Psychophysiology, 54 (2017), 279–288. Wiley Periodicals, Inc. Printed in the USA.

DOI: 10.1111/psyp.12782

Potential benefits of mindfulness during pregnancy on maternal autonomic nervous system function and infant development

MARIJKE A.K.A. BRAEKEN,[a,b,c] ALEXANDER JONES,[d] RENÉE A. OTTE,[a] IVAN NYKLÍČEK,[e] AND BEA R.H. VAN DEN BERGH[a,c,f]

[a]Faculty of Social and Behavioural Sciences, Tilburg University, Tilburg, The Netherlands
[b]REVAL Rehabilitation Research Center, Biomedical Research Institute, Faculty of Medicine and Life Sciences, Hasselt University, Hasselt, Belgium
[c]Department of Psychology, KU Leuven, Leuven, Belgium
[d]Institute of Cardiovascular Science, University College London, London, UK
[e]Center for Research in Psychology in Somatic Diseases (CoRPS), Department of Medical and Clinical Psychology, Tilburg University, Tilburg, The Netherlands
[f]Department of Welfare, Public Health and Family, Flemish Government, Brussels, Belgium

Abstract

Mindfulness is known to decrease psychological distress. Possible benefits in pregnancy have rarely been explored. Our aim was to examine the prospective association of mindfulness with autonomic nervous system function during pregnancy and with later infant social-emotional development. Pregnant women ($N = 156$) completed self-report mindfulness and emotional distress questionnaires, and had their autonomic function assessed in their first and third trimesters, including heart rate (HR), indices of heart rate variability (HRV), preejection period (PEP), and systolic (SBP) and diastolic blood pressure (DBP). The social-emotional development of 109 infants was assessed at 4 months of age. More mindful pregnant women had less prenatal and postnatal emotional distress ($p < .001$) and higher cardiac parasympathetic activity: root mean square of successive differences (RMSSD: $p = .03$) and high-frequency (HF) HRV ($p = .02$). Between the first and third trimesters, women's overall HR increased ($p < .001$), and HRV (RMSSD, HF HRV, and low-frequency (LF) HRV: $p < .001$) and PEP decreased ($p < .001$). In more mindful mothers, parasympathetic activity decreased less (RMSSD: $p = .01$; HF HRV: $p = .03$) and sympathetic activity (inversely related to PEP) increased less (PEP: $p = .02$) between trimesters. Their offspring displayed less negative social-emotional behavior ($p = .03$) compared to offspring of less mindful mothers. Mindfulness in pregnancy was associated with ANS changes likely to be adaptive and with better social-emotional offspring development. Interventions to increase mindfulness during pregnancy might improve maternal and offspring health, but randomized trials are needed to demonstrate this.

Descriptors: Mindfulness, Autonomic nervous system, Emotional distress, Pregnancy, Offspring's social emotional development

Pregnancy is associated with marked cardiovascular adaptations such as increased stroke volume (SV) and heart rate (HR; Abbas, Lester, & Connolly, 2005; Carlin & Alfirevic, 2008; Hill & Pickinpaugh, 2008; Silversides & Colman, 2007). The autonomic nervous system (ANS) plays a central role in these changes. It is known that ANS activity is shifted toward higher sympathetic and lower vagal modulation (e.g., reduced heart rate variability [HRV]) over the course of pregnancy (Kuo, Chen, Yang, Lo, & Tsai, 2000). The increased SV and HR generate higher cardiac output to offset the drop in total peripheral resistance that occurs early in pregnancy (Abbas et al., 2005). The net effect is a slight decrease in mean blood pressure with the decline in diastolic blood pressure (DBP) being larger than the systolic blood pressure (SBP) fall (Abbas et al., 2005). Since cardiac output keeps rising until the end of pregnancy and systemic vascular resistance steadily recovers (Clark et al., 1989; Easterling, Benedetti, Schmucker, & Millard, 1990; Thornburg, Jacobson, Giraud, & Morton, 2000), blood pressure measures return to prepregnancy levels by term (Christian, 2012; Hermida et al., 2000).

Failure of cardiovascular adaptation during pregnancy may lead to complications such as hypertension, preeclampsia or other cardiovascular diseases (Faber et al., 2004; Thayer, Yamamoto, & Brosschot, 2010; Voss et al., 2000; Walther et al., 2005, 2006). These disorders are associated with greater risks of preterm birth, chronic hypertension, maternal cardiovascular morbidity, and neonatal morbidity/mortality (Cuevas & Germain, 2011; Magnussen,

The authors are grateful to the parents and infants for their continued participation in our study. The Prenatal Early Life Stress (PELS) study is supported by the national funding agencies of the European Science Foundation participating in the Eurocores Program EuroSTRESS programme. The PELS study was initiated by BVdB and conducted in collaboration with Vivette Glover (Imperial College London), Stephan Claes (KU Leuven) and Alina Rodriguez (Uppsala University Sweden). BVdB is supported by the European Commission Seventh Framework Programme (FP7–HEALTH.2011.2.2.2-2 BRAINAGE, Grant agreement no: 279281).

Address correspondence to: Bea R. H. Van den Bergh, Ph.D., Prof., Faculty of Social and Behavioural Sciences, Tilburg University, Warandelaan 2, PO Box 90153, 5000 LE Tilburg, The Netherlands. E-mail: Bea.vdnBergh@uvt.nl

PSYCHOPHYSIOLOGY

Vatten, Smith, & Romundstad, 2009; Young, Levine, & Karumanchi, 2010; Zhang et al., 2007).

A number of mental disorders have also been linked to detrimental cardiovascular changes in pregnancy. For example, maternal emotional distress or depressive symptoms are associated with abnormal cardiovascular function, such as more reduction in parasympathetic activity (Shea et al., 2008) and a larger increase in blood pressure (hypertension and preeclampsia; Kurki, Hiilesmaa, Raitasalo, Mattila, & Ylikorkala, 2000; Qiu, Sanchez, Lam, Garcia, & Williams, 2007; Qiu, Williams, Calderon-Margalit, Cripe, & Sorensen, 2009). Furthermore, both hypertension disorders (Robinson et al., 2009, 2013; Whitehouse, Robinson, Newnham, & Pennell, 2012) and maternal emotional distress (Räikkönen, Seckl, Pesonen, Simons, & Van den Bergh, 2011; Van den Bergh, Mulder, Mennes, & Glover, 2005) during pregnancy are linked to adverse behavior and developmental outcomes in infancy, childhood, and adulthood.

Psychopharmaceuticals reduce maternal prenatal stress/depression and high levels of blood pressure effectively, but their use during pregnancy is often inappropriate because the potential risks to fetal development may outweigh the benefits for the mother and fetus (Duley, Henderson-Smart, & Meher, 2006; Ericson, Källén, & Wiholm, 1999; Kulin et al., 1998; Mulder, Ververs, de Heus, & Visser, 2011).

A better way to cope effectively with stress, anxiety, and depression during pregnancy may be to make enhanced use of mental resources such as mindfulness. Mindfulness is an adaptive mental state, often described as the attention to moment-to-moment experience with an accepting and nonjudgmental attitude (Baer, Smith, Hopkins, Krietemeyer, & Toney, 2006; Williams, 2008), or as a receptive attentiveness to present experience that can improve both mental and physical/physiological health (Hofmann, Sawyer, Witt, & Oh, 2010; Nyklíček, Mommersteeg, Van Beugen, Ramakers, & Boxtel, 2013), but studies concerning the physiological effects of mindfulness during pregnancy are lacking.

Therefore, the present study was designed to test the hypotheses that mindfulness would be associated with (a) better cardiovascular adaptation during pregnancy, (b) lower maternal emotional distress, and (c) better social-emotional development of the infant at 4 months.

