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Autonomic Functioning in Mothers With Interpersonal Violence-Related Posttraumatic Stress Disorder in Response to Separation–Reunion

ABSTRACT: *This study characterizes autonomic nervous system activity reactive to separation–reunion among mothers with Interpersonal Violence-Related Posttraumatic Stress Disorder (IPV-PTSD). Heart-rate (HR) and high frequency heart-rate-variability (HF-HRV) were measured in 17 IPV-PTSD-mothers, 22 sub-threshold-mothers, and 15 non-PTSD mother-controls while interacting with their toddlers (12–48 months). Analyses showed IPV-PTSD-mothers having generally lower HR than other groups. All groups showed negative correlations between changes in HR and HF-HRV from sitting- to standing-baseline. During initial separation, controls no longer showed a negative relationship between HR and HF-HRV. But by the second reunion, the negative relationship reappeared. IPV-PTSD- and sub-threshold-mothers retained negative HR/HF-HRV correlations during the initial separation, but stopped showing them by the second reunion. Results support that mother-controls showed a pattern of autonomic regulation suggestive of hypervigilance during initial separation that resolved by the time of re-exposure. PTSD-mothers showed delayed onset of this pattern only upon re-exposure, and were perhaps exhibiting defensive avoidance or numbing during the initial separation/reunion. © 2013 Wiley Periodicals, Inc.* Dev Psychobiol 56: 748–760, 2014.

Keywords: *maternal PTSD; interpersonal violence; parenting; heart-rate; heart-rate variability; stress physiology; emotion regulation; co-activation*

INTRODUCTION

In the United States alone, interpersonal violence (IPV) is quite prevalent. Over one million women are victims of physical assault by an intimate partner yearly (U.S. Department of Justice, Bureau of Justice Statistics, "Intimate Partner Violence in the United States," December 2006). Many of these women have also been victims of sexual assault, as well as child physical and/or sexual abuse. As many as 56% of women who have experienced exposures to IPV develop related posttraumatic stress disorder (PTSD; Rees et al., 2011). PTSD is essentially a disorder of dysregulation of emotion and arousal (Blechert, Michael, Vriends, Margraf, & Wilhelm, 2007). Affected adults who are parents can have additional difficulties that interfere with their relationship with their young children. For example, mothers' participation in the emotional and physiologic co-regulation with their children is essential to the subsequent development of capacities for self-regulation and prosocial behavior (Fonagy & Target, 2005;

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Oosterman & Schuengel, 2007). It is thus likely that the psychophysiology of PTSD-affected mothers may impair a developmentally critical maternal function that can negatively impact the intergenerational transmission of violence and violent traumatization. In this study, we aimed to understand what characterizes autonomic nervous system (ANS) functioning among mothers suffering from Interpersonal Violence-Related Posttraumatic Stress Disorder (IPV-PTSD) in response to the salient interpersonal stressors of separation and reunion with their toddlers.

ANS functioning within this population and particularly in response to the interpersonally stressful condition of mother's separation from their toddlers versus the non-stressful condition of free-play with their toddlers was important to study for several reasons: Prior studies have shown that mothers suffering from IPV-PTSD differ from non-PTSD controls in terms of their caregiving behavior, HPA-axis stress reactivity (i.e., salivary cortisol response), and neural activity in response to mother–child separation. Yet little is known about ANS functioning among IPV-PTSD mothers. Caregiving behavior in terms of maternal responsiveness to child social bids was inversely correlated with maternal IPV-PTSD symptom severity (Schechter et al., 2010). Maternal salivary cortisol response among mothers with histories of child maltreatment and PTSD was found to reflect hyporeactivity to the laboratory stressor of mother–child separation with child car-seat restraint during the first year of life (Brand et al., 2010). Maternal neural activity in response to viewing videotaped scenes of mother–child separation and play in the MRI-scanner among IPV-PTSD mothers compared to non-PTSD controls was characterized by significantly less medial prefrontal cortical activity and greater limbic activity (Schechter et al., 2012).

ANS functioning in response to the interpersonal stressor of mother–child separation in IPV-PTSD mothers thus remains a heretofore unexplored area that clearly could be informative as to the precise nature and extent of these women's difficulties in day-to-day mother–child interactions. If one hypothesizes that mothers with IPV-PTSD are more vulnerable than non-PTSD controls to the triggering of a hypervigilant state of mind during routine interactions that lead to anticipated or actual child distress, then we would expect the ANS to reflect the physiologic correlate of hypervigilant state of mind. The examination of the relationship between maternal heart-rate (HR) and heart-rate variability (HRV), specifically at high frequencies during mother–child separation in the laboratory might therefore lead to better understanding of how IPV-PTSD mothers view and interact with their children during routine interpersonally stressful moments, which in turn could lead to improved intervention.

Given that one crucial aspect of such disturbances may well be avoidance of child distress that is perceived as a threatening stimulus, IPV-PTSD mothers may have more difficulty in setting limits with their toddler's normative hostile aggression (Cohen, Hien, & Batchelder, 2008; Schechter et al., 2008). It is currently thought that the development of later conduct disorder involving enactment of IPV is directly linked to the primary caregiver's difficulty in containing and setting limits with children's normative hostile aggression during the first 5 years of life. (Tremblay et al., 2004). Thus, identification of maternal patterns of ANS functioning linked to the presence of IPV-PTSD during stressful parent-child interactions such as mother–child separation is crucial to understand potential biobehavioral mechanisms of intergenerational transmission of violence and related trauma within families.

