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Regular Article

Public health nurse-delivered cognitive behavioral therapy for postpartum depression: Assessing the effects of maternal treatment on infant emotion regulation

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Abstract

The effects of maternal postpartum depression (PPD) on offspring emotion regulation (ER) are particularly deleterious as difficulties with ER predict an increased risk of psychopathology. This study examined the impact of maternal participation in a public health nurse (PHN)-delivered group cognitive behavioral therapy (CBT) intervention on infant ER. Mothers/birthing parents were ≥ 18 years old with an Edinburgh Postnatal Depression Scale (EPDS) score ≥ 10, and infants were < 12 months. Between 2017 and 2020, 141 mother–infant dyads were randomized to experimental or control groups. Infant ER was measured at baseline (T1) and nine weeks later (T2) using two neurophysiological measures (frontal alpha asymmetry (FAA) and high-frequency heart rate variability (HF-HRV)), and informant-report of infant temperament. Mothers were a mean of 30.8 years old (SD = 4.7), 92.3% were married/ common-law, and infants were a mean of 5.4 months old (SD = 2.9) and 52.1% were male. A statistically significant group-by-time interaction was found to predict change in HF-HRV between T1 and T2 ($F(1,68.3) = 4.04$, $p = .04$), but no significant interaction predicted change in FAA or temperament. Results suggest that PHN-delivered group CBT for PPD may lead to adaptive changes in a neurophysiological marker of infant ER, highlighting the importance of early maternal intervention.

Keywords: Postpartum depression; emotion regulation; neurophysiology; psychotherapy; mother; infant

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Introduction

Postpartum depression (PPD) is a major public health problem that can have long-term adverse effects on mothers and birthing parents, and their infants (Gaynes et al., 2005; Heim & Binder, 2012; Kingston et al., 2012; Tronick & Reck, 2009). One in five mothers and birthing parents will develop PPD (Gaynes et al., 2005) while up to one in three experience elevated levels of symptoms that do not exceed diagnostic thresholds for a diagnosis of major depressive disorder (MDD; Meaney, 2018). Mothers/ birthing parents with PPD can experience significant suffering in the short and longer-term if PPD remains untreated. PPD may lead to persistent major depression (Horowitz & Goodman, 2004), elevated rates of substance misuse (Chapman & Wu, 2013), and problems in their relationships (Goodman, 2004). Intervening early can play an important role in improving these outcomes.

Left untreated, PPD costs $125,000 (CAD; Bauer et al., 2016) over the life span, 72% of which is due to emotional, behavioral, and/or cognitive problems in offspring (Bauer et al., 2016; Goodman et al., 2011; Slomian et al., 2019). The effects of PPD on offspring emotion regulation (ER) may be particularly deleterious as difficulties with ER predict an increased risk of most forms of psychopathology, as well as sub-optimal educational and labor market outcomes (Calkins et al., 2019; Moffitt et al., 2011; Panari et al., 2020; Shannon et al., 2007).

In the first year of life, infants are yet to develop the higher-order cortical processes that govern ER and as a result, rely on their caregivers to regulate their emotions (Porges & Furman, 2011). It is not until the second year of life where maturation of ER systems allows toddlers to actively regulate their own emotional states (Calkins & Hill, 2007). Exposure to PPD negatively influences early postnatal interactions with mothers, which is believed to disrupt optimal ER development, and ultimately have a programming effect on the sensitive neuronal circuits that rapidly develop during the early postnatal period (Van den Bergh, 2011). There is evidence that infants as young as three to six months old, exhibit deficits in ER capacity measured with behavioral and neurophysiological markers as a result of PPD exposure (Field et al., 1988, 1995).

The autonomic nervous system (ANS; Porges, 2007; Thayer et al., 2009) and corticolimbic circuits in the brain (Field et al., 2002; Fox, 1991; Lusby et al., 2014, 2016) are key systems involved in the development of ER, and measures of their activity are robust indicators of emotion regulatory capacity. High-frequency heart rate variability (HF-HRV) is a measure of the flexibility of the ANS to adapt to environmental conditions (Propper & Moore, 2006),

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while frontal alpha asymmetry (FAA) indexes the relative activation of the left versus right frontal regions of the brain. Both HF-HRV and FAA can be used to measure ER capacity in preverbal infants and are among the earliest markers (Field et al., 2002; Fox, 1991; Lusby et al., 2014, 2016; Porges, 2007; Thayer et al., 2009). Infants exposed to PPD tend to exhibit lower HRV and greater right FAA at rest, both of which are indicative of ER capacity and an increased risk of psychiatric problems (Bornstein and Suess, 2000; Coan & Allen, 2004; Mason, 1975; Thayer & Brosschot, 2005).