Methods

Participants

This sample consisted of 156 pregnant women who were recruited at midwiferies and a hospital in Tilburg (The Netherlands) and surroundings. They had low obstetric risk as judged by the midwiferies and hospitals and made no use of medication or drugs. The longitudinal nature of the study and the fact that women participated on a voluntary basis may explain the biased sample with a higher education in comparison with the general population of pregnant women (see Table 1). We had access to medical records of 145 women for whom blood pressure data were obtained, and 109 mothers completed the questionnaire about the social-emotional development of the infant after birth. The Medical Ethics Committee of the St. Elisabeth hospital in Tilburg (The Netherlands) and the Dutch Central Committee on Research Involving Human Subjects approved the study, which was conducted in full compliance with the Helsinki Declaration. All women and their partner provided informed, written consent.

Procedure

The design of the study is prospective with the following assessment times:

1. First trimester (between 8 and 14 weeks of gestation): the first assessment of mothers' cardiovascular functioning and emotional distress.
2. Second trimester (between 15 and 22 weeks of gestation): the assessment of mothers' mindfulness (performed once only because it is considered to be a stable disposition that has substantial relationships with Big Five personality traits; Giluk, 2009). The wording of the mindfulness questionnaire avoids suggesting a specific time frame in order to assess mindfulness trait (Walach, Buchheld, Buttenmüller, Kleinknecht, & Schmidt, 2006).
3. Third trimester (between 31 and 37 weeks of gestation): the same assessments as in the first trimester.
4. Postnatal (mothers: 2–4 months after delivery): the third assessment of mothers' emotional distress.
5. Postnatal (infant: at 4 months of age): assessment of social-emotional development by the mother of the infant (see below).

Instruments

Mindfulness. The Freiburg Mindfulness Inventory–short form was used to assess mindfulness (Walach et al., 2006). It consists of 14 items covering central aspects of mindfulness, including attention to external and internal phenomena in the present moment (e.g., "I am open to the experience of the present moment") and acceptance (e.g., "I accept unpleasant experiences"). Items are scored on a scale from 1 to 4. The short form has an adequate internal consistency in the published original ($\alpha = .86$) and Dutch ($\alpha = .79$) versions (Klaassen, Nyklíček, Traa, & De Nijs, 2012), as well as in this study ($\alpha = .85$).

Emotional distress. The Edinburgh Depression Scale is a 10-item self-report measure designed to screen women for symptoms of depression and emotional distress during pregnancy and the postnatal period (Cox, Holden, & Sagovsky, 1987). Women indicated before 15 weeks of gestation, at 31–37 weeks of gestation, and 2–4 months after birth how they felt during the preceding 7 days. The reliability and validity of the original and Dutch versions are adequate (Nyklíček, Scherders, & Pop, 2004). In our sample, the internal consistency was adequate during the first ($\alpha = .82$) and third ($\alpha = .85$) trimester of pregnancy. Both questionnaires were completed at home.

ECG and ICG recording. A 25-min experimental session assessing cardiovascular function was conducted in each participant's home, in a quiet room. The session consisted of five testing phases, lasting 5 min each. We used a validated (Taelman et al., 2009; Vlemincx, Taelman, De Peuter, Van Diest, & Van den Bergh, 2011) stress protocol, where stress was induced in the second and fourth phase with complex mental arithmetic problems, while the other three phases consisted of relaxation with peaceful pictures and restful music. Mothers' electrocardiogram (ECG) and impedance cardiography (ICG) were recorded using seven Ag/AgCl electrodes and the Vrije Universiteit Ambulatory Monitoring system (VU-AMS; Goedhart, van der Sluis, Houtveen, Willemsen, & de Geus, 2007). The electrodes were arranged according to the VU-AMS configuration guidelines. This system provides continuous

Table 1. *Descriptive Statistics for Variables Related to Infants and Mothers*

	N	*M*	(*SD*)	Percent
Infants				
Gestation length (weeks)	106	39.57	(1.49)	
Birth weight (g)	109	3357.38	(679.63)	
Apgar score above 8				
At 5 min	108/109			99.08
At 10 min	109			100.00
Males	51/109			46.79
Age (weeks)	109	13.48	(5.30)	
Total score social-emotional development	109	13.94	(10.67)	
Self-regulation	109	5.55	(6.64)	
Communication	109	0.78	(2.06)	
Affect problems	109	2.94	(3.98)	
Interaction with people	109	0.78	(2.47)	
Adaptive functioning	109	3.76	(5.58)	
Mothers				
Mindfulness	156	39.91	(6.19)	
Emotional distress (postpartum)	113	4.76	(4.30)	
BMI before pregnancy (kg/m^2)	156	24.19	(4.11)	
Education (higher education)	156			67.74
Parity	156	0.61	(0.65)	

	1st trimester			3rd trimester			
	n	*M*	(*SD*)	*n*	*M*	(*SD*)	*p* value
HR, HRV and PEP[a]							
HR (bpm)	124	82.43	(8.89)	128	90.03	(9.44)	<.001
RMSSD (ln ms)	124	3.36	(0.51)	128	2.96	(0.54)	<.001
HF (ln ms^2)	124	5.96	(0.98)	128	5.20	(1.06)	<.001
LF (ln ms^2)	124	6.44	(0.70)	128	5.84	(0.74)	<.001
PEP (ms)	119	73.04	(20.38)	118	60.02	(21.27)	<.001
Systolic blood pressure (mmHg)	101	113.05	(10.46)	84	113.77	(10.29)	.75
Diastolic blood pressure (mmHg)	100	67.06	(7.42)	84	68.77	(9.54)	.12
Emotional distress (prenatal)	124	5.69	(4.20)	128	5.16	(4.15)	.84
Age	124	32.59	(4.28)	128	32.77	(4.35)	

Note. BMI = body mass index; HR = heart rate; HRV = HR variability; PEP = preejection period; RMSSD = root mean square of successive differences; HF = high-frequency; LF = low-frequency.
[a]Averaged across mental arithmetic task phases.

measurements of HR, indices of HRV, and preejection period (PEP, an index of cardiac sympathetic drive, see below).

Blood pressure. Maternal SBP and DBP data were retrieved from medical records. Similar to the ECG/ICG recordings, blood pressure was measured in the first and third pregnancy trimester within 3 weeks of the date of the ECG/ICG recording in all cases. For both pregnancy trimesters, there was only one blood pressure measurement. Three pregnant women with abnormally high blood pressure (> 140/90 mmHg) were excluded as outliers.

Birth outcomes. All pregnancies were dated using the first day of the last menstrual period, which was provided by the participants at recruitment. Each infant's day of birth was retrieved from medical records. Based on these data, gestation length at birth was calculated. Offspring birth weight was retrieved from medical records, as well as information on the infant's health immediately after birth. The infant's health was assessed immediately after birth using the Apgar score, which evaluates a newborn baby on five simple criteria (i.e., appearance, pulse, grimace, activity, respiration; Apgar, 1953).

Infant social-emotional development. When the children were between 4 and 5 months old, mothers filled out the Ages and Stages Questionnaire–Social-Emotional (Squires, Bricker, & Twombly, 2002) at home. It consists of 22 items and measures social-emotional problems, behavioral problems, and social competencies on 3-point Likert scales. It is a parent-reported screening instrument for infants, which consists of 5 subscales, namely self-regulation, communication, affect, interaction with people, and adaptive functioning. All infants had a total score below 45. In a clinical setting, scores higher than 45 would be required to meet criteria for further psychological evaluation. One outlier was removed (2.5 standard deviations from the mean; Upton & Cook, 2014).