PTSD in Adults and Autonomic Nervous System Physiology

Generally speaking, PTSD can be characterized both as (1) a failure of extinguishing and (2) an over-generalizing the fear-response (Rothbaum & Davis, 2003) with the classical symptom triad of re-experiencing, avoidance, and hyperarousal. Typically, the affected individual remains hypervigilant and initiates a fear response to and subsequent avoidance of traumatic reminders. The presence of psychophysiologic symptoms in association with PTSD has led to a body of research on the role of the autonomic nervous system, particularly in adults, often using measurements of HR and HRV as markers of sympathetic and parasympathetic regulation, both at baseline and following stimuli that evoke traumatic memories.

Some studies of PTSD are related to single-event, acute, or otherwise non-IPV type trauma such as a motor vehicle accident, combat exposure, or terrorism. These studies found elevated baseline HR, and greater HR increases and diminished reductions in high frequency HRV to a laboratory stressor (Blanchard, Hickling, & Taylor, 1991). The relatively few studies of patients with repetitive exposures to interpersonally violent (IPV) types of trauma such as child physical and sexual abuse as well as subsequent physical and/or sexual assault during adulthood resulting in PTSD have been characterized differently (see Table 1). Included in Table 1 are only studies that involved control groups and that pertained to IPV consisting of physical and/or sexual assault throughout the life span. The majority of women who suffer from IPV-PTSD have most often experienced violence repeatedly over a prolonged

Table 1. Review of Studies Examining ANS Functioning Among Patients With IPV-PTSD

Comparison of IPV-PTSD vs. Controls in:	Studies	Cause for PTSD in Cases	Stressor	Results
Baseline HR	Schmahl et al. (2004)	IPV		No difference
	Halligan et al. (2006)	IPV		No difference
	Hauschildt et al. (2011)	IPV		No difference
Reaction of HR to a stressor	Shin et al. (1999)	CSA only	Trauma script driven Imagery	Greater HR change in PTSD patients
	Metzger et al. (1999)	CSA only	Startling tones	Greater HR change in PTSD patients
	Lanius et al. (2002)	IPV	Trauma script driven Imagery	No difference in HR change
	Schmahl et al. (2004)	IPV	Trauma scripts auditory	No difference in HR change
	Halligan et al. (2006)	IPV	Assault recall task	Less HR change in PTSD patients
HRV	Hauschildt et al. (2011)	IPV	Trauma-evocative videos	PTSD negatively correlated with HRV
Change in HR relative to change in HRV	No prior studies			

period often beginning during childhood and continuing into adulthood; this group tends to develop chronic PTSD that is also referred to in the literature as "complex PTSD" (van der Kolk, Roth, Pelcovitz, Sunday, & Spinazzola, 2005). For the purposes of simplicity, we refer to this type of PTSD as IPV-PTSD in this paper.

In some studies, IPV-PTSD patients have not shown elevated baseline heart rates compared to controls (Halligan, Michael, Wilhelm, Clark, & Ehlers, 2006; Lanius et al., 2002; Schmahl et al., 2004). Two studies involving subjects exposed to child sexual abuse showed elevated HR in response to a stressor (Metzger et al., 1999; Shin et al., 1999); but three studies that included both physical and sexual violence exposure did not (Halligan et al., 2006; Lanius et al., 2002; Schmahl et al., 2004). One of those studies found a lower HR in response to stressors among IPV-PTSD patients (Halligan et al., 2006). Another study points out that a laboratory stressor that does not directly cue for specific traumatic memories but rather that stimulates the subject's thinking about her traumatic experience, may be associated with a different psychophysiologic pattern of response (Michael, Halligan, Clark, & Ehlers, 2007). This type of stressor involves the subject being placed in a situation in which she is not directly confronted with frightening traumatic reminders but in which she is stimulated to think about her trauma. The latter occurs often via presentation of an associated element or a suggestion to recall the event. This exposure may produce a different pattern of response than having a direct reminder, such as a blatant image of male-female violence. In relation to HRV among IPV-PTSD patients, at least one study showed decreased HRV in response to a stressor (Hauschildt, Peters, Moritz, & Jelinek, 2011). To our knowledge, no prior studies have examined the change in HR relative to change in HRV among IPV-PTSD patients.

Maternal Behavior as Related to IPV-PTSD in Mothers of Very Young Children

Mothers with IPV-PTSD are more likely to display fearful behavior with their young child (Lyons-Ruth & Block, 1996; Schechter et al., 2008). Such behavior can be observed as avoidant or withdrawing behavior during the mother's interactions with her toddler upon reunion in the aftermath of a brief mother–child separation enacted in the laboratory. For example, IPV-PTSD mothers in comparison to non-PTSD controls have been shown not to respond as frequently to their child's bids for joint attention following the laboratory stressor of parent-child separation as they had prior to that stressor (Schechter et al., 2010). And, they had difficulty in setting limits with their child during daily interactions (Cohen et al., 2008). A clinical sample of IPV-PTSD mothers showed a level of avoidant and withdrawing behavior with their toddlers that was positively correlated with the severity of maternal IPV-PTSD symptoms (Schechter et al., 2008).

Previous research has suggested that women with IPV-PTSD, when they become mothers, may develop a fear-response even to their own infants and young children (Schechter et al., 2012). A number of factors make such a response more likely during parenting of infants, toddlers, and preschoolers. This may be related to the fact that infants and pre-school age children do not regulate their emotions, arousal, and aggression well. Their often traumatic outbursts of negative affect accompanied by high arousal when distressed (i.e., acute separation anxiety or a temper tantrum) may frighten a parent with a history of trauma. Moreover, panicked and angry responses in the parent in response to the distressed child may also remind the parent of the perpetrator of the IPV that she had experienced. During routine parent-child separations, the parent's observation of the helpless and frightened emotional expression of the child may resonate with prior experience of violence victimization and/or exposure. Additionally, any physical or gestural resemblance the child has to a perpetrator of violence towards the mother may represent a trigger of maternal traumatic stress.

