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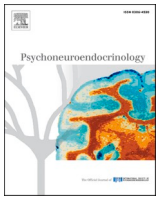

Stress responses of infants and mothers to a still-face paradigm after traumatic childbirth

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ABSTRACT

Introduction: One-third of women experience childbirth as traumatic and some develop symptoms of childbirth-related posttraumatic stress symptoms (CB-PTSD symptoms). Whether CB-PTSD symptoms negatively impact on physiological and psychological stress responses in mothers and their offspring and whether they are associated with mother-infant synchrony is not clear. This study aimed to investigate stress responses of (1) mothers with CB-PTSS, (2) of their infant, and (3) the physiological mother-child-synchrony at six months postpartum.
Method: Psychophysiological (cortisol and vagal tone) and psychological stress responses of mothers and infant's (n=31 dyads) from the *Swiss TrAumatic biRth Trial* (NCT03576586) were assessed during a face-to-face still-face paradigm (FFSF-R).
Results: There was a significant time effect in maternal stress responses for salivary cortisol, vagal tone, and for maternal subjective stress. As expected, mothers' subjective stress increased during the stress task and mothers vagal tone changed during the first stressful period but not during the second, whereas cortisol unexpectedly decreased over the FFSF-R. Infant negative mood increased over the experiment, but there were no physiological changes. However, a significant interaction effect for mother-infant synchrony during the second reunion period of the FFSF-R was found.
Conclusion: Although mothers and their infants were subjectively stressed, they showed only limited physiological stress responses.

1. Introduction

Although childbirth is a positive lifetime event, up to 46 % of women experience it as traumatic (i.e., perceived life threat for themselves and/or their infant during birth) (American Psychiatric Association, 2022; Horesh et al., 2021). Following such traumatic childbirth, mothers can develop childbirth-related posttraumatic stress symptoms, which include re-experiencing of the traumatic moments, cognitive and behavioral avoidance, negative alterations in mood and cognitions, and hyperarousal (Horesh et al., 2021). Today, up to 5 % suffer from clinically relevant CB-PTSD symptoms and 12 % show subclinical CB-PTSS after traumatic birth (Heyne et al., 2022). PTSD symptoms due to other traumatic experiences are related to increased chronic subjective stress levels and dysregulated stress responses including cortisol dysregulation and reduced vagal tone (Schneider and Schwerdtfeger, 2020).

Such dysregulated stress responses are also found in mothers after traumatic birth with increased life threat to her or her infant, including higher perceived stress levels, dysregulated cortisol and vagal responses when exposed to an infant crying stress paradigm (Sandoz et al., 2021). However, dysregulated stress responses in mothers with CB-PTSD symptoms have not been investigated so far.

Dysregulated physiological stress responses resulting from a trauma exposure are not limited to the mothers but provoke greater reactivity to stimuli due to intergenerational transmission of stress and trauma

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(Bowers and Yehuda, 2016) and changes in stress responses in infants (Tees et al., 2010; Foss et al., 2022). According to the model of intergenerational transmission of stress in humans, maternal stress vulnerability can be transmitted to their infant at three key moments: before conception via the gametes; during the pregnancy through the uterine environment; and during the postpartum period via early mother-infant interactions (Bowers and Yehuda, 2016; Horsch and Stuijfzand, 2019). A growing body of biological evidence supports the view of an altered HPA axis activity in mothers as a cornerstone for the intergenerational transmission of stress-related psychopathology to offspring (Bowers and Yehuda, 2016, Laurent et al., 2013, Essex et al., 2002). Previous studies demonstrated a transgenerational transmission of dysregulated cortisol levels to the offspring in children of mothers after severe trauma exposure before pregnancy and during their pregnancy (Hendrix et al., 2022; Hjort et al., 2021; Brand et al., 2010; Bosquet Enlow et al., 2009; Foss et al., 2022). There is even some evidence that life trauma history in combination with perinatal trauma resulted in reduced infant heart rate recovery after a stress condition (Bosquet Enlow et al., 2009). Further, severe postpartum mental health problems (e.g., depression, anxiety disorder, bipolar disorder) were related to infant dysregulated stress responses and less adaptation to a challenging condition (Broeks et al., 2021). However, mothers with CB-PTSD symptoms were not included in this study and therefore, it remains unclear whether CB-PTSD symptoms are related to similar dysregulated stress responses in infants.

There are several theoretical ways in which maternal PTSD might impact on the offspring. Firstly, the impact might happen indirectly through more negative parenting styles, more family conflicts (Flanagan et al., 2020; Van Sieleghem et al., 2022), lower maternal sensitivity (Cook et al., 2018), less adequate interaction distance with the child (Ionio and Di Blasio, 2014), and more complications with the mother-infant bonding (Stuijfzand et al., 2020; Devita et al., 2023). Secondly, such high levels of maternal stress also impact on regular physical contact with the infant and breastfeeding initiation and duration (Garthus-Niegel et al. 2018), all of which might negatively influence early infant development (Cook et al., 2018; Garthus-Niegel et al. 2018; Stuijfzand et al., 2020). These changes in parental behavior may result in a lack of buffering stress, causing more negative and less positive infant mood, potentially earlier exhaustion (i.e., resulting in sleepiness), and dysregulated physiological stress responses. To assess such lack of maternal stress buffering, mostly interaction disruption tasks, such as the face-to-face still-face paradigm (FFSF) or its repeated version (FFSF-R) have been used (Haley and Stansbury, 2003; Jones-Mason et al., 2018; Provenzi et al., 2016). Exploratory studies in healthy participants revealed that mothers' vagal tone decreased during the FFSF (as theoretically assumed) and increased during the reunion period when the mother retakes interaction with her infant and soothes the infant (Moore et al., 2009; Ham and Tronick, 2006), whereas it remains unstudied for mothers with CB-PTSD symptoms.