Data Processing and Statistical Analyses

ECG and ICG data were processed using custom software written in MATLAB R2012b (Mathworks, Natick, MA) to obtain HR and indices of sympathetic (PEP) and parasympathetic (root mean square of successive differences [RMSSD] and high-frequency [HF] HRV) or both (low-frequency [LF] HRV) ANS activity, according to published standards (Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology, 1996). ECG beat detection was carried out with the Hilbert transform algorithm (Benitez, Gaydecki, Zaidi, & Fitzpatrick, 2001). Potentially erroneous beat detections were identified using a standard approach and screened by the researchers for validity (Berntson, Quigley, Jang, & Boysen, 1990). As HRV measures are right skewed, they were log-transformed to normality. PEP was calculated from the ICG as the interval between R-wave

Table 2. *Multilevel Regression Analyses Relating Mindfulness to HR, RMSSD, and HF HRV*

	HR			Ln RMSSD HRV			Ln HF HRV		
	Coefficient	*SE*	*p*	Coefficient	*SE*	*p*	Coefficient	*SE*	*p*
Mindfulness	-0.16	0.11	.16	0.004	0.005	.4	0.01	0.01	.31
Trimester (3rd vs. 1st)	7.84	2.13	<.001	-0.29	0.09	.001	-0.57	0.19	.003
Mindfulness × Trimester	-0.01	0.05	.84	0.006	0.002	<.01	0.01	0.005	.03
Emotional distress	0.01	0.08	.88	<0.001	.003	.90	0.01	0.01	.45
Higher education	0.04	1.44	.98	0.006	0.06	.92	0.04	0.13	.74
HR	–	–	–	-0.04	0.001	<.001	-0.07	0.003	<.001
Age	-0.29	0.16	.06	-0.03	0.01	<.001	-0.06	0.01	<.001
BMI	0.25	0.16	.13	0.001	0.01	.86	-0.01	0.01	.62
Constant	91.95	7.45	<.001	7.31	0.32	<.001	13.61	0.71	<.001

$N = 156$.

onset and the B point. This B point was identified using an extrapolation technique (Jones, 2006).

All analyses were conducted using Stata 12.1. Multilevel (i.e., pregnancy trimester and mental arithmetic task phase) regression analyses were conducted to examine the potential association between mindfulness and cardiovascular adaptation during pregnancy. Interaction effects between mindfulness and task phase were computed to test whether the association between mindfulness and HR, HRV, or PEP differed between stress versus rest. Interaction effects between mindfulness and the pregnancy trimester were also computed to test whether potential changes in HR, HRV, PEP, or BP over the course of pregnancy are related to the mother's level of mindfulness. The multilevel models were adjusted for emotional distress, level of education, age, and body mass index (BMI; Vallejo, Márquez, Borja-Aburto, Cárdenas, & Hermosillo, 2005). The models predicting HRV and PEP were also adjusted for HR.

In addition, a multilevel (i.e., time of measurement: first and third pregnancy trimester, and 2–4 months postpartum) regression analysis, adjusted for the common potential confounders of level of education, age, and BMI, was used to investigate how mindfulness is related to maternal emotional distress.

Finally, the associations between maternal mindfulness and the continuous variables of social-emotional development were tested for significance by generating bootstrapped regression analyses with 95% confidence intervals (5,000 iterations) as no normal distribution of the residuals could be achieved by transforming the data. In these analyses, maternal age, education, and emotional distress, and infants' sex, birth weight, and gestation length at birth were controlled.

Results

Characteristics of mothers and children are shown in Table 1. Mothers who provided data on the social-emotional development of the offspring ($N = 109$) did not differ from mothers who did not provide these data ($N = 47$) regarding age, education level, emotional distress, or mindfulness ($p > .10$).

Mindfulness and Cardiovascular Adaptation During Pregnancy

Adjusted for age, education level, emotional distress, and BMI, mindfulness was significantly positively associated with RMSSD HRV ($b = 0.01$, $SE = 0.01$, $p = .03$) and HF HRV ($b = 0.03$, $SE = 0.01$, $p = .02$). There were also marginally significant relationships between mindfulness and LF HRV ($b = 0.02$, $SE = 0.01$, $p = .07$), PEP ($b = 0.46$, $SE = 0.25$, $p = .06$), and HR ($b = -0.20$, $SE = 0.11$, $p = .07$). These associations between mindfulness and HRV and PEP were not significant after adjustment for HR ($p > .05$). No association was found between mindfulness and baseline SBP or DBP ($p > .05$).

HR increased across trimesters ($b = 7.42$, $SE = 0.34$, $p < .001$), while RMSSD ($b = -0.07$, $SE = 0.02$, $p < .001$), HF HRV ($b = -0.16$, $SE = 0.04$, $p < .001$), LF HRV ($b = -0.23$, $SE = 0.04$, $p < .001$), and PEP ($b = -11.71$, $SE = 1.04$, $p < .001$) all decreased. DBP increased marginally across trimesters ($b = 1.88$, $SE = 1.02$, $p = .06$).

The results depicted in Table 2 and 3 show a significant interaction between mindfulness and the trimester of pregnancy on RMSSD HRV ($p = .01$), HF HRV ($p = .03$), and PEP ($p = .02$), after adjustment for HR, emotional distress, age, BMI, and level of education. This indicates that the more mindful pregnant women were, the less RMSSD, HF HRV, and PEP declined during pregnancy (Figure 1a,b,c). The decrease in LF HRV and increases of HR, DBP, and SBP over the course of pregnancy were not significantly different for different levels of mindfulness ($p > .05$; see Table 2 and 4, and Figure 1d,e,f,g).

No evidence was found for an interaction between mindfulness and the different phases of the experimental session for any ANS measure ($p > .05$).

Table 3. *Multilevel Regression Analyses Relating Mindfulness to LF HRV and PEP*

	Ln LF HRV			PEP		
	Coefficient	*SE*	*p*	Coefficient	*SE*	*p*
Mindfulness	0.01	0.01	.45	0.23	0.26	.37
Trimester (3rd vs. 1st)	-0.39	0.24	.09	-24.66	5.71	<.001
Mindfulness × Trimester	0.004	0.01	.49	0.33	0.14	.02
Emotional distress	0.01	0.01	.13	-0.11	0.20	.59
Higher education	0.03	0.10	.77	1.42	3.18	.66
HR	-0.04	0.003	<.001	-0.23	0.07	.001
Age	-0.04	0.01	<.001	-0.17	0.35	.62
BMI	-0.02	0.01	.09	-1.13	0.36	.002
Constant	11.24	0.60	<.001	116.11	17.82	<.001

Note. LF HRV: $N = 156$; PEP: $N = 150$.