Mothers with IPV-PTSD typically show both on subjective and objective measures, difficulty in remaining available for the regulation of their very young child's emotion, arousal and aggression particularly in during and immediately following a stressful interaction such as separation from and reunion with mother (Schechter et al., 2010). The child senses a loss of connectedness and can then become more distressed. Porges (2007) has suggested that these behavioral mechanisms both mirror and are mirrored by threats that interfere with the individual's capacity to maintain an "affiliative" mode of functioning. This condition is characterized by greater vagal tone that allows the individual to turn his attention to survival strategies. The latter implies vagal withdrawal and activation of the sympathetic branch of the ANS. What Porges terms "affiliative" when it comes to the parenting of a toddler, implies also the parental function of regulation of emotion, arousal, and aggression, in line with what Tremblay et al. (2004) had described. One study (Oosterman & Schuengel, 2007) demonstrated that in typically-functioning children ages 3–6 years and their mothers, the laboratory stressor of separation is sufficient to elicit vagal withdrawal in the children, but for the these healthy children - and even those with insecure attachment styles - was not sufficient to activate the sympathetic branch of the ANS. The authors interpret the vagal withdrawal as in line with a rupture of the affiliative mode at least for the child and as evidence of the regulatory function of the parent.

IPV-PTSD mothers compared to non-PTSD controls have shown neural activation patterns that suggest less cortico-limbic regulation of arousal and negative emotion in response to reviewing videos of their own and unfamiliar children in separation versus play. These mothers reported a higher subjective feeling of being "stressed" than controls (Schechter et al., 2012). The study of ANS functioning of IPV-PTSD mothers as compared with non-PTSD controls would serve to validate further both behavioral observations and findings related to maternal neural activity in response to viewing separation.

The Current Study

Despite the wealth of psychophysiologic research on adults with PTSD, relatively little attention has been paid to characterizing autonomic function in traumatized mothers during emotionally-charged interactions with their very young children (Hairston et al., 2011; Jovanovic et al., 2011; Tkaczyszyn et al., 2012). In particular, what has not yet been described is maternal physiologic response to stress during separation for those mothers with IPV-PTSD versus controls. Such information could represent a potential biomarker of therapeutic change during or following interventions that aim to help traumatized parents, their infants and young children, and their relationship with them. Accordingly, this study focuses on maternal HR and HRV in response to separation and reunion versus sitting/standing baselines among mothers with IPV-PTSD versus mothers with sub-diagnostic threshold symptoms of PTSD and non-PTSD controls.

We included mothers who displayed sub-diagnostic threshold symptoms as this group of patients is quite frequently seen in clinical settings and very often endures significant suffering and/or impairment even though DSM-IV diagnostic criteria for PTSD are not met. Such patients often have previously met these full diagnostic criteria but with treatment; or due to other factors over time, they no longer meet full criteria. They were included in the comparisons also to test the possibility that this commonly encountered clinical group of mothers would display a similar pattern of autonomic regulation when experiencing interpersonal stress with their child to that of the group of mothers who met full criteria for a diagnosis of current IPV-

PTSD, which would be distinct from that of non-PTSD controls.

Hypotheses

In general, we hypothesized that IPV-PTSD mothers would respond to anticipated or actual child distress upon mother–child separation in the lab with hypervigilance that would be related to an aspect of the interaction triggering PTSD symptoms. We expected that this hypervigilance would be reflected in the characteristics of the mother's HR and HRV. More specifically, we hypothesized that:

(1) Control and IPV-PTSD subjects would not differ with regard to average HR across all periods.
(2) HR would increase during periods of separation from their children in both controls and PTSD mothers, but HR increases would be greater in PTSD mothers.
(3) HF-HRV would be decreased during periods of separation from their children in both controls and PTSD mothers, but the decreases in HF-HRV would be greater in PTSD mothers.

METHODS

Participants and Their Recruitment

Study participants were 54 mothers and their children (18–48 months of age) recruited from community pediatric clinics. All participants were reached through IRB-approved flyers posted on bulletin boards and distributed among staff in the clinics and main medical center buildings. Flyers targeted mothers with children age 1–4 years of age. The flyers did not specify intergenerational violence or child maltreatment as specific stressors of interest so as not to bias the sampling. In a follow-up phone call, research staff stated to the parent that the study was designed to look at how stress in parents' lives affected their relationships with their young children. Participants were compensated with \$50 and toys and/or books for their child. Mothers were adults who suffered no disability that would preclude participation.

Procedures

This project was developed in collaboration with the Hispanic Anxiety Disorders Clinic at the New York State Psychiatric Institute, using the same measures and their translations that were back-translated by Caribbean Spanish native speakers and that had been used, validated, and reliability-tested within this population at NYSPI and at other institutions serving similar communities (Marshall et al., 2007; Schechter et al., 2000). All assessments, included interviews and child–parent observations were conducted by licensed mental health professionals at the Irving Center for Clinical Research, Columbia University Medical Center. All interviews were done in Spanish with those mothers who preferred to be interviewed in Spanish. Permission to conduct this study was obtained from the institutional review board of the Columbia University Department of Psychiatry.

Mothers or their clinicians in the pediatric clinics contacted the research coordinator to make an appointment for informed consent and screening (1 hr). Of the 103 mothers that were screened, 77 completed the clinical visits, out of which 54 had viable autonomic nervous system data. Inclusion criteria included child age, and that the child had spent the majority of his life with mother. Exclusion criteria included active psychosis and-or substance abuse and-or mental or physical disability in mother or child that would adversely impact participation. No women or children were excluded for these reasons. The 26 women that did not participate declined to return for one or both of the videotaped visits following the screening. Twenty-three women did not have valid autonomic nervous system data due to interference with wireless transmission of the ECG signal, or to recording or other mechanical failures preventing reliable acquisition of the signal. Visits included filling out maternal reports about herself and her child as well as evaluation and observation by experienced clinicians. Observations of mother–child behavior were videotaped and physiology including autonomic nervous system monitoring using commercially available equipment (James Long, Inc.)—see further descriptions of measurement of autonomic functioning below.

