Maternal mindfulness and anxiety during pregnancy affect infants' neural responses to sounds

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Abstract

Maternal anxiety during pregnancy has been consistently shown to negatively affect offspring neurodevelopmental outcomes. However, little is known about the impact of positive maternal traits/states during pregnancy on the offspring. The present study was aimed at investigating the effects of the mother's mindfulness and anxiety during pregnancy on the infant's neurocognitive functioning at 9 month of age. Mothers reported mindfulness using the Freiburg Mindfulness Inventory and anxiety using the Symptom Checklist at ±20.7 weeks of gestation. Event-related brain potentials (ERPs) were measured from 79 infants in an auditory oddball paradigm designed to measure auditory attention - a key aspect of early neurocognitive functioning. For the ERP-responses elicited by standard sounds, higher maternal mindfulness was associated with *lower* N250 amplitudes ($p<.01$, $\eta^2=.097$), whereas higher maternal anxiety was associated with *higher* N250 amplitudes ($p<.05$, $\eta^2=.057$). Maternal mindfulness was also positively associated with the P150 amplitude ($p<.01$, $\eta^2=.130$). These results suggest that infants prenatally exposed to higher levels of maternal mindfulness devote *fewer* attentional resources to frequently occurring irrelevant sounds. The results show that positive traits and experiences of the mother during pregnancy may also affect the unborn child. Emphasizing the beneficial effects of a positive psychological state during pregnancy may promote healthy behavior in pregnant women.

*Keywords***:** event-related potential; auditory attention, cognitive development; mindfulness; anxiety; infant.

Introduction

Research under the "prenatal programming hypothesis" examines the short and long-term consequences of the conditions of the prenatal environment for the offspring's health and disease risk (Barker, 2004). To date, accumulating evidence has demonstrated that prenatal exposure to maternal psychological distress affects neurocognitive functioning in the child. This effect probably results from induced alterations to fetal brain development and physiology (Van den Bergh *et al.*, 2005; Räikkönen *et al.*, 2011; Van den Bergh, 2011). Although the majority of the research in this field has focused almost exclusively on effects of exposure to early adverse conditions, prenatal exposure to maternal well-being might also "program" infant development and health. For example, Sriboonpimsuay and colleagues (2011) showed that the incidence of preterm birth was reduced in mothers who received meditation intervention during pregnancy as compared to the control group (i.e. those who underwent routine prenatal care). These results highlight the relevance of positive maternal experiences during pregnancy and their possible beneficial effects for both the mother and the child. Therefore, to cover the full scope of prenatal programming, one should also study the effects of positive experiences and traits during pregnancy on the offspring.

A good candidate for such a positive trait might be mindfulness, as many studies to date have reported associations between self-reported mindfulness (as a trait) and psychological health (for a review, see Keng *et al.*, 2011). Being mindful refers to a state of mind consisting of two key elements: (1) An alert mode of perceiving all mental contents (i.e. perceptions, sensations, cognitions, and emotions) and (2) a friendly, accepting, and non-judgmental attitude towards those mental contents (Kohls *et al.*, 2009). Being more mindful has been associated with better work-family balance among working parents (Allen and Kiburz, 2012) and better emotion-regulation (Goodall *et al.*, 2012). These two factors could contribute to a more healthy pregnancy, which, in turn, may provide a better environment for the fetus. Mindfulness interventions have been developed recently for pregnant women and their effects on psychological stress experience during pregnancy have been evaluated. The initial trials suggested beneficial effects of mindfulness interventions for normal populations of pregnant women as they reduced anxiety and depressive symptoms in mothers both pre- and postnatally (Vieten and Astin, 2008; Dunn *et al.*, 2012). A recent randomized controlled trial also found reduced maternal anxiety after mindfulness intervention in pregnant women with elevated anxiety levels (Guardino *et al.*, 2013). To our knowledge, only the study conducted by Sriboonpimsuay and colleagues (2011) reported effects of mindfulness intervention during pregnancy on birth outcomes (i.e. lower preterm birth weight in the intervention group) and no studies have been published on child developmental and health outcomes. Hence, the current study investigated the effects of dispositional maternal mindfulness during pregnancy and its effects on infant neurocognitive functioning.

A key aspect of early neurocognitive functioning is auditory attention. Auditory attention is an essential building block for developmental milestones, such as speech and language acquisition (Molfese, 2000; Benasich *et al.*, 2002; Benasich *et al.*, 2006; Kushnerenko *et al.*, 2013). It is important for infants to learn to organize the auditory input by rapidly extracting higher-level relationships and regularities from the sensory environment while becoming less responsive to variance in primary sensory features (Kushnerenko *et al.*, 2007). Auditory event-related potentials (ERPs) have long been employed to study these processes in infants and young children. The ERP method is suitable for testing this target group as ERPs can be recorded without the need for a behavioral response and in the absence of focused attention. Further, neurophysiological measures, such as ERPs, can be linked to the neurobiological processes involved in information processing. Despite these advantages, few human studies examining prenatal programming have incorporated neurophysiological measures (Mennes *et al.*, 2009; Buss *et al.*, 2010; Hunter *et al.*, 2012). In the current study, we measured ERPs from nine month old infants in a passive auditory oddball paradigm designed to measure the processing of frequent and rare sound events. Infants were presented with a repetitious train of “standard” sounds, which was occasionally interspersed with acoustically (i.e. white noise sounds and novel sounds) or temporally deviant sounds.