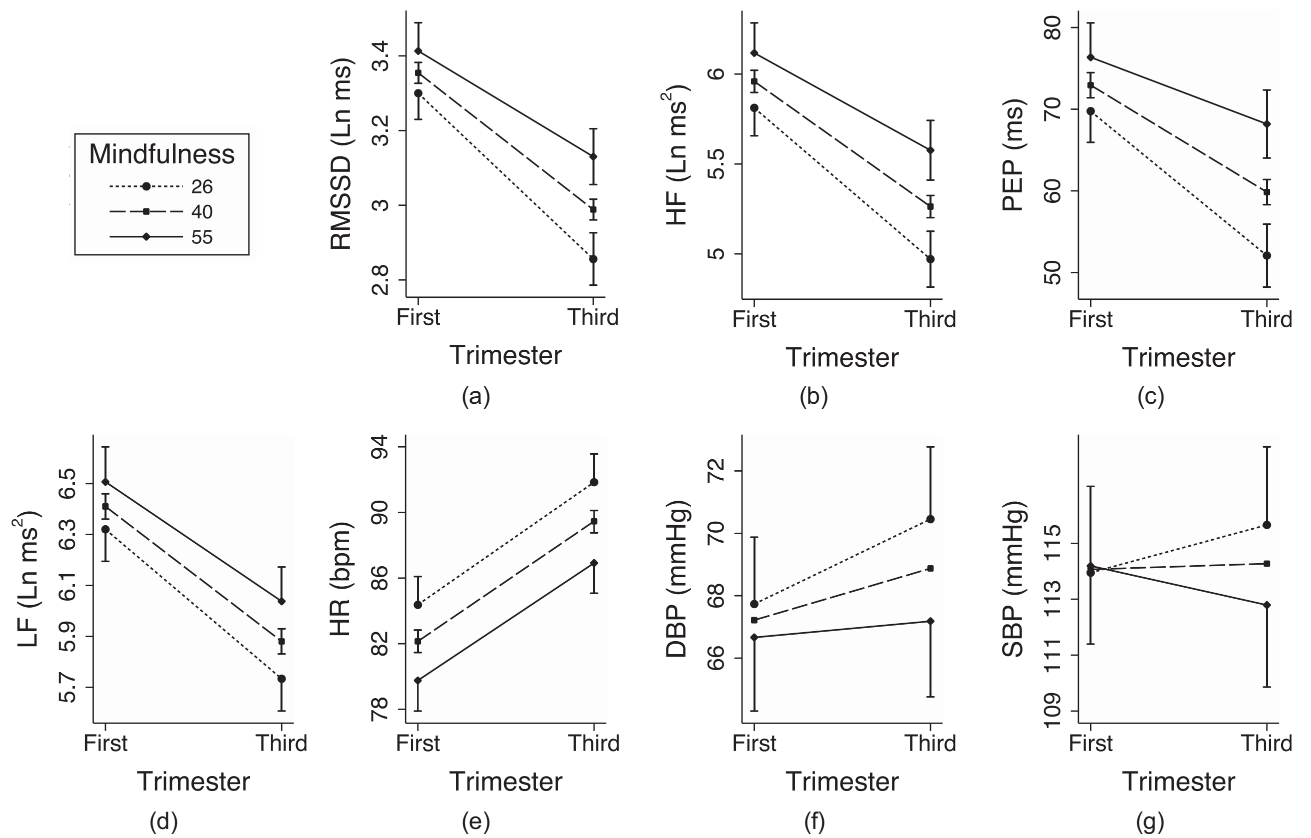

Figure 1. The association between mindfulness and cardiovascular measures over the course of pregnancy, namely, RMSSD HRV (a), HF HRV (b), PEP (c), LF HRV (d), HR (e), DBP (f), and SBP (g). Plots are based on estimated marginal means from multilevel regression analyses showing interactions between mindfulness and pregnancy trimester. Minimum, average, and maximum scores for mindfulness in our sample are, respectively, 26, 40, and 55.

Mindfulness and Emotional Distress

Mindfulness was negatively associated with emotional distress, after adjustment for education level, age, and BMI (b = -0.06, SE = 0.01, $p < .001$).

There was no significant effect of time of measurement ($p > .05$) or interaction between mindfulness and time of measurement ($p > .05$). This indicates that women who are more mindful tend to experience less emotional distress regardless of when emotional distress was measured (i.e., in first trimester, in third trimester, or 2–4 months postpartum).

Mindfulness and Infant Social-Emotional Development

While the subscales self-regulation, affect, communication, and interaction with people of social-emotional development as scored by the mother 4 months after birth were not significantly related with mindfulness, bootstrapped regression analyses showed evidence for an association between the subscale adaptive functioning and mindfulness (observed coefficient [OC] = -0.18; 95% CI = [-0.29, -0.06], p = .003), indicating that infants of mothers who are more mindful tend to have better adaptive functioning. The association remained significant after controlling for sex, birth weight,

Table 4. *Multilevel Regression Analyses Relating Mindfulness to SBP and DBP*

	SBP			DBP		
	Coefficient	*SE*	*p*	Coefficient	*SE*	*p*
Mindfulness	0.15	0.18	.41	0.03	0.14	.83
Trimester (3rd vs. 1st)	6.21	7.40	.40	5.66	6.45	.38
Mindfulness × 3rd Trimester	-0.14	0.18	.44	-0.09	0.16	.55
Emotional distress	0.05	0.20	.79	0.27	0.16	.09
Higher education	0.82	1.99	.68	0.56	1.54	.72
Age	-0.05	0.22	.81	0.15	0.17	.38
BMI	0.75	0.26	.004	0.43	0.21	.04
Constant	91.01	11.79	<.001	48.79	9.26	<.001

N = 124.

gestation length, infant's age, mother's education level, and postnatal emotional distress (OC = -0.19; 95% CI = [-0.37, -0.02], $p = .03$). None of the covariables showed significant associations with adaptive functioning (95% CI includes zero, $p > .05$).

Discussion

This study investigated whether mindfulness is associated with ANS function during pregnancy and assessed the associations of mindfulness with concurrent and future maternal mental health and offspring social-emotional development. More mindful pregnant women had better cardiovascular adaptation during pregnancy (i.e., less decrease in cardiac parasympathetic activity) and less emotional distress, both during and after pregnancy, and higher cardiac parasympathetic activity (reflected by RMSSD and HF HRV). Furthermore, their offspring showed less negative social-emotional behavior compared to offspring of less mindful mothers.

Over the course of pregnancy, all mothers experienced significant increases of HR and marginally significant increases of DBP. PEP, RMSSD, HF, and LF HRV fell between the first and third pregnancy trimester. These findings are in line with previous research (Abbas et al., 2005; Christian, 2012; Hermida et al., 2000; Kuo et al., 2000; Silversides & Colman, 2007). Cardiac parasympathetic activity (RMSSD and HF) did not decrease as much and sympathetic activity (inversely related to PEP) did not increase as much in mothers who were more mindful. These changes in RMSSD, HF, and PEP were still related to mindfulness after adjustment for possible confounders. Importantly, emotional distress was not predictive of autonomic nervous system function. Hence, it suggests that the effect of mindfulness is not mediated by emotional distress or that our measure of emotional distress did not capture the part of distress that may be relevant in this context. Possibly, some other mechanism is at stake. For instance, in brain research, it has been found that mindfulness is associated with activity in prefrontal regions and regions of the anterior cingulate cortex, important for both attention processes and autonomic nervous system functioning (Hölzel et al., 2007, 2013).

Decreased parasympathetic activity and increased sympathetic activity are characteristics of a highly activated (stressed) cardiovascular system. Therefore, it can be argued that mothers who are more mindful maintained a more relaxed physiological state through pregnancy. The benefits of doing so for the offspring are unknown, but we found that offspring of more mindful mothers showed better adaptive functioning in infancy, suggesting a possible benefit. If replicated, further studies will be required to determine whether this benefit arises from improved fetomaternal health in pregnancy, enhancing fetal neurodevelopment, or from postnatal benefits of being raised by more mindful mothers.

Despite published calls for studies to examine physiological concomitants of stress when examining the effectiveness of body-mind interventions during pregnancy (Beddoe & Lee, 2008), we could only find two published studies that have evaluated the effects of a relaxation intervention on HRV and BP during pregnancy (Little et al., 1984; Satyapriya, Nagendra, Nagarathna, & Padmalatha, 2009). Both studies show that HF HRV tends to increase during relaxation exercises (Little et al., 1984; Satyapriya et al., 2009) and Satyapriya et al. (2009) suggest this is even enhanced during later stages of pregnancy. We could not find any study about the relationship between mothers' mindfulness operationalized using a trait questionnaire and HRV and BP during pregnancy. In the present study, mindfulness was related to RMSSD and HF HRV, but no significant associations were found with HR, LF HRV, or PEP. This suggests that mindfulness is predominantly related to parasympathetic activity. The association between mindfulness and parasympathetic activity did not differ between resting versus stress conditions, suggesting that mindfulness may be related to increased parasympathetic activity in general rather than to stress reactivity. However, we used a mild stressor in consideration of the pregnant status of our participants. Therefore, we cannot exclude the possibility that a stronger stressor such as the Trier Social Stress Test might have provoked different stress responses in more mindful women compared to women with lower levels of mindfulness (Holt, 2012; Kemeny et al., 2012; Nyklíček et al., 2013).