Measures: Demographics, Life-Events and Psychopathology

The Demographic and Treatment History Questionnaire, is a standard measure consisting of 33 items adapted from the Structured Clinical Interview for the DSM-IV (First, Spitzer, Gibbon, & Williams, 1995). In addition to typical demographic data (age of mother and child, child gender, household income), this measure also asked items like: "Has your child's father ever been physically violent with you?" and "Have you ever taken out an Order of Protection?"

The Clinician Administered PTSD Scale (CAPS; Blake et al., 1995) was administered in order to confirm salient traumatic life-events and to assess the diagnosis of PTSD and PTSS severity. The CAPS' overall internal consistency is high; and symptom-clusters (re-experiencing, avoidance, and arousal) represent unified constructs ($\alpha = .76$–$.88$; Blake et al., 1995). The diagnosis of current PTSD was made when there was a convergence of three sources of data: the CAPS (score ≥ 55), along with the subject's self-report about her present symptoms using the Posttraumatic Symptom Checklist—Short Version (PCL-S; Weathers & Ford, 1996) with a score ≥ 45, and if the judgment of the clinician conducting the interview session was in agreement with the result. Additionally, in order to measure and control for the effect of co-morbid depressive symptoms on HR and HRV, given the common co-occurrence of depression with PTSD (Breslau, Peterson, Kessler, & Schultz, 1999), we used the Beck Depression Inventory II (BDI; Beck, Steer, & Brown, 1996).

At the start of the visit, after measurement of sitting and standing baselines, mothers were instructed, when given a hand-signal by the clinician to take the stopwatch, go outside of the playroom, and then stand quietly in the hallway in front of the door. After 3 min, measured from the time mothers got up to go out until they were standing behind the door, they were instructed to knock and re-enter the playroom, and to play with their child. After this reunion (2 min), which was followed by a 2 min clean-up period and a new 4 min play activity, the mother was given a signal to leave the playroom again. This was followed by another reunion.

Children's responses to separation were measured via the Separation Distress Scale (SDS; Schechter & McCaw, 2005) as applied to video excerpts of the separation sequences so as to see if there were group differences in child distress, which could be heard by mothers through the door, and could thus affect mothers' physiologic response. The SDS involved the use of a 5-point rating scale that was applied by two independent trained raters who were naïve to child and maternal history. The consistency of the response of the child to separation across both bouts of separation was robust (Cronbach's alpha = .82). Inter-rater reliability was excellent (ICC = .95, $p < .001$).

ECG Acquisition, Measurement, and Data Analysis

The ECG was obtained during six 2-min time periods (sitting, standing, separation-1, reunion-1 separation-2, reunion-2). ECG electrodes were placed just beneath the level of the heart, right upper rib cage and the upper back. In order to control for mother's position during separation, HR and HRV was analyzed only after 1 min into the separation sequence to ensure that mother would be standing behind the door and that the standing baseline would be the relevant comparison condition. In addition, periods with ECG artifact, usually associated with movement, were removed from the 2 min period during the separation condition that remained. During reunion, mothers generally returned to the seated position shortly after re-entering the playroom so as to be able to continue playing with their child.

ECG Analysis

The ECG signal was amplified using an SA Instrumentation Isolated Bioamplifier (James Long Company) and was sampled at a rate of 1,000 samples per second. The digitized data were saved for subsequent R-wave marking and R-wave to R-wave interval (RRI) analyses using customized software designed for displaying, marking and analyzing ECG data (Gmark, Ledona Consulting, NY). An automated peak/trough marking routine embedded in the display program marked each R-wave in the record. These marks were checked visually for accuracy and any necessary corrections in the placement of these marks were made manually. After marking R-waves, the program computed, for the six periods, mean RRI, and from that, mean HR (in beats per minute), standard deviation of the RRIs (SD-RRI, in msec). In addition, from spectral analyses variability in RRI from .15 to .5 Hz was integrated to provide a measure of high frequency RRI (and HR) variability (HF-RRV), and as an indirect index of vagal modulation of HR (Hedman, Hartikainen, Tahvanainen, & Hakumaki, 1995). For this latter measure, spectra were calculated on each 60-s epoch using an interval method for computing Fourier transforms (Bigger et al., 1996). Prior to computing Fourier transforms, the mean of the RRI series was subtracted from each value in the series, the residual series was filtered using a Hanning window (Aubert et al., 1999), and the power within the high-frequency band was summed. Estimates of spectral power were adjusted to account for attenuation produced by the Hanning filter. Global variation in RRi variability was measured as the standard deviation of the R-wave-to-R-wave interval (SD-RRi).

Hypothesis Testing and Group Statistics

Effects of group, period, and interactions between group and period with regard to HR, SD-RRI, and HF-RRV were obtained from repeated measures ANOVAs. In addition to asking if the three groups differed with regard to differences in mean HR and mean HRV, we also addressed the question of whether the groups differed with regard to mode of ANS regulation. The concept of mode of regulation refers to the idea of autonomic space introduced by Berntson, Cacioppo, and Quigley (1991). In the autonomic space framework, it is possible for sympathetic and parasympathetic influences on HR to not only be reciprocal but also to exhibit co-activation (or co-inhibition) under certain conditions. In the co-activation mode, it is possible to have increases in parasympathetic activity but no net change in HR when the increases in parasympathetic activity are paralleled by increases in sympathetic activity. As an indirect index of these differences in mode of regulation we measured the relationship between changes in HR and changes in HF-RRV. In this approach, a significant negative correlation between changes in HR and changes in HF-RRV are taken as evidence of a reciprocal mode of ANS regulation. The absence of a negative correlation between changes in HR and changes in HF-RRV is taken as tentative evidence of a co-activational mode of regulation. To capture a potentially more valid measure of the correlation between changes in HR versus changes in HF-RRV, we computed partial correlations, that is, correlations between change in HR and change in HF-RRV after controlling change in SD-RRi as a marker of sources of HR variance that does not exclusively occur at high frequencies. In addition to reporting the significance levels of these partial correlations, we also determined if these correlations were different among groups.