Although the auditory ERP components observed in infants are often not easily comparable to those obtained in adults (de Haan, 2006), the results of a longitudinal study by Kushnerenko et al. (2002) have shown similarities between some of the infantile ERP components and those observed in children and adults. The authors have suggested that the P150 component found in infants may be the precursor of the P100 response observed in children, which then develops into the adult P1 response. Functionally, this component is typically interpreted as an indicator of preferential attention to the auditory input and suppression of unattended information (Key *et al.*, 2005). Kushnerenko et al. (2002) also argued that the infant N250 recorded at 12 months of age could be considered similar to the N250 in children and the adult N2. The adult N2 has been associated with the orienting response and target selection (Key *et al.*, 2005). Finally, development of the infantile large positive component (PC) leads to the emergence of the P3a response in children and adults (Kushnerenko et al., 2002). The P3a has been proposed to reflect stimulus driven attention switching (Knight, 1996; Escera *et al.,* 2000; Polich, 2007). In nine month old infants, the ERP response elicited by standard and temporal deviant sounds typically carry both the P150 and the N250; the responses elicited by rare environmental (novel) sounds usually only show a PC response; white noise sounds typically elicit an ERP-response that comprises all three of the above components (see Kushnerenko *et al.*, 2013).

ERP-studies in adults have associated individual differences in dispositional mindfulness with differences in information processing (e.g. Brown *et al.*, 2013). Here we examine the possible effects of dispositional mindfulness during pregnancy on neurocognitive functioning in the offspring. Support for the notion that maternal traits/states during pregnancy may affect neurocognitive functioning of the offspring comes from ERP-studies examining the effects of prenatal and perinatal exposure to other maternal traits/states, such as prenatal maternal anxiety. These studies consistently associated prenatal (Mennes *et al.*, 2009; Hunter *et al.*, 2012; Van den Bergh *et al.*, 2012) and perinatal exposure (Harvison *et al.*, 2009) to elevated maternal anxiety with altered neurocognitive functioning in the offspring. For example, Mennes and colleagues (2009) found altered ERP patterns in response to an endogenous cognitive control task in 17 year old boys exposed to high maternal anxiety during pregnancy. Because mindfulness and anxiety are negatively correlated (e.g. Brown and Ryan, 2003; Walsh *et al.*, 2009), we hypothesized that prenatal exposure to maternal mindfulness and anxiety would affect the offspring in opposite ways.

Methods

Participants

The current study was part of the Prenatal Early Life Stress (PELS) project, an ongoing prospective cohort study, following pregnant women and their offspring from the first trimester of pregnancy onwards. All participating parents provided written informed consent. The Medical Ethical Committee of a local hospital approved the study, which was conducted in full compliance with the Helsinki declaration.

A total of 178 women had been recruited in the 15^{th} week and 12 women between the 16^{th} and 22^{nd} week of pregnancy from a general hospital and four midwife practices. Tests were administered to them three times during pregnancy (T1, T2, T3; once in each trimester) and they were invited with their infant for postnatal observations either at two or four (T4) and once again at nine months after birth (T5). Here, we analyzed the data of those mother-infant dyads of which both maternal mindfulness and anxiety data at T2 and ERP data at nine months were available. From the 128 infants that were brought to the ERP-measurement, two were excluded due to missing mindfulness and anxiety data, two due to technical problems, thirty-five due to excessive movements/artifacts and or excessive crying/fussiness, and four infants because of premature birth (i.e., before week 36 of gestation and/or a birth weight below 2500 grams). We also excluded six infants who fell asleep during the experiment, because previous studies suggested that the state of alertness affects the auditory ERPs (Friederici *et al.*, 2002; Otte *et al.*, 2013). For a full overview of the inclusion and exclusion of mother-infant dyads, see the flowchart in Figure 1.

The final sample consisted of 78 mothers and their 79 nine-month-olds (42 girls, one pair of twins). The infants had a mean age of 43.90 weeks (SD = 1.84) and a mean gestational age at birth of 39.98 weeks (SD = 1.26). The mothers had a mean age of 32.09 years (SD =5.55) at the time of the ERP measurement. All infants were healthy and had passed a screening test for hearing impairment performed by a nurse from the infant health care clinic between the fourth and seventh day after birth. The screening test was a simple, non-invasive test utilizing otoacoustic emissions for detecting hearing deficits.

Measurements

Table 1 describes the sample of the mothers and their infants including demographic characteristics and scores on the mindfulness and anxiety questionnaires.

