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Parental and romantic attachment shape brain processing of infant cues

Omri Weisman, Ruth Feldman*, Abraham Goldstein

Department of Psychology and the Gonda Brain Sciences Center, Bar-Ilan University, Ramat Gan 52900, Israel

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ABSTRACT

Periods of bond formation are associated with evolutionary-adaptive reorganization of physiological and behavioral responses and increased attention to attachment-related cues. We measured event-related potential responses to infant stimuli among new parents, new lovers, and romantically unattached singles ($N = 65$). For parents, infant stimuli included own and unfamiliar infant. Viewing unfamiliar infants, parents and lovers exhibited greater activation at 140–160 and 300–500 ms post-stimulus compared to singles at occipital–lateral (N170) and central–frontal (P3a) sites, indicating greater initial attention to infant cues. Parents exhibited lowest amplitudes in the parietal-distributed P300 component, implicated in controlled attention, towards the unfamiliar infant but greatest response to their own infant in the same waveform. These findings are the first to demonstrate that periods of bond formation activate brain reactivity to parenting-related cues. Parents' heightened response to own infant accords with evolutionary models underscoring the need to direct resources to the survival and well being of one's own offspring.

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1. Introduction

Evolutionary models on the formation of attachment bonds in humans suggest that human attachment draws on its evolutionary heritage and that the biological basis of parental and romantic attachment share similar mechanisms and are consistent with those observed during periods of bond formation in other mammals (Belsky, 1997; Carter et al., 2005). In support, research on the biological basis of bonding in humans has pointed to similarities in the mechanisms supporting parental and romantic attachment. For instance, neuro-imaging studies found increased activations in similar brain areas among romantic partners and new parents in response to pictures of the attachment target, including striatal, reward, and vigilance-related structures, such as the nucleus accumbens, anterior cingulate, and amygdala (Aron et al., 2005; Leibenluft et al., 2004; Nitschke et al., 2004; Ranote et al., 2004; Strathearn et al., 2008; Swain et al., 2007). The overlap between brain areas activated during the initial stages of romantic love and those involved in the development of parental love for the infant was taken to suggest that parental and romantic love share several underlying mechanisms (Bartels and Zeki, 2000, 2004; Feldman, in press-a). Research on the neuroendocrine basis of bonding has yielded similar results. An increase in testosterone levels was observed in new fathers as well as in new male lovers (Burnham et al., 2003); first-time and experienced marmosets

monkey fathers exhibited greater vasopressin receptors in their brain (Kozorovitskiy et al., 2006); plasma vasopressin levels were associated with parenting-related brain areas in fathers (Atzil et al., submitted for publication); and an increase in plasma oxytocin levels was found among mothers and fathers following the birth of their first child as well as among romantic partners during the initial period of falling in love (Feldman, in press-b; Gordon et al., 2010; Schneiderman et al., submitted for publication).

Little research, however, assessed whether parental or romantic attachment affects the different stages of information processing and whether the two periods of bond formation alter the temporal patterns of brain responsivity to attachment-relevant cues in a similar manner. Studies assessing event-related potentials (ERPs) demonstrated differences in the cortical response to infant stimuli between parents and non-parents (Proverbio et al., 2006, 2007; Grasso et al., 2009). Similarly, research has addressed the response of romantic partners to love-related facial stimuli (Langeslag et al., 2007). Yet, no study to our knowledge has addressed the ERP response of parents and new lovers to attachment-relevant cues in a single study.

One advantage of measuring ERP is that the various waveform components reflect different stages of information processing and index distinct cognitive mechanisms, such as specific perceptual processes or automatic and controlled allocation of attention. An example of such perceptual component is the N170, a posterior–lateral negative amplitude peaking at a latency of approximately 170 ms post-stimulus, associated with the structural encoding of faces (Bentin et al., 1996; Carmel and Bentin, 2002). With regard to this component, Proverbio et al. (2006) found

* Corresponding author. Tel.: +972 3 531 7943; fax: +972 3 535 0267.
E-mail address: feldman@mail.biu.ac.il (R. Feldman).

a gender by parental status interaction. Fathers exhibited larger N170 amplitude than mothers while observing unfamiliar infant faces, suggesting significant gender differences within the parent group, whereas no difference was found in the response of non-parents, both female and male, to infant stimuli (Proverbio et al., 2006).