RESULTS

Sample Characteristics

Among the 54 mother–child participants, maternal ages ranged from 19 to 46 years, with a mean age of 30 years

Table 2. Demographic Variables by Group

	Mean (SD)				
	Non-PTSD	Sub-Threshold	PTSD	*F*(2,52)	*p*-value
Number of subjects	15	22	17		
Mother's age in years (SD)	30.7 (7.8)	28.0 (6.1)	30.4 (6.8)	0.91	.406
Child age in months (SD)	29.6 (9.9)	25.1 (8.8)	33.8 (10.4)	3.93	.026
Child sex (% boys)	53%	47%	56%	.14	.870
With partner (%)	60%	73%	63%	.82	.445
Maternal education in years (SD)	14.7 (3.8)	12.4 (2.6)	12.6 (1.9)	3.62	.034
Household income in thousands of dollars (SD)	60 (38)	32 (17)	19 (19)	11.04	<.001

Table 3. Distribution of Risk-Factor and Psychopathology Variables Across Groups

	Mean (SD)				
Variable	Non-PTSD	Sub-Threshold	PTSD	*F*(2,52)	*p*-value
Number of subjects	15	22	17		
Child's father violent	13%	36%	52%	2.89	.064
Violent events experienced by mother (SD)	.7 (1.3)	2.3 (1.5)	3 (2.1)	7.26	.002
Maternal suicide attempt	0%	36%	41%	4.49	.016
CAPS (SD)	12.87 (20.50)	64.45 (23.81)	95.88 (16.30)	62.43	>.001
PCL-S (SD)	17.33 (.82)	31.54 (7.05)	58.64 (7.56)	186.09.41	>.001
BDI-II (SD)	4.60 (4.31)	11.27 (7.63)	26.41 (10.67)	31.71	>.001

(SD = 7); child age ranged from 18 to 48 months, and the mean age was 29 months (SD = 10). The sample was 86% Hispanic, 11% African-American, and 3% "other". The average household income was $36,000. The average number of years of maternal education was 13. There were significant group differences with respect to child age, maternal education, and, most significantly, family income. These differences are reflected in Table 2.

One-way ANOVAS testing for differences among the three groups showed that, as would be expected, subject groups differed significantly in whether the number of violent experiences (df: 2;52; $F = 6.46$; $p = .003$), depression (df: 2;52; $F = 38.54$; $p < .001$), lifetime PTSD (df: 2;52; $F = 64.35$; $p < .001$), current PTSD (df: 2;52; $F = 173.41$; $p < .001$), suicide attempts (df: 2;52; $F = 4.91$; $p = .01$), and whether the father of the child is violent (df: 2;52; $F = 3.31$; $p = .05$; see Table 3).

Based on analyses of the results of the SDS, children of IPV-PTSD and sub-threshold mothers did not differ significantly in their level of distress during separation when compared to children of non-IPV controls (F [2,52] = .44, $p > .6$). There also was no significant period-by-group interaction.

Most of the IPV-exposed women with PTSD or sub-threshold PTSD symptoms in this study (88%) reported a history of physical and/or sexual abuse and/or family violence exposure dating back to early childhood. The average for the last occurrence of violence exposure was 3 years prior to the laboratory procedure (range 19 years to 1 month prior). These mothers are thus characterized as having had chronic exposure to violence and chronic related PTSD.

We co-varied the level of maternal education, child age and household income given significant group differences for these variables. Accounting for household income, level of maternal education, and child age did not in any case significantly alter the model. Controlling for level of child separation distress independent of age, as coded by two naive raters, similarly did not alter the model (i.e., PTSD-mothers children did not express more or less distress than controls). We also co-varied maternal depression which was typically co-morbid with maternal PTSD in the majority of cases so as to assess its effect on autonomic functioning and found that it did not significantly alter the model.

Average HR and HR in Response to Separation Stress

To assess group differences in average HR we performed a repeated measures ANOVA for the three

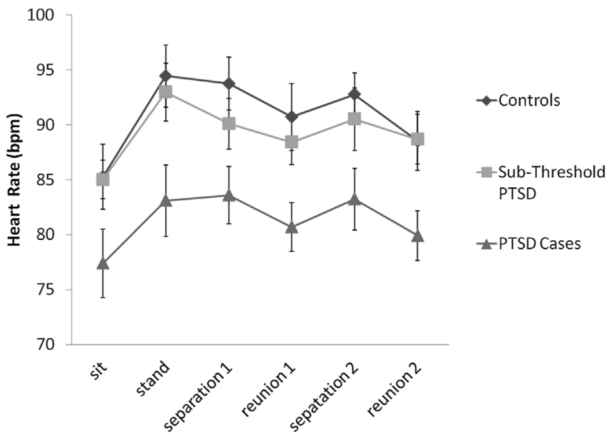

FIGURE 1 This figure shows the mean (±SE) heart rates for the three groups of mothers (controls, sub-threshold PTSD, and PTSD cases) across six periods (sit, sitting; sta, standing; sep1, separation 1; reu 1, reunion 1; sep2, separation 2; reu 2, reunion 2).