Mindfulness. Maternal mindfulness was measured using the Dutch short version of the Freiburg Mindfulness Inventory (FMIs-14; Walach *et al.*, 2006). The original FMI is a self-report questionnaire developed in line with the concept of Buddhist psychology, but requires no knowledge of Buddhism or meditation to complete (Walach *et al.*, 2006). The shorter FMIs-14 consists of 14 items with four point Likert scales ranging from 1 (*rarely*) to 4 (*almost always*). Higher aggregate scores indicate higher mindfulness. The FMIs-14 was shown to measure a single dimension and shows good internal consistency (α=.86; Walach *et al.*, 2006).

Anxiety. Maternal anxiety was measured using the Dutch version of the anxiety subscale of the Symptom Checklist (SCL-90; Arrindel and Ettema, 1981). This SCL-90 anxiety subscale is a self-report measure of anxiety symptoms, consisting of 10 items with five point Likert scales ranging from 0 (*not at all*) to 4 (*extremely*). Higher aggregate scores indicate higher anxiety. The scale has good convergent and divergent validity and has good internal consistency (α=.88 for the anxiety subscale; Arrindell and Ettema, 2003).

ERP paradigm. ERPs were measured in a passive auditory oddball paradigm. The stimulus sequences consisted of four different types of sound events: A frequent standard sound (probability of .7) and three types of infrequent deviant events (each with a probability of .1). The standard was a complex tone with 500 Hz base frequency presented following an inter-stimulus-interval (ISI; offset-to-onset) of 300 ms. Standard tones were constructed from the three lowest partials, with the intensity of the second and third partials set 6 and 12 dB lower, respectively, than that of the base harmonic. The deviant sounds were (1) the same tone as the standard but following a shorter ISI of 100 ms (‘ISI-deviant’); (2) a white noise segment (‘white noise’, 300 ms ISI); and (3) 150 unique environmental sounds such as a slamming door, a barking dog, etc. (‘novel sound’, 300 ms ISI). All stimuli had durations of 200 ms and were presented at an intensity of 75 dB SPL. In total, 1500 stimuli were delivered. They were divided into five stimulus blocks, each containing 300 stimuli. The stimuli were presented in a semi-random order with the restriction that novel/white noise sounds were always preceded by at least two standard tones, and consecutive ISI-deviants were always separated by at least two sounds with a regular ISI (standard, novel, or white noise).

Procedure

Mindfulness and anxiety questionnaires were administered to mothers at the beginning of the second trimester (T2: mean gestation = 20.72 weeks, SD = 2.06) in their home. To control for postnatal anxiety, the same anxiety questionnaire was also administered to most mothers (N=57) ca. 10 months after birth (T5: mean = 44.09 weeks, SD = 1.84). The ERP-measurement took place ca. nine months after birth in a dimly lit and sound-attenuated room at the Developmental Psychology Laboratory of the university. The complete procedure took approximately 60 minutes including electrode placement and removal. During the EEG recording, infants sat on their parents' lap with two loudspeakers placed at a distance of 80 cm from the infant's head, one on each side. The whole experimental procedure was recorded with two cameras of which the first one was placed behind and the other facing the infant and the parent. The camera recordings were used to detect episodes when the baby was crying or moving; these episodes were then excluded from the analyses.

ERP measurement and data processing

EEG was recorded with BioSemi ActiveTwo amplifiers (www.biosemi.com) with a sampling rate of 512 Hz, using caps with 64-electrode locations placed according to the extended International 10-20 system. We analyzed data from the following nine electrode sites: F3, Fz, F4, C3, Cz, C4, P3, Pz and P4. The standard BioSemi reference (CMS-DRL) was used (see www.biosemi.com/faq/cms&drl.htm for details) and two additional electrodes were placed on the left and right mastoids, respectively and mathematically combined off-line to produce an average mastoids reference derivation. All electrophysiological analyses were conducted using the BrainVision Analyzer 2 software package (Brain Products, Munich, Germany). Off-line filter settings consisted of a 50 Hz notch filter and a zero-phase Butterworth bandpass 1.0 – 30 Hz (slope 24 dB) filter. Subsequently, the data were segmented into epochs of 600 ms duration including a 100 ms pre-stimulus period. Epochs with a voltage change exceeding 150 µV within a sliding window of 200 ms duration or with changes exceeding the speed of 80 µV/ms at any of the nine electrodes were rejected from further analysis. Trials that preceded the ISI deviant were removed from the analysis because late responses to these sounds overlapped the early responses elicited by the ISI deviant. The average number of remaining trials included in the analyses of the four stimulus types were as follows, standard: 730; ISI-deviant: 118; white noise: 102; novel: 105. ERPs were averaged separately for the four different stimulus types (standard, ISI-deviant, white noise, novel) and baseline-corrected to the average voltage in the 100 ms pre-stimulus period.

Time windows for measuring the various ERP components were selected on the basis of the grand average ERPs measured from the 9 electrode locations, separately for the standard and the three oddball stimuli (see Figure 2). Mean amplitudes were measured from the following time windows/stimuli: a window from 100 to 200 ms for the standard, the ISI-deviant, and the white noise sound to capture the P150-waveform; for the N250, the window was set from 200 to 300 ms for the standard tone and the ISI-deviant and from 150 to 250 ms for the white noise sound in the response to which this component peaked earlier; the window for the PC component was set between 250 and 400 ms for the white noise and novel sounds (the only ones eliciting this component).