Another relevant ERP component is the P300, a positive deflection at centro-parietal electrodes peaking around 300 ms after the event. The P300 is considered to reflect allocation of attention to infrequent events and the updating of the current context representation in working memory (Donchin et al., 1986). This specific waveform, also referred to as P3b, is often obtained with the “oddball” paradigm. In this paradigm two stimuli are presented in a random series, one stimulus appears significantly less frequently, and the subject is instructed to respond to the infrequent event. After initial sensory processing, the brain compares the current stimulus to the previous oddball stimulus stored in working memory. When a new stimulus is processed, attention mechanisms are engaged and form an “update” of the memory representation for the stimulus context to elicit the P300 (Donchin et al., 1986). Thus, the P300 is produced when attention resources are allocated to memory updating (Polich and Criado, 2006). These events are also thought to be associated with long-term storage, since larger P300 amplitudes are observed for remembered events (Paller et al., 1988; Johnson, 1995). In the Proverbio et al. (2006) study, fathers and mothers showed significantly larger amplitude 300 ms post-stimulus in parietal sites compared to non-parents when viewing unfamiliar infant faces. Similarly, both birth and adoptive mothers were found to exhibit larger P300 amplitudes towards own children stimuli as compared with other infants and adult stimuli (Grasso et al., 2009), indicating that parental attachment may impact this level of processing.

Related to the P300 is the P3a component (or novelty P3), which similarly peaks around 300 ms after an event but in frontal rather than parietal scalp sites. The P3a is elicited by unattended, as well as attended, novel or deviant stimuli (Escera et al., 2000), thus reflecting the effects of automatic mechanisms. The P3a is considered to reflect a cognitive ‘orienting response’ towards the stimulus (e.g., Friedman et al., 2001; Goldstein et al., 2002). To date, little research has addressed the effects of human attachment on the P3a component. Although the P3a and P300 are separate components with distinct functional significance and responding to different antecedent conditions, they greatly overlap in time and are usually elicited by the same stimuli. Deviant stimuli in oddball series elicit both the classical P300 and P3a component, but with different spatial distributions and reactions to experimental variables (Spencer et al., 2001).

In light of the above, the present study aimed to examine alterations in brain responses to attachment-relevant cues associated with the first stages of parental and romantic attachment. We measured the ERP responses of parents following the birth of their first child, lovers who began a romantic relationship within the past three months, and romantically unattached non-parent singles to infant stimuli using an oddball paradigm. Infant stimuli are the most salient attachment cues and mark the apex of the evolutionary-based bonding process (Belsky, 1997; Carter et al., 2005). We thus expected that periods of both parental and romantic bond formation would result in changes to the various stages of information processing of this evolutionary salient stimulus. Among parents, infant stimuli included both a picture of their own infant’s face and an unfamiliar infant’s face so that responses to the specific attachment target could be compared to the general responses to infant cues. In order to augment the ERP components mentioned above, infant pictures were embedded in an oddball series containing landscapes as the frequent stimulus, and the relevant N170, P3a and P300 ERP components were assessed. Our goal

was to assess the response to infant cues in general, not in comparison to other faces. For this reason, we chose the most neutral images – landscapes – as the standard stimuli.

Several hypotheses were proposed. First, consistent with evolutionary accounts, we expected to find similar brain responses in new parents and new lovers towards unfamiliar-infant stimuli as compared to those of non-involved singles, suggesting shared underlying neural mechanisms during periods of parental and romantic bond formation. Second, we expected that both male and female parents would exhibit greater responses towards own-versus other-infant stimuli. Finally, in light of the relatively little and inconsistent data on the effects of gender on infant face processing, this issue was explored as a study question.