In parallel, infants experience more distress when maternal buffering is missing and less again when mothers reengage with their infant and positively respond to its emotional state (Mesman et al., 2009; Moore et al., 2009; Jones-Mason et al., 2018; Abney et al., 2021). This stress perception is accompanied by a suppression of vagal tone and a reactivation during the reunion period, according to the polyvagal theory (Porges, 2007) empirically confirmed in infants during a FFSF (Moore et al., 2009; Jones-Mason et al., 2018). Further, infant cortisol release increases during the FFSF paradigm (see meta-analysis of Provenzi et al., 2016), but less in those and their mothers with early childhood trauma (Broeks et al., 2021).

Infants of mothers with CB-PTSD symptoms showed more negative emotions and distress in the relaxing play period than others and more avoidant behavior (Ionio and Di Blasio, 2014), but maternal stress responses remain unclear. Maternal PTSD symptoms are related to chronic maternal stress, which limits the ability to respond adequately to the infant's needs, and buffer the infants' distress through synchronisation of the maternal and the infant's physiological stress systems (DePasquale, 2020), supporting the infant's stress system during its maturation (Abney et al., 2021).

Mother-infant-synchrony is determined by maternal sensitivity (Feldman, 2007). Typically, such high synchrony can be found in resting conditions, such as free play periods (Davis et al., 2018) and relaxing conditions where mothers interact in a caring and supportive way (Coppola et al., 2016). However, it is lower when mothers do not respond to the infant's emotional needs (Coppola et al., 2016).

To the best of our knowledge, besides the exploratory study on behavioral responses (Ionio and Di Blasio, 2014), neither physiological stress responses of mothers with CB-PTSD symptoms and their infants nor mother-infant synchrony in such dyads has been investigated so far. In light of the above, the aim of the study was to investigate perceived stress and physiological stress responses of mothers with PTSD symptoms and their infants and their synchrony. This secondary data analyses aimed at investigating changes in stress responses (perceived stress, behavioral responses and physiological responses) to a still face paradigm of mothers and their infants after traumatic birth experiences. Further, we were interested in investigating whether mother-child synchrony during free play or recovery periods and during the FFSF-R can be found.

2. Material and methods

2.1. Participants

Participants were drawn from a double-blind multi-centre randomised controlled trial (i.e., the Swiss traumatic birth Trial; START) testing the efficacy of an early maternal behavioral intervention on maternal CB-PTSD symptoms (NCT03576586) that involved measurements at $\leq$ 6 hours, $\leq$ 1 week, and 6 weeks and 6 months postpartum (Sandoz, et al., 2019). Mothers and their infants were recruited at the maternity postnatal ward and enrolled in the study at $\leq$ 6 hours postpartum between August 2018 and October 2021 at two Swiss University hospitals (Sandoz, et al., 2019). Mothers were asked to respond to four questions related to maternal perception of traumatic birth (own life threat or infant threat, frightened during birth and feeling helpless during birth) on a 7-point likert scale and in case of showing signs of traumatic birth were recruited for the study. All mothers and their infants were included in the study if the mother (1) had an unplanned caesarean section at $\geq$34-week gestation, (2) had perceived her birth as traumatic, gave (3) birth to a live infant, and (4) provided written informed consent (Sandoz, et al., 2019). Mothers were excluded in case of (1) established intellectual disability or current psychotic illness, (2) limited language skills that did not allow participation in the assessments, (3) a severe maternal or infant illness, (4) a requirement for the infant to have intensive care, or (5) an alcohol abuse and/or illegal drug use during pregnancy (Sandoz, et al., 2019). A total of 146 mother-infant dyads were included in the main study, of which 31 mother-infant dyads completed all assessments at 6 months postpartum.

2.2. Procedures

START procedures were approved by the local research ethics committee (reference no. 2017–02142) and were conducted in accordance with the Declaration of Helsinki. Mothers completed the self-report PTSD Checklist for DSM-5 (PCL-5) (Blevins et al., 2015) to assess maternal CB-PTSD symptoms, gave their written informed consent during hospitalisation and were invited to a testing afternoon with their infant at six months postpartum at the hospital or, if not otherwise possible, at home (e.g., due to Covid-19 restrictions).

The testing afternoon started at 1 pm and included the FFSF-R (Sandoz, et al., 2019) and a set of questionnaire to re-assess CB-PTSD symptoms. After a first welcome and some general instructions about the afternoon, an electrocardiogram (ECG) device was attached to the chest of the mother and the infant. Then mothers were asked to play with their

infant for 15 minutes with always the same set of toys at disposal (Fig. 1); this was considered as the baseline period (C1). This play time was followed by the FFSF-R (Haley and Stansbury, 2003) and at the end by a recovery period where mothers were encouraged to sooth their infant and sit calmly for 30 minutes.

The FFSF-R consisted of a sequence of mother-infant play interaction periods without toys (*A_1, relaxed condition)* followed by alternating still-face periods. A total of three play interactions and two still-face periods (i.e., A_1-B_1-A_2-B_2-A_3 model) with each period lasting 2 min was used (Haley and Stansbury, 2003) (see Fig. 1). In the still-face periods, mothers were unresponsive by showing a neutral facial expression while staring at their infant and not touching their infant (B, stress conditions). During play interaction periods, mothers resumed normal social interactions with their infant, and were allowed to touch and comfort their infant (i.e., first reunion (A_2) and second reunion (A_3)) (Haley and Stansbury, 2003; Provenzi et al., 2016). Before the FFSF-R, mothers received instructions, but were left alone with their infants in the experimental room during the task.

Infant and maternal behaviors were recorded during baseline and during the FFSF-R for quality reasons. Cameras were discreetly placed in the corners of the experimental room and mothers were instructed that they could stop at any time if infant distress levels became unbearable. During the testing, psychophysiological measures were taken at different time points (see Fig. 1), including cortisol sampling during baseline (5 min before FFSF-R (C1)), and during recovery to identify the cortisol peak (at mid-recovery (+10 min for mother, +18 min for infant), and late recovery (at +28 min after the FFSF-R for both) (C2 and C3). Infant behavioral stress responses (IPS) and maternal perceived stress (MPS) was assessed during baseline, after the FFSF-R and recovery.