Parent reports are a commonly used method of measuring infant temperament as they are easy to collect, cost-effective, and less time-consuming than collecting non-parental informant-reports. Temperament provides a measure of an infant's innate disposition to reacting behaviorally and emotionally to stimuli and represents stable, trait-related differences in regulatory capacity (Rothbart, 2007). The Infant Behavior Questionnaire-Revised (IBQ-R) Very Short-Form is a widely used and validated informant-report measure of infant regulatory temperament (Putnam et al., 2014). In particular, the orienting/ regulatory capacity domain of the is a reliable indicator of infant ER capacity and has been used in studies of maternal PPD interventions to measure infant ER (Krzeczkowski et al., 2021; Putnam et al., 2008). Given the influence that maternal mood can have on parental reports of infant ER, we complemented this method of assessing ER capacity with two physiological measures (HF-HRV and FAA).

Even though the long-term adverse effects of PPD and its impact on ER capacity in infants is well known, just 15% of mothers and birthing parents in developed countries will receive evidence-based treatment for PPD (Ko et al., 2012). Numerous barriers to care for mothers/birthing parents with PPD exist including a lack of affordable and preferred treatment options (e.g., psychotherapy) and long waitlists (Goodman, 2009; Jones, 2019). Task-shifting the treatment of PPD from specialized experts to those with less psychiatric training (e.g., public health nurses; PHNs) is one means through which treatment access can be improved (e.g., Van Lieshout et al., 2022). While some evidence suggests that PHNs can deliver effective individual interpersonal psychotherapy (IPT; Dennis et al., 2020) and group cognitive behavioral therapy (CBT) for PPD (Van Lieshout et al., 2020), it is not clear if such interventions can have a positive effect on infant ER capacity.

To date, just four studies have examined the impact of treating maternal PPD on infant ER capacity (Amani et al., 2023; Cohen et al., 2002; Krzeczkowski et al., 2021; Stein et al., 2018). Three of these studies used an experimental design (e.g., randomized controlled trials (RCTs); Amani et al., 2023; Cohen et al., 2002; Stein et al., 2018) and found evidence to suggest that maternal treatment for PPD may have a positive influence on infant ER capacity. However, in Cohen and colleagues (2002) and Stein and colleagues (2018) work, maternal treatment began after the first postnatal year, despite this period of time being important for infant ER development (Calkins et al., 2019; Tottenham, 2019) and in both studies, only single observational measures of infant behavior were used to assess ER capacity. It is important to note that observational and parent-report measures of infant behavior alone may not capture the full scope of ER (Fox, 1998) and may lack the sensitivity to detect important changes. To date, just two studies have measured infant ER capacity following maternal treatment using physiological measures (Amani et al., 2023; Krzeczkowski et al., 2021). Using an observational study design, Krzeczkowski and colleagues found increased HF-HRV and a shift from right to left FAA following nine weeks of group CBT for PPD delivered by experts to mothers in a specialized perinatal mental health clinic meeting DSM-5 diagnostic criteria for MDD (Krzeczkowski et al., 2021). However, given the observational design and a lack of a depressed control group, this study was not able to rule out whether changes in infants were due to treatment or potential confounding factors (Metelli & Chaimani, 2020). Similarly, recent work by our group has found evidence of change in infant FAA and HF-HRV following nine weeks of maternal participation in a peer-delivered group CBT intervention (Amani et al., 2023).

Relative to treatments delivered by expert therapists in hospital settings, structured group interventions delivered by PHNs in community settings could have the potential to be more broadly, effectively, and efficiently scaled to improve PPD and infant ER capacity. To help realize this substantial public health potential, the objective of the present study was to determine if participation in a nine-week PHN-delivered group CBT intervention could lead to potentially adaptive changes in infant ER capacity as indexed by two neurophysiological markers (HF-HRV and FAA) and parental reports of infant temperament.

Methods

This study included mother–infant pairs who were part of a parallel-group, single-site, RCT assessing the effectiveness of a nine-week PHN-delivered group CBT intervention for PPD (Van Lieshout et al., 2022). This study took place in Ontario, Canada (*ClinicalTrials.gov identifier*: NCT03039530*)* between April 1, 2017 to January 20, 2020. Mother–infant dyads were randomized in a 1:1 ratio to experimental or control groups. Blocked randomization with block sizes of four, six, and eight was conducted by a statistician using R and implemented by the study coordinator using Research Electronic Data Capture (REDCap; Harris et al., 2009).

