

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

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22 **Word count:** 4927 (total number of words in text); 204 (abstract)

23

**Abstract**

1  
2 Maternal anxiety during pregnancy has been consistently shown to negatively affect offspring  
3 neurodevelopmental outcomes. However, little is known about the impact of positive maternal  
4 traits/states during pregnancy on the offspring. The present study was aimed at investigating  
5 the effects of the mother's mindfulness and anxiety during pregnancy on the infant's  
6 neurocognitive functioning at 9 month of age. Mothers reported mindfulness using the  
7 Freiburg Mindfulness Inventory and anxiety using the Symptom Checklist at  $\pm 20.7$  weeks of  
8 gestation. Event-related brain potentials (ERPs) were measured from 79 infants in an auditory  
9 oddball paradigm designed to measure auditory attention - a key aspect of early  
10 neurocognitive functioning. For the ERP-responses elicited by standard sounds, higher  
11 maternal mindfulness was associated with *lower* N250 amplitudes ( $p < .01$ ,  $\eta^2 = .097$ ), whereas  
12 higher maternal anxiety was associated with *higher* N250 amplitudes ( $p < .05$ ,  $\eta^2 = .057$ ).  
13 Maternal mindfulness was also positively associated with the P150 amplitude ( $p < .01$ ,  
14  $\eta^2 = .130$ ). These results suggest that infants prenatally exposed to higher levels of maternal  
15 mindfulness devote *fewer* attentional resources to frequently occurring irrelevant sounds. The  
16 results show that positive traits and experiences of the mother during pregnancy may also  
17 affect the unborn child. Emphasizing the beneficial effects of a positive psychological state  
18 during pregnancy may promote healthy behavior in pregnant women.

19  
20 **Keywords:** event-related potential; auditory attention, cognitive development; mindfulness; anxiety;  
21 infant.



1 the fetus. Mindfulness interventions have been developed recently for pregnant women and  
2 their effects on psychological stress experience during pregnancy have been evaluated. The  
3 initial trials suggested beneficial effects of mindfulness interventions for normal populations  
4 of pregnant women as they reduced anxiety and depressive symptoms in mothers both pre-  
5 and postnatally (Vieten and Astin, 2008; Dunn *et al.*, 2012). A recent randomized controlled  
6 trial also found reduced maternal anxiety after mindfulness intervention in pregnant women  
7 with elevated anxiety levels (Guardino *et al.*, 2013). To our knowledge, only the study  
8 conducted by Sriboonpimsuay and colleagues (2011) reported effects of mindfulness  
9 intervention during pregnancy on birth outcomes (i.e. lower preterm birth weight in the  
10 intervention group) and no studies have been published on child developmental and health  
11 outcomes. Hence, the current study investigated the effects of dispositional maternal  
12 mindfulness during pregnancy and its effects on infant neurocognitive functioning.

13         A key aspect of early neurocognitive functioning is auditory attention. Auditory  
14 attention is an essential building block for developmental milestones, such as speech and  
15 language acquisition (Molfese, 2000; Benasich *et al.*, 2002; Benasich *et al.*, 2006;  
16 Kushnerenko *et al.*, 2013). It is important for infants to learn to organize the auditory input by  
17 rapidly extracting higher-level relationships and regularities from the sensory environment  
18 while becoming less responsive to variance in primary sensory features (Kushnerenko *et al.*,  
19 2007). Auditory event-related potentials (ERPs) have long been employed to study these  
20 processes in infants and young children. The ERP method is suitable for testing this target  
21 group as ERPs can be recorded without the need for a behavioral response and in the absence  
22 of focused attention. Further, neurophysiological measures, such as ERPs, can be linked to the  
23 neurobiological processes involved in information processing. Despite these advantages, few  
24 human studies examining prenatal programming have incorporated neurophysiological  
25 measures (Mennes *et al.*, 2009; Buss *et al.*, 2010; Hunter *et al.*, 2012). In the current study, we

1 measured ERPs from nine month old infants in a passive auditory oddball paradigm designed  
2 to measure the processing of frequent and rare sound events. Infants were presented with a  
3 repetitious train of “standard” sounds, which was occasionally interspersed with acoustically  
4 (i.e. white noise sounds and novel sounds) or temporally deviant sounds.