2.3. Measures

2.3.1. CB-PTSD symptoms

Maternal CB-PTSD symptoms were assessed with the self-report PTSD Checklist for DSM-5 (PCL-5) (Blevins et al., 2015). The PCL-5 is a 20-item self-report questionnaire measuring PTSD symptoms over the past month according to the DSM-5 and assesses the four symptom clusters of PTSD (range: 0–80; higher scores indicate greater symptom severity). Instructions were updated so that the assessed symptoms were specifically related to the unplanned caesarean section. A symptom is considered present when the corresponding item is scored≥2. The internal validity of the PCL-5 was excellent (Cronbach's α=0·92).

2.3.2. Salivary cortisol

Infant and maternal salivary cortisol was collected three times (at baseline (5 min before FFSF-R for mother and infant), at mid recovery period after the stress condition (+10 min for mother, +18 min for

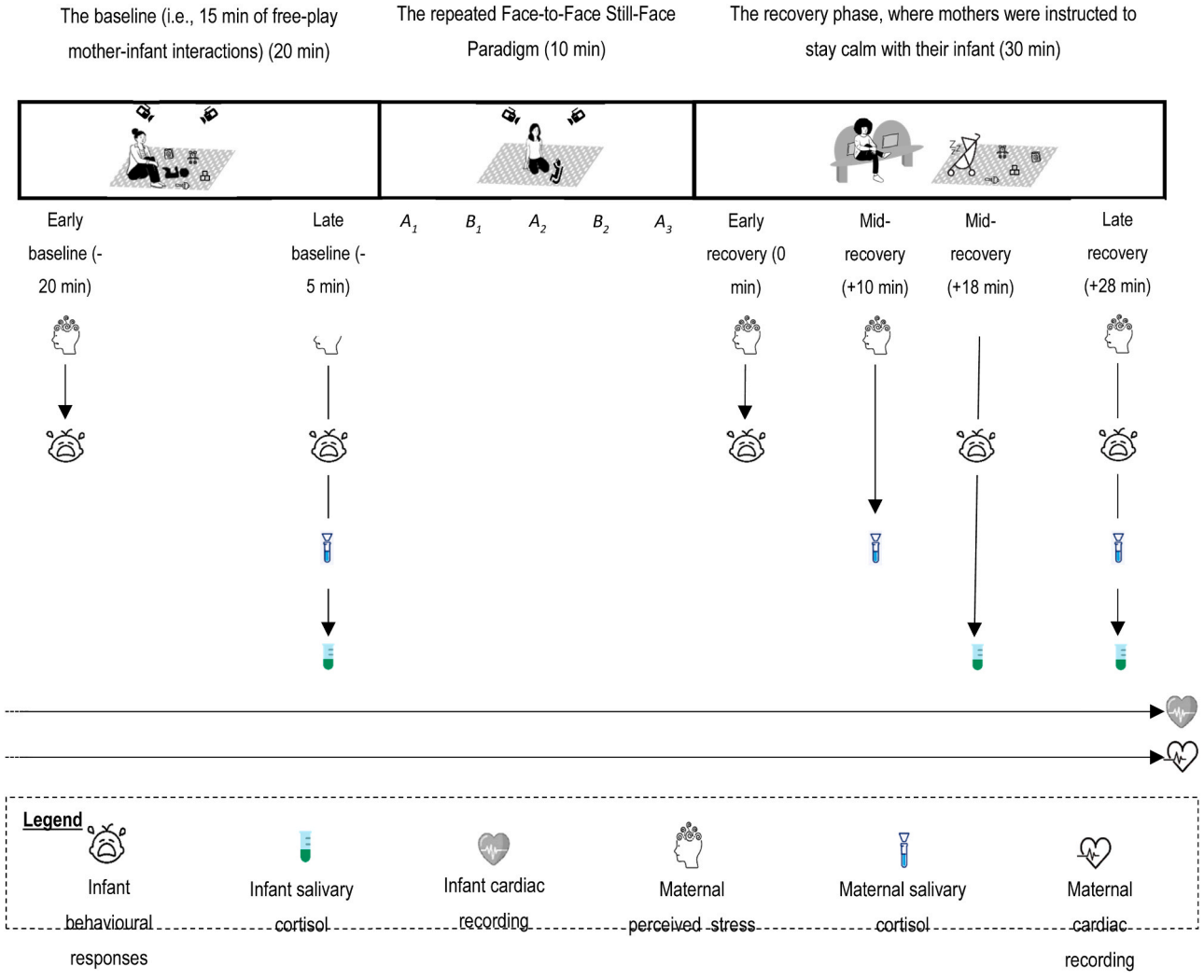

Fig. 1. The testing procedure and measurements. A_1, B_1, A_2, B_2, and A_3 = 2-min episodes of the repeated face-to-face still-face paradigm, with A_1 referring to normal play interaction, B_1 and B_2 to still-face episodes, and A_2, and A_3 to reunion episodes.

infant), and late recovery (at +28 min after the FFSF-R for both)) by using Salivette® (Sarstedt, Sevelen, Germany) and SalivaBio Infant's Swab (Salimetrics, State College, USA) (Fig. 1). Mid recovery sampling of the mother and infant were both taken during a 10 min comforting and free play period, but sampling was not possible in parallel, as infants were upset and comforting them was first needed before they could tolerate the swabs. Maternal and infant samples were taken in parallel, and each sampling lasted approximately 90 seconds for infants and 60 seconds for mothers. Prior to assessment, mothers were asked not to eat or drink 30 minutes before saliva sampling and to avoid breastfeeding during the testing. Saliva samples were frozen and stored at ≤20°C until analysed at the biochemical laboratory of the Clinical Psychology and Psychotherapy Department at the University of Zurich (Switzerland), where luminescence immunoassay based on the competition principle was used for assaying cortisol levels (nmol/L) (IBL, Hamburg, Germany). Inter- and intra-assay coefficients of variance of cortisol were ≤ 5 %.