Experimental group participants enrolled in the nine-week intervention in addition to receiving treatment as usual (TAU) from their healthcare providers, while control participants received TAU alone. Since healthcare is universally available in Ontario, Canada, TAU could include medications and/or psychotherapy from a physician and/or clinician at a provincially funded facility/ program. Participants could also access private therapists or any other treatments they wished.

The current study was a secondary analysis of a study whose primary objective was to examine if PHN-delivered group CBT for PPD could effectively treat maternal PPD. *A priori* power analysis determined that a sample of 136 participants (68 per arm) would provide adequate statistical power to address this maternal PPD objective. It is important to note that studies examining infant ER capacity have been of a similar sample size (Field et al., 1995; Lusby et al., 2014).

Data were collected at baseline (T1) and nine weeks later (posttreatment in the experimental group; T2). No data were collected at a T3 time point (6 months posttreatment) because of COVID-19 pandemic-related restrictions on face-to-face research in Ontario, Canada. Mothers completed questionnaires electronically using REDCap (Harris et al., 2009) and infant physiological data were collected during in-person study visits at T1 and T2. In-person study visits took place at Niagara Region Public Health. The present study was approved by the Hamilton Integrated Research and the Niagara Region Public Health Ethics Boards. Participants provided informed consent prior to randomization. No study methods changed after trial commencement.

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Mother–infant dyads were recruited both through social media advertising (e.g., Facebook, Instagram) and healthcare providers (e.g., PHNs, midwives, physicians, etc.). Participants could self-refer to the study or be referred by a healthcare provider and had to be ≥ 18 years old, have an infant < 12 months, and an Edinburgh Postnatal Depression Scale (EPDS) score ≥ 10. This EPDS cutoff is typically used in primary care settings to detect PPD (Earls et al., 2010) and was selected because almost 30% of mothers experience these levels of symptoms (Meaney, 2018). In addition, the use of EPDS enabled us to maximize eligibility and the public health relevance of our findings. Participants were also free of bipolar, psychotic, and current substance use disorders as per the Mini International Neuropsychiatric Interview (MINI; Sheehan et al., 1998), as well as free of borderline or antisocial personality disorders.

Six PHNs were trained to deliver the nine-week group CBT intervention which was effective in improving depression and anxiety in mothers (Van Lieshout et al., 2022). The intervention consisted of nine weekly two-hour sessions delivered by two PHNs. The first half of each session consisted of core CBT content, while the second half included psychoeducation and a group discussion of relevant topics (e.g., sleep, utilizing supports; Van Lieshout et al., 2017, 2020). No formal psychotherapy supervision took place during the intervention delivery, but an expert therapist was available to the PHNs to provide clinical support if needed.

Sociodemographic (maternal and infant age, infant sex, household income, maternal marital status and education), clinical (EPDS scores, Penn State Worry Questionnaire (PSWQ) scores, MDD diagnosis, psychotropic medication use), and infant temperament data (IBQ-R Very Short-Form) were self-reported by mothers, while in-person physiological data were acquired from infants during in-person study visits. Participants in both study arms reported on mental health services and psychotropic medication use during the nine-week treatment period using the Healthcare Resource Utilization Questionnaire (HRUQ; Van Lieshout et al., 2022), based on the Canadian Community Health Survey (CCHS) and adapted for use in the postpartum period (Gravel & Béland, 2005).

Participant characteristics

Mothers were 30.8 years old (SD = 4.7), 95.5% were born in Canada, 2.3% in England, 1.1% in Japan and 1.1% in Kenya, 92.3% were married or common-law, and had 17.9 (SD = 3.4) years of education. Of those in the present study, 67.3% had a MDD diagnosis and 29.9% were taking a psychotropic medication at the start of the study. Infants were a mean age of 5.4 months old (SD = 2.9) with a range of 2–12 months at baseline and 52.1% were male. No statistically significant differences were found in sociodemographic or clinical characteristics between experimental and control groups at baseline.

Physiological data were collected from infants during a six-minute resting-state task. Electrocardiographic (ECG) and Electroencephalography (EEG) recordings were taken while mothers were asked to hold their infant while sitting upright and facing a screensaver. Mothers were instructed not to speak to their infant and to refrain from moving them. Physiological recordings did not begin until dyads were given time to acclimate to the testing room and at a time when infants were calm but alert. Testers remained hidden behind a partition during physiological recordings.