2. Methods

2.1. Participants

The final sample included 65 adults (35 men). Twenty-four of the participants were mothers and fathers 6 months after the birth of their first child (13 men, age range 22–33 years). Nineteen were lovers who began a romantic relationship within the past 3 months (10 men, age range 19–31 years) and the average length of romantic relationship was 2.5 months. Twenty-two participants were singles who were currently not involved in a romantic relationship (12 men, age ranged 20–28 years). Lovers and single participants had no children. In the parents and lovers groups both partners were encouraged to participate in the experiment, although they were scheduled to participate in the experiment separately and on different occasions. All participants completed at least 12 years of education and self-reported as being healthy. Among parents, all had infants who were physically healthy since birth, were born at term in a singleton birth, and the infant was the first child to both parents. There were no significant differences between groups with respect to age, education, or male/female ratio. Exclusion criteria included high depression score ($BDI > 9$), high anxiety score ($STAI > 43$) and, for parents, self-reports of extreme infant difficulty on the Infant Care Questionnaire (ICQ) as assessed during the recruitment phase. Distributions of attachment styles of parents and romantic couples (attachment anxiety: mean = 51.69, SD = 15.58 and attachment avoidance: mean = 56.89, SD = 19.43) were similar to normal population.

EEG was recorded from 13 additional subjects but these were excluded from the final analyses due to technical problems (e.g., excessive eye-movement and other artifacts, bad channels, or not performing the task correctly). Participants were recruited through ads in a university campus and the surrounding neighborhoods, and were given a small gift for their participation.

2.2. Stimuli and task procedure

Subjects were presented with two color target stimuli of a 6-month-old infant face with neutral expression, each presented 30 times (20% of all images viewed) and 120 standard landscape stimuli taken from the International Affective Picture System (IAPS; Lang et al., 1999), each presented twice (80% of all images viewed). Infant pictures were collected from parents prior to the experimental session and were standardized for size, resolution, and face presentation. Parents saw one image of their own infant and one from an unfamiliar infant selected at random from the picture pool. Lovers and singles received two different faces from the pool. The order of all stimuli was fully randomized and presented in a visual oddball design, in which infant images were the target, infrequent stimuli and landscapes were the standard, frequent stimuli. Participants were instructed to press a key whenever an infant’s face appeared on screen. Pictures were presented for 300 ms, with an inter-trial interval of 1000 ms with a random jitter of ± 100 ms.

2.3. Acquisition and analysis of electrophysiological data

EEG was recorded continuously using a 64-channel geodesic net (Electrical Geodesics Inc.). Impedance was kept below 40 k Ω , as recommended for this system with high-input impedance. All channels were preprocessed on-line by means of 0.1 Hz high-pass and 100 Hz low-pass filtering and digitized at a rate of 250 Hz. Data were filtered offline with a low-pass 40 Hz filter. EEG recordings were segmented into 1 s epochs (100 ms pre-stimulus to 900 ms post-stimulus). Segments with excessive artifacts were removed after visual inspection. Remaining eye-movement artifacts were corrected with a regression procedure (Gratton et al., 1983). ERP waveforms were calculated by averaging all artifact-free, correct trials for each stimulus type for each participant. Mean amplitude was calculated at time windows and electrode groups which captured the main activity for each component, and included a negativity peaking 140–160 ms post stimulus over lateralized occipito-temporal electrodes (N170; channels TP9, P7, P9, PO7, POO10, PO8, P10, P8), a central–frontal positivity peaking 300–500 ms post stimulus (P3a; channels FCz, FCC1h, FC1, FCC2h, FC2), and a central–parietal positivity also peaking at 300–500 ms (P300; channels CP1, P1, CPz, PZ, P2, CP2, Cz), as shown in Fig. 1. In this study, the P3a and P300