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

23         ERP-studies in adults have associated individual differences in dispositional  
24 mindfulness with differences in information processing (e.g. Brown *et al.*, 2013). Here we  
25 examine the possible effects of dispositional mindfulness during pregnancy on neurocognitive

1 functioning in the offspring. Support for the notion that maternal traits/states during  
2 pregnancy may affect neurocognitive functioning of the offspring comes from ERP-studies  
3 examining the effects of prenatal and perinatal exposure to other maternal traits/states, such as  
4 prenatal maternal anxiety. These studies consistently associated prenatal (Mennes *et al.*, 2009;  
5 Hunter *et al.*, 2012; Van den Bergh *et al.*, 2012) and perinatal exposure (Harvison *et al.*,  
6 2009) to elevated maternal anxiety with altered neurocognitive functioning in the offspring.  
7 For example, Mennes and colleagues (2009) found altered ERP patterns in response to an  
8 endogenous cognitive control task in 17 year old boys exposed to high maternal anxiety  
9 during pregnancy. Because mindfulness and anxiety are negatively correlated (e.g. Brown and  
10 Ryan, 2003; Walsh *et al.*, 2009), we hypothesized that prenatal exposure to maternal  
11 mindfulness and anxiety would affect the offspring in opposite ways.

## 12 **Methods**

### 13 **Participants**

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

19 A total of 178 women had been recruited in the 15<sup>th</sup> week and 12 women between the  
20 16<sup>th</sup> and 22<sup>nd</sup> week of pregnancy from a general hospital and four midwife practices. Tests  
21 were administered to them three times during pregnancy (T1, T2, T3; once in each trimester)  
22 and they were invited with their infant for postnatal observations either at two or four (T4)  
23 and once again at nine months after birth (T5). Here, we analyzed the data of those mother-  
24 infant dyads of which both maternal mindfulness and anxiety data at T2 and ERP data at nine  
25 months were available. From the 128 infants that were brought to the ERP-measurement, two

1 were excluded due to missing mindfulness and anxiety data, two due to technical problems,  
2 thirty-five due to excessive movements/artifacts and or excessive crying/fussiness, and four  
3 infants because of premature birth (i.e., before week 36 of gestation and/or a birth weight  
4 below 2500 grams). We also excluded six infants who fell asleep during the experiment,  
5 because previous studies suggested that the state of alertness affects the auditory ERPs  
6 (Friederici *et al.*, 2002; Otte *et al.*, 2013). For a full overview of the inclusion and exclusion  
7 of mother-infant dyads, see the flowchart in Figure 1.

8           The final sample consisted of 78 mothers and their 79 nine-month-olds (42 girls, one  
9 pair of twins). The infants had a mean age of 43.90 weeks (SD = 1.84) and a mean gestational  
10 age at birth of 39.98 weeks (SD = 1.26). The mothers had a mean age of 32.09 years (SD  
11 =5.55) at the time of the ERP measurement. All infants were healthy and had passed a  
12 screening test for hearing impairment performed by a nurse from the infant health care clinic  
13 between the fourth and seventh day after birth. The screening test was a simple, non-invasive  
14 test utilizing otoacoustic emissions for detecting hearing deficits.

## 15 **Measurements**

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

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

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

7           **ERP paradigm.** ERPs were measured in a passive auditory oddball paradigm. The  
8 stimulus sequences consisted of four different types of sound events: A frequent standard  
9 sound (probability of .7) and three types of infrequent deviant events (each with a probability  
10 of .1). The standard was a complex tone with 500 Hz base frequency presented following an  
11 inter-stimulus-interval (ISI; offset-to-onset) of 300 ms. Standard tones were constructed from  
12 the three lowest partials, with the intensity of the second and third partials set 6 and 12 dB  
13 lower, respectively, than that of the base harmonic. The deviant sounds were (1) the same  
14 tone as the standard but following a shorter ISI of 100 ms ('ISI-deviant'); (2) a white noise  
15 segment ('white noise', 300 ms ISI); and (3) 150 unique environmental sounds such as a  
16 slamming door, a barking dog, etc. ('novel sound', 300 ms ISI). All stimuli had durations of  
17 200 ms and were presented at an intensity of 75 dB SPL. In total, 1500 stimuli were delivered.  
18 They were divided into five stimulus blocks, each containing 300 stimuli. The stimuli were  
19 presented in a semi-random order with the restriction that novel/white noise sounds were  
20 always preceded by at least two standard tones, and consecutive ISI-deviants were always  
21 separated by at least two sounds with a regular ISI (standard, novel, or white noise).