Our findings are in line with studies of nonpregnant women, which found that components of mindfulness-based stress reduction interventions tend to increase the parasympathetic ANS mediated component (HF) of HRV (Ditto, Eclache, & Goldman, 2006; Leonaite & Vainoras, 2010; Paul-Labrador et al., 2006; Sarang & Telles, 2006; Takahashi et al., 2005; Tang et al., 2009; Wu & Lo, 2008), although this was not found in all studies (Nyklíček et al., 2013).

In contrast to its positive association with parasympathetic activity, mindfulness was not significantly associated with BP during pregnancy in our study, although other studies have found that systematic relaxation training was associated with lower SBP and DBP in pregnant women compared to a control group (Little et al., 1984) and that meditation can reduce blood pressure (SBP and DBP) in nonpregnant participants (Anderson, Liu, & Kryscio, 2008; Chiesa & Serretti, 2010; Goldstein, Josephson, Xie, & Hughes, 2012; Nyklíček et al., 2013). More mindful mothers did demonstrate less increase in DBP over the course of their pregnancies in our study, but this finding was only marginally significant. In our study, BP was not measured at the same time as our other measures, relying upon clinical measurements recorded in the obstetric record according to standard clinical practice. This may have resulted in increased measurement error in this variable that could have weakened associations with mindfulness.

Previous studies have suggested that reduced HRV during pregnancy is an indicator of increased risk of developing gestational hypertension or preeclampsia (Macdonald-Wallis et al., 2012), which may be detrimental to the offspring with effects such as low birth weight (Ananth, Peedicayil, & Savitz, 1995). Therefore, the potential of mindfulness as a means to protect against declining HRV during pregnancy should be examined as a possible risk-reduction intervention. However, the effectiveness of this approach cannot be assessed without randomized controlled trials of interventions designed to increase mindfulness during pregnancy.

Previously, several authors have shown that mindfulness in nonpregnant women predicts self-regulated behavior and positive emotional states and that it is related to lower mood disturbance and less distress (Baer et al., 2006, 2008; Brown & Ryan, 2003). To our knowledge, our study is the first to demonstrate a similar relationship in pregnancy, finding negative associations between mindfulness and emotional distress. This is in line with earlier findings that techniques enhancing mindfulness during pregnancy reduce anxiety and perceived stress for up to 2 months after the intervention (Bastani, Hidarnia, Kazemnejad, Vafaei, & Kashanian, 2005; Beddoe, Paul Yang, Kennedy, Weiss, & Lee, 2009; Vieten & Astin, 2008). Remarkably, the relationship between mindfulness and emotional distress was significant both during pregnancy and postpartum. Previous research demonstrated that mindfulness-based cognitive therapy during pregnancy might cause a decline in measures of depression and that this improvement can continue into the postnatal period (Dunn, Hanieh, Roberts, & Powrie, 2012). Our findings offer further support for this notion, suggesting that mindfulness might indeed reduce the risk of postpartum emotional distress, independently of prenatal emotional distress. We would recommend that future studies include a postnatal mindfulness measurement to better understand the relationship between (prenatal) mindfulness and postnatal emotional distress.

Previously, it was shown that high maternal mindfulness during pregnancy is associated with fewer infant social-emotional development problems (van den Heuvel, Johannes, Henrichs, & Van den Bergh, 2015) and with alterations in infant ERPs elicited during a passive auditory oddball paradigm (van den Heuvel, Donkers, Winkler, Otte, & Van den Bergh, 2014). In the present study, mindfulness was also found to be associated with the social-emotional development of the offspring. Specifically, more mindful mothers had offspring with more adaptive functioning. The subscale measuring this construct assesses the infant's success or ability to cope with physiological needs (e.g., sleeping, eating, elimination, safety; Squires et al., 2002). These kinds of regulatory problems are known to predict adverse social and adaptive behavior and lower cognition in preschool-aged children (Schmid, Schreier, Meyer, & Wolke, 2010; Wolke, Schmid, Schreier, & Meyer, 2009). Other social-emotional development measures in this study were not associated with mindfulness. We are not certain (a) whether this finding truly reflects a very specific altered social-emotional development in adaptive functioning, (b) whether other subscales of the questionnaire were not sufficiently sensitive in our young age group, or (c) whether it will be a robust finding of future studies. Although the questionnaire was designed for 3- to 8-month-old infants, many of the measures are likely to be more suitable to children at the upper end of this age range. Our participants were 4 months old, and their data on communication and interaction with others, for example, may not have been clearly observable to mothers and may have had limited power to reveal the influence of maternal mindfulness. The possibility of a chance finding, although it cannot be ruled out, seems unlikely, in light of the fact that this specific effect was highly significant, and would remain significant if a correction for multiple testing were applied.

Study Limitations

Infant development was rated by the mother, who also rated her own mindfulness. This could be regarded as a study limitation. However, controlling for mother's mood (emotional distress) in the analyses should have limited the effects of any potential reporting bias. In future studies, it might be better to corroborate maternal reports by other observers. As mentioned previously, blood pressure was not measured at the same time as our other measures, but relied upon measurements taken routinely by clinical staff, which probably increased measurement error for blood pressure variables. Therefore, the blood pressure measurements could not be combined with our impedance recordings to calculate peripheral resistance, which could have provided possible further explanations of the relationship between mindfulness and the ANS function in pregnancy. Furthermore, our study did not include any respiration measures, making it difficult to exclude the possibility that the relationships between mindfulness and ANS are an artifact of individual differences in respiration style.

Mindfulness was assessed as a stable trait to examine more tonic effects on the autonomic nervous system. Although such conceptualization has been shown to be reliable and valid (Brown & Ryan, 2003), mindfulness has also been claimed to be trainable as a skill (Baer et al., 2006; Bishop, 2002; Kiken, Garland, Bluth, Palsson, & Gaylord, 2015), which indeed has been shown in various intervention studies (e.g., see a review by Gu, Strauss, Bond, & Cavanagh, 2015). Future studies may examine whether a mindfulness intervention during pregnancy can positively affect mindfulness, ANS function, or infant development.

There was a modest attrition in participant numbers for the postnatal observations of infant development and mother's emotional distress. However, women who took part in all aspects of the study did not differ from those not completing these later assessments for important measures such as age, education level, emotional distress, or mindfulness.

Strengths and Conclusion

Our study has a number of strengths. Compared to previous studies, we examined a relatively large population of pregnant women and included both psychophysiological and psychological data from the first pregnancy trimester onward. Most prior studies have focused on the second or third trimester only. There are numerous studies that have focused on the effects of negative emotions (anxiety and depression) during pregnancy. However, very few studies have sought to establish underlying mechanism and resources able to counteract the effects of these negative emotional states. Our study provides support for the possibility that enhancing psychological characteristics such as mindfulness could be beneficial. Based on our findings, we would recommend that trials of positive psychological interventions, such as mindfulness training, should be carried out in pregnant women. These interventions might offer a safe alternative to pharmaceuticals for combating the detrimental effects of pregnancy-related stress, anxiety, and depression on the health of mothers and their offspring.