High-frequency heart rate variability (HF-HRV)

ECG data were collected with the Mindware Mobile Impedance Cardiograph (Mindware Technologies Ltd Gahanna, OH). ECG electrodes were placed on infants' right shoulder blade and their left-most lower back. HF-HRV was calculated from the ECG trace by extracting the power spectrum that corresponds with respiration for infants (0.24–1.04 Hz; Laborde et al., 2017). Data were acquired during the six-minute resting-state task using Biolab software (version 3.2.3, Mindware Technologies Ltd Gahanna, OH) and analyzed in 30-s segments. Mindware HRV Analysis software was used to first inspect the data visually for artifacts, then to conduct manual corrections (e.g., adding missing heartbeats, correcting mis-identified heartbeats) and next to analyze the data on a 0.24–1 Hz frequency range. Higher values of resting HF-HRV are reflective of more adaptive control and flexibility of the nervous system to handle stress (Porges, 2007; Thayer et al., 2009).

Frontal alpha asymmetry (FAA)

EEG data were collected using a custom dry EEG headband developed by InteraXon for infant use (Krigolson et al., 2017; Ratti et al., 2017). In addition to their portability and ease-of-use, other infant studies suggest that they can collect reliable EEG data (Krigolson et al., 2017; Neto et al., 2021). Each headband includes 5 sensors, two temporoparietal (TP9 and TP10), two frontal (AF7 and AF8), and a fifth reference electrode in the center of the forehead (Fpz). Data were sampled at 250 Hz and sent from the headband sensors to the MINDMonitor app (Mind Monitor, 2015) where data were bandpass filtered between 1 and 100 Hz, notch filtered at 60 Hz and epoched to one second intervals before a real-time Fast Fourier Transformation (FFT) was performed. Data were then saved in comma separated value (CSV) format. Next, they were visually inspected for segments with noise or weak signals (e.g., repeating values) that were then removed from analysis. To calculate FAA, the log-transformed alpha power (4–8 Hz) at the left frontal hemisphere (AF7) was subtracted from the right frontal hemisphere (AF8). Alpha frequency bands in infants are typically within the 4–9 Hz range (Fox et al., 2001; Marshall et al., 2002). Greater resting relative right frontal asymmetric activity (indicated by values < 0) reflects a predisposition to experiencing negative emotions, having more withdrawal-related tendencies, and is predictive of later psychopathology (Coan & Allen, 2004), while greater relative left frontal asymmetric activity is reflective of more approach-oriented behavior and positive emotionality.

Temperament

Mothers reported infant temperament using the IBQ-R Very Short-Form, a 37-item questionnaire where infant behavior is rated on a 7-point scale (Putnam et al., 2006, 2014). *A priori*, we decided to examine the orienting/regulatory capacity domain of the IBQ-R as the maternally reported measure of infant ER capacity. This domain is a reliable marker of infant regulatory capacity (Putnam et al., 2008), and higher scores suggest greater ER capacity and correlate with greater infant HF-HRV and left FAA (Krzeczkowski et al., 2021). Using the 12 items of the orienting/regulatory capacity domain of the IBQ-R, we calculated Cronbach's alpha and found $a = .60$. It is important to highlight that the internal consistency of this measure, while acceptable, should be considered when interpreting these findings.

Analysis plan

T tests and chi-square tests were used to analyze differences in baseline characteristics between groups. Potential predictors of attrition on offspring ER capacity outcomes (HF-HRV, FAA, IBQ-R) were also examined. Maternal depressive symptoms (mean

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Table 1. Participant baseline characteristics

	Experimental Group	Control Group
Sample size, N	57	50
Infant age, months, *mean* (SD)	5.3 (2.7)	5.5 (3.1)
Infant sex, male, %	57.7%	45.5%
Maternal age, years, *mean* (SD)	31.4 (4.9)	30.2 (4.5)
Household income, *mean* (SD)[1]	$77 663 (42 052.9)	$78 693 (43 859.9)
Marital status, %		
Single	4.3%	11.4%
Married/common-law	95.6%	88.6%
Maternal education (# Years, *mean* (SD))	17.7(3.5)	18.0 (3.3)
Baseline EPDS, *mean* (SD)	16.1 (4.4)	15.7 (3.7)
Baseline PSWQ-7, *mean* (SD)	64.6 (8.8)	63.9 (9.4)
Maternal psychotropic medication Use %	29.8%	30%
Current MDD diagnosis, Yes, %	66.7 %	68%

EPDS scores) stratified by group at T1 and T2 were calculated to assess the treatment effect in mothers included in the present study sample.

