecure infant attachments (Dykas & Cassidy, 2011).

One way to operationalize behavioral responses to infant cry signals is using a hand-grip dynamometer to measure whether participants squeeze with excessive force when they are exposed to infant signals. For example, Crouch, Skowronski, Milner, and Harris (2008) showed that parents at risk for child abuse who were primed with hostile words tended to use more excessive force when they were exposed to videotaped segments of crying, smiling and quiet infants. Furthermore, the hand-grip dynamometer was used to study the effect of perceived control on punitive force when teaching a computer game to children believed to be at a distant location (Bugental, Lewis, Lin, Lyon, & Kopeikin, 1999). Women with low perceived control used high levels of punitive force when children were ambiguously responsive to their instructions. Excessive use of punitive force was interpreted as an analogue of reactive force to children's disobedience, which is in line with other studies that showed that high levels of handgrip force are related to socially dominant behaviors (Gallup, O'Brien, White, & Wilson, 2010). According to Bugental et al. (1999), adults who have a negatively distorted view of the motives of children might use exaggerated punitive force as a defense against the power of children. In a recent study, Bakermans-Kranenburg et al. (2012) found that oxytocin, a neuropeptide that is important for mother-infant bonding (Carter, 1998; Galbally, Lewis, Van IJzendoorn, & Permezel, 2011), reduced the use of excessive force during exposure to infant crying in individuals who experienced little harsh discipline in their childhood. Low levels of oxytocin have been observed in mothers with insecure attachment representations as assessed with the AAI (but coded with the Crittenden system, Strathearn, Fonagy, Amico, & Montague, 2009) and low oxytocin levels have been related to reduced sensitive responsiveness to infant signals (Feldman, Gordon, Schneiderman, Weisman, & Zagoory-Sharon, 2010; Feldman, Weller, Zagoory-Sharon, & Levine, 2007). In the present study we used the hand-grip dynamometer to assess the use of excessive force during exposure to infant crying in individuals with secure *versus* insecure AAI classifications. As insecure individuals tend to process infant cues in a more negative manner (Leerkes & Siepak, 2006), we expect that they will use more excessive force during exposure to infant crying than individuals with a secure representation.

The neural mechanism underlying the perception of infant cry signals has been the focus of several functional Magnetic Resonance Imaging (fMRI) studies. These studies have shown that a highly interactive cognitive-affective neural network is involved in the perception of infant crying (Bos, Panksepp, Bluthé, & van Honk, 2012). The amygdala is an important functional hub within this network. It is activated during exposure to infant crying (Lorberbaum et al., 2002; Riem et al., 2011; Seifritz et al., 2003) and it is connected with other brain regions that are involved in the perception and evaluation of crying such as the orbitofrontal cortex (OFC) and the anterior cingulate cortex (ACC) (Riem et al., 2012). The amygdala is part of the limbic system and is involved in the detection of threat and the experience of fear and aversion (Davis & Whalen, 2001; Fusar-Poli et al., 2009; Gamer, Zurowski, & Buchel, 2010; Morris et al., 1998). Heightened amygdala activation is an indication of hyperemotionality and has been observed in depression and anxiety disorders (Rauch et al., 2000; Yang et al., 2010) and in intrusive mothers (Atzil, Hendler, & Feldman, 2011). Several fMRI studies also indirectly point to a role of the amygdala in the processing of attachment-related information. For example, Buchheim et al. (2006) found elevated amygdala activation in individuals with unresolved loss during the Adult Attachment Projective (AAP). Increased amygdala responses have also been observed in individuals with high self-reported anxious attachment during the observation of angry facial expression conveying negative feedback about task performance (Vrtička, Andersson, Grandjean, Sander, & Vuilleumier, 2008).

However, self-report questionnaires have been shown to overlap only marginally with the AAI (Roisman et al., 2007), and little research has been conducted on the neurobiological processes underlying the perception of infant signals and AAI representations as classified with the extensively validated standard Main, Goldwyn and Hesse (2003) coding system. Previous fMRI studies on the influence of adult attachment representation mainly focused on the perception of infant facial expressions. Strathearn et al. (2009) examined neural responses to own infant smiling and sad faces in first-time mothers and found that mothers with an insecure attachment representation (as assessed with the Crittenden coding system) showed less activation in dopaminergic reward centers such as the ventral striatum compared with secure mothers. In a recent study, Lenzi et al. (in press) found that individuals with a dismissing attachment representation showed increased activation in the limbic and mirror neuron system and greater deactivation in the OFC and ACC in response to infant facial expressions compared with individuals with a secure representation, possibly reflecting dismissing mothers' affective dysregulation and lack of emotional investment in attachment relationships. Furthermore, Galynker et al. (2012) examined the influence of depression and attachment insecurity (measured with the AAI) on neural responses to images of the participant's mother, friend or a stranger. They found that insecure attachment was associated with enhanced activation in brain regions related to affectively motivated behavior and memory. However, no effects of attachment security on amygdala activation were found, possibly because of the absence of negative affective stimuli.