Statistical analysis

Firstly, using Pearson's correlation, we checked whether the correlation between mindfulness and anxiety measured at T2 was negative, as was expected on the basis of previous results (e.g. Brown and Ryan, 2003; Walsh *et al.*, 2009). Three series of repeated-measures ANCOVAs were then conducted to test the effects of maternal mindfulness and anxiety on the infant's ERP amplitudes: One with "Mindfulness", one with prenatal (T2) "Anxiety", and one with postnatal (T5) anxiety as the continuous predictor. The latter was introduced for comparing the effects of pre- and postnatal anxiety on the ERP responses. Instead of dichotomizing the variables, continuous predictors were used, because dichotomizing might lead to loss of information, effect size, power, risks missing nonlinear effects, and may cause problems in comparing and aggregating findings across studies (e.g. MacCallum *et al.*, 2002). In each ANCOVA, two within-subject factors "Frontal-Central-

Parietal" X "Left-Middle-Right" were also included for assessing effects of the scalp topography of these components. Separate ANCOVAs were performed per stimulus type (standard, ISI-deviant, white noise, and novel sounds) and peak (P150, N250, and PC, where applicable). For significant interactions between the target variables (mindfulness and anxiety) and the "Frontal-Central-Parietal" factor, post hoc tests were conducted by separate ANCOVAs for the frontal (F3, Fz, F4), central (C3, Cz, C4), and parietal arrays of electrodes (P3, Pz, P4). Except for the ANCOVAs with T5 anxiety, gestational age and birth weight of the infants were selected as covariates, because previous studies showed effects of gestational age and birth weight on cognitive functioning (e.g. Fellman *et al.*, 2004; Shenkin *et al.*, 2004) and brain development (e.g. Poston, 2012; van den Heuvel *et al.*, under revision). Postnatal anxiety at T5 was also selected as a covariate to control for possible postnatal effects of anxiety. The covariates were first correlated with the AERP measures using Pearson's correlation and only added to the ANCOVAs if significant correlations were found. All statistical analyses were performed using IBM SPSS 19.0 for Windows. All significant results are reported together with the partial η^2 effect size values; $\alpha = .05$.

Results

Maternal mindfulness and anxiety during pregnancy (T2) were negatively correlated (r=-.270; p<.05). Maternal anxiety measured during pregnancy (T2) and maternal anxiety measured ca. 10 months after birth (T5) were positively correlated (r=.308; p<.05).

Figure 2 shows that all major components are clearly fronto-centrally distributed. The ERP effects of maternal mindfulness and anxiety at T2 on the infants' ERP response to the standard sound is illustrated in Figure 3A and B. For illustration purposes only, the infants were divided into low and high maternal mindfulness/anxiety groups and the responses separately averaged for these groups. A mean cut-off was used for the mindfulness measure; the cut-off score (15) for the SCL-90 anxiety subscale was taken from the average for the normal population (Derogatis *et al.*, 1974). Note that in the statistical analyses both of these measures were included as continuous predictors. Because we found no significant association (p > .05) between the P150 and N250 amplitudes and the covariates (i.e. gestational age, birth weight, and maternal anxiety at T5), no covariates were entered for the analysis of the results reported below.

For the ERPs elicited by standard tones, a significant positive association was obtained between maternal mindfulness and the P150 amplitude ($F(1,77) = 10.476$, $p = .002$, $\eta^2 = .120$; Figure 3C) and a significant negative association between maternal mindfulness and the N250 amplitude ($F(1,77) = 8.504$, $p = .005$, $\eta^2 = .099$; Figure 3D). For the N250 amplitude, also a significant interaction between mindfulness and the “Frontal-Central-Parietal” factor was found ($F(2,77)= 14.743$, $p=.009$, $\eta^2=.066$). Follow-up tests showed that the effect of mindfulness was significant at frontal and central scalp locations ($F(1,77)= 8.515$, $p=.005$, $\eta^2=.100$, and $F(1,77)= 8.841$, $p=.004$, $\eta^2=.103$, respectively), but not at parietal sites. For the rare deviant stimuli (i.e. ISI-deviant, white noise, and novel sound) no significant associations were found between maternal mindfulness and any of the ERP amplitudes.

Higher prenatal (T2) maternal anxiety was significantly associated with larger N250 amplitudes for the standard sound ($F(1,77) = 8.177$, $p = .005$, $\eta^2 = .096$; Figure 3E)[1]. Scalp distribution factors did not yield significant main effects or interactions with other factors. For the rare deviant stimuli (i.e. ISI-deviant, white noise and novel), no significant associations were found between maternal anxiety and any of the ERP amplitudes. Finally, postnatal (T5) maternal anxiety was not significantly associated with the measured ERP amplitudes.

Discussion

[1] The association remained significant ($F(1,76)= 6.319$, $p=.014$, $\eta^2=.077$) even after removing the extreme case (SCL-score = 28; see Figure 3E) from the analysis.