We used linear mixed effects models (LMM) with restricted maximum likelihood estimation to examine the effect of the intervention on all three infant outcomes. This type of analysis is widely used in clinical trials as it can account for missing data (Chakraborty & Gu, 2019). Using a two-level hierarchy, outcome data at T1 and T2 were nested within each participant to assess the effect of the intervention over time between groups. To account for unobserved heterogeneity at the level of the individual participant and control for clustering effects, a random-effects intercept was included in the model. Lastly, we controlled for experimental participants participating in different CBT groups by including CBT group assignment as a fixed effect in our model. For outcomes that showed a statistically significant group-by-time interaction, we examined the simple effect of each group on the outcome over time. Intervention effect was calculated for each outcome using means and standard deviations of outcome measures at T1 and T2 in the experimental group.

Results

Table 1 includes a summary of maternal and infant characteristics stratified by treatment group. A total of 141 mothers were randomized to experimental or control groups between April 1, 2017 to January 20, 2020 (Figure 1). Participants in both study arms reported on mental health services and psychotropic medication use during the nine-week treatment period. At the nine-week follow-up (T2), 38.8% mothers (19/49) in the experimental group reported taking a psychotropic medication, while 27.0% mothers (10/37) in the control group did. In the experimental group, 4.1% (2/49) participants attended a crisis support program (e.g., mental health line), 12.2% (6/49) saw a psychiatrist, and 16.3 % (8/49) saw a social worker. In the control group, 2.7% (1/37) attended a crisis support program (e.g., mental health line), 13.5 % (5/37) saw a psychiatrist, 5.4% (2/37) saw a psychologist and 13.5 % (5/37) saw a social worker. There were no statistically significant differences in mental health service or psychotropic medication use between groups.

The CBT groups attended by the experimental group included an average of 6 participants. Eighty-eight percent of participants attended 5 or more of their 9 CBT sessions.

At T1, 107 dyads provided data on at least one outcome measure and 78 participants provided these data at T2 (Fig. 1). At T1, 53 experimental dyads and 40 control group dyads attended in-person study visits. At T2, 37 experimental dyads and 24 control group dyads attended in-person study visits. Table 2 includes means, standard deviations, and sample sizes for each outcome measure at each data collection point.

We found no sample characteristics at baseline (infant age, infant sex, maternal age, household income, marital status, education, MDD diagnosis, and psychiatric medication) to predict loss to follow-up in the experimental and control group. Levels of maternal depressive symptoms (EPDS scores) at T1 did not predict loss to follow-up at T2 in either the experimental ($F(1,49) = 1.46$, $p = .23$) or control group ($F(1,41) = .04$, $p = .84$). While the missingness we experienced appears to be unrelated to the data itself, it is likely that our data were missing not at random (MNAR) as the missingness may be due to outside factors not reflected in the data. From T1 to T2, attrition did not differ between groups for HF-HRV or IBQ-R scores, but loss to follow-up for FAA was 22.2% in the experimental group and 51.5% in the control group ($X^2 = 9.23$, $p < .01$).

PPD symptoms

In the present study, those in the experimental group had EPDS scores that decreased from 16.1 (SD = 4.4) to 10.6 (SD = 4.6) after treatment, while individuals in the control group manifested a slight decrease in EPDS scores from 15.8 (SD = 3.8) at T1 to 13.1 (SD = 5.0) at T2. Improvement in the experimental group was greater than the control group ($t(77.45) = 2.65$,$p = .01$) and the magnitude of treatment effect was large ((Hedges' g) = *1.2).*

High-frequency heart rate variability

Infant HF-HRV was not different between experimental and controls groups at T1. A statistically significant group-by-time interaction predicted change in HF-HRV between T1 and T2 ($F(1,68.3) = 4.04$, $p = .04$), suggesting that maternal treatment predicted change in infant HF-HRV. The B coefficient of the interaction term indicates that the mean difference in slope (change in RSA over T1 to T2) between the treatment and control groups was $B = .59$ ($p = .04$). The slope of the treatment group representing mean change over time ($B = .83$, $p < .01$) was statistically significant while the control group was not ($B = .22$, $p = .22$). The magnitude of the treatment effect was medium (*Hedges'* $g = .76$) and suggests that infants' ER improved with maternal treatment.