In the present study we investigated amygdala responses to infant crying in individuals with secure and insecure attachment representations, using the 'gold standard' for adult attachment, the AAI (Hesse, 2008). Considering that the amygdala seems to be involved in both adult attachment and the perception of infant signals, we examined whether amygdala hyperactivity mediates the relation between insecure attachment representation and negative emotional and/or behavioral responses to infant crying. In 10-year-old children amygdala hyperactivity was found to mediate the association between adverse early attachment experiences (growing up in institutionalized care) and decreased eye-contact during dyadic interaction (Tottenham et al., 2011). This indicates that early adverse attachment experiences affect amygdala activity, possibly because of the vulnerability of the amygdala to environmental exposures in early life (Lupien, McEwen, Gunnar, & Heim, 2009; Sabatini et al., 2007), which in turn influences social behavior. Amygdala hyperactivity might thus be one of the mechanisms underlying the association between adult attachment representation and emotional and/or behavioral responses to infant crying.

To our knowledge, this is the first study to investigate the influence of adult attachment representation as assessed with the AAI on neural, emotional and behavioral responses to infant crying. We examined amygdala activation, feelings of irritation, and the use of excessive force during exposure to infant crying. We hypothesized that 1) insecure individuals experience more irritation during the perception of infant crying than individuals with a secure representation; 2) insecure individuals use more excessive force as indicated by grip strength using a hand-grip dynamometer during exposure to infant crying; 3) individuals with insecure attachment representations show heightened amygdala activation during exposure to infant crying compared to individuals with a secure representation; 4) the relation between attachment representation and emotional or behavioral responses to infant crying is mediated by amygdala activation.

Method

Participants

Participants were selected from a larger study investigating caregiving responses and physiological reactivity to infant crying (Out, Pieper, Bakermans-Kranenburg, & Van IJzendoorn, 2010). The original sample consisted of 50 male and 134 female adult twin pairs. A group of 43 right-handed women, 21 from MZ twin pairs and 22 from DZ twin pairs were selected to participate in an fMRI study investigating the influence of oxytocin administration on neural responses to infant crying. Data for the current study were acquired from the 21 participants (12 MZ, 9 DZ, no pairs) who were randomly assigned to the placebo condition. Data regarding oxytocin effects on neural responding to infant crying has been presented elsewhere (Riem et al., 2011). Participants were screened for hearing impairments, MRI contraindications, pregnancy, psychiatric or neurological disorders, alcohol and drug use and did not have children of their own. At the time of fMRI data acquisition the mean age of the participants was 29.05 years (*SD* =7.55, range 22-49). Permission for this study was obtained from the Medical

Ethics Committee of the Leiden University Medical Center and all participants gave informed consent.

Procedure
Participants were invited to the lab for 2 waves of data collection. In the first session, the AAI was administered in a quiet room. In the second session, fMRI data acquisition was performed and emotional and behavioral responses to infant crying were measured. After explaining the fMRI procedure participants were instructed to comfortably position themselves on the scanner bed. Cushions were placed between the head coil and the participant in order to prevent head movement. Participants were instructed to attend to the sounds they would hear in the fMRI scanner. After fMRI scanning participants rated how much irritation they felt while listening to the crying sounds, and the handgrip-force task was administered.

Measures
Adult Attachment Interview. Ratings and classifications of adult attachment representations were derived from the Adult Attachment Interview (AAI; Main et al., 1985, 2008), which was conducted during a lab session. The AAI is considered to be the gold standard for assessing attachment representations (Hesse, 2008). The AAI is an hour-long, semi-structured interview which assesses an individual's current state of mind with respect to attachment. Participants are asked about their childhood attachment experiences with their parents and how they think they were affected by these experiences, as well as about the current relationship with their parents. It is the coherence of discourse rather than the content of the autobiographical account that determines their attachment classification (see Hesse, 2008, for a detailed description of the assessment). Coding of the AAI yields one of three main adult attachment classifications: Secure-Autonomous (F), Insecure-Dismissing (Ds), and Insecure-Preoccupied (E). Adults with the F classification tend to value attachment relationships, to describe their attachment experiences (whether positive or negative) coherently, and to consider them important in the development of their personality. Adults with the Ds classification tend to idealize their childhood experiences without being able to provide concrete illustrations, or tend to minimize the importance of attachment in their own lives. Adults with the E classification tend to emphasize the impact, often negative, of their attachment experiences. They are still very much involved and preoccupied with these experiences. An additional classification, unresolved (U), is assigned when an interview shows signs of unresolved trauma or loss.