2.3.3. Heart rate variability

The ECG device Firstbeat Bodyguard 2© (Firstbeat Technologies Ltd., Jyväskylä, Finland) was used to record cardiac activity continuously via a portable device with two electrodes placed on the mother's and infant's chest (Fig. 1). Data was analyzed using Kubios HRV Standard software (ver. 3.2.0). Artefacts were visualized and treated with Kubios' artefact correction where needed. Time-domain parameters were calculated for selected 2-minutes recordings at different time points throughout the testing using the Fast Fourier Transformation, to define root mean square of successive RR intervals differences (RMSSD; ms) representing vagal tone. Hence, eight 2-minutes recordings were chosen for analysis: one during late baseline, one during each episode of the FFSF-R (A_1, B_1, A_2, B_2, and A_3), and one at mid- and late recovery.

2.3.4. Infant behavioral stress response

Infant behavioral response was assessed by a trained researcher who observed and rated the infant current alertness using the alertness scale of the Brazelton Neonatal Behavioral Assessment Scale (Brazelton and Nugent, 2011) at different time points during the testing session. The scale includes six different states of alertness with 1 = *deep sleep state*, 2 = *light sleep state*, 3 = *drowsy state*, 4 = *awake, alert state*, 5 = *fussy state*, and 6 = *crying state*. Assessment of these states of alertness was done by two raters using the video recordings of the sessions.

For statistical purposes, we transformed these behaviors into "sleeping" (i.e., state of alertness 1, 2, and 3), "positive mood" (i.e., state of alertness 4) and "negative mood" (i.e., state of alertness 5 and 6). The "sleeping" modality was disregarded from the analysis, as its frequency was not high enough to consider further.

2.3.5. Maternal stress perception

Mothers were repeatedly asked to respond to the question "*To what extent do you feel stressed at the moment?*" using a visual analogue scale rating from 1 = *not at all stressed* to 5 = *extremely stressed* (Fig. 1) (Sandoz et al., 2021).

2.3.6. Psychosocial and medical information

Maternal age at childbirth, maternal education level, and maternal civil status were collected via self-report and data on gestational age and infant age was retrieved from medical records.

2.4. Statistical analysis

Analyses were conducted with R v4.0.2 (R Core Team, 2021). Missing values ranged from 0 to 9 (i.e., 29 % of the observations), depending on the variable and time points, and were imputed using multiple imputation techniques (i.e., Additive Regression, Bootstrapping, and Predictive Mean Matching from the Hmisc v4.5–0 package). There was no selective attrition and missing values were due to problems in cortisol sampling or insufficient data quality of ECG measure. Outliers were identified at the variables in scope and dyad (mother/infant) level using the 75th percentile - 25th percentile interval ±1.5*IQR and ±3*IQR threshold. They were then winsorized (i.e., low values were replaced by the 5th quantile and high values by the 95th quantile).

To analyse maternal and infant psychophysiological stress responses to the FFSF-R, linear Mixed Effect (LME) models were calculated to detect the main effects of time while controlling for the effect of group (i.e., intervention *vs.* control), and taking into account the random effect of the participants (i.e., either the mother or the infant). Effect sizes were estimated with eta squared and power analysis was based on 200 simulations. Further, contrast analyses were performed using pairwise comparisons of estimated marginal means. For the infant time effect, only the "positive mood" and "negative mood" were used, with the "positive mood" modality being interpreted as no stress and the "negative mood" as stress. Proportion differences of infant behavioral stress response were assessed with G-Tests (G-tests are likelihood-ratio or maximum likelihood statistical significance tests), and the effect size was measured as Cramer's V. The relationship between the perceived stress for mothers/ infant behavioral response and the stress phases, controlling for group, was assessed using a logistic regression. Finally, the associations between maternal and infant physiological stress responses patterns were measured using Linear Mixed Effect models (LME), considering the nested structure of the data, and effect sizes were estimated with eta squared. We used standardized scores, two-tailed significance, and $\alpha < .05$ for all statistical tests.

3. Results

A total of 31 mothers with a mean age of 33.48 years (SD = 4.53) and their infants (mean age 6.01 months, SD = 0.21) participated in this study. CB-PTSD symptoms in participants ranged from M=9.10 (SD= 9.75) at 6 weeks to M=8.47 (SD=9.95) at 6 months. Descriptive values of the sample are shown in Table 1.

All mothers had experienced a traumatic birth and reported CB-PTSD symptoms. Mean values of physiological stress responses before, during and after the task and perceived stress levels of mothers are presented in Table 1.

Infant behavioral responses during the testing were assessed through changes in negative and positive mood and sleeping behavior after the FFSF condition. (see Table 2). More children showed negative mood during early recovery than during any other period, whereas the number of children showing positive mood decreased over the time and did not completely return to the same level as before the FFSF-R. Sleeping was only prevalent in a few children at baseline and early after the task, but slightly increased during late recovery period and could not be taken into consideration for any further data analysis.

3.1. Maternal stress responses

As illustrated in Table 3, analyses of maternal stress responses showed a significant time effect for salivary cortisol, HR, RMSSD, and perceived stress in mothers with CB-PTSD symptoms. In detail, a large time effect was found for maternal cortisol, but contrary to our hypothesis, cortisol decreased from baseline to 10 min post-stress, where an increase would be expected (C1 and C2) (see Fig. 2). In addition, a moderate time effect was also revealed for maternal RMSSD ($F(7, 210) = 3.87$, $p = .001$, partial $\eta 2 = 0.11$), with a RMSSD mean increase from baseline to the first still-face period of the FFSF-R (B_1), and further a decrease at late recovery 2.

Finally, a large time effect was found for maternal perceived stress ($F(4, 120) = 5.38$, $p < .001$, partial $\eta 2 = 0.15$). Contrast analysis revealed a significant increase of maternal perceived stress during the FFSF-R, followed by a decrease during recovery. Fig. 2 display maternal means of physiological stress reactivity and pereived stress during the different

Table 1
Descriptives of the study sample (n = 31).