Frontal alpha asymmetry

At T1, mean FAA was not statistically significantly different between the experimental and control group infants. Results of the LMM indicated that there was no statistically significant group-by-time interaction to predict change in FAA scores over time ($F(1,57.7) = .25$, $p = .62$), suggesting that maternal treatment did not lead to changes in infant FAA. Experimental group means in Table 2 indicate that at T1 (FAA = .08) and T2 (FAA = .05), mean

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Table 2. Impact of maternal treatment on measures of infant emotion regulation

	Time 1			Time 2					
Outcome	Experimental Mean (SD)	*n*	ControlMean (SD)	*n*	ExperimentalMean (SD)	*n*	ControlMean (SD)	*n*	*Hedge's g*
FAA	.08 (.22)	45	.07 (.24)	33	.05 (.16)	35	.07 (.16)	16	.15
HF-HRV	3.40 (.99)	47	3.32 (.87)	37	4.20 (1.11)	34	3.55 (.83)	22	.76[1]
IBQ-R-REG	5.23 (.82)	56	5.07 (.77)	50	5.30 (.64)	45	5.19 (.67)	33	.09

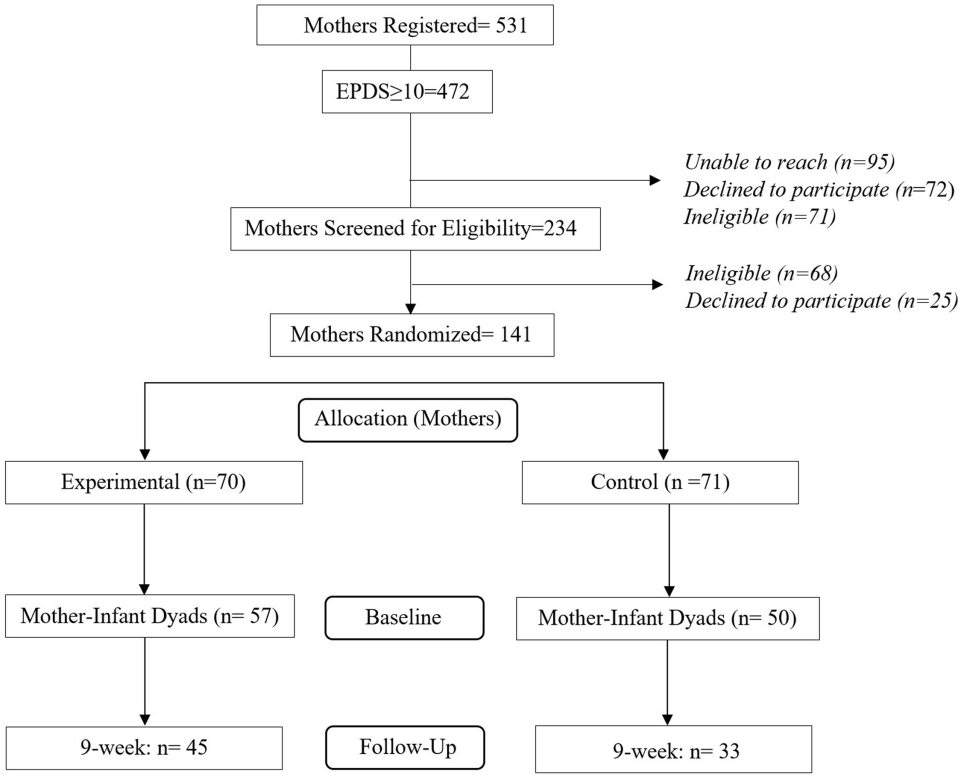

Figure 1. CONSORT flow diagram.

frontal asymmetric activity did not change substantially and remained as more left FAA following maternal treatment.

Orienting/regulatory capacity (temperament)

At baseline, infants in the experimental and control group did not differ in IBQ-R. Mean scores at T1 and T2, stratified by group are presented in Table 2. To assess the effect of the intervention on maternal reports of infant ER capacity, we used LMM to examine the orienting/regulatory capacity domain of the IBQ-R. Results of LMM indicated that there was no statistically significant group-by-time interaction to predict orienting/regulatory capacity ($F(1,85.8) = .000$, $p = .99$). Means reported in Table 2 suggest that maternal report of infant temperament was similar at both time points in both treatment arms.

Discussion

The results of this study suggest that PHN-delivered group CBT for PPD can lead to clinically significant improvements in PPD symptoms in mothers, as well as adaptive changes in a neurophysiological marker of infant ER capacity (HF-HRV). However, it did not lead to statistically significant improvements in infant FAA or maternal reports of infant temperament.