Interviews were audio-recorded, transcribed verbatim, and scored according to the standard AAI classification system (Main et al., 2008). The interviews were anonymously assigned and coded blindly by 3 raters who were trained to be reliable to the coding standards of the Berkeley laboratory of Mary Main and Erik Hesse. Scores for coherence of mind and unresolved trauma were are assigned using a nine-point rating scale (Hesse, 2008). Mean score for coherence of mind in the current sample was 4.53 (*SD* = 2.08). Seven participants were classified as secure, four participants as dismissing, four participants as preoccupied and six participants as unresolved. Subjects were reclassified as either secure (autonomous) or insecure (dismissing, preoccupied, unresolved), resulting in a group of 14 insecure participants and a group of 7 secure participants. In addition, participants were reclassified as unresolved or not unresolved, resulting in a group of 6 participants with an unresolved state of mind and 15 participants without an unresolved state of mind. For one participant it was not possible to assign a coherence of mind score because some AAI questions were missing due to problems with audio-recording. The missing value of this participant, who was classified as secure by two independent expert raters, was replaced by the mean coherence of mind score of individuals with a secure classification.

Emotional and behavioral responses to infant crying. After fMRI scanning the participants were asked to report whether they felt irritated while listening to the crying sounds on a 5-point Likert scale (1 = not irritated, 5 = irritated). In addition, an adult hand dynamometer was used as an indicator of the use of excessive force during listening to infant crying. The dynamometer (model TSD121C) weighed 315 g and was 185-mm long, 42-mm wide and 30-mm thick, with an isometric range from 0 to 100 kg. Squeeze intensities (in kg) were transferred directly from the dynamometer to the AcqKnowledge software program (version 3.8; Biopac Systems, 2004). Matlab (version 7.8.0, Mathworks, MA, USA) was used to identify peak intensities for each squeeze. Participants were asked to squeeze the handgrip dynamometer as hard as possible and then at 50% of their maximal handgrip strength. They performed as many trials as necessary for training, with their performance displayed on a monitor to check the 50% level of each second handgrip, until they were able to modulate the force of their second squeeze to half the strength of their first squeeze. Then the monitor was directed away from the participant in order to prevent them from receiving feedback regarding their performance during the remainder of the task.

The handgrip-force task was administered on a laptop using E-Prime software (version 2.0; Psychology Software Tools, Inc., PA, USA). During the task participants were seated in front of a computer screen wearing headphones (type König CMP). As a prompt, the words 'squeeze maximally' were displayed briefly in the middle of the screen, after 2 s followed by the prompt 'squeeze at half strength', thus prompting the participants to perform a brief firm squeeze followed by a brief squeeze half the strength. After baseline squeezing (no sound), participants were requested to squeeze the handgrip dynamometer eight times at full and half strength, respectively, the first four times listening to infant laughter and then four times listening to infant crying. In the current study we focus on squeezing during infant crying only. Squeezing differences during infant crying and laughter between the placebo and the experimental group are presented elsewhere (Bakermans-Kranenburg et al., 2012).In that report, attachment representations have not been presented because they were not yet available at that time. The infant laughter sound (duration = 2 min, average fundamental frequency = 215.96 Hz, constant volume) and the infant crying sound (duration = 2 min, average fundamental frequency = 360.06, constant volume) from Groh and Roisman (2009) were used. The intervening time between full- and half-strength prompts was 2 s; the intervening time period between half-strength and the next full-strength prompt was 25 s. Similar to Bakermans-Kranenburg et al. (2012) and Crouch et al. (2008), grip strength modulation was calculated by dividing the half-strength squeeze intensity by the full-strength squeeze intensity, so that scores of over 0.50 indicated excessive force on the half-strength squeeze attempt. As a result of fatigue the last trial yielded too many missing data. Therefore we decided to use the first three trials during infant crying, for which we added the numbers of trials with too much physical force (>0.50).

Neural responses to infant crying. Blood oxygenation-level dependent responses to infant crying were measured with fMRI. Participants were instructed to attend to the sounds they would hear and they listened to the sounds through MRI compatible headphones. Cry sounds were derived from the spontaneous crying of a healthy 2-day old infant. A 10-s portion of the sustained period of crying was selected. The peak fundamental frequencies (Peak F0) of the entire cry were 515 ± 15 Hz. Two new 10-s cry sounds with overall Peak F0 of 714.5 Hz (700 Hz cry) and 895.8 Hz (900 Hz cry) were created by digitally increasing the pitch of the original cry (Dessureau, Kurowski, & Thompson, 1998; Out et al., 2010; Schuetze & Zeskind, 2001; Schuetze, Zeskind, & Das Eiden, 2003). We focused on neural responses to infant crying at different frequencies, because infant cries range from 500 Hz in normal, healthy infants to 900 Hz (and even higher) in infants in pain or with medical and neurological conditions (Soltis, 2004). We did not expect to find differences in brain activation between the frequency conditions, as there was no significant effect of frequency in a previous study on neural responses to infant crying (Riem et al., 2011). Neutral auditory control stimuli were created identical to the original auditory stimuli in terms of duration, intensity, spectral content, and amplitude envelope but lacking an emotional meaning. The participants did not perceive much irritation during exposure to the control sounds collapsed across frequencies ($M = 1.95$, $SD = 1.27$) and there was no significant difference in reported irritation between secure and insecure individuals ($t(19) = -0.72$, $p = .48$). Cry and control sounds were presented in eight cycles, each cycle consisting of six sounds (Cry 500 Hz, Cry 700 Hz, Cry 900 Hz, Control 500 Hz, Control 700 Hz, Control 900 Hz). The order of presentation of sounds within each cycle was random; the intertrial interval was 6 s. Cry sounds were collapsed across pitches to reduce the number of statistical tests.