The aim of the present study was to examine the effects of the mother's mindfulness and anxiety during pregnancy on neurocognitive functioning in the offspring. We found significant opposite effects of maternal mindfulness and anxiety during pregnancy on how infants processed repetitive sounds. In contrast, none of the ERPs elicited by rare auditory events were significantly affected by the independent variables. Whereas effects of maternal anxiety during pregnancy on offspring neurocognitive functioning have already been previously reported (Mennes *et al.*, 2009; Buss *et al.*, 2010; Van den Bergh *et al.*, 2012), our results show that maternal mindfulness may also affect neurocognitive functioning in the offspring.

Associations between maternal mindfulness and anxiety during pregnancy and their effects on the infants' auditory ERP responses

As was expected from results of previous studies (Brown and Ryan, 2003; Walsh *et al.*, 2009), a negative correlation was observed between maternal mindfulness and anxiety in the current group of pregnant women and, in line with our hypothesis, we found opposite effects of maternal mindfulness and anxiety on the ERPs elicited by the frequent standard tones: Higher maternal mindfulness was associated with *lower* N250 amplitudes, whereas higher maternal anxiety was associated with *higher* N250 amplitudes. Higher maternal mindfulness was also associated with higher P150 amplitudes. P1, the putative adult analogue of P150 is regarded as reflecting early preattentive processes extracting sound features (e.g. Näätänen and Winkler, 1999; Picton, 2010). Thus higher P150 amplitudes may reflect more thorough/elaborate feature extraction in babies of mothers with higher mindfulness scores. In adults, the various subcomponents of N2 (N2a, b, and c - see Pritchard *et al.*, 1991), the putative analogue of the infantile N250, have been associated with various cognitive processes (e.g. selective attention, stimulus identification) evaluating the incoming sound. The lower N250 amplitude found for infants exposed to higher levels of maternal mindfulness during pregnancy might be a consequence of these infants having formed more accurate preattentive representations (i.e. higher P1) and, therefore not needing to process the repetitious standard sound more elaborately. In sum, infants prenatally exposed to higher levels of maternal mindfulness may devote *less* processing to the uninformative repetitious sounds, whereas infants prenatally exposed to higher levels of maternal anxiety may process such sounds *more* extensively. These results suggest that prenatal exposure to maternal mindfulness and anxiety affects neurocognitive functioning in the offspring in at least partly opposite ways.

Significant effects were only observed for the frequent standard sound but not for the rare deviant sounds. This suggests that the infants' deviance detection mechanism was not affected by exposure to maternal mindfulness (or anxiety) during pregnancy. The fact that both mindfulness and anxiety only exerted influence on the responses elicited by the standard sound could mean that these maternal states/traits affect processes involving habituation. Neural habituation has been defined as a process by which the neural response decreases over time during repeated stimulation (Thompson and Spencer, 1966). This is more likely to take place for the high-probability standard sound than for the low-probability deviant sounds. Because extensive and continuous processing of the oft-repeated standard is largely unnecessary, habituation to this stimulus could be considered as adaptive. Building on this line of reasoning, the lower amplitude of the N250 for infants prenatally exposed to higher mindfulness could indicate stronger habituation processes in these infants, which might be a sign of more adaptive brain functioning. In contrast, the fact that higher N250 amplitude was associated with higher maternal anxiety could be interpreted as reflecting weaker habituation processes in these infants, possibly indicating less adaptive brain functioning. The latter suggestions is compatible with the results of Turner et al. (2005), who reported that children of anxious parents were less likely to habituate to fear-relevant auditory and visual stimuli.

More research is necessary, however, to test whether infants prenatally exposed to higher levels of maternal mindfulness possess stronger habituation processes.

The non-significant correlations for the ERP responses elicited by the deviant sounds may be possibly attributed to relatively higher noise levels in the deviant-sound responses due to the lower average number of trials for the deviant sounds compared to that for the standard tones. However, at least the novel sounds and the white noise segment used in our study have been shown to elicit ERP responses of higher amplitudes than the standard tone. Therefore, the signal-to-noise ratio for equal numbers of trials is better for these sounds than for the tone stimuli, such as the standard (Kushnerenko et al., 2007) and thus fewer number of trials are needed to achieve the same S/N ratio. Further, the average trial numbers for all three deviants was relatively high and the study includes a large group of infants compared with most studies recording auditory ERPs in infants. Taken these together, the lack of significant correlations between maternal mindfulness/anxiety during pregnancy and the ERP responses elicited by the deviant sounds is likely a robust finding of this study. Future research could focus on exploring the mechanisms selectively affecting the processing of repetitive sounds but leaving the deviance detection mechanism intact.