## 22 **Procedure**

23           Mindfulness and anxiety questionnaires were administered to mothers at the beginning  
24 of the second trimester (T2: mean gestation = 20.72 weeks, SD = 2.06) in their home. To  
25 control for postnatal anxiety, the same anxiety questionnaire was also administered to most



1 mothers (N=57) ca. 10 months after birth (T5: mean = 44.09 weeks, SD = 1.84). The ERP-  
2 measurement took place ca. nine months after birth in a dimly lit and sound-attenuated room  
3 at the Developmental Psychology Laboratory of the university. The complete procedure took  
4 approximately 60 minutes including electrode placement and removal. During the EEG  
5 recording, infants sat on their parents' lap with two loudspeakers placed at a distance of 80 cm  
6 from the infant's head, one on each side. The whole experimental procedure was recorded  
7 with two cameras of which the first one was placed behind and the other facing the infant and  
8 the parent. The camera recordings were used to detect episodes when the baby was crying or  
9 moving; these episodes were then excluded from the analyses.

#### 10 **ERP measurement and data processing**

11 EEG was recorded with BioSemi ActiveTwo amplifiers ([www.biosemi.com](http://www.biosemi.com)) with a  
12 sampling rate of 512 Hz, using caps with 64-electrode locations placed according to the  
13 extended International 10-20 system. We analyzed data from the following nine electrode  
14 sites: F3, Fz, F4, C3, Cz, C4, P3, Pz and P4. The standard BioSemi reference (CMS-DRL)  
15 was used (see [www.biosemi.com/faq/cms&drl.htm](http://www.biosemi.com/faq/cms&drl.htm) for details) and two additional electrodes  
16 were placed on the left and right mastoids, respectively and mathematically combined off-line  
17 to produce an average mastoids reference derivation. All electrophysiological analyses were  
18 conducted using the BrainVision Analyzer 2 software package (Brain Products, Munich,  
19 Germany). Off-line filter settings consisted of a 50 Hz notch filter and a zero-phase  
20 Butterworth bandpass 1.0 – 30 Hz (slope 24 dB) filter. Subsequently, the data were segmented  
21 into epochs of 600 ms duration including a 100 ms pre-stimulus period. Epochs with a voltage  
22 change exceeding 150  $\mu$ V within a sliding window of 200 ms duration or with changes  
23 exceeding the speed of 80  $\mu$ V/ms at any of the nine electrodes were rejected from further  
24 analysis. Trials that preceded the ISI deviant were removed from the analysis because late  
25 responses to these sounds overlapped the early responses elicited by the ISI deviant. The

1 average number of remaining trials included in the analyses of the four stimulus types were as  
2 follows, standard: 730; ISI-deviant: 118; white noise: 102; novel: 105. ERPs were averaged  
3 separately for the four different stimulus types (standard, ISI-deviant, white noise, novel) and  
4 baseline-corrected to the average voltage in the 100 ms pre-stimulus period.

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

#### 14 **Statistical analysis**

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

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

## 16 **Results**

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

20 Figure 2 shows that all major components are clearly fronto-centrally distributed. The  
21 ERP effects of maternal mindfulness and anxiety at T2 on the infants’ ERP response to the  
22 standard sound is illustrated in Figure 3A and B. For illustration purposes only, the infants  
23 were divided into low and high maternal mindfulness/anxiety groups and the responses  
24 separately averaged for these groups. A mean cut-off was used for the mindfulness measure;  
25 the cut-off score (15) for the SCL-90 anxiety subscale was taken from the average for the

1 normal population (Derogatis *et al.*, 1974). Note that in the statistical analyses both of these  
 2 measures were included as continuous predictors. Because we found no significant  
 3 association ( $p > .05$ ) between the P150 and N250 amplitudes and the covariates (i.e.  
 4 gestational age, birth weight, and maternal anxiety at T5), no covariates were entered for the  
 5 analysis of the results reported below.