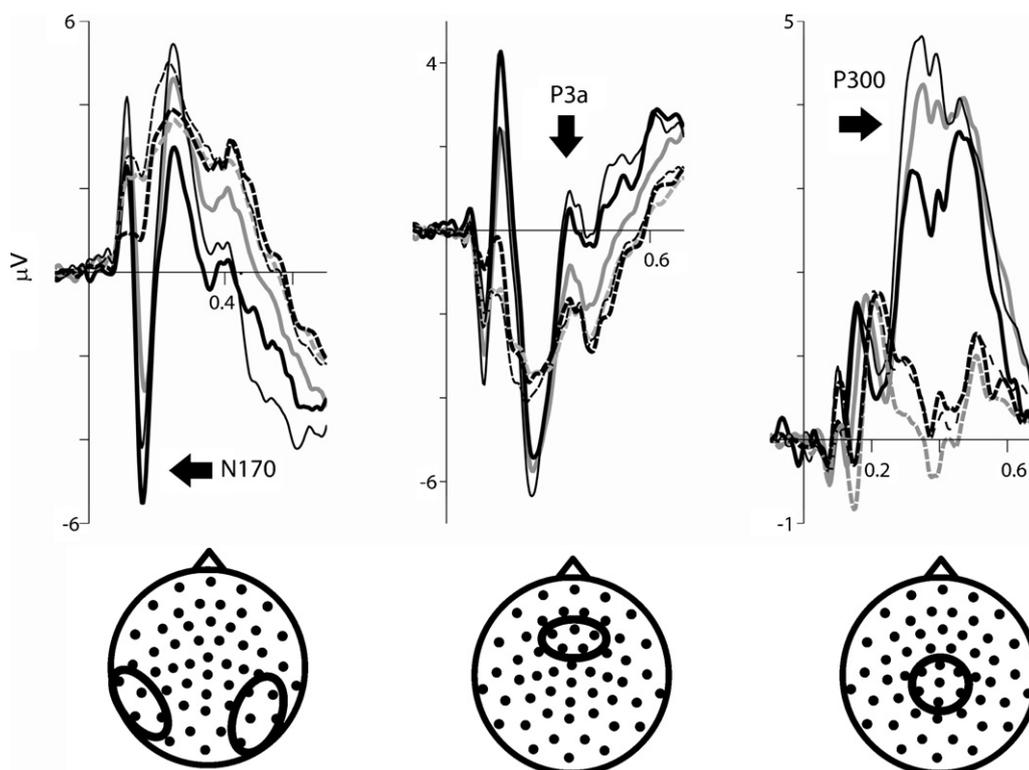


Fig. 1. Grand averages ERP waveforms towards other-infant (full lines) and landscape (dotted lines) stimuli. Bold lines represent parents, thin lines depict lovers, and gray lines depict singles. Figures are of temporal–occipital (left), frontal (center), and central–parietal (right) electrode sites. Voltage in (μV) is plotted positive up.

components greatly overlapped in time. However, as can be seen in figure, the waveforms for the frontal and parietal sites have different shapes and responded differently to the various conditions, showing a classical P3a/P300 distinction (Goldstein et al., 2002).

2.4. Statistical analysis

After electrode sites were identified for each component as detailed above, mean amplitude of the N170, P3a and P300 components were analyzed using mixed-model analyses of variance (ANOVAs) with group (parents, lovers, singles) and gender (females, males) as the between-subject variables, stimuli type (infant face vs. landscape) as the within-subject factor, and average amplitude ERPs in microvolts as the dependent variable. Parents' waveforms included only half the number of infant stimuli, thus differences in amplitude could result due to different signal to noise ratio. To check for this possibility analyses were repeated using only one of the infant faces for lovers and singles. The pattern of the results did not change and thus, only the results of the full analysis are reported below. Parents' response towards own- versus other-infant stimuli was analyzed using mixed ANOVAs with gender as the between subjects factor and stimuli type (own infant vs. other infant) as the within-subjects factor. When analyses yielded significant effects, further univariate ANOVAs and Bonferroni post hoc comparisons were carried out.

3. Results

3.1. Group effects

3.1.1. N170

A mixed model ANOVA revealed a significant effect of stimuli type, $F(1, 59) = 65.39$, $p < 0.001$, partial $\eta^2 = 0.52$, with participants showing overall more negative (i.e., larger) N170 amplitude towards infant stimuli as compared to landscapes ($M = .59 \mu\text{V}$ and $2.77 \mu\text{V}$, respectively). The stimuli type by group interaction was significant, $F(2, 59) = 8.66$, $p < 0.05$, partial $\eta^2 = 0.22$. Post hoc tests revealed that the differential response to infants relative to landscapes was significantly higher for parents and couples than for single participants, Bonferroni $p < 0.001$.

3.1.2. P3a

In the parallel analysis of P3a amplitude, a significant effect of stimuli type emerged, $F(1, 59) = 34.58$, $p < 0.001$, partial $\eta^2 = .37$, with participants showing overall more positive (i.e., larger) P3a amplitude towards infant stimuli as compared to landscapes ($M = -.51 \mu\text{V}$ and $-2.22 \mu\text{V}$, respectively). The interaction of stimuli type by group was significant, $F(2, 59) = 3.84$, $p < 0.05$, partial $\eta^2 = .11$. Post hoc tests revealed that parents and lovers showed greater differential responses to infants than singles, Bonferroni $p < 0.05$.