Variable		Intervention		Control		Total sample	
		N	M (SD)	N	M (SD)	N	M (SD)
Parity							
	0	6		9		15	
	1	3		8		11	
	2	3		1		4	
	3	1		0		1	
Gravidity							
	1	8		7		15	
	2	2		8		10	
	3	1		2		3	
	4 and more	2		1		3	
Gestational age		13	40.05 (1.17)	18	39.79 (1.76)	31	39.9 (1.52)
Civil status							
	single	1		7		8	
	couple	11		11		22	
	separated	0		0		0	
Education							
	Apprenticeship completed	2		4		6	
	University completed	9		13		22	
	other	1		1		2	

Table 2
Infant and maternal psychophysiological stress response characteristics (n = 31).

Variables	Infants			Mothers		
	Intervention (n=13) *M* (*SD*)	Control (n=18) *M* (*SD*)	Total (n=31) *M* (*SD*)	Intervention (n=13) *M* (*SD*)	Control (n=18) *M* (*SD*)	Total (n=31) *M* (*SD*)
Salivary cortisol [nmol/L]						
Late baseline (C1)	3.2, (1.47)	2.34, (1.19)	2.7, (1.36)	2.3, (1.11)	1.61, (0.89)	1.9, (1.03)
Mid-recovery (C2)	3.4, (2.01)	2.84, (1.67)	3.07, (1.81)	1.8, (0.73)	1.43, (0.79)	1.59, (0.77)
Late recovery (C3)	3.2, (1.81)	2.76, (2.02)	2.94, (1.92)	1.67, (0.79)	1.12, (0.55)	1.35, (0.7)
RMSSD [ms]						
Late baseline	10.29, (4.79)	11.8, (4.8)	11.16, (4.78)	27.62, (17.3)	30.43, (15.37)	29.25, (15.98)
A_1	13.78, (4.13)	13.51, (3.45)	13.62, (3.69)	29.07, (15.34)	33.36, (13.55)	31.56, (14.24)
B_1	12.89, (4.81)	12.32, (4.85)	12.56, (4.76)	42.16, (26.94)	39.4, (28.26)	40.56, (27.29)
A_2	12.68, (9.14)	12.59, (5.44)	12.63, (7.09)	31.13, (17.18)	34.3, (20.15)	32.97, (18.72)
B_2	11.48, (5.16)	12.29, (4.63)	11.95, (4.79)	32.36, (19.2)	32.85, (13.82)	32.64, (15.99)
A_3	10.62, (5.07)	12.96, (3.95)	11.98, (4.53)	29.19, (14.2)	28.89, (10.86)	29.01, (12.15)
Mid-recovery	10.48, (4.8)	12.03, (5.47)	11.38, (5.17)	31.73, (14.13)	37.55, (15.22)	35.11, (14.82)
Late recovery	15.44, (10)	14.15, (10.61)	14.69, (10.21)	31.17, (15.96)	32.06, (12.18)	31.69, (13.65)
Maternal perceived stress						
Early baseline	-	-	-	1.85, (0.88)	1.39, (0.7)	1.58, (0.8)
Late baseline	-	-	-	1.31, (0.63)	1.28, (0.67)	1.29, (0.64)
Early recovery	-	-	-	2.23, (1.01)	1.89, (1.23)	2.03, (1.14)
Mid-recovery	-	-	-	1.46, (0.66)	1.33, (0.49)	1.39, (0.56)
Late recovery	-	-	-	1.5, (0.87)	1.36, (0.68)	1.42, (0.75)

Note: A_1, B_1, A_2, B_2, and A_3 = 2-min episodes of the repeated face-to-face still-face paradigm, with A_1 referring to normal play interaction, B_1 and B_2 to still-face episodes, and A_2, and A_3 to reunion episodes; C1 = 1st salivary cortisol sample at the end of the baseline; C2 = 2nd salivary cortisol sample during mid-recovery; C3 = 3rd salivary cortisol sample during late recovery; RMSSD = root mean square of successive RR interval differences.

Table 3
Infant behavioral responses (n=31 infants).

Stress phases	Negative mood			Positive mood			Sleeping		
	Intervention	Control	Total	Intervention	Control	Total	Intervention	Control	Total
Early baseline	0	1	1	11	16	27	2	0	2
Late baseline	3	3	6	8	14	22	2	1	3
Early recovery	5	7	12	6	9	15	2	2	4
Mid-recovery	3	4	7	7	11	18	2	2	4
Late recovery	3	2	5	5	10	15	4	4	8

phases of the FFSF-R paradigm.

3.2. Infant stress responses

Analyses on infant stress responses revealed a large time effect for infant HR ($F(7, 210) = 4.69$, $p < 0.001$, partial $\eta 2 = 0.02$) and a medium time effect (Cramer's $V = 0.317$) for behavioral responses stress ($G = 14.253$, $p = .007$). No significant time effects were found for infants' salivary cortisol or RMSSD values (Fig. 2).