FMRI data acquisition and analysis

Scanning was performed with a standard whole-head coil on a 3-T Philips Achieva MRI system (Philips Medical Systems, Best, the Netherlands) in the Leiden University Medical Center. Cushions were placed between the head coil and the participant in order to prevent head movement. First, a T1-weighted anatomical scan was acquired (flip angle = 8°, 140 slices, voxelsize .875×.875×1.2 mm). For fMRI, a total of 360 T2*-weighted whole-brain EPIs were acquired (TR = 2.2 s; TE = 30 ms, flip angle = 80°, 38 transverse slices, voxelsize 2.75×2.75×2.75 mm (+10% interslice gap)). In accordance with Leiden University Medical Center policy, all anatomical scans were examined by a radiologist from the Radiology department. No anomalous findings were reported.

Data analysis was carried out using FEAT (FMRI Expert Analysis Tool) Version 5.98, part of FSL (FMRIB's Software Library, www.FMRIb.ox.ac.uk/fsl; (Smith et al., 2004). The following pre-statistics processing was applied: motion correction (Jenkinson, Bannister, Brady, & Smith, 2002), non-brain removal (Smith, 2002), spatial smoothing using a Gaussian kernel of full-width-at-half-maximum 5.0 mm, and high-pass temporal filtering (highpass filter cutoff = 50.0 s). Functional scans were registered to T1-weighted images, which were registered to standard space (Jenkinson et al., 2002; Jenkinson & Smith, 2001).

In native space, functional activation was examined using general linear model analysis. Each sound (Cry 500 Hz, 700 Hz, 900 Hz and Control 500 Hz, 700 Hz, 900 Hz) was modeled separately as a square-wave function. Each predictor was then convolved with a double gamma hemodynamic response function and its temporal derivative was added to the model, giving 12 predictors. The contrast $\text{Cry}_{\text{combined 500, 700, 900 Hz}} > \text{Control}_{\text{combined 500, 700, 900 Hz}}$ was assessed. Data regarding functional activation of other brain regions during exposure to infant crying at different frequencies is presented elsewhere (Riem et al., 2011). The first-level contrast images and the corresponding variance images were transformed to standard space and submitted to second-level mixed-effects group region of interest analyses with the right and left amygdala (>50% probability, defined using the Harvard–Oxford subcortical atlas, http://www.fmrib.ox.ac.uk/fsl/data/atlas-descriptions.html#ho). Centered coherence of mind scores were added to the model as a regressor and we assessed the positive and the negative contrast of this regressor to examine the positive and negative correlation between functional activation during infant crying (versus control sounds) and coherence of mind. Furthermore, in an additional analysis we tested for group differences using two-sample t-tests on the Cry > Control contrast with the unresolved versus not unresolved comparison (unresolved > not unresolved and unresolved < not unresolved). Age and menstrual cycle (centered) were included as confound regressors in the model in all analyses. The statistical images were thresholded using clusters determined by $Z > 2.3$ and a cluster corrected significance threshold of $p < .05$ (Worsley, 2001). Mean Z values for voxels that were significantly related to coherence of mind during infant crying compared with control sounds were derived using Featquery (FMRIb.ox.ac.uk/fsl/feat5/featquery.html). Thus, the mean Z value was calculated across the significant cluster falling within the amygdala region of interest.

RESULTS

Emotional and behavioral data

Irritation. In Table 1 the means of emotional and behavioral responses to infant crying for each attachment classification are presented. Coherence of mind tended to be related to reported irritation during exposure to infant crying ($r = -.37$, $p = .10$),. Similarly, insecurely attached individuals tended to report more irritation during exposure to infant crying compared with securely attached individuals ($t(19) = 1.73$, $p = .10$) (insecure: $M = 3.83$, $SD = 1.21$, secure: $M = 2.86$, $SD = 1.24$;). Effect sizes for the association between feelings of irritation and coherence or security of attachment were large (Cohen's *d* amounted to 0.80 in both cases). The four-way attachment classification (F, Ds, E, U) did not have a significant effect on reported irritation during the exposure to infant crying ($F(3,17) = 1.87$, $p = .17$). Neither was there a significant difference in reported irritation between individuals with an unresolved state of mind versus without an unresolved state of mind during exposure to crying ($t(19) = 0.99$, $p = .34$, d = 0.48).