References

Abbas, A. E., Lester, S. J., & Connolly, H. (2005). Pregnancy and the cardiovascular system. *International Journal of Cardiology*, *98*(2), 179–189. doi: 10.1016/j.ijcard.2003.10.028

Ananth, C. V., Peedicayil, A., & Savitz, D. A. (1995). Effect of hypertensive diseases in pregnancy on birthweight, gestational duration, and small-for-gestational-age births. *Epidemiology*, *6*(4), 391–395. doi: 10.1097/00001648-199507000-00011

Anderson, J. W., Liu, C., & Kryscio, R. J. (2008). Blood pressure response to transcendental meditation: A meta-analysis. *American Journal of Hypertension*, *21*(3), 310–316. doi: 10.1038/ajh.2007.65

Apgar, V. (1953). A proposal for a new method of evaluation of the newborn infant. *Anesthesia & Analgesia*, *32*(4), 260–267. doi: 10.1213/00000539-195301000-00041

Baer, R. A., Smith, G. T., Hopkins, J., Krietemeyer, J., & Toney, L. (2006). Using self-report assessment methods to explore facets of mindfulness. *Assessment*, *13*(1), 27–45. doi: 10.1177/1073191105283504

Baer, R. A., Smith, G. T., Lykins, E., Button, D., Krietemeyer, J., Sauer, S., . . . Williams, J. M. G. (2008). Construct validity of the five Facet Mindfulness Questionnaire in meditating and nonmeditating samples. *Assessment*, *15*(3), 329–342. doi: 10.1177/1073191107313003

Bastani, F., Hidarnia, A., Kazemnejad, A., Vafaei, M., & Kashanian, M. (2005). A randomized controlled trial of the effects of applied relaxation training on reducing anxiety and perceived stress in pregnant women. *Journal of Midwifery & Women's Health*, *50*(4), e36–e40. doi: 10.1016/j.jmwh.2004.11.008

Beddoe, A. E., & Lee, K. A. (2008). Mind-body interventions during pregnancy. *Journal of Obstetric, Gynecologic, and Neonatal Nursing*, *37*(2), 165–175. doi: 10.1111/j.1552-6909.2008.00218.x

Beddoe, A. E., Paul Yang, C. P., Kennedy, H. P., Weiss, S. J., & Lee, K. A. (2009). The effects of mindfulness-based yoga during pregnancy on maternal psychological and physical distress. *Journal of Obstetric, Gynecologic, & Neonatal Nursing*, *38*(3), 310–319. doi: 10.1111/j.1552-6909.2009.01023.x

Benitez, D., Gaydecki, P. A., Zaidi, A., & Fitzpatrick, A. P. (2001). The use of the Hilbert transform in ECG signal analysis. *Computers in Biology and Medicine*, *31*, 399–406. doi: 10.1016/s0010-4825(01)00009-9

Berntson, G. G., Quigley, K. S., Jang, J. F., & Boysen, S. T. (1990). An approach to artifact identification: Application to heart period data. *Psychophysiology*, *27*(5), 586–598. doi: 10.1111/j.1469-8986.1990.tb01982.x

Bishop, S. R. (2002). What do we really know about mindfulness-based stress reduction? *Psychosomatic Medicine*, *64*(1), 71–83. doi: 10.1097/00006842-200201000-00010

Brown, K. W., & Ryan, R. M. (2003). The benefits of being present: Mindfulness and its role in psychological well-being. *Journal of Personality and Social Psychology*, *84*(4), 822–848. doi: 10.1037/0022-3514.84.4.822

Carlin, A., & Alfirevic, Z. (2008). Physiological changes of pregnancy and monitoring. *Best Practice & Research Clinical Obstetrics & Gynaecology*, *22*(5), 801–823. doi: 10.1016/j.bpobgyn.2008.06.005

Chiesa, A., & Serretti, A. (2010). A systematic review of neurobiological and clinical features of mindfulness meditations. *Psychological Medicine*, *40*(8), 1239–1252. doi: 10.1017/S0033291709991747

Christian, L. M. (2012). Physiological reactivity to psychological stress in human pregnancy: Current knowledge and future directions. *Progress in Neurobiology*, *99*(2), 106–116. doi: 10.1016/j.pneurobio.2012.07.003

Clark, S. L., Cotton, D. B., Lee, W., Bishop, C., Hill, T., Southwick, J., … Phelan, J. (1989). Central hemodynamic assessment of normal term pregnancy. *American Journal of Obstetrics and Gynecology*, *161*(6 Pt 1), 1439–1442. doi: 10.1016/0002-9378(89)90900-9

Cox, J. L., Holden, J. M., & Sagovsky, R. (1987). Detection of postnatal depression. Development of the 10-item Edinburgh Postnatal Depression Scale. *British Journal of Psychiatry*, *150*, 782–786. doi: 10.1192/bjp.150.6.782

Cuevas, A. M., & Germain, A. M. (2011). A failed pregnancy stress test: A new and under-recognized cardiovascular risk factor. *Current Atherosclerosis Reports*, *13*(4), 285–286. doi: 10.1007/s11883-011-0182-3

Ditto, B., Eclache, M., & Goldman, N. (2006). Short-term autonomic and cardiovascular effects of mindfulness body scan meditation. *Annals of Behavioral Medicine*, *32*, 227–234. doi: 10.1207/s15324796abm3203_9

Duley, L., Henderson-Smart, D. J., & Meher, S. (2006). Drugs for treatment of very high blood pressure during pregnancy. *Cochrane Database of Systematic Reviews*, *3*, CD001449. doi: 10.1002/14651858.CD001449.pub2

Dunn, C., Hanieh, E., Roberts, R., & Powrie, R. (2012). Mindful pregnancy and childbirth: Effects of a mindfulness-based intervention on women's psychological distress and well-being in the perinatal period. *Archives of Women's Mental Health*, *15*(2), 139–143. doi: 10.1007/s00737-012-0264-4

Easterling, T. R., Benedetti, T. J., Schmucker, B. C., & Millard, S. P. (1990). Maternal hemodynamics in normal and preeclamptic pregnancies: A longitudinal study. *Obstetrics and Gynecology*, *76*(6), 1061–1069.

Ericson, A., Källén, B., & Wiholm, B. E. (1999). Delivery outcome after the use of antidepressants in early pregnancy. *European Journal of Clinical Pharmacology*, *55*(7), 503–508. doi: 10.1007/s002280050664

Faber, R., Baumert, M., Stepan, H., Wessel, N., Voss, A., & Walther, T. (2004). Baroreflex sensitivity, heart rate, and blood pressure variability in hypertensive pregnancy disorders. *Journal of Human Hypertension*, *18*(10), 707–712. doi: 10.1038/sj.jhh.1001730

Giluk, T. L. (2009). Mindfulness, Big Five personality, and affect: A meta-analysis. *Personality and Individual Differences*, *47*(8), 805–811. doi: 10.1016/j.paid.2009.06.026

Goedhart, A. D., van der Sluis, S., Houtveen, J. H., Willemsen, G., & de Geus, E. J. (2007). Comparison of time and frequency domain measures of RSA in ambulatory recordings. *Psychophysiology*, *44*(2), 203–215. doi: 10.1111/j.1469-8986.2006.00490.x

Goldstein, C. M., Josephson, R., Xie, S., & Hughes, J. W. (2012). Current perspectives on the use of meditation to reduce blood pressure. *International Journal of Hypertension*, *2012*, 578397. doi: 10.1155/2012/578397

Gu, J., Strauss, C., Bond, R., & Cavanagh, K. (2015). How do mindfulness-based cognitive therapy and mindfulness-based stress reduction improve mental health and wellbeing? A systematic review and meta-analysis of mediation studies. *Clinical Psychology Review*, *37*, 1–12. doi: 10.1016/j.cpr.2015.01.006

Hermida, R. C., Ayala, D. E., Mojón, A., Fernández, J. R., Alonso, I., Silva, I., … Iglesias, M. (2000). Blood pressure patterns in normal pregnancy, gestational hypertension, and preeclampsia. *Hypertension*, *36*(2), 149–158. doi: 10.1161/01.hyp.36.2.149

Hill, C. C., & Pickinpaugh, J. (2008). Physiologic changes in pregnancy. *Surgical Clinics of North America*, *88*(2), 391–401, vii. doi: 10.1016/j.suc.2007.12.005

Hofmann, S. G., Sawyer, A. T., Witt, A. A., & Oh, D. (2010). The effect of mindfulness-based therapy on anxiety and depression: A meta-analytic review. *Journal of Consulting and Clinical Psychology*, *78*(2), 169. doi: 10.1037/a0018555