A logistic regression of the infant behavioral responses to stress against time revealed that compared to early baseline, the odds of expressing a positive mood decreased by 86.47 % at late baseline (p

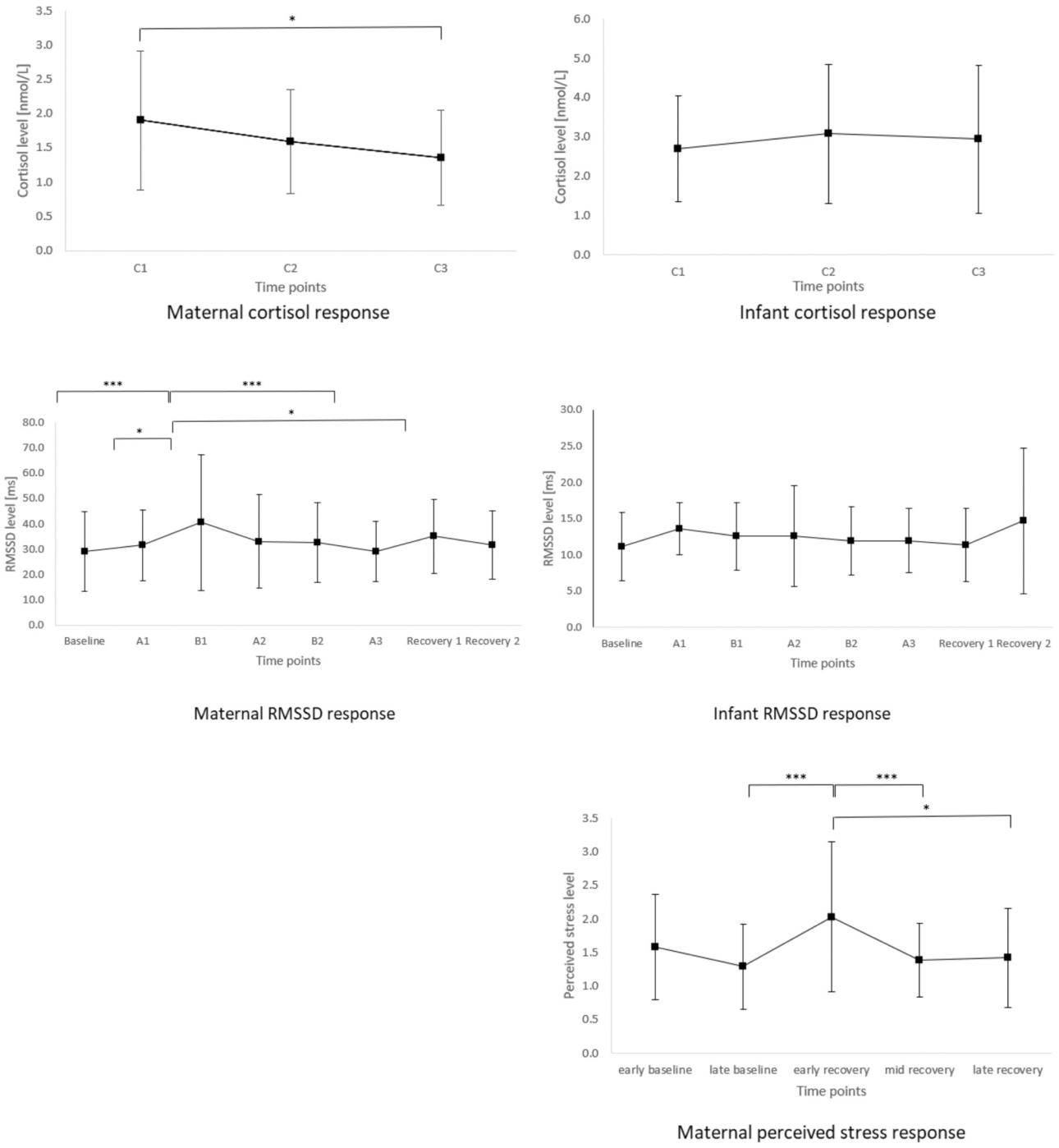

Fig. 2. Infant and maternal stress responses. Square points represent the response means, and the vertical bars represent the response standard deviations. Significance: p <.001 ***; p <.01 **; p <.05 *. A_1, B_1, A_2, B_2, and A_3 = 2-min episodes of the repeated face-to-face still-face paradigm, with A_1 reflects free-play interaction, B_1 *and* B_2 reflects still-face episodes, and A_2 and A_3 reflects reunion episodes; C1, C2, C3 = salivary cortisol sample at baseline, mid- and late recovery period; EE1, EE2, EE3, EE4, and EE5 = infant perceived stress measurement at baseline (EE1 and EE2) and recovery (early (EE3), mid (EE4) and late (EE5); RMSSD = root mean square of successive RR interval differences during different periods (before, during and after the FFSF-R); VAS1, VAS2, VAS3, VAS4, and VAS5 = maternal perceived stress measurement during baseline (early (VAS1) and late baseline (VAS2) and during recovery (early (VAS3), mid (VAS4) and late recovery (VAS5)). Note: The labeling of the Y-axes differs between infant and maternal outcomes for illustrative purposes.

=.07), by 95.40 % at early recovery (p <.001), by 90.46 % at mid-recovery (p =.03), and by 88.92 % at late recovery (p =.05) (Table 4), with a medium effect size (Cramer's V = 0.317).

3.3. Relation between maternal and infant physiological stress responses

Analyses of the LME model investigating the influence of maternal stress responses on infant stress responses (with time point as fixed effect and the dyad as a random effect to account for the dependency between observations from the same dyad) revealed a significant interaction effect only for RMSSD ($F(7, 208.57) = 2.404$, $p = .022$) (see Table 4). More specifically, maternal and infant RMSSD responses at the first reunion period (A_2), were associated ($\beta = 0.216$, $p < .001$), but not for any other time period. No significant interaction effects were found for salivary

Table 4
Time and group effects (n = 31).

Indice	Participants	Group effect	Time effect	Time effect size	Power (Time effect)
Cortisol	Infant	F(1, 29) = 1.53, p = 0.225	F(2, 60) = 0.75, p =.478	0.02 [0,1]	19.7 [17.28, 22.3]
	Mother	F(1, 29) = 4.48, p = 0.043	F(2, 60) = 8.78, p <.001	0.23 [0.077, 1]	97.2 [95.98, 98.13]
RMSSD	Infant	F(1, 29) = 0.14, p = 0.715	F(7, 210) = 1.7, p =.109	0.06 [0,1]	70.3 [67.36, 73.12]
	Mother	F(1, 29) = 0.12, p = 0.733	F(7, 210) = 3.87, p =.001	0.11 [0.034, 1]	97.4 [96.21, 98.29]
Perceived stress	Mother	F(1, 29) = 1.48, p = 0.233	F(4, 120) = 5.38, p =.001	0.15 [0.048, 1]	96.3 [94.94, 97.38]

Note. Time effect sizes are expressed in term of partial eta squared ($\eta 2 > 0.01$ indicates a small effect; $\eta 2 > 0.06$ a moderate effect; $\eta 2 > 0.14$ a large effect. Power was calculated based on 200 simulations. RMSSD = root mean square of successive RR interval differences.