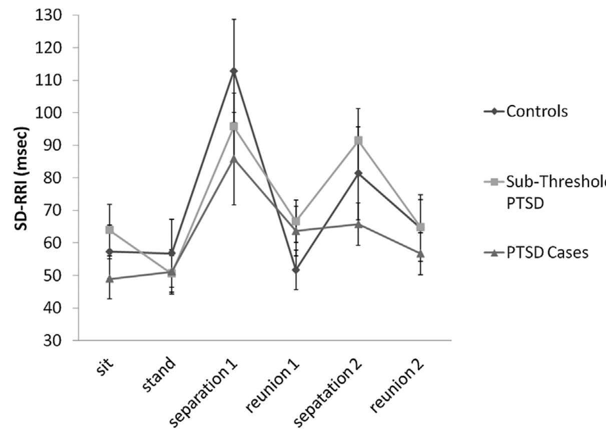

FIGURE 2 This figure shows the mean (±SE) standard deviation of RR-intervals (SD-RRI) for the three groups of mothers (controls, sub-threshold PTSD, and PTSD cases) across six periods (sit, sitting; sta, standing; sep1, separation 1; reu 1, reunion 1; sep2, separation 2; reu 2, reunion 2).

groups of subjects (controls, intermediate-group, IPV-PTSD-cases) across six time periods (sitting, standing, separation-1, reunion-1 separation-2, reunion-2; see Fig. 1). Results showed a main effect of group (df $= 2{,}51$; $F = 4.58$, $p = .015$). Post hoc analyses indicated PTSD-cases had lower HR than either Control or Sub-threshold group ($p < .025$), and the Sub-threshold group was not different from controls ($p = .62$).

There was an effect of time period (df $= 5{,}255$, $F = 17.34$, $p < .001$), which was accounted for by increases in HR from sitting to standing and between separations and reunions (sitting to standing, $p = .001$; standing to separation-1, $p = .27$; separation-1 to reunion-1, $p = .018$; reunion-1 to separation-2, $p = .054$; separation-2 to reunion-2, $p = .007$). The interaction between group and time period was not significant.

R to R Variability

Figure 2 shows the mean standard deviations of RR-intervals (SD-RRI: global heart period variable) for the three groups of subjects across the six time periods. There was no significant main effect between and time period; however, there was an effect of time period on SD-RRI (df $= 5$, 255; $F = 13.88$, $p < .001$). There was no significant change in SD-RRI to standing ($p = .52$) but there were significant increases in SD-RRI during each of the two separations ($p < .001$ and .007, respectively) and, significant decreases from the separations to the two reunions ($p < .001$ and $p < .001$).

For high frequency variability in RR-intervals (HF-RRV, Figure 3) there was no significant main effect of group nor interaction between group and time period. The effect of time period was significant (F $[5{,}255] = 5.11$, $p < .001$). The source of the effect for changes in HF-RRV over time periods was due to significant decreases in HF-RRV from sitting to standing ($p = .045$) and, similar to SD-RRI, increases to each separation (.001, .073), and decreases from separations to reunions (.020, .049).

ANS Mode of Regulation

To assess relationships between changes in HR and changes in HRV we conducted partial correlation analyses in which changes in HR from one period to

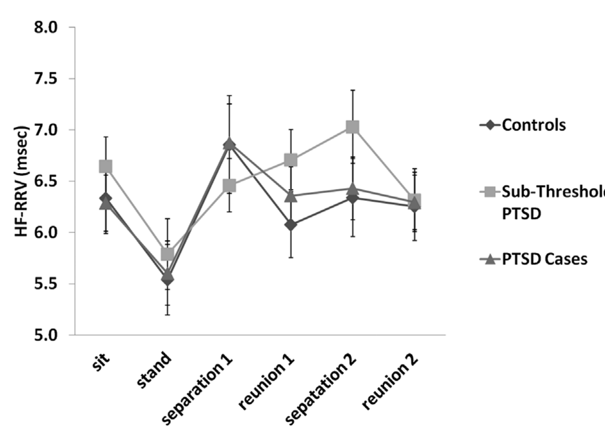

FIGURE 3 This figure shows the mean (±SE) high frequency RR-interval variability (HF-RRV) for the three groups of mothers (controls, sub-threshold PTSD, and PTSD cases) across six periods (sit, sitting; sta, standing; sep1, separation 1; reu 1, reunion 1; sep2, separation 2; reu 2, reunion 2).

Table 4. Partial Correlations Between Change in HR and Change in Heart-Rate Variability Corrected for SD-RRi

Change	Controls	Sub-Threshold PTSD	PTSD Cases
Sitting to standing	−.546 (.035)	−.493 (.020)	−.531 (.011)
Standing to first separation	.431 (.109)	−.363 (.097)	−.584 (.004)
First separation to first reunion	.116 (.681)	−.266 (.231)	−.745 (<.001)
First reunion to second separation	−.469 (.078)	.141 (.531)	−.416 (.054)
Second separation to second reunion	−.811 (<.001)	−.066 (.770)	.101 (.655)

the next were correlated with period-to-period changes in HF-RRV after controlling for the SD-RRi. Consistent with HF-RRV being a marker for parasympathetic (vagal) activity, the increases in HR in response to standing were associated with decreases in HF-RRV. These negative correlations were significant ($p < .05$) for all three groups. These findings are consistent with a "reciprocal mode" of autonomic regulation of HR (Berntson et al., 1991). The negative correlations from these analyses are shown for the three groups in Table 4 and Figure 4 (see sit to stand).