3.1.3. P300

A mixed model ANOVA revealed significant effect for stimuli type, $F(1, 59) = 194.91$, $p < 0.001$, partial $\eta^2 = 0.76$, with participants showing overall larger P300 amplitude towards infant stimuli as compared to landscapes ($M = 3.71 \mu\text{V}$ and $0.34 \mu\text{V}$, respectively). The group main effect was not significant, $F < 1$. However, the interaction between stimuli type and group was significant, $F(2, 59) = 3.64$, $p < 0.05$, partial $\eta^2 = 0.11$. Post hoc comparisons of difference scores showed that the interaction was due to parents having significantly lower P300 amplitudes evoked by other-infant stimuli as compared to lovers and singles.

3.2. Gender effects

3.2.1. N170

The stimuli type \times gender interaction was significant, $F(1, 59) = 4.20$, $p < 0.05$, partial $\eta^2 = 0.06$. Overall, women showed lower differential responses to infants. Post hoc tests indicated that this was due to single women showing the lowest differential responses to infants than the other participants, Bonferroni $p < 0.05$.

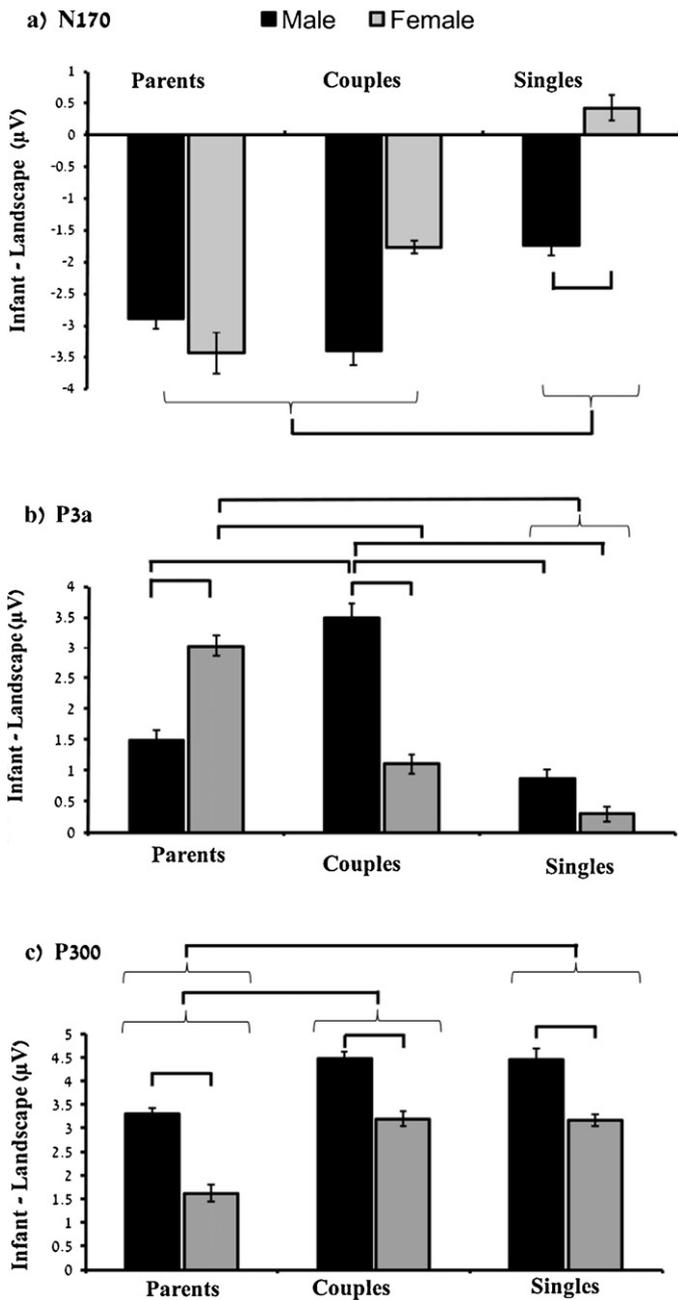


Fig. 2. Amplitude differences between other-infant stimuli and landscapes for parents, couples and singles in the N170 (a), P3a (b), and P300 (c) components. Gray bars depict females and black bars depict males. Error bars denote standard errors. Hooks indicate significant differences between conditions.