Table 5
Influence of maternal physiological stress responses on infant physiological stress responses.

Indice	Mother outcome effect	Time effect	Mother outcome * Stress phases
Cortisol	F(1, 84.099) = 0.014, p =.906	F(2, 60.692) = 0.669, p =.516	
			F(2, 61.984) = 1.313, p =.276
RMSSD	F(1, 169.99) = 0.639, p =.425	F(7, 203.61) = 1.771, p =.095	
			F(7, 208.57) = 2.404, p =.022

Stress phase	Estimate	Std. Error	t value	Pr(>|t|)
Late baseline	0.0341	0.0552	0.6185	.5411
A_1	0.0538	0.0470	1.1449	.2616
B_1	−0.0259	0.0320	−0.8099	.4246
A_2	0.2157	0.0577	3.7369	.0008
B_2	0.0109	0.0556	0.1968	.8454
A_3	0.0553	0.0684	0.8076	.4259
Mid-recovery	0.0620	0.0638	0.9712	.3395
Late recovery	0.1156	0.1372	0.8429	.4062

Note: Mother outcome * Stress phases is the interaction of maternal outcome effect and stress phases effect. F tests are type II Wald F tests with Kenward-Roger df. Estimates are beta coefficients related to maternal outcomes. A_1, B_1, A_2, B_2, and A_3 = 2-min episodes of the repeated face-to-face still-face paradigm, with A_1 referring to normal play interaction, B_1 and B_2 to still-face episodes, and A_2, and A_3 to reunion episodes; RMSSD = root mean square of successive RR interval differences.

cortisol.

4. Discussion

This observational lab-based study as part of the study protocol of START investigated perceived stress and physiological stress responses of mothers after traumatic childbirth and their infant during an experimental stress task (the FFSF-R) and the mother-infant synchrony of these responses. The results showed that there was a significant time effect in maternal stress responses for salivary cortisol, vagal tone, and perceived stress in mothers with CB-PTSD symptoms, although unexpectedly, cortisol decreased from baseline to 10 min post-stress. Analyses on infant stress responses revealed time effects for behavioral stress responses. No significant time effects were found for infants' salivary cortisol or RMSSD values. Further, in terms of mother-infant synchrony, there was only a significant interaction effect for RMSSD during the first reunion period (A_2) of the FFSF-R.

4.1. Stress responses of mothers with CB-PTSD symptoms

There was no increase in salivary cortisol in response to the FFSF-R, as mothers started with relatively high levels of cortisol already at baseline. It is likely that this increased HPA activation may have been linked to them anticipating their participation in a research study. Furthermore, the fact that their infant participated as well might have been an additional source of stress, augmenting the mean baseline salivary cortisol level. Moreover, the stress paradigm was carried out as part of a whole afternoon of study assessments and the baseline period was part of a filmed free-play interaction with their infant. It is possible that mothers might have found it stressful to be filmed whilst interacting with their infant, as they may have worried about being judged with regards to their parenting competencies. Perhaps an appropriate salivary cortisol baseline could have been obtained by carrying out a baseline period without the interaction being filmed. Additionally, a study found diminished blood cortisol responses in breastfeeding mothers at two months postpartum (Bauer et al., 2020). These results may have been relevant for our sample, as most mothers still breastfed their infant, even if not exclusively anymore. Our results are somewhat in line with an experimental study showing that mothers at risk of CB-PTSD compared to those at low risk of CB-PTSD showed lower salivary cortisol release in response to an infant crying stress paradigm (Sandoz et al., 2021). They are also comparable to a sample of mothers with PTSD following interpersonal violence who, compared to healthy controls, showed blunted cortisol reactivity to a laboratory stressor (Cordero et al., 2017). Interestingly, this latter study also found that the HPA-axis dysregulation characterized by low cortisol reactivity was additionally associated with reduced activation of emotion processing brain areas and parenting impairment in response to child stress (Cordero et al., 2017). Whilst interacting with their infant, low maternal cortisol reactivity may negatively impact maternal behavior, as cortisol in response to stress enhances amygdala connectivity, the medial prefrontal cortex, and other areas that are important for emotional processing (Quaedflieg et al., 2015), such as the identification of facial expression of emotion. Another study reported that low maternal cortisol was associated with a lack of sensitivity to distressed infant cues (Crockett et al., 2013). Further, severely disrupted maternal communication during the still-face paradigm was associated with a greater divergence between maternal and infant cortisol levels (Crockett et al., 2013).

Findings of this study revealed a significant increase of subjective stress in mothers during the FFSF-R, followed by a decrease during the recovery period. This clearly indicates that mothers experienced the FFSF-R paradigm, which was originally designed to elicit stress responses in infants, as stressful. This increased subjective stress response is comparable to the above-mentioned sample of mothers at risk of developing CB-PTSD (Sandoz et al., 2021). Vagal tone (measured by RMSSD values) changed between baseline and the first still-face period of the FFSF-R, as described in previous studies (e.g., Ham and Tronick, 2006; Moore et al., 2009). This finding confirms theoretical assumptions that during maintenance of neutral expressions, and therefore

abstaining from social engagement, results in an increase of vagal tone in mothers. However, there was no significant change of vagal tone at the point where the still-face period was repeated. We assume that this second non-adaptation of vagal tone might be related to limited resources of mothers with CB-PTSD symptoms which cause limited flexibility of maternal vagal tone to adapt stressful conditions when repeated. However, there is no data on the maternal response of a repeated FFSF and comparisons are therefore not possible. Further, during the second period of the reunion, we found that mothers showed a non-significant decrease in vagal tone, which is consistent with the idea to respond to the distress of the child and reengage and sooth it (Ham and Tronick, 2006). Such non-responsiveness to a still-face challenge has been described in depressed individuals (Rottenberg et al., 2003; Gentzler et al., 2009), and might be related to the altered chronic stress level and increased dopamine and norepinephrine concentrations, all of which influence vagal tone.