Next, we determined the direction and significance of the relationships between changes in HR and changes in HF-RRV across all time periods (sitting to standing, standing to separation-1, separation-1 to reunion-1, reunion-1 to separation-2, and separation-2 to reunion-2). The correlations derived from these analyses for all three groups are also shown in Figure 4. . As noted above, a significant negative correlation would be consistent with a reciprocal mode of autonomic regulation, that is, an inverse relationship between changes in HR and changes in parasympathetic activity (HF-RRV). In controls, there was a significant reciprocal relationship between HR and HF-RRV when subjects stood, but upon the first separation, the changes in HR and HF-RRV no longer evidenced this reciprocal relationship (i.e., the correlation is not negative for this change). The controls continued to show an absence of a negative correlation, that is, absence of reciprocal relationship, during the first reunion. During the second separation the changes in HR and changes in HF-RRV were nearly significant ($p = .09$) and the changes to the second reunion had returned to a significant negative correlation ($p < .001$). Within the sub-threshold group of controls, there was evidence of a reciprocal mode of regulation from sitting to standing, but not for any of the other period to period changes. For the PTSD group, there was a reciprocal mode of regulation from sitting to standing, standing to first separation, and from first separation to first reunion. However, changes in response to the second separation and reunion did not show this reciprocal mode of regulation, that is, there was no significant correlation between changes in HR and changes in HF-RRV.

In order to test whether there were more significant correlations of those changes than would be expected by chance, we performed a binomial analysis. We found 6 of the 15 correlations computed were significant which was much greater than expected by chance ($p < .001$).

DISCUSSION

This study is the first to our knowledge to have examined autonomic nervous system functioning among mothers with IPV-PTSD and to have tested these mothers' ANS response to an interpersonally stressful interaction with their toddler (i.e., separation). The study tested the following hypotheses: (1) Control and IPV-PTSD subjects would not differ with regard to average HR across all periods; (2) HR would increase during periods of separation from their children in both controls and PTSD mothers, but HR increases would be greater in PTSD mothers; and (3) HF-RRV would be decreased during periods of separation from their children in both controls and PTSD mothers. However, the decreases in HF-RRV would be greater in PTSD mothers.

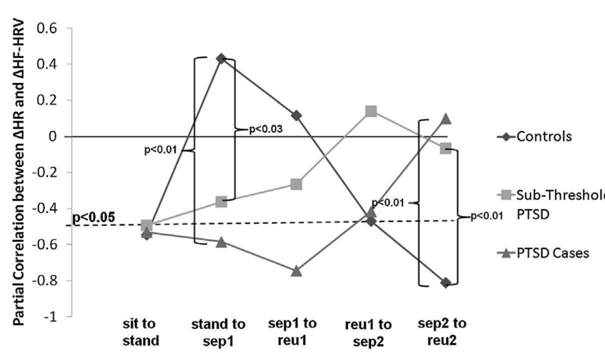

FIGURE 4 This figure shows partial correlations of the relationship between change in heart-rate versus change in high frequency RR-interval variability (HF-RRV), while controlling for change in SD-RRi for the three groups of mothers (controls, sub-threshold PTSD, and PTSD cases) across period to period changes (sitting to standing, standing to separation 1, separation 1 to reunion 1, reunion 1 to separation 2, separation 2 to reunion 2).

None of our three a priori hypotheses was supported. Yet we did find group differences in average HR and, from post-hoc regression analyses characterizing the relationship of changes in HR to changes HF-RRV across time periods, results suggesting that the groups differed with regard to mode of autonomic regulation.

Group Differences in Average Heart-Rate

Others have reported no differences in HR between controls and PTSD subjects (Halligan et al., 2006; Hauschildt et al., 2011; Schmahl et al., 2004). In contrast, we found that across all periods, PTSD case mothers had significantly lower HRs than either Control or Sub-threshold mothers. It is possible that genetic factors may play a role in these findings. That is, genetic vulnerability for expressing PTSD may be linked factors that contribute to a low HR. However, other factors may also contribute. Regulation of mean HR comes not only from direct innervation of the heart but also from circulating catecholamines released from the adrenal medulla. Interestingly, two reports have described lower levels of 24 hr urinary catecholamines among PTSD patients when measured months after the occurrence of the traumatic life event(s) to which the PTSD is related (Murburg, McFall, Lewis, & Veith, 1995; Videlock et al., 2008). These observations would support the hypothesis that lower adrenal output of catecholamines could account for the lower HRs we observed (Videlock et al., 2008).

Group Differences in the Relationship of Changes in HR to Changes HF-RRV Across Time Periods

All three groups displayed a similar mode of autonomic regulation upon standing that was characterized by changes in HR that were negatively correlated with changes in HRV. We interpret this finding as being consistent with what has been termed a reciprocal mode of autonomic regulation (Berntson et al., 1991). However, the control group, but not the PTSD groups, no longer demonstrated this mode of regulation upon the first bout of separation–reunion; that is, in controls, during the first separation changes in HR that were not correlated with changes in HRV. We interpret this pattern of results to be consistent with the mode of autonomic regulation that has been termed co-activation (Berntson et al., 1991). Interestingly, with repeated experience of separation–reunion, controls returned to the reciprocal mode of autonomic regulation as if they had realized that their child was safe and thus could return to baseline, consistent with an affiliative mode of social functioning.

In contrast to this pattern, IPV-PTSD and sub-threshold mothers did not show a co-activated mode in response to the first bout of separation–reunion; but they did do so by the time of the second reunion. We suggest that this characteristic group difference is due to IPV-PTSD mothers' efforts to avoid a negative interaction with her child in which these mothers anticipate helpless, fearful, and/or aggressive mental states in their child and themselves. These anticipated mental states are reminiscent of aspects of mothers' exposure to IPV. With re-exposure to the separation–reunion, it is as if the IPV-PTSD mothers' capacity for avoidance and numbing is no longer sustainable; and they enter into the co-activated state that is associated with hypervigilance (Wessa, Jatzko, & Flor, 2006).