Holt, M. P. (2012). *Dispositional mindfulness and cardiovascular functioning under stress: Predictions of social evaluative stress reactivity and recovery* (Unpublished doctoral dissertation, Virginia Commonwealth University). Retrieved from http://scholarscompass.vcu.edu/cgi/viewcontent.cgi?article=3763&context=etd

Hölzel, B. K., Hoge, E. A., Greve, D. N., Gard, T., Creswell, J. D., Brown, K. W., … Lazar, S. W. (2013). Neural mechanisms of symptom improvements in generalized anxiety disorder following mindfulness training. *NeuroImage*, *2*, 448–458. doi: 10.1016/j.nicl.2013.03.011

Hölzel, B. K., Ott, U., Hempel, H., Hackl, A., Wolf, K., Stark, R., & Vaitl, D. (2007). Differential engagement of anterior cingulate and adjacent medial frontal cortex in adept meditators and non-meditators. *Neuroscience Letters*, *421*(1), 16–21. doi: 10.1016/j.neulet.2007.04.074

Jones, A. (2006). *Prenatal development and later neuroendocrine control of cardiovascular function: Testing the stress hypothesis* (Unpublished doctoral dissertation, University of Southampton).

Kemeny, M. E., Foltz, C., Cavanagh, J. F., Cullen, M., Giese-Davis, J., Jennings, P., … Ekman, P. (2012). Contemplative/emotion training reduces negative emotional behavior and promotes prosocial responses. *Emotion*, *12*, 338–350. doi: 10.1037/a0026118

Kiken, L. G., Garland, E. L., Bluth, K., Palsson, O. S., & Gaylord, S. A. (2015). From a state to a trait: Trajectories of state mindfulness in meditation during intervention predict changes in trait mindfulness. *Personality and Individual Differences*, *81*, 41–46. doi: 10.1016/j.paid.2014.12.044

Klaassen, K., Nyklíček, I., Traa, S., & De Nijs, R. (2012). Distressed personality is associated with lower psychological well-being and life satisfaction, but not disability or disease activity in rheumatoid arthritis patients. *Clinical Rheumatology*, *31*, 661–667. doi: 10.1007/s10067-011-1905-0

Kulin, N. A., Pastuszak, A., Sage, S. R., Schick-Boschetto, B., Spivey, G., Feldkamp, M., … Cook, L. (1998). Pregnancy outcome following maternal use of the new selective serotonin reuptake inhibitors. *JAMA*, *279*(8), 609–610. doi: 10.1001/jama.279.8.609

Kuo, C. D., Chen, G. Y., Yang, M. J., Lo, H. M., & Tsai, Y. S. (2000). Biphasic changes in autonomic nervous activity during pregnancy. *British Journal of Anaesthesia*, *84*(3), 323–329.

Kurki, T., Hiilesmaa, V., Raitasalo, R., Mattila, H., & Ylikorkala, O. (2000). Depression and anxiety in early pregnancy and risk for preeclampsia. *Obstetrics & Gynecology*, *95*(4), 487–490. doi: 10.1097/00006250-200004000-00003

Leonaite, A., & Vainoras, A. (2010). Heart rate variability during two relaxation techniques in post-MI men. *Electronics and Electrical Engineering*, *5*(101), 107–110. doi: 10.1016/j.jelectrocard.2010.12.122

Little, B. C., Hayworth, J., Benson, P., Hall, F., Beard, R. W., Dewhurst, J., & Priest, R. G. (1984). Treatment of hypertension in pregnancy by relaxation and biofeedback. *Lancet*, *1*(8382), 865–867. doi: 10.1016/s0140-6736(84)91337-0

Macdonald-Wallis, C., Lawlor, D. A., Fraser, A., May, M., Nelson, S. M., & Tilling, K. (2012). Blood pressure change in normotensive, gestational hypertensive, preeclamptic, and essential hypertensive pregnancies. *Hypertension*, *59*(6), 1241–1248. doi: 10.1161/HYPERTENSIONAHA.111.187039

Magnussen, E. B., Vatten, L. J., Smith, G. D., & Romundstad, P. R. (2009). Hypertensive disorders in pregnancy and subsequently measured cardiovascular risk factors. *Obstetrics & Gynecology*, *114*(5), 961–970. doi: 10.1097/AOG.0b013e3181bb0dfc

Mulder, E. J. H., Ververs, F. F. T., de Heus, R., & Visser, G. H. A. (2011). Selective serotonin reuptake inhibitors affect neurobehavioral development in the human fetus. *Neuropharmacology*, *36*(10), 1961–1971. doi: 10.1038/npp.2011.67

Nyklíček, I., Mommersteeg, P. M. C., Van Beugen, S., Ramakers, C., & Boxtel, G. J. V. (2013). Mindfulness-based stress reduction and physiological activity during acute stress: A randomized controlled trial. *Health Psychology*, *32*(10), 1110–1113. doi: 10.1037/a0032200

Nyklíček, I., Scherders, M. J., & Pop, V. J. (2004). Multiple assessments of depressive symptoms as an index of depression in population-based samples. *Psychiatry Research*, *128*, 111–116. doi: 10.1016/j.psychres.2004.05.017

Paul-Labrador, M., Polk, D., Dwyer, J. H., Velasquez, I., Nidich, S., Rainforth, M., … Merz, N. B. (2006). Effects of a randomized controlled trial of transcendental meditation on components of the metabolic syndrome in subjects with coronary heart disease. *Archives of Internal Medicine*, *166*(11), 1218–1224. doi: 10.1001/archinte.166.11.1218

Qiu, C., Sanchez, S. E., Lam, N., Garcia, P., & Williams, M. A. (2007). Associations of depression and depressive symptoms with preeclampsia: Results from a Peruvian case-control study. *BMC Women's Health*, *7*, 15. doi: 10.1186/1472-6874-7-15

Qiu, C., Williams, M. A., Calderon-Margalit, R., Cripe, S. M., & Sorensen, T. K. (2009). Preeclampsia risk in relation to maternal mood and anxiety disorders diagnosed before or during early pregnancy. *American Journal of Hypertension*, *22*(4), 397–402. doi: 10.1038/ajh.2008.366

Robinson, M., Mattes, E., Oddy, W. H., de Klerk, N. H., Li, J., McLean, N. J., … Newnham, J. P. (2009). Hypertensive diseases of pregnancy and the development of behavioral problems in childhood and adolescence: The Western Australian Pregnancy Cohort Study. *Journal of Pediatrics*, *154*(2), 218–224. doi: 10.1016/j.jpeds.2008.07.061

Robinson, M., Oddy, W. H., Whitehouse, A. J., Pennell, C. E., Kendall, G. E., McLean, N. J., … Newnham, J. P. (2013). Hypertensive diseases of pregnancy predict parent-reported difficult temperament in infancy. *Journal of Developmental & Behavioral Pediatrics*, *34*(3), 174–180. doi: 10.1097/DBP.0b013e31827d5761

Räikkönen, K., Seckl, J. R., Pesonen, A. K., Simons, A., & Van den Bergh, B. R. (2011). Stress, glucocorticoids and liquorice in human pregnancy: Programmers of the offspring brain. *Stress*, *14*(6), 590–603. doi: 10.3109/10253890.2011.602147

Sarang, P., & Telles, S. (2006). Effects of two yoga based relaxation techniques on heart rate variability (HRV). *International Journal of Stress Managment*, *13*(4), 460–475. doi: 10.1037/1072-5245.13.4.460

Satyapriya, M., Nagendra, H. R., Nagarathna, R., & Padmalatha, V. (2009). Effect of integrated yoga on stress and heart rate variability in pregnant women. *International Journal of Gynecology &Obstetrics*, *104*(3), 218–222. doi: 10.1016/j.ijgo.2008.11.013

Schmid, G., Schreier, A., Meyer, R., & Wolke, D. (2010). A prospective study on the persistence of infant crying, sleeping and feeding problems and preschool behaviour. *Acta Paediatrica*, *99*(2), 286–290. doi: 10.1111/j.1651-2227.2009.01572.x

Shea, A. K., Kamath, M. V., Fleming, A., Streiner, D. L., Redmond, K., & Steiner, M. (2008). The effect of depression on heart rate variability during pregnancy. A naturalistic study. *Clinical Autonomic Research*, *18*(4), 203–212. doi: 10.1007/s10286-008-0480-1

Silversides, C. K., & Colman, J. M. (2007). Physiological changes in pregnancy. In C. Oakley & C. A. Warnes (Eds.), *Heart disease in pregnancy*. (2nd ed., pp. 6–17). Malden, MA: Blackwell Publishing.