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

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

## 22 Discussion

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<sup>1</sup> 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.

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

#### 10 **Associations between maternal mindfulness and anxiety during pregnancy and their** 11 **effects on the infants' auditory ERP responses**

12 As was expected from results of previous studies (Brown and Ryan, 2003; Walsh *et al.*,  
13 2009), a negative correlation was observed between maternal mindfulness and anxiety in  
14 the current group of pregnant women and, in line with our hypothesis, we found opposite  
15 effects of maternal mindfulness and anxiety on the ERPs elicited by the frequent standard  
16 tones: Higher maternal mindfulness was associated with *lower* N250 amplitudes, whereas  
17 higher maternal anxiety was associated with *higher* N250 amplitudes. Higher maternal  
18 mindfulness was also associated with higher P150 amplitudes. P1, the putative adult analogue  
19 of P150 is regarded as reflecting early preattentive processes extracting sound features (e.g.  
20 Näätänen and Winkler, 1999; Picton, 2010). Thus higher P150 amplitudes may reflect more  
21 thorough/elaborate feature extraction in babies of mothers with higher mindfulness scores. In  
22 adults, the various subcomponents of N2 (N2a, b, and c - see Pritchard *et al.*, 1991), the  
23 putative analogue of the infantile N250, have been associated with various cognitive  
24 processes (e.g. selective attention, stimulus identification) evaluating the incoming sound. The  
25 lower N250 amplitude found for infants exposed to higher levels of maternal mindfulness

1 during pregnancy might be a consequence of these infants having formed more accurate  
2 preattentive representations (i.e. higher P1) and, therefore not needing to process the  
3 repetitious standard sound more elaborately. In sum, infants prenatally exposed to higher  
4 levels of maternal mindfulness may devote *less* processing to the uninformative repetitious  
5 sounds, whereas infants prenatally exposed to higher levels of maternal anxiety may process  
6 such sounds *more* extensively. These results suggest that prenatal exposure to maternal  
7 mindfulness and anxiety affects neurocognitive functioning in the offspring in at least partly  
8 opposite ways.

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

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

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

### 17 **Possible mechanisms**

18         The fact that mindfulness and anxiety exert influence on the same type of information  
19 processing might point to shared underlying mechanisms. However, the mechanisms by  
20 which the psychological traits/states of the mother “program” the infants’ brain during  
21 pregnancy are not yet known. One often proposed mechanism is the exposure to excessive  
22 levels of cortisol, the so-called “stress hormone”. The human fetus is relatively protected  
23 against direct exposure to high cortisol concentrations as in the placenta 50–90% of maternal  
24 cortisol is converted to biologically inactive cortisone by the enzyme 11 $\beta$ -hydroxysteroid-  
25 dehydrogenase (11 $\beta$ -HSD-2) (Mulder *et al.*, 2002). However, high maternal anxiety in

1 pregnancy may lead to down-regulation of placental  $11\beta$ -HSD2 (O'Donnell *et al.*, 2012).  
2 Although cortisol is crucial for fetal tissue proliferation and differentiation, exposure to  
3 excessive levels of this hormone due to maternal stress can have negative consequences for  
4 birth outcome and development, such as e.g. increased risk for premature birth (Sandman *et*  
5 *al.*, 2006) and impaired cognitive performance (Davis and Sandman, 2010). Since  
6 dispositional mindfulness has been linked to reduced cortisol levels (Brown *et al.*, 2012) and  
7 anxiety is associated with enhanced cortisol levels (Pluess *et al.*, 2010), the suggestion of  
8 cortisol secretion as one of the underlying mechanisms appears to be reasonable. Being  
9 mindful during pregnancy could make the mother less vulnerable to stressful events. Indeed  
10 mindfulness has been linked to psychological health (Keng *et al.*, 2011), better work-family  
11 balance (Allen and Kiburz, 2012) and better emotion-regulation (Goodall *et al.*, 2012). In  
12 sum, mindfulness could prevent the negative consequences of prenatal exposure to stress on  
13 the fetus whereas anxiety during pregnancy might enhance vulnerability to stress in the fetus.