3.2.2. P3a

The third-order interaction (stimuli type × group × gender) was significant, $F(2, 59) = 3.81, p < .05$, partial $\eta^2 = 0.11$. Post hoc analyses on difference scores showed that males in a romantic relationship showed larger responses than fathers, females in a relationship and single participants, but mothers showed greater responses than females in a relationship and singles (all $p < 0.05$) (Fig. 2).

3.2.3. P300

There was a significant main effect for gender, with males showing overall larger amplitudes, $F(1, 59) = 8.42, p < 0.01$, partial $\eta^2 = 0.12$. The stimuli type × gender interaction reached significance, $F(1, 59) = 9.02, p < .01$, partial $\eta^2 = 0.13$. Post hoc tests showed that the difference in P300 amplitudes between infant and

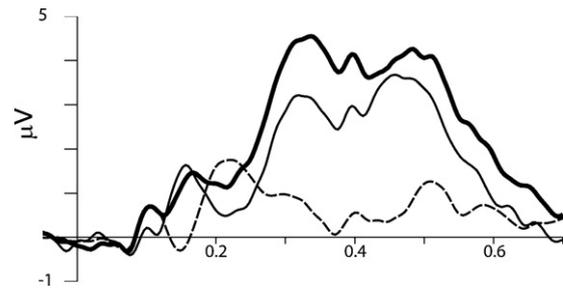


Fig. 3. Grand averages ERP waveforms of parents at central-parietal sites. Bold line depicts responses to own-infant images, thin line depicts responses to other-infant pictures, and dotted line depicts responses to landscapes. Voltage in (μV) is plotted positive up.

landscapes was greater for men than for women participants, Bonferroni $p < 0.05$.

3.3. Parents' own versus other infant

A comparison of parents' mean N170 amplitude towards own-versus other-infant stimuli using a mixed ANOVA yielded no significant effects, $F(1, 22) < 1$. For the P3a amplitude, only a marginal main effect for stimuli type emerged, $F(1, 22) = 3.44, p = 0.07$, with parents showing somewhat greater P3a amplitude towards own-infant than towards unfamiliar-infant stimuli. For the P300, a main effect for stimuli type emerged, $F(1, 22) = 4.93, p < 0.05$, partial $\eta^2 = 0.18$, with parents showing greater amplitude towards own-infant as compared to unfamiliar-infant stimuli (Fig. 3). Visual inspection of the waveforms seemed to indicate that own/unfamiliar differences began already at an earlier stage. However, a follow-up analysis on the 200–300 ms time-window did not show statistically significant differences, $F(1, 22) = 1.4, n.s$. It is worth mentioning that P300 amplitudes evoked by own infants in parents were not different from those evoked by other-infants in singles and lovers, $F < 1$. Thus, although parents showed lower responses to other-infant stimuli as compared to lovers and singles, their response towards own-infant stimuli was not decreased.

4. Discussion

Evolutionary models of human attachment suggest that periods of parental and romantic bond formation share underlying mechanisms. In this study, we examined brain response to salient attachment cues in three distinct components of information processing in new parents and new lovers using ERP. Overall, the results support evolutionary perspectives by demonstrating increased initial attention and orienting responses to infant cues among both parents and new lovers. Specifically, three main findings emerged. First, while viewing an unfamiliar infant face, parents and lovers exhibited greater activation at 140–160 ms (N170) and 300–500 ms (P3a but not P300) post-stimulus as compared to romantically unattached singles. Such increased activations, found in lateralized-occipital and frontal-central scalp areas, imply that the new experience of being a parent or newly involved in a romantic relationship strengthens perceptually driven brain patterns that are involved in the processing of parenting-relevant cues. These results lend support to perspectives contending that parental and romantic attachment share some common mechanisms (Carter et al., 2005), and suggest that already in the first stages of falling in love these evolutionary-based processes begin to be activated.