An increasing number of studies are examining the impact of maternal PPD treatment on infant outcomes, including markers of emotional, behavioral, and cognitive development (Meager & Milgrom, 1996; Ammerman et al., 2015; Bilszta et al., 2012; Cicchetti et al., 2000; Cohen et al., 2002; Cooper et al., 2003; Fonagy et al., 2016; Forman et al., 2007; Handley et al., 2017; Hart et al., 1998; Kersten-Alvarez et al., 2010; Misri et al., 2006; Onozawa et al., 2001; Stein et al., 2018b; Toth et al., 2006; Van Doesum et al., 2008; Verduyn et al., 2003). While only three of these measured markers of offspring ER capacity, they did report some positive influence of maternal treatment (Cohen et al., 2002; Krzeczkowski et al., 2021; Stein et al., 2018). However, two of these examined infant ER following maternal interventions delivered after the first postnatal year and both relied on observational assessments alone (Cohen et al., 2002; Stein et al., 2018). While the third study intervened in the first year of life and used physiological measures of ER capacity, their sample was restricted to patients in a specialty perinatal mental health clinic and used an observational design with no PPD controls. The current study utilized a stronger study design (e.g., RCT), included mothers with a range of levels PPD symptoms

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living in the community, and a cost-effective and preferred, scalable treatment delivered by public health professionals (PHNs).

After nine weeks of treatment with group CBT for PPD, the present study found a statistically significant increase in infant HF-HRV of medium effect size. This is consistent with Krzeczkowski and colleagues' observational study of an intervention delivered by expert therapists (Krzeczkowski et al., 2021) and a second RCT of group CBT delivered by mothers who had previously recovered from PPD (Amani et al., 2023). Increases in infant HF-HRV suggest greater flexibility of the ANS through the activity of the vagus nerve (Porges, 2007; Porges & Furman, 2011; Quigley & Moore, 2018).

During the first year of life, the vagal circuitry that governs an infant's sympathetic nervous system's fight or flight response begins coordinating its circuits with higher-order cortical processes (Porges, 2007), resulting in the biobehavioral pathway that underlies the social engagement system (SES; Porges, 2007; Porges & Furman, 2011). This enables infants to use their social environment to regulate their emotions rather than relying on the more primitive fight or flight system (Porges & Furman, 2011). In fact, resting-state HF-HRV indexes the balance of activity between these two systems (Porges & Furman, 2011). Since the socioemotional environment plays a key role in SES development (Porges & Furman, 2011), maternal PPD can negatively impact its development. Infants actively facilitate SES development by seeking out opportunities to engage with their mothers (Atzil et al., 2018). However, mothers with PPD are more likely to miss their infants' cues and can fail to help their infants' regulate their emotions (Moore & Calkins, 2004). Given the sensitivity of the SES to an infant's social environment, even subtle changes (e.g., better recognition of infants' cues by mothers) may have contributed to the adaptive changes in resting-state HF-HRV observed. Indeed, maternal treatment may have reduced mothers' symptoms of depression and/or anxiety and enabled their infants to better self-regulate, or maternal symptomatic improvements might have helped them to better engage their infants and enhance their self-regulation. However, since we did not specifically examine the factors that may change in mothers following treatment, we cannot say for certain why maternal treatment led to an increase in infant HF-HRV.

While the neurophysiological systems that underlie ER development exhibit immerse plasticity during the first postnatal year, we believe that the magnitude of our observed changes over our nine-week study period may not have occurred as a result of developmental maturation and change alone. In the first year of life, infants possess rudimentary ER capacity (i.e., thumb suckling, turning attention away from stimuli) and so rely heavily on their caregivers to support emotion regulatory capacity (Porges & Furman, 2011). As a result, the development and maturation of core ER regulatory systems must be examined in the context of salient environmental conditions (e.g., maternal mood and behavior) that shape the development of these systems. For instance, while HF-HRV increases across the first year of life, we would not expect to see increases of our reported magnitude within the nine-week study period (Bar-Haim et al., 2000). Additionally, evidence suggests that children exposed to early adversity and who are at-risk for mental disorders do not exhibit typical developmental increases in HF-HRV (Gentzler et al., 2012). Furthermore, while the development of systems underlying frontal EEG asymmetry assessed at resting state appear to remain stable across infancy (Brooker et al., 2017), continued exposure to depression into childhood may result in increasingly right frontal EEG asymmetry (Goldstein et al., 2016). Finally, it is important to note that if infants experienced differential developmental maturation during the study period, we would expect randomization to balance these effects across the treatment and control groups.