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



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

### 7 **Clinical applications**

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

### 22 **Conclusion**

23         The results of the current study indicate that (1) infants' processing of the standard but  
24 not the deviant sounds (ISI-deviant, white noise, novel) is affected by prenatal exposure to  
25 maternal mindfulness and anxiety and (2) mindfulness and anxiety exert, at least partly,

1 opposite effects on the infant's ERP responses to repetitive sounds. We suggest that infants  
2 prenatally exposed to higher levels of maternal mindfulness devote *less* in-depth processing to  
3 frequently occurring, irrelevant stimuli and/or they habituate *faster* to these stimuli. In  
4 contrast, infants prenatally exposed to higher levels of maternal anxiety process such  
5 uninformative sounds *more* extensively and/or they habituate *slower* to these stimuli. This  
6 difference might stem from infants prenatally exposed to higher maternal mindfulness pre-  
7 attentively forming more accurate perceptual representations. The current study contributes to  
8 the field of prenatal programming by showing that negative traits and experiences of the  
9 mother during pregnancy are not the only ones to have an effect on the child, as is often  
10 emphasized in the literature. Positive traits of the mother during pregnancy may also  
11 “program” the infant.

12

1 **Funding**

2 Research funding was generated from the Brain and Cognition Programme of the Dutch  
3 Organisation for Scientific Research (NWO), through ESF. BVdB is supported by European  
4 Commission Seventh Framework Programme (FP7– HEALTH.2011.2.2.2-2 BRAINAGE,  
5 Grant agreement no: 279281). IW is supported by the Hungarian Scientific Research Fund  
6 (OTKA K101060) grant.

1 **Acknowledgements**

2 The authors are grateful to the parents and infants for their participation in our study and to  
3 the students who helped with the data collection. The study described is part of the Prenatal  
4 Early Life Stress (PELS) project, one of four collaborative project of ‘EuroSTRESS’, a  
5 EUROCORES programme focused on stress and mental health and launched by European  
6 Science Foundation (ESF) in 2008. BVdB is project leader of PELS, and principal  
7 investigator (PI) for the Netherlands. We thank Vivette Glover (Imperial College London; PI  
8 for UK), Stephan Claes (KU Leuven; PI for Belgium) and Alina Rodriguez, associated partner  
9 (Uppsala University Sweden) for the collaboration in the PELS project.

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10 99.

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

<i>Infants (N=79)</i>	<b>N</b>	<b>%</b>	<b>M (SD)</b>
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)
<i>Mothers (N=78)</i>	<b>N</b>	<b>%</b>	<b>M (SD)</b>
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	
Primigravida	29	37.2	

2 Note FMI = Freiburg Mindfulness Inventory; SCL-90 = anxiety subscale of the Symptom Checklist; T2 = during

3 second trimester; T5 = ca. 10 months after birth; \*N=21 mothers included in the study did not complete the

4 postnatal questionnaire.