Handgrip force. We examined whether attachment representation was related to excessive use of handgrip force during exposure to infant crying. We found a significant negative correlation between coherence of mind and excessive use of handgrip force ($r = -.47$, $p < .05$). In addition, there was a significant difference between securely and insecurely attached individuals on excessive use of handgrip force ($t(19) = 3.11$, $p < .01$, Cohen's $d = 1.38$). Insecurely attached individuals more often used excessive handgrip force ($M = 2.57$, $SD = 0.65$) compared with securely attached individuals ($M = 1.57$, $SD = 0.79$). Furthermore, the four-way attachment classification showed significant differences in excessive handgrip force ($F(3,17) = 4.06$, $p < .05$). A priori contrasts showed that individuals with a preoccupied attachment representation more often used excessive force during exposure to infant crying compared with individuals with a secure attachment representation ($t(6.00) = 4.80$, $p < .01$, unequal variances). In addition, the difference between secure individuals and individuals with a dismissing attachment representation ($M = 2.50$, $SD = 0.58$) was marginally significant ($t(8.15) = 2.24$, $p = .06$, unequal variances). The difference between individuals with an unresolved state of mind versus individuals with a secure attachment representation for use of excessive handgrip force was not significant ($t(10.56) = 1.71$, $p = .12$, unequal variances). There was no significant difference in use of excessive handgrip force between individuals with an unresolved state of mind versus without an unresolved state of mind ($t(19) = 0.33$, $p = .75$).

In addition, to test whether the effects of attachment representation on handgrip force were specific to infant crying, we also examined use of excessive force during exposure to infant laughter. The interaction between group (secure, insecure) and condition (crying, laughter) was significant, $F(1,19) = 7.03$, $p = .016$. During the laughter condition there was no significant difference in use of excessive force between secure and insecure individuals ($t(19) = -0.62$, $p = .54$).

Table 1. Means (*M*) and standard deviations (*SD*) of reported irritation and handgrip force in response to cry sounds for individuals with a secure (F), dismissing (Ds), preoccupied (E) and unresolved (U) attachment representation.

Attachment classification	*n*	Irritation to Cry		Handgrip force	
		M	*SD*	*M*	*SD*
F	7	2.86	1.24	1.57	0.79
Ds	4	4.42†	1.17	2.50†	0.58
E	4	3.08	1.62	3.00**	0.00
U	6	3.94†	0.83	2.33	0.82

Higher than F: $^{\dagger}p < .10$, $^{**}p < .01$

Neuroimaging data

The contrast of infant crying (500 Hz, 700 Hz, 900 Hz) versus control sounds (500 Hz, 700 Hz, 900 Hz) revealed significant activation in the region of interest analysis of the right amygdala (Cluster size = 66 voxels, peak $Z = 3.22$, MNI coordinates x,y,z (mm) = 22, -8, -16) ($p < .05$, corrected by cluster threshold ($Z > 2.3$). In addition, we found a significant negative correlation ($r = -.56$, $p < .01$) between coherence of mind and right amygdala activation during exposure to infant crying compared to control sounds (Cluster size = 18 voxels, peak $Z = 2.77$, MNI coordinates x,y,z (mm) = 20, -2, -22) (see Figure 1). Higher scores for coherence were related to less right amygdala activation. The left amygdala was not significantly activated during infant crying compared to control sounds and there was no significant correlation between left amygdala activation and coherence of mind. Furthermore, there was no significant difference in amygdala activation between individuals with an unresolved state of mind versus individuals without an unresolved state of mind.

An ANOVA was performed to examine the effect of adult attachment representation on mean Z-values extracted from the right amygdala. Adult attachment representation was significantly associated with amygdala activation ($F(3,17) = 3.31$, $p < .05$). A priori contrasts showed that individuals with preoccupied and dismissing attachment representations showed increased amygdala activation during infant crying (relative to control sound) compared with individuals with a secure attachment representation (E: $t(17) = 2.50$, $p < .05$, Cohen's $d = 2.35$, Ds: $t(17) = 2.67$, $p < .05$, Cohen's $d = 2.83$). However, individuals with an unresolved state of mind did not show increased amygdala activation compared with individuals with a secure attachment representation ($t(17) = 1.31$, $p = .21$) (see Figure 2) and there was no significant correlation between amygdala activation and scores on unresolved loss ($r = -.03$, $p = .90$).

We examined the correlation between amygdala activation and reported irritation and use of excessive force in order to investigate whether amygdala activation mediated the relation between attachment representation and emotional or behavioral responses to infant crying. There was no significant correlation between amygdala activation and reported irritation during exposure to infant crying or between amygdala activation and use of excessive force, thus indicating that associations between attachment representation and reported irritation or handgrip force was not mediated by amygdala activation.