Possible mechanisms

The fact that mindfulness and anxiety exert influence on the same type of information processing might point to shared underlying mechanisms. However, the mechanisms by which the psychological traits/states of the mother “program” the infants’ brain during pregnancy are not yet known. One often proposed mechanism is the exposure to excessive levels of cortisol, the so-called “stress hormone”. The human fetus is relatively protected against direct exposure to high cortisol concentrations as in the placenta 50–90% of maternal cortisol is converted to biologically inactive cortisone by the enzyme 11β-hydroxysteroid-dehydrogenase (11β-HSD-2) (Mulder *et al.*, 2002). However, high maternal anxiety in pregnancy may lead to down-regulation of placental 11β-HSD2 (O'Donnell *et al.*, 2012). Although cortisol is crucial for fetal tissue proliferation and differentiation, exposure to excessive levels of this hormone due to maternal stress can have negative consequences for birth outcome and development, such as e.g. increased risk for premature birth (Sandman *et al.*, 2006) and impaired cognitive performance (Davis and Sandman, 2010). Since dispositional mindfulness has been linked to reduced cortisol levels (Brown *et al.*, 2012) and anxiety is associated with enhanced cortisol levels (Pluess *et al.*, 2010), the suggestion of cortisol secretion as one of the underlying mechanisms appears to be reasonable. Being mindful during pregnancy could make the mother less vulnerable to stressful events. Indeed mindfulness has been linked to psychological health (Keng *et al.*, 2011), better work-family balance (Allen and Kiburz, 2012) and better emotion-regulation (Goodall *et al.*, 2012). In sum, mindfulness could prevent the negative consequences of prenatal exposure to stress on the fetus whereas anxiety during pregnancy might enhance vulnerability to stress in the fetus.

Although ERPs were measured early in development, postnatal influences could have also affected the neurocognitive functioning of the infants. Maternal anxiety and mindfulness during pregnancy may be related to attachment, parenting styles, and ways of taking care of the infant. These factors may, therefore be partly responsible for the observed association between maternal prenatal anxiety/mindfulness and some of the ERP responses. On the other hand, we have found no significant association between the mothers' postnatal anxiety at nine months after birth and the P150 and N250 amplitudes. Thus the effects found cannot be attributed to the influences of anxiety on the mother-child interaction between birth and nine months of age. Unfortunately the mothers' postnatal mindfulness was not measured. More mindful mothers could have, for instance, (also) affected their infants' brain through more mindful parenting or less postnatal stress. Possible genetic factors cannot be disregarded either; mindful mothers might give birth to babies more disposed towards mindfulness.

Nevertheless, human studies evaluating the consequences of stressful life events on development, such as natural disasters (Laplante et al., 2004), suggest that the effects of prenatal stress cannot be explained by genetic predispositions alone. To isolate the effects of prenatal maternal mindfulness from possible postnatal effects and to eliminate genetic influences, future randomized controlled trials are needed with mindfulness interventions for pregnant women.

Clinical applications

The current results could help to suggest directions to nurses, midwives, general practitioners, and gynecologists in providing pregnant women with information about potentially positive prenatal programming effects and in this way contribute to healthier pregnancy. Highly anxious mothers may feel guilty in response to the message that being anxious during pregnancy negatively affects their baby and might in turn experience increased anxiety levels instead of decreased levels. By stressing the potential of mindfulness instead, a positive message can be provided to them. Further, the current results emphasize the possible strengths of a mindfulness intervention for pregnant women. Such an intervention for pregnant women suffering from anxiety may be a very desirable alternative to pharmacological interventions, since several studies have described the detrimental effects of psychopharmacological treatment during pregnancy on the fetus (e.g. Mulder *et al.,* 2011). However, more research into the effects of maternal mindfulness during pregnancy is necessary before firm conclusions about the potential benefits for the infants' neurocognitive functioning can be drawn.

Conclusion

The results of the current study indicate that (1) infants' processing of the standard but not the deviant sounds (ISI-deviant, white noise, novel) is affected by prenatal exposure to maternal mindfulness and anxiety and (2) mindfulness and anxiety exert, at least partly, opposite effects on the infant's ERP responses to repetitive sounds. We suggest that infants prenatally exposed to higher levels of maternal mindfulness devote *less* in-depth processing to frequently occurring, irrelevant stimuli and/or they habituate *faster* to these stimuli. In contrast, infants prenatally exposed to higher levels of maternal anxiety process such uninformative sounds *more* extensively and/or they habituate *slower* to these stimuli. This difference might stem from infants prenatally exposed to higher maternal mindfulness pre-attentively forming more accurate perceptual representations. The current study contributes to the field of prenatal programming by showing that negative traits and experiences of the mother during pregnancy are not the only ones to have an effect on the child, as is often emphasized in the literature. Positive traits of the mother during pregnancy may also "program" the infant.