Squires, J., Bricker, D., & Twombly, E. (2002). *Ages and stages questionnaires: Social-emotional*. Baltimore, MD: Brookes.

Taelman, J., Vandeput, S., Spaepen, A., Huffel, S., Sloten, J., Verdonck, P., … Haueisen, J. (2009). Influence of mental stress on heart rate and heart rate variability. *Proceedings of the International Federation for Medical and Biological Engineering*, *22*, 366–1369.

Takahashi, T., Murata, T., Hamada, T., Omori, M., Kosaka, H., Kikuchi, M., … Wada, Y. (2005). Changes in EEG and autonomic nervous activity during meditation and their association with personality traits. *International Journal of Psychophysiology*, *55*(2), 199–207. doi: 10.1016/j.ijpsycho.2004.07.004

Tang, Y. Y., Ma, Y., Fan, Y., Feng, H., Wang, J., Feng, S., … Li, J. (2009). Central and autonomic nervous system interaction is altered by short-term meditation. *Proceedings of the National Academy of Sciences of the United States of America*, *106*(22), 8865–8865. doi: 10.1073/pnas.0904031106

Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology. (1996). Heart rate variability. Standards of measurement, physiolocial interpretation, and clinical use. *European Heart Journal*, *17*, 354–381. doi: 10.1093/oxfordjournals.eurheartj.a014868

Thayer, J. F., Yamamoto, S. S., & Brosschot, J. F. (2010). The relationship of autonomic imbalance, heart rate variability and cardiovascular disease risk factors. *International Journal of Cardiology*, *141*(2), 122–131. doi: 10.1016/j.ijcard.2009.09.543

Thornburg, K. L., Jacobson, S. L., Giraud, G. D., & Morton, M. J. (2000). Hemodynamic changes in pregnancy. *Seminars in Perinatology*, *24*(1), 11–14. doi: 10.1016/s0146-0005(00)80047-6

Upton, G., & Cook, I. (2014). *A dictionary of statistics* (3rd ed.). Oxford, UK: Oxford University Press.

Vallejo, M., Márquez, M. F., Borja-Aburto, V. H., Cárdenas, M., & Hermosillo, A. G. (2005). Age, body mass index, and menstrual cycle influence young women's heart rate variability—A multivariable analysis. *Clinical Autonomic Research*, *15*(4), 292–298. doi: 10.1007/s10286-005-0272-9

Van den Bergh, B. R. H., Mulder, E. J., Mennes, M., & Glover, V. (2005). Antenatal maternal anxiety and stress and the neurobehavioural development of the fetus and child: Links and possible mechanisms. A review. *Neuroscience & Biobehavioral Reviews*, *29*(2), 237–258. doi: 10.1016/j.neubiorev.2004.10.007

van den Heuvel, M. I., Donkers, F. C., Winkler, I., Otte, R. A., & Van den Bergh, B. R. (2014). Maternal mindfulness and anxiety during pregnancy affect infants' neural responses to sounds. *Social Cognitive and Affective Neuroscience*, *10*(3), 453–460. doi: 10.1093/scan/nsu075

van den Heuvel, M. I., Johannes, M. A., Henrichs, J., & Van den Bergh, B. R. (2015). Maternal mindfulness during pregnancy and infant socio-emotional development and temperament: The mediating role of maternal anxiety. *Early Human Development*, *91*(2), 103–108. doi: 10.1016/j.earlhumdev.2014.12.003

Vieten, C., & Astin, J. (2008). Effects of a mindfulness-based intervention during pregnancy on prenatal stress and mood: Results of a pilot study. *Archives of Women's Mental Health*, *11*(1), 67–74. doi: 10.1007/s00737-008-0214-3

Vlemincx, E., Taelman, J., De Peuter, S., Van Diest, I., & Van den Bergh, O. (2011). Sigh rate and respiratory variability during mental load and sustained attention. *Psychophysiology*, *48*(1), 117–120. doi: 10.1111/j.1469-8986.2010.01043.x

Voss, A., Malberg, H., Schumann, A., Wessel, N., Walther, T., Stepan, H., & Faber, R. (2000). Baroreflex sensitivity, heart rate, and blood pressure variability in normal pregnancy. *American Journal of Hypertension*, *13*(11), 1218–1225. doi: 10.1016/s0895-7061(00)01199-7

Walach, H., Buchheld, N., Buttenmüller, V., Kleinknecht, N., & Schmidt, S. (2006). Measuring mindfulness—The Freiburg mindfulness inventory (FMI). *Personality and Individual Differences*, *40*(8), 1543–1555. doi: 10.1016/j.paid.2005.11.025

Walther, T., Wessel, N., Baumert, M., Stepan, H., Voss, A., & Faber, R. (2005). Longitudinal analysis of heart rate variability in chronic hypertensive pregnancy. *Hypertension Research*, *28*(2), 113–118. doi: 10.1291/hypres.28.113

Walther, T., Wessel, N., Malberg, H., Voss, A., Stepan, H., & Faber, R. (2006). A combined technique for predicting pre-eclampsia: Concurrent measurement of uterine perfusion and analysis of heart rate and blood pressure variability. *Journal of Hypertension*, *24*(4), 747–750. doi: 10.1097/01.hjh.0000217858.27864.50

Whitehouse, A. J., Robinson, M., Newnham, J. P., & Pennell, C. E. (2012). Do hypertensive diseases of pregnancy disrupt neurocognitive development in offspring? *Paediatric and Perinatal Epidemiology*, *26*(2), 101–108. doi: 10.1111/j.1365-3016.2011.01257.x

Williams, J. M. G. (2008). Mindfulness, depression and modes of mind. *Cognitive Therapy and Research*, *32*, 721–733. doi: 10.1007/s10608-008-9204-z

Wolke, D., Schmid, G., Schreier, A., & Meyer, R. (2009). Crying and feeding problems in infancy and cognitive outcome in preschool children born at risk: A prospective population study. *Journal of Developmental & Behavioral Pediatrics*, *30*(3), 226–238. doi: 10.1097/dbp.0b013e3181a85973

Wu, S. D., & Lo, P. C. (2008). Inward-attention meditation increases parasympathetic activity: A study based on heart rate variability. *Biomedical Research*, *29*(5), 245–250. doi: 10.2220/biomedres.29.245

Young, B. C., Levine, R. J., & Karumanchi, S. A. (2010). Pathogenesis of preeclampsia. *Annual Review of Pathology: Mechanisms of Disease*, *5*, 173–192. doi: 10.1146/annurev-pathol-121808-102149

Zhang, J., Villar, J., Sun, W., Merialdi, M., Abdel-Aleem, H., Mathai, M., . . . Carroli, G. (2007). Blood pressure dynamics during pregnancy and spontaneous preterm birth. *American Journal of Obstetrics and Gynecology*, *197*(2), e161–e166. doi: 10.1016/j.ajog.2007.03.053

(Received February 4, 2016; Accepted September 12, 2016)