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

2

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

5

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

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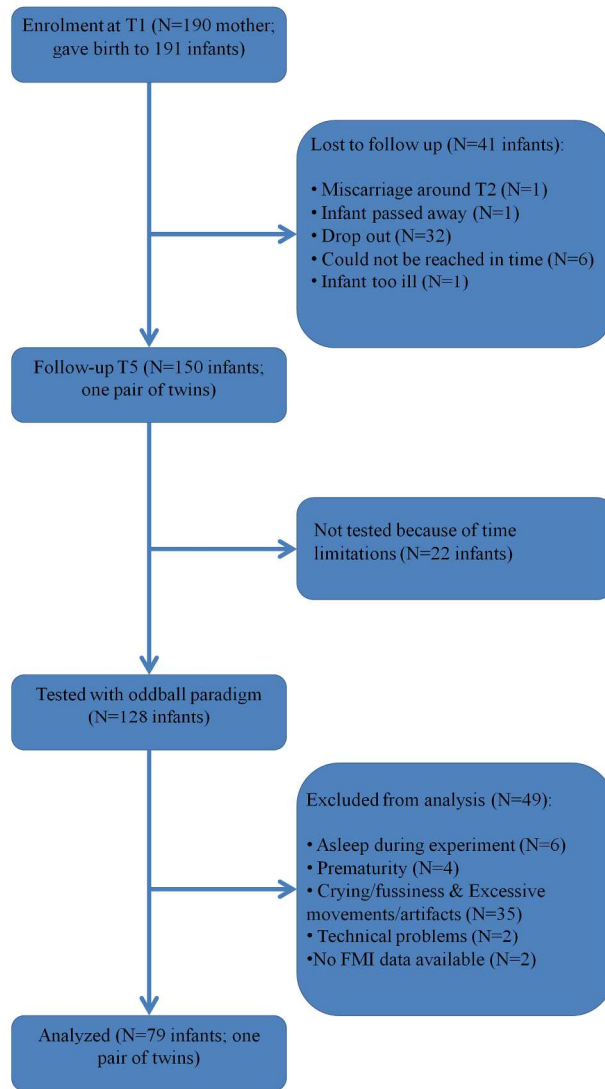


Figure 1. Flowchart of inclusion and exclusion of the participating mothers–infant dyads. 800x1000mm (78 x 78 DPI)