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Table 1. Characteristics of the participating mother-infant dyad sample

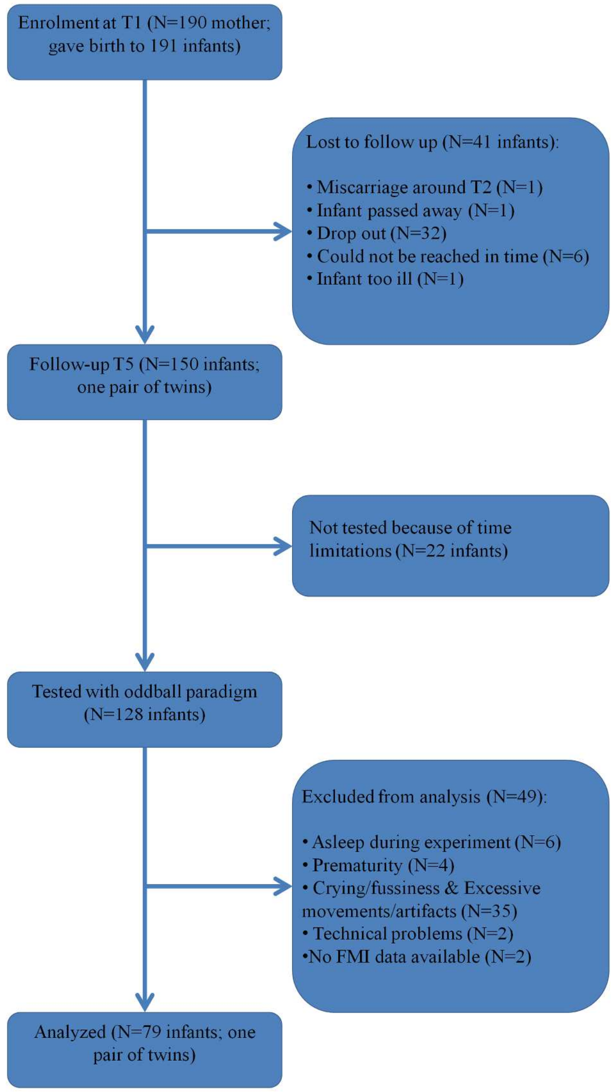
Infants (N=79)	**N**	**%**	**M (SD)**
Age at EEG-measurement (weeks)	79		43.9 (1.84)
Sex			
Girl	42	53.2	
Boy	37	46.8	
Birth weight (grams)	79		3495.25 (487.26)
Gestational age at birth (weeks)	77		39.98 (1.26)
Mothers (N=78)	**N**	**%**	**M (SD)**
Age (years)	78		32.09 (5.55)
FMI sum at T2	78		40.66 (6.30)
SCL-90 sum at T2	78		13.13 (3.39)
SCL-90 sum at T5	57*		13.26 (5.02)
Education			
Primary or secondary	6	7.7	
General vocational training	22	28.2	
Higher vocational training	34	43.6	
University degree or higher	16	20.5	
Primagravida	29	37.2	

Note FMI = Freiburg Mindfulness Inventory; SCL-90 = anxiety subscale of the Symptom Checklist; T2 = during second trimester; T5 = ca. 10 months after birth; *N=21 mothers included in the study did not complete the postnatal questionnaire.

Figure 1. Flowchart of inclusion and exclusion of the participating mothers–infant dyads.

Figure 2. Group-average (N=79) ERP-responses to standard tones, ISI-deviants, white noise segments, and novel sounds (columns) at electrodes F3, Fz, F4, C3, Cz, C4, P3, Pz, P4 (rows).

Figure 3. Group-average (N=79) central (Cz) ERP-response to the standard sound of infants of mothers with low (blue line) and high (green line) mindfulness (**A**) and anxiety (**B**). The scatterplots shows the correlation between maternal mindfulness and the amplitude of (**C**) the first positive-going wave 'P150' (measured from the 100-200 ms post-stimulus interval) and (**D**) the first negative-going wave 'N250' (200-320 ms). Panel (**E**) shows the scatterplot for the correlation between maternal anxiety and the amplitude of the 'N250' component. **Notes**: The statistical analyses were performed with mindfulness and anxiety as continuous predictors (**C, D** and **E**). Panels **A** and **B** are for illustration purposes, only.