Discussion

Our study is the first to validate the standard Berkeley Adult Attachment Interview with functional Magnetic Resonance Imaging by demonstrating that adult attachment representation influences neural, emotional and behavioral responses to infant crying. Individuals with an insecure attachment representation showed heightened amygdala activation during exposure to infant crying compared with individuals with a secure attachment representation. In addition, insecure individuals tended to experience more irritation during the perception of infant crying and they used more excessive force as indicated by grip strength

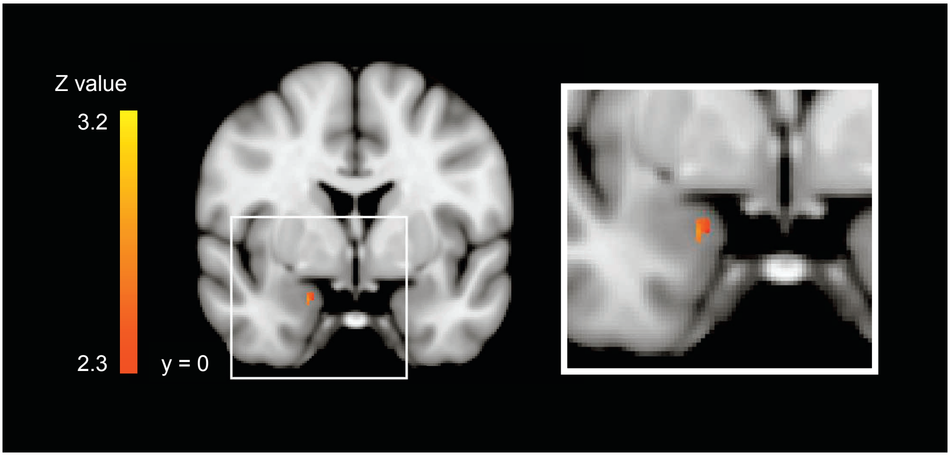

Figure 1. Significant correlation between coherence of mind and right amygdala activation during exposure to infant crying (500, 700, 900 Hz) compared with control sounds (500, 700, 900 Hz). Region of interest analysis, p < .05, corrected by cluster threshold (Z > 2.3). The right side of the brain corresponds to the left hemisphere and vice versa.

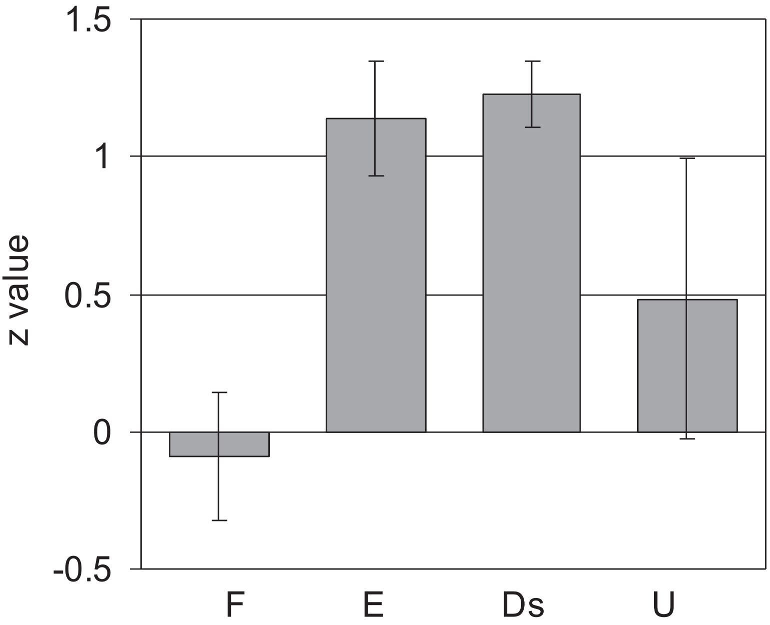

Figure 2. Z-values (*M, SE*) of right amygdala activation during infant crying compared with control sounds for individuals with a secure (*n* = 7), preoccupied (*n* = 4), dismissing (*n* = 4) and unresolved state of mind (*n* = 6).

using a hand-grip dynamometer compared with individuals with a secure representation. Amygdala hyperactivity might explain why insecure individuals experience more aversive and angry feelings during exposure to infant crying and why they respond inconsistently to infant signals or reject their infants' attachment behavior. Our findings indicate that differences between attachment classifications can be observed at the neural level and extend previous studies that used physiological measures such as skin conductance and autonomic reactivity to validate the AAI (Beijersbergen, Bakermans-Kranenburg, Van IJzendoorn, & Juffer, 2008; Dozier & Kobak, 1992).

Infant crying has been described as a paradoxical signal (Soltis, 2004). It elicits warm, empathic feelings in parents and enhances infant survival by stimulating parental proximity and care (Bowlby, 1969/1982; Dix, 1991). Maternal sensitivity to infant crying has been shown to predict infant attachment security with more explanatory power than maternal sensitivity to infant signals in non-distress settings (McElwain & Booth-LaForce, 2006), suggesting that infant crying plays a crucial role in the formation of the attachment bond between mother and child.