With regard to the P300 component, a different pattern emerged in parents and lovers, with parents showing lower mean amplitudes towards unfamiliar infant faces as compared to lovers and singles. This shift in cortical activation was explained by the

parents' differential response towards own versus other-infant cues at this specific stage of processing. Thus, the data indicate that at the level of higher cognitive processing and re-appraisal of the presented information in relation to previously stored knowledge, parents' allocation of resources split into "own" and "unfamiliar" and at that stage the attachment target becomes the recipient of the parents' information processing focus. These findings are consistent with evolutionary accounts which underscore the selectivity of attachment and indicate that parents learn to distinguish their own infants from others and direct resources to the survival and well-being of their own progeny (Belsky, 1997; Leckman et al., 2004). These findings are also consistent with previous reports on the selective responsiveness to the attachment target using both fMRI and ERP methodologies (Bartels and Zeki, 2004; Grasso et al., 2009; Swain et al., 2007). The current results contribute to this body of research by showing that the effects of "ownness" in the parents' ERP response is evident only during the relatively later stages of information processing and not during its earlier stages of more perceptual or stimulus-driven processing. Possibly, the experience of parenting increases the parent's initial attention to all infant cues, similar to the ubiquitous and immediate fight-or-flight response, but only during the later stages of processing it is possible to fine-tune and differentiate the processing of own versus other infant, leading to a re-framing of the "own" infant cue in a different manner.

Interestingly, our data show that males were more attuned than females towards unfamiliar-infant stimuli in two of the three ERP components tested here – the N170 and P300. Male lovers and mothers exhibited a greater P3a response as compared to fathers and female lovers. Admittedly, the effects of gender reported here are small and should be considered cautiously, but they may contribute to the ongoing debate on male–female bias in the processing of social stimuli and are inconsistent with the intuitive assumption that women pay more attention to social or reproductive-related stimuli (e.g., Proverbio et al., 2008). The findings that already during the first period of falling in love men pay more attention to infant cues than women is somewhat surprising. It may suggest that men's brains are more attuned to parenting cues than commonly thought or, conversely, that while entering into a romantic relationship, men may become increasingly worried about their partner's desire for children and their increased attention to infant stimuli is based on apprehension and the need to be more "guarded". The effects of attachment-relevant stimuli on the male brain at different periods of bond formation requires much further research in order to understand more fully the biological, behavioral, and mental components of bond formation in men and the current results may provide a first step.

Limitations of the study relate to the absence of familiar other-infant stimuli to control for familiarity effects. It is possible that the parental bias towards own-infant stimuli found here with respect to the P300 component is related to the fact that the own infant face is a familiar stimulus. It is also possible that the fact that parents were presented with two different target stimuli, the face of own child (more emotionally laden) and an unfamiliar infant face, added a new emotional dimension to the oddball task in this group, making it difficult to make a direct comparison to the other two groups. However, it is worth noting that P300 amplitudes to the familiar own-infant pictures in parents were not higher than those evoked by unfamiliar infants in singles and lovers. Thus, the effect appears to be attributed to the attenuation of responses towards other infants and not to an increase in response due to familiarity. Using some form of a familiarization procedure (see Bobes et al., 2007; Grasso et al., 2009) may help in future studies tease apart the effects of "ownness", a central mechanism underlying processes of attachment, from the mere effect of familiarity at the cortical–temporal level. Another limitation of the study is that we

compared brain responses to infant faces with responses to landscapes in order to evoke strong P3a and P300 responses. Thus, it can be argued that our findings may not be specific to infant faces, but to faces or infrequent targets in general. However, we find it not very likely that new lovers and parents would react differently than singles to any target type.

Our findings offer a first glimpse into the cognitive mechanisms involved in human attachment, especially in the formation of selective and enduring attachment bonds and the inclusion of another person as an attachment partner – whether an infant or a romantic lover. Since most studies to date investigated the neural correlates of bond formation and facial stimuli processing mainly among female participants, significantly more research is required to understand the brain reorganization associated with male love and fatherhood, as well as the specific changes both males and females undergo at the transition to parenthood. Attachment and bonding are among the most meaningful experiences of human life and much further research is required to provide a better understanding on the mechanisms involved in human love under both normative and high-risk conditions.

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