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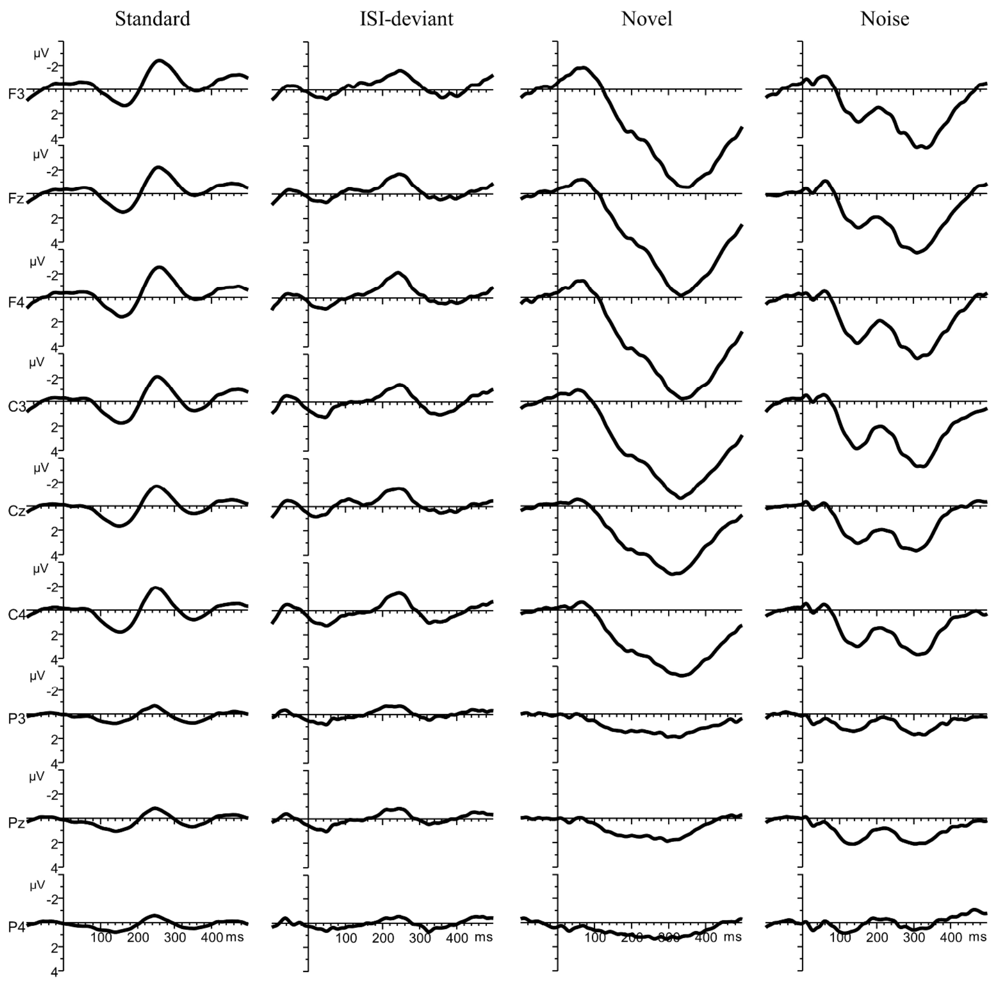

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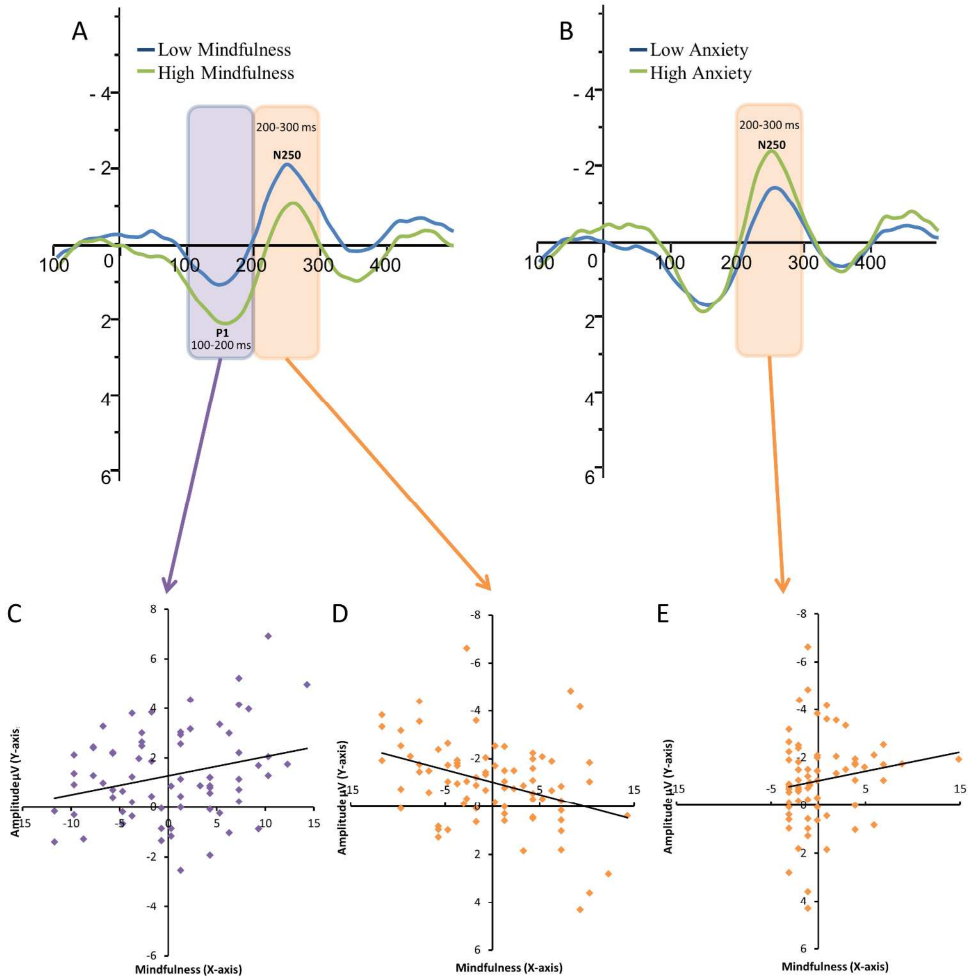

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