On the other hand, crying also elicits negative emotions such as aversion and anger (Dix, 1991; Dix et al., 2004) and excessive infant crying can even trigger child abuse and neglect (Soltis, 2004). In the Netherlands, six months after the infant's birth nearly 6 % of the parents report that they have shaken, smothered or slapped their infant in order to stop the crying (Reijneveld et al., 2004). The likelihood of using insensitive parenting responses is increased when parents have strong negative emotional reactions to crying (Dix et al., 2004). These negative emotions undermine sensitive child-oriented parental responses such as feeding or soothing the child. Thus, parental negative emotional reactions to crying may play a crucial role in the development of insecure infant attachment. Our findings that insecure individuals tend to experience more irritation and use more excessive force during exposure to infant crying support this notion and are in line with previous research showing that insecure individuals are less accurate at identifying infant emotions and more likely to make negative attributions about a crying infant.

In addition, our findings also converge with event-related potential (ERP) studies on neural responding to infant signals. For example, Fraedich, Lakatos and Spangler (2010) examined event-related potentials during the presentation of infant emotion faces in mothers with secure and insecure attachment representations, measured with the Adult Attachment Projective (AAP) (George, West, & Pettem, 1999). They found that insecure mothers showed a more pronounced negativity in the face sensitive N170 component, and smaller N200 and P300 amplitudes in response to infant faces. This might indicate that secure mothers have a more efficient face perception and allocate more attention to social and face stimuli. However, in terms of format, structure and content the AAP is not isomorphic to the AAI, and the load of validating evidence for the latter still has to emerge for the AAP. In a study using ERPs in response to neutral, happy and fearful faces Zhang Li, and Zhou (2008) found that avoidant Chinese undergraduate students showed different N1, N2, P2, and N400 components compared to secure or anxious students, suggesting differences in both earlier, automatic encoding of faces and later, more elaborative retrieval of emotional information. However, they used the Experiences in Close Relationships scale to assess attachment style.

Few studies have been conducted on adult attachment representations associated with neural responding to infant signals. Only one study investigated the neurobiological mechanism underlying the perception of infant stimuli in individuals classified with the standard Main, Goldwyn and Hesse (2003) coding system. In this study, Lenzi et al. (in press) examined neural activation during observing and imitating infant facial expression in individuals with secure and dismissing attachment representations. Individuals with dismissing attachment representations showed more activation in motor, limbic and mirror brain regions, indicating that they were more emotionally reactive to infant stimuli than secure individuals. In contrast to the present study, insecure individuals did not show increased amygdala activation, possibly because individuals were presented with happy, neutral and distressed infant faces. Infant crying is one of the most important attachment behaviors, alerting parents when the infant is in danger (Soltis, 2004). Therefore, it might be more emotionally salient than visual infant stimuli, with larger individual differences in amygdala activation as a result.

In a study using the Crittenden coding system for adult attachment, dismissing mothers showed increased activation in brain regions related to disgust and decreased activation in neural reward areas in response to happy and sad infant faces. Unfortunately, the use of the Crittenden coding system hampers the comparability with the findings in the present study, and with a host of other validating evidence for the AAI. Although our results are in line with two other neuroimaging studies that point to a role of the amygdala in insecure attachment, these studies used the AAP or self-report measures of attachment (Buchheim et al., 2006; Vrtička et al., 2008). Self-report measures and the Adult Attachment Interview may not be used interchangeably to examine the neural base of attachment because they have little empirical or conceptual overlap (Roisman et al., 2007). Greater convergence in the way in which adult attachment is measured and what paradigm is used in the fMRI sessions would advance our understanding of the mechanisms underlying attachment representations and parenting.

Contrary to our expectations, the relation between attachment representation and emotional or behavioral responses to infant crying was not mediated by amygdala activation. This seems to indicate that feelings of irritation and the use of excessive force in response to infant crying in insecure individuals can not be solely explained by a hyperactive amygdala. Other brain regions might be involved in attachment-related influences on the perception of infant crying, for example brain regions important for empathy and emotion understanding such as the insula and the inferior frontal gyrus (IFG). In a previous study, we found that intranasal administration of oxytocin, a hormone that enhances parental sensitivity and parent-infant bonding (Naber, Van IJzendoorn, Deschamps, Van Engeland, & Bakermans-Kranenburg, 2010), decreased amygdala responses and increased insula and IFG responses to infant crying (Riem et al., 2011). These findings point to a role of empathy-related brain regions in sensitive parenting that might be associated with adult attachment representations.

Alternatively, since our control sounds were neutral and lacked human-like connotations, it is hard to know exactly what aspect of infant crying is being reflected in the neural responses, as the cry sounds may reflect a composite of factors (human sounds, infant sounds, distressing sounds). The amygdala response might thus be relatively non-specific whereas the emotional and behavioral responses may have been more specific to the distressing components of infant crying. In that case it would not be surprising that the amygdala responses did not mediate the relation between attachment representation and responses to crying. Indeed, it should be noted that the emotional and behavioral responses were observed in reaction to the cry sounds in comparison to infant laughter. To test the alternative interpretation emotional and behavioral responses should be registered in a comparison between infant cry and scrambled sounds. It should be noted, however, that there is a limit to the number of stimuli that can be presented within and outside the scanner.