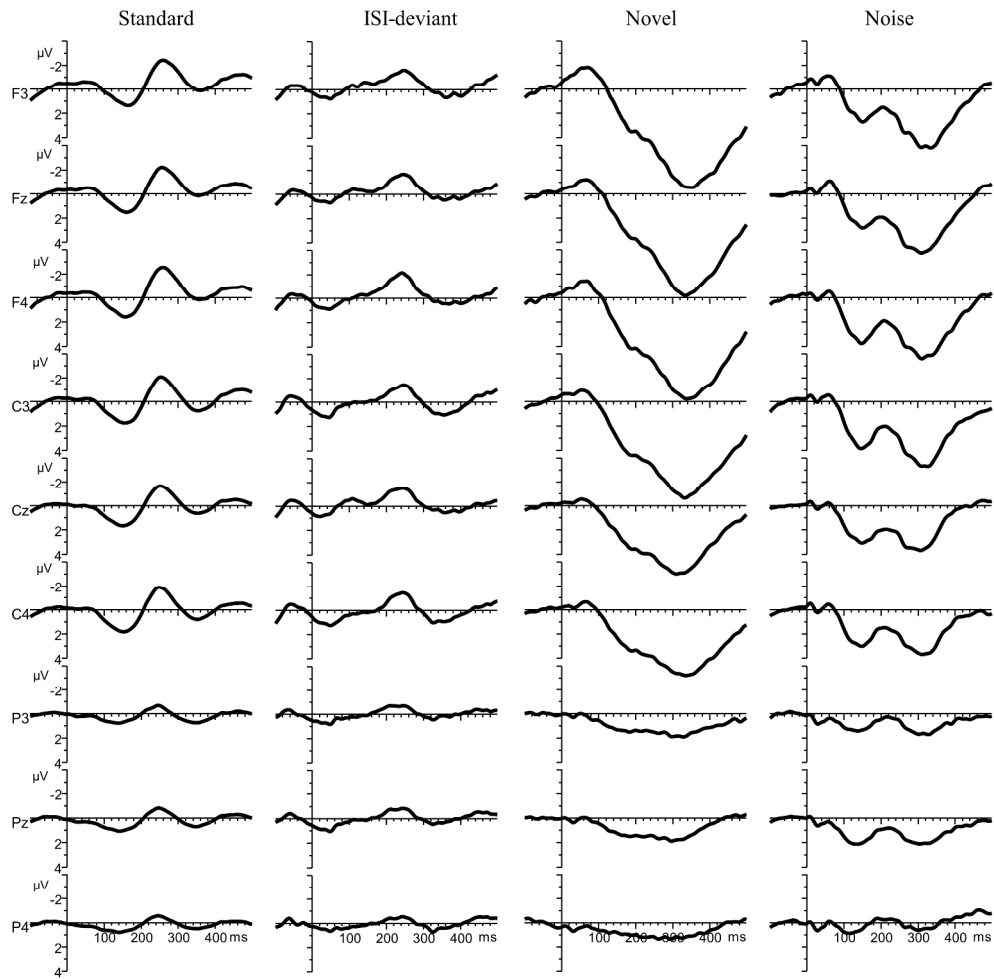


Figure 2. Group-average (N=79) ERP-responses to standard tones, ISI-deviants, white noise segments, and novel sounds (columns) at electrodes F3, Fz, F4, C3, Cz, C4, P3, Pz, P4 (rows).  
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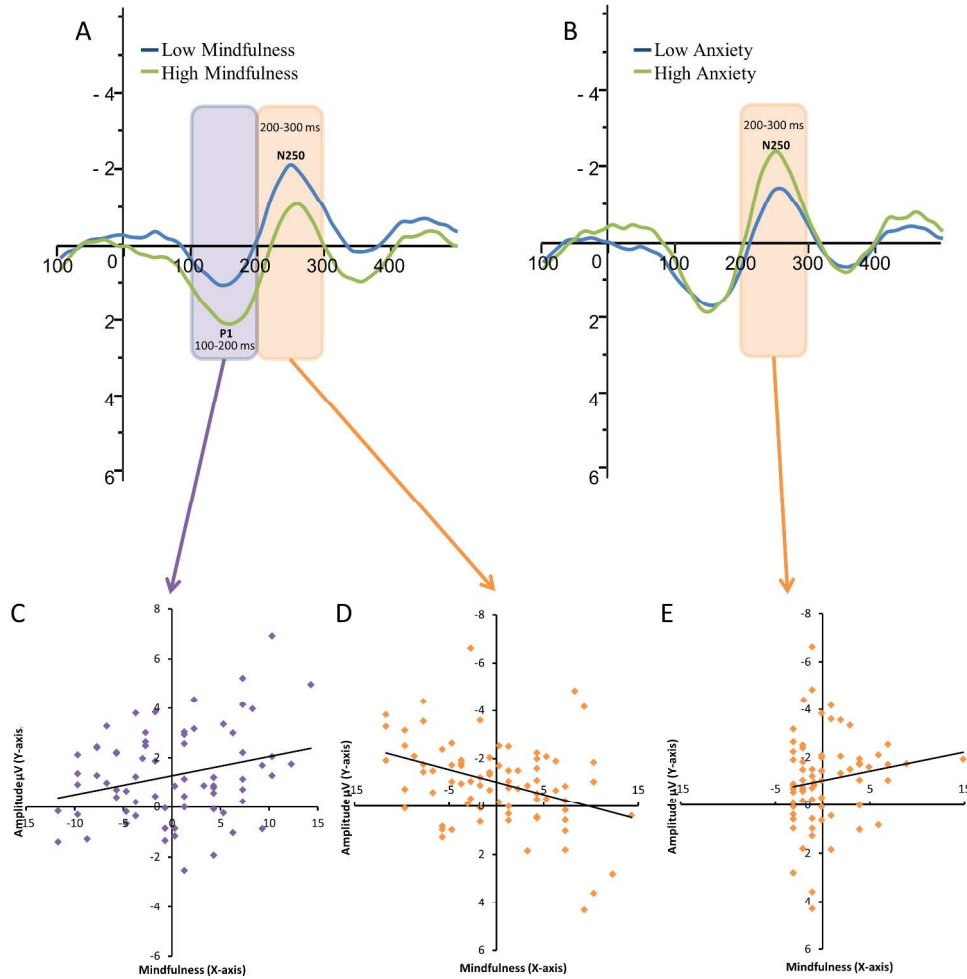


Figure 3. Group-average (N=79) central (Cz) ERP-response to the standard sound of infants of mothers with low (blue line) and high (green line) mindfulness (A) and anxiety (B). The scatterplots shows the correlation between maternal mindfulness and the amplitude of (C) the first positive-going wave 'P150' (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.

1000x1000mm (78 x 78 DPI)