Group differences in HR and in the pattern of change of HR relative to change in HF-RRV highlight the importance of this line of research in that these differences may represent useful biomarkers for further study of mechanisms that fuel intergenerational transmission of IPV and related trauma, as well as of interventions that can interrupt such transmission. While the existence of a co-activational mode of regulation in human subjects was first described in the autonomic space model proposed by Berntson et al. (1991), Iwata and LeDoux (1988) had previously presented results from an experiment with rats that defined one specific condition in which the co-activated mode occurs. Their results showed that this mode of regulation is used when animals are exposed to a stimulus that is previously associated with shock. That is, a co-activation mode of autonomic regulation may be invoked in anticipation of an adverse event and may thus represent hypervigilance to danger.

Perhaps when mothers left their infant behind in the room, they adopted a regulatory strategy that enhanced their ability to respond quickly to a perceived threat to their child. By increasing simultaneously sympathetic and parasympathetic input to the heart, a rapid and maximal response to the threat would be assured simply by reducing parasympathetic input, leaving only the sympathetic output for fight or flight. Our results suggest that non-PTSD controls maintained this physiologic correlate to hypervigilance during the first separation period, and even retained this mode during the first 2 min of the reunion. But, once having experienced the first separation, and understanding that it did not represent an actual threat, these control subjects had returned to their baseline reciprocal mode of regulation during the second separation and reunion periods.

Unlike controls however, IPV-PTSD and sub-threshold mothers apparently remained in the reciprocal mode of regulation during the first separation and reunion. This suggests that they likely were not at first appraising the separation from their children in the same way as did the controls. We speculate that the IPV-PTSD and sub-threshold mothers were able on the initial experience of separation to avoid or psychologically numb their awareness of the child's state of mind. Yet upon repeated exposure, these defenses broke down; and they entered into a co-activated, hypervigilant state that did not extinguish by the second bout of reunion.

A shortcoming of this study was that we did not have adequate behavioral data related to maternal states of mind across the different time periods as well as maternal reading of their child's state of mind. We were thus unable to test this hypothesis definitively and to discern whether IPV-PTSD mothers were experiencing more or less psychological stress during the first bout of separation–reunion versus the second. This would be important to examine in future studies. Prior research has supported that IPV-PTSD mothers misread their children's emotional cues during separation–reunion (Schechter et al., 2006). When confronted with the videotaped excerpt of their child during separation, their initial appraisal of anger and controlling behavior often shifts to a more accurate appraisal of a mental state of helplessness and fear. This avoided mental state of helplessness and fear, is of course, similar to what the IPV-PTSD mothers experienced when they were victimized. In support of this delay in adopting a co-activational mode of autonomic regulation, further studies with similar samples have demonstrated that mothers with IPV-PTSD exhibit avoidance of child negative emotion after separation (i.e., upon reunion) yet feel increasing stress over the course of repeated separations (Schechter et al., 2008, 2010). This subjective sense of stress has been associated with cortico-limbic dysregulation during functional neuroimaging of IPV-PTSD as compared to non-PTSD controls while exposed to video excerpts of their own and unfamiliar children during separation versus play (Schechter et al., 2012). Further supporting the notion of avoidance as central to the IPV-PTSD and sub-threshold mothers' pattern of autonomic regulation in the present study are findings that show that women with chronic IPV-PTSD have been observed to at least transiently buffer or down-regulate their arousal to emotionally salient stimuli by means of one key aspect of PTSD-related avoidance, namely psychological numbing (Frewen et al., 2008, 2012).

Limitations

Limitations of the present study included relatively small group sizes that limited the statistical power to do more complex analyses. In future studies, analyses would benefit from additional focus on computing relationships between HR and HRV within each subject (i.e., individual differences) during a given period (i.e., separation) as opposed to relying on group averages between periods to make the co-activation interpretation within a larger sample. Given the nature of our study and logistic constraints, we could not adequately control for individual differences in motor activity between subjects, or for the possibility that subject-mothers would not follow correctly the given instructions. It is possible therefore that differences in motor activity between controls and PTSD/sub-threshold mothers may have accounted for some of the group differences in autonomic regulation. However, ongoing extensions of this work in which motor activity is more carefully monitored do not indicate this to be the case (Cordero et al., 2013).

Our approach to testing whether the model of autonomic regulation differed in the PTSD subjects revealed findings suggesting this to be true. However, to our knowledge, our statistical approach was novel and required multiple correlation tests. As we did not adjust alpha for performing these multiple tests, these findings must be viewed as tentative and in need of replication. We must also acknowledge that the evidence supporting different modes of autonomic regulation (i.e., reciprocal vs. co-activation) is indirect. Because there is no marker of sympathetic regulation of HR, and administration of autonomic blockers is unacceptable in these vulnerable populations, the specific contribution of the sympathetic nervous system was difficult to test with certainty.

CONCLUSIONS

We interpret our results to suggest that among non-PTSD controls, there is a co-activation of sympathetic and parasympathetic activity upon an initial exposure to a novel interpersonal stressor, namely, mother/child separation. We believe that this co-activation reflects a hypervigilent autonomic and psychological state that prepares the mother for a maximal response should that mother perceive actual danger to her child during the laboratory procedure. IPV-PTSD and sub-threshold mothers do not show this mode of regulation in response to the initial separation, thus suggesting a diminished ability to perceive the threat associated with separation. With repeated separations, normal mothers learn that the separation is not a real threat. They thus no longer respond with a sympathetic and parasympathetic co-activation. In contrast, with repeated separations, IPV-PTSD and sub-threshold mothers begin to show co-activation that lingers. This delayed and lingering coactivated state suggests that these mothers become and then remain hypervigilant later than controls. These physiologic findings converge with previous findings that suggest that behavioral and HPA-axis dysregulation in traumatized mothers compromises their ability to engage in mutual regulation of emotion and arousal with their toddlers during and after naturalistic stressors such as separation. Clinical implications include the possible use of cardiac electrophysiology together with cortisol measurement to examine the progress and outcome of interventions that target mother–child relationship disturbances in the context of maternal PTSD.

NOTES

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