



The Family Biorhythm: Contributions of the HPA and HPG Axes to Neuroendocrine Attunement

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Received: 20 January 2023 / Revised: 4 April 2023 / Accepted: 7 April 2023 /
Published online: 14 April 2023

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Abstract

Objective The vast majority of research on biobehavioral influences on development has focused on mothers and infants, whereas research on paternal biobehavioral influences remains sparse. This study aims to increase understanding of paternal influences on the biobehavioral dynamics of the family unit, using a multi-system approach.

Methods Participants consisted of 32 predominantly high-risk families recruited during pregnancy who completed monthly questionnaires and in-home visits when infants were 4, 12, and 18 months of age. In-home visits included semi-structured interaction tasks and saliva samples for cortisol and progesterone assays.

Results Mothers and infants, but not fathers and infants, showed adrenocortical attunement, with the strongest attunement at 18 months. Second, mothers' couple satisfaction did not significantly impact infants' cortisol levels or mother-infant cortisol attunement, but mothers' progesterone moderated the relationship between couple satisfaction and infant cortisol levels such that mothers with low couple satisfaction, but high progesterone, had infants with lower cortisol levels. Finally, mothers' and fathers' progesterone levels were attuned across the time points.

Conclusions This is some of the first evidence of the establishment of the family biorhythm and suggests that fathers play an indirect role in facilitating mother-infant adrenocortical attunement.

Keywords Cortisol · Progesterone · Parent-infant attunement · Relationship Satisfaction · HPA-axis · HPG-axis

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Introduction

The human neuroendocrine systems function to guide phenotypic and behavioral changes to internal and external environmental cues by allocating attentional and other resources to fine-tune neural pathways (Geary & Flinn, 2001; Gluckman et al., 2005; Ponzi et al., 2020). The sensitivity of neuroendocrine systems to environmental information is linked to downstream effects on human development (Ruttle et al., 2011). In infancy, neuroendocrine systems downregulate sensitivity based on social and environmental stressors, such that youth in more stressful environments often have blunted responses relative to youth from less stressful environments (Del Giudice et al., 2011). The calibration of infant neuroendocrine function largely depends on biological attunement with parents (Del Giudice et al., 2011; Ellis & Boyce, 2008).

Impact of Fathers on Maternal Social Support, Stress, and Hormonal Attunement

Feldman's (2012) model of Bio-Behavioral Synchrony provides a foundation to understand the interplay between parent-infant physiology and behavior coordination, and its overall impact on infant development. Broadly, this model posits that as infants age, they will engage in a series of mutually responsive behaviors and participate in a series of physiological regulatory behaviors that helps foster attachment between infants and caregivers. For example, by the time an infant reaches their third month of life, they are engaging in a series of behaviors (e.g., eye gaze, facial expressions) that create affiliative bonds with their mothers and fathers (Feldman, 2007). However, although caregivers and infants can begin to establish synchrony via shared behaviors, synchrony can also be established through the coordination of underlying hormonal and physiological systems—referred to in this paper as biological attunement (Carollo et al., 2021; Feldman, 2012; Pratt et al., 2017).

Biological attunement is the physiological coordination between dyads that can influence the sensitivity of neuroendocrine systems to events in later development (Ruttle et al., 2011). Notably, mother-infant adrenocortical attunement, commonly measured via the activity of the hypothalamic-pituitary-adrenal axis (HPAa), appears to be an indicator of important outcomes, and is associated with maternal sensitivity and dyadic coordination (Hibel et al., 2015; Ruttle et al., 2011). Mother-infant HPAa attunement is sensitive to environmental and social stressors, such that dyads living in environments of harshness and unpredictability show lower attunement than dyads living in secure and predictable environments (Byrd-Craven & Clauss, 2019; Saxbe et al., 2019).

Although there is substantial evidence for mother-infant physiological attunement, little work has been done on the triadic *family biorhythm* that occurs between mothers, fathers, and infants. Even though their role varies more widely than that of mothers, fathers play a critical role in development (Geary, 2000). There is evidence that the social support a mother receives can moderate the link between maternal stress and infant outcomes, and can also influence maternal sensitivity (Feldman et al., 2000; Tester-Jones et al., 2015). As such, fathers may contribute to infant development by promoting mother-infant bonds, including HPAa attunement. Asynchronies in the mother-infant biorhythm are predicted by poor social support (Clauss et

al., 2018) and associated with poorer learning outcomes (Thompson & Trvathan, 2008). The quality of father involvement has been linked to cognitive and language outcomes, particularly in high-risk populations (e.g., low income, poor quality education, lack of social support, rural/inner-city; Burchinal et al., 2008; Garbarino & Sherman, 1980; Lutfiyya et al., 2012), even after first considering maternal effects and the quality of available childcare (Harewood et al., 2016), and health outcomes (Arnold, 2009; Hibel et al., 2015; Nepomnaschy & Flinn, 2009). This could indicate that for high-risk families, fathers may mitigate the other negative impacts of social and environmental stressors on family health and development, therefore it is important to understand how these influences coalesce to impact development.