Another explanation for the finding that the amygdala did not mediate the relation between insecure adult attachment and emotional and behavioral responses to crying might be that disruptions in amygdala *connectivity* also play a role in the negative perception of infant crying in insecure individuals. The amygdala is strongly connected with other brain regions within a neural network involved in the perception and evaluation of crying (Riem et al., 2012), and neural disorganization within this network has been associated with anxious parenting (Atzil et al., 2011). Tottenham et al. (2011) found that amygdala hyperactivity to fearful faces mediated the relation between adverse rearing experiences and decreased eye-contact during dyadic interaction, and they suggested that early adversity may have affected amygdala development and caused long-term structural abnormalities (Sabatini et al., 2007). Adult attachment and early rearing experiences have been shown to be distinct constructs since experiences in subsequent social relationships influence how individuals represent past and present attachment experiences (Waters, Hamilton, & Weinfield, 2000; Weinfield, Sroufe, & Egeland, 2000). Therefore, systematic differences in structural amygdala development are unlikely to be found in individuals with different attachment classifications in non-clinical samples.

Our finding that the amygdala plays a role in the perception of crying in individuals with insecure attachment representation is not consistent with the proposition that the attachment system is located in the orbitofrontal cortex (OFC) (Schore, 2001). The OFC is involved in reward processing, emotional regulation, and the perception of infant signals (Banks, Eddy, Angstadt, Nathan, & Phan, 2007; Kringelbach, 2005; Kringelbach et al., 2008; Stein et al., 2007). For example, it exhibits a very rapid and specific response to an infant face and it has been suggested that this might be the brain basis for the "innate releasing mechanism" described by Lorenz (Kringelbach et al., 2008). However, it is by no means the only brain region involved in attachment. By using Wittgensteins analogy, Coan (2008) suggested that searching for the identification of a single attachment neural construct is like 'trying to find the real artichoke by peeling away all its leaves'. Because so many brain regions are involved in attachment, it can not be reduced to a single neural construct. For example, parental responses to infant crying require activation of multiple cortical and subcortical neural systems involved in functions ranging from the processing of visual and auditory information to complex processes such as affection, emotional regulation, and memory. Moreover, efficient interaction between these systems is needed in order to respond to a crying infant in a sensitive way (Atzil et al., 2011; Riem et al., 2012). Thus, the attachment system most likely relies on a comprehensive neural network and insensitive responsiveness in insecure adults can not be explained by malfunctioning or dysregulation of a single neural construct.

The limitations of this study should be noted. First, our findings can only be generalized to women without children. The choice for women without children increased the comparability of our participants in terms of their experiences with infant crying. Attachment-related influences on emotional, behavioral and neural responding to infant crying might be even more pronounced when parents are exposed to their own infant's crying. For example, Seifritz et al. (2003) showed that neural responses to infant vocalizations dramatically changed with parental status, with parents showing more amygdala activation than nonparents. Second, as we compared neural responses to infant crying with neutral control sounds, it is unclear whether insecure individuals show amygdala hyperactivity specifically during exposure to infant crying, or whether the amygdala is also hyperactive during other vocal emotional stimuli. However, our finding that insecure individuals do not show excessive force in response to infant laughter indicates that the effects of attachment representations may be more pronounced during exposure to infant crying compared with other emotional stimuli. Another limitation of the present study is the small sample size, which led to the combination of insecure classifications in the analyses and to relatively low power for the analyses. The large effect sizes for the association between coherence or security of attachment and feelings of irritation would have reached significance in a somewhat larger sample. Since the combination of time-consuming AAI research and an expensive fMRI investigation leads to an almost impossible mission for a single research group we hope that we will be joined in the next future by other teams, examining the neurobiological processes underlying the separate dismissing, preoccupied and unresolved attachment representations in larger samples. Furthermore, future studies may examine the role of other brain regions and the functional connectivity between brain regions in individuals with different attachment representations. The amygdala has often been described as a functional hub because of its high degree of connectivity with other brain regions. In a previous study, we found that the oxytocin enhances connectivity between the amygdala and the OFC and the ACC during exposure to infant laughter, indicating that efficient amygdala connectivity might be one of the mechanisms underlying sensitive responsiveness (Riem et al., 2012). Disruptions in amygdala connectivity have been observed in patients with depression and anxiety disorders (Dannlowski et al., 2009; Pillay, Gruber, Rogowska, Simpson, & Yurgelun-Todd, 2006) and might also play a role in insecure attachment representations.

In conclusion, our study is the first to show that neural differences in response to infant crying are associated with adult attachment representations. Our results provide fMRI validation of the Adult Attachment Interview and extend previous behavioral validation studies. We found that insecure individuals tended to experience more irritation, and they used more excessive force as indicated by grip strength and showed heightened amygdala activation during exposure to infant crying compared to individuals with a secure representation. Amygdala hyperactivity might be one of the mechanisms underlying the experience of negative emotions during exposure to infant crying in insecure individuals and might explain why insecure parents have more difficulty responding to their crying infant in a sensitive way.