4.2. Stress responses of infants

There was no significant change in the infant's salivary cortisol in this sample, confirming the results of a study on infants of mothers with severe postpartum mental health problems where cortisol showed less increase in response to a stress task (Broeks et al., 2021). Such reduced adaptation is in line with the intergenerational transmission that has been discussed in the literature (Bowers and Yehuda, 2016) and emphasizes the association of a maternal trauma on the child's stress physiology. Further, the traumatic birth itself or the birth procedure might also have affected the infant's stress responses.

In parallel to the lack of cortisol reactivity, there was no clear change of the child's vagal tone during the FFSF-R paradigm, as is expected in healthy samples (see review Jones-Mason et al., 2018). However, two previous studies found a similar non-suppression of the vagal tone during FFSF (Montirosso et al., 2014; Provenzi et al., 2015), which might be related to the fact that half of the infants (50–55,3 %) did not suppress vagal tone (Montirosso et al., 2014; Provenzi et al., 2015). This can prolong infants' stress levels and negative mood (Provenzi et al., 2015) and take longer to express neutral or positive mood (Provenzi et al., 2015), indicating less optimal mother-child-interactions and lower levels of dyadic synchrony (Moore and Calkins, 2004), as well as less maternal sensitivity. These extended influences on mood were also found in our study where infants showed a consistent decrease in positive mood over the testing afternoon.

4.3. Relations between maternal and infant physiological stress responses

Our results on the influence of maternal stress responses on infant stress responses showed a significant interaction effect only for vagal tone/ RMSSD (but not for salivary cortisol), specifically at the second reunion period, but not at any other time period. Previous studies have shown that infants of more synchronous dyads managed better affect regulation to a stressor, as assessed by changes in affective behaviors and vagal tone (e.g., (Moore and Calkins, 2004; Pratt et al., 2015). The mother's own physiological regulation of vagal activity also influenced her infant's behavior and physiology (e.g., Leerkes et al., 2016; Moore et al., 2009). Research focusing on mother-infant physiological synchrony in mothers with mental health problems is scarce. Heart rate synchrony was reported to not differ between mothers with or without depression, although the total sample size was small (n = 16) (Field et al., 1989). Mother-infant dyads with mothers reporting higher maternal anxiety showed higher synchrony in physiological arousal (Smith et al., 2021). So far, our study is the first to study mother-infant physiological regulation in mothers with CB-PTSD symptoms.

4.4. Strengths and limitations

To our knowledge, this is the first study investigating mothers with CB-PTSD symptoms and their infants' stress responses in a validated lab-based stress paradigm. Based on the limited evidence, this theory-driven study used an exploratory approach which contributes to the better understanding of intergenerational transmission of stress-and trauma-related consequences. Further studies will be needed to confirm the results and improve the understanding of mother-infant physiological responses after traumatic birth. A strength of the study is the detail of assessment, including parallel measurements of maternal and infant responses by considering biological, subjective and behavioral dimensions and continuous measures of CB-PTSD symptom severity. Further, preterm infants had been excluded from study participation and therefore the impact of preterm on physiological stress responses could be controlled for.

There are several limitations in this study. Firstly, the sample size was relatively small and did not allow to distinguish between the intervention and non-intervention group or investigate any moderator or influencing factor (e.g. pre-pregnancy trauma), although the sample size is comparable to other published studies (Provenzi et al., 2016).

Furthermore, hormonal activation, which is triggered during breastfeeding, can influence the cortisol release, and blunt the cortisol response within the hour following breastfeeding. As mothers were allowed to breastfeed just before the experiment, this might have influenced our results, but mothers stayed on their own with the child and data on breastfeeding was not collected. Further, the relevance of maternal sensitivity on the mother-infant interaction during a still face paradigm has recently been shown (Fuertes et al., 2024) but due to the low quality of video recordings, analysis of video material was not possible. Although the FFSF paradigm was clearly explained to the mothers, we observed that a few mothers had difficulties to show a neutral expression to their infant and to only sooth him/ her when allowed. In addition, being exposed to a stressful task and being filmed at the same time, could have produced more pronounced stress responses than those occurring in a daily context. Future studies should aim to have a larger sample size and confirm the differential response to repeated stressors. Finally, it would be helpful to compare mother-infant dyads with CB-PTSD symptoms with those without regarding their stress responses and to investigate the long-term impact on the infant's development.

5. Conclusion

This study provides first evidence on the association of CB-PTSD symptoms and maternal and infant stress responses. Although mothers' and infants' subjective stress response was adequate, physiological stress responses were limited, which might indicate a dysregulation of the stress response system that can impact on the mother's and infant's mental health in the long term. The findings might help to better understand that these mothers and their infants show a higher vulnerability due to their limited adaptation to stress conditions and the related increased risk calls for a close monitoring of these dyads and an early intervention.

CRediT authorship contribution statement

Camille Deforges: Writing – review & editing, Writing – original draft, Project administration, Data curation, Conceptualization. **Alain Lacroix:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Formal analysis. **Nadine Messerli-Bürgy:** Writing – review & editing, Writing – original draft, Validation, Supervision, Methodology, Conceptualization. **Vania Sandoz:** Writing – review & editing, Writing – original draft, Visualization, Project administration, Data curation, Conceptualization. **Antje Horsch:** Writing – review & editing, Writing – original draft, Validation, Supervision, Project administration, Methodology, Funding acquisition, Conceptualization. **Nicole Sekarski:** Writing – review & editing, Validation, Supervision, Conceptualization.

Declaration of Competing Interest

None

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