Unlike our previous trial of a peer-delivered PPD intervention (Amani et al., 2023) and Krzeczkowski and colleagues' observational study (2021), we did not observe changes in FAA or maternally reported ER capacity following treatment. It is not clear why our results differ, but it could be due to differences in sample characteristics and/or intervention delivery. Our sample was recruited from the community, and just 67.3% were diagnosed with MDD, compared to Krzeczkowski and colleagues' clinical sample where all had MDD (Krzeczkowski et al., 2021). Moreover, participants in the peer-led RCT had fewer years of education and a lower mean household income (Amani et al., 2023) than the present study. As a result, infants in the present study may have had less exposure to negative environmental factors (maternal depression, socioeconomic disadvantage) and so were more limited in the amount they could improve, reducing their ability to initiate changes to large-scale neural networks. FAA and temperament assess stable (Brooker et al., 2017; Müller et al., 2015), trait-related (Fox, 1994; Rothbart, 2007; Smith et al., 2016) mechanisms through which infants interact with their environment (e.g., approach-withdrawal tendencies; Harmon-Jones & Gable, 2017) and both result from the coordinated activity of multiple brain regions (Davidson, 2000; Posner et al., 2012). Therefore, changes in FAA and temperament may require larger changes in an infant's environment relative to infant HF-HRV, which is sensitive to more acute changes in socioemotional environments (Atzil et al., 2018), or take longer to manifest.

There may be additional reasons why we did not find change in infant FAA and temperament following maternal treatment. First, infants in our treatment group exhibited greater left frontal asymmetric activity prior to treatment (0.08), while infants in Krzeczkowski et al., presented greater right frontal asymmetric activity at baseline (Krzeczkowski et al., 2021). Second, we used a relatively new mobile, dry EEG system to measure FAA, and we may have had inadequate statistical power to detect changes in FAA and temperament. Using means and SD of change from T1 to T2, we calculated *post hoc* power calculations (G*Power Version 3.1.9.7) on all three outcomes. We found that although we had sufficient statistical power (0.96) to detect changes in HF-HRV, the power to detect differences in FAA and IBQ-R changes was much lower (0.16 and 0.12, respectively). Of note, a study of a maternal PPD intervention with a similar sampling frame and sample size ($n = 80$ at pre- and post-intervention time points) and that measured the same outcomes detected change in maternal report of temperament, infant FAA and HF-HRV (Krzeczkowski et al., 2021). In this study, the observed effect was Cohen's $d = 0.60$. Based on their observed effect, alpha of 0.05, and power set to 0.8, we would need a sample of 90 dyads to see an effect of this magnitude. Additionally, sensitivity analysis determined that the minimally important effect size for FAA and IBQ-R were 1.20 and 0.84, respectively. Suggesting that with our sample size, an effect of this magnitude or greater would need to be found in order to distinguish it from a null effect.

The results of this study should also be examined in the context of some further limitations. In our study, most of our participants were Canadian-born, married, had several years of post-secondary education, and all lived in a region where healthcare is universally

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available. Therefore, our findings may not be generalizable to all groups with PPD. Another limitation is that we only collected place of birth in this study. It is also important to note that our sample size is small and *post hoc* power calculations suggest that we may not have had adequate statistical power to detect changes in two of our infant outcomes (FAA and IBQ-R). Additionally, more participant attrition was observed in the control group, and they also completed FAA measures less often, highlighting the need for future research to more thoroughly examine whether infant FAA may change in response to maternal treatment.

Because physiological data from infants were collected in community settings, we used the MUSE EEG band for its portability and practicality. While it may have affected our FAA findings, a previous RCT by our group using this technology did replicate the findings of an observational study that used a full dense array EEG system (Krzeczkowski et al., 2021). It is also important to note that the IBQ-R Very Short Form (VSF) was designed for infants 3 to 12 months old. While the majority of infants were 3 months or older (79.8%) at the first data collection time point, 20.2 % of infants in the present study were less than 3 months old. Lastly, the pandemic limited our ability to examine timepoints beyond the immediate posttreatment period, highlighting the need to examine the longer-term effects of maternal PPD treatment on infant ER capacity.

Considering the possibility that at least some mothers with PPD also experienced prenatal depression, or at least elevated symptoms of depression during pregnancy, and since fetal exposure to maternal prenatal depression may lead to *in utero* alterations in key physiological systems involved in ER (Kinsella & Monk, 2009), the presence of maternal prenatal depression is an important factor to consider in future research. Including these data could provide the field with a greater understanding of the potential for maternal treatment to mitigate infant risks due to exposures both prenatally and postnatally.

The findings of this study suggest that delivery of group CBT for PPD task-shifted to PHNs effectively reduced symptoms of depression in mothers and led to adaptive increases in infant HF-HRV after just nine weeks. These results suggest that treating maternal PPD could have the potential to alter infant ER capacity and neurophysiology at the level of the ANS. However, maternal treatment did not lead to changes in FAA or maternal reports of temperament, and so studies of larger samples examining outcomes over longer time periods are required. While our work highlights the importance of early maternal intervention and its potential public health impact, more work is needed to further our understanding of the mechanisms responsible for putative infant ER change, and the potential long-term impact of early PPD treatment.

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