Paternal support appears to buffer the impact of chronic stress on preterm birth rate, with higher paternal support associated with lower risk of preterm birth even for mothers reporting high chronic stress (Ghosh et al., 2010). Additionally, fathers can have direct, indirect, and moderating effects on child social, cognitive, and health outcomes (Geary & Flinn, 2001), yet the potential influence fathers may have on the mother-infant biorhythm and associated regulation of the infant stress response remains underexplored. Further, we do not know whether fathers are unique in their support or caregiving, or whether it is alloparental support (i.e., childcare from non-parental sources; Kenkel et al., 2017) in general that is associated with positive child outcomes, despite several calls to determine the causal nature of these relationships (Bjorklund & Ellis, 2014). The majority of research on fathers' contributions to infant and child outcomes is conducted on small samples of primarily white, upper-middle class and highly educated parents (Gordon et al., 2010; Storey et al., 2011), and fewer still examine physiological data (Harewood, et al., 2016; Flinn et al., 1996). Because mothers from high-risk environments are at greater risk for experiencing both social and environmental stressors that may impact overall.

Father Physiological Changes and Progesterone Attunement

Fathers experience a cascade of physiological changes leading up to, and immediately following, childbirth. These physiological changes have been tied to behavioral changes that can foster partner relationship quality, strengthen parent-infant bonds, and support the overall health and development of their families (Saxbe et al., 2017). For example, research has found that declines in father testosterone leading up to, and immediately following the birth of their child, can foster father-mother relationship quality, and promote father investment in his offspring (Bos et al., 2018; Kuo et al., 2018; Saxbe et al., 2017) Furthermore, research has found fathers who engage in more attentive and sensitive parenting behaviors are more likely to have high basal cortisol levels and high cortisol activity to acute stressors than fathers who do not engage in attentive or sensitive parenting (Beijers et al., 2022; Kuo et al., 2018) However, notably, the majority of the established research has been conducted in predominantly low-risk samples; more research is needed to understand how these changes in behavior and physiology may apply to high-risk samples.

Although research has shown that fathers experience physiological changes in preparation and response to fatherhood, these physiological associations have rarely been studied within the mother-father-infant triad, and the impacts of other hormonal

moderators of behavior in families remain largely unexplored, including the products of the hypothalamic-pituitary-gonadal axis (HPGa), namely progesterone, which is associated with dyadic affiliation and relationship quality (Edelstein et al., 2016). Progesterone is a steroid and most known for its role in the menstrual cycle and pregnancy. Though its role in the stress response is complex, progesterone and allopregnanolone, a metabolite of progesterone, are elevated during times of stress (Herrera et al., 2016), though whether they serve suppressive or permissive roles on the HPAa is unclear (Gaffey & Wirth, 2014; Stephens et al., 2016). What is clear is that progesterone is associated with social affiliative motives (Brown, Fredrickson, et al., 2009; Schultheiss et al., 2004). Within the context of a close relationship, progesterone may serve to buffer social stressors and may be an index of perceived social support or closeness (Rankin et al., 2021).

Progesterone likely serves an important role in regulating responses to both caregiving activities and affiliation and support of one's partner. Many of these studies have focused on the impact of progesterone in the context of oral contraception and partner satisfaction, and they have found some important implications for its role in partner choice (Roberts et al., 2012; Russell et al., 2014). In naturally cycling women, progesterone has been associated with more positive evaluations of their relationship with their partner (Righetti et al., 2020). Yet, in men, the study of progesterone has been often neglected—particularly in studies of fatherhood. The few studies investigating progesterone in fathers have shown that progesterone responds to caretaking activities and is influenced by caretaking experience (e.g., caring for multiple children; Gettler et al., 2013). However, progesterone has not been systematically investigated in fathers within a relationship and caregiving context.

Current Study

This study is among the first to explore the interrelationships among multiple systems involved in developmental psychobiological processes occurring in early life using a multi-method approach. This rich data set provides unique information about the family landscape and origins of individual differences in developmental outcomes that depend on dyadic and triadic family interactions. The current study was designed to test three hypotheses examining how family relationships are associated with neuroendocrine attunement in a predominantly high-risk sample. First, we hypothesized that mothers and infants would show attunement across time as evidenced by salivary cortisol collected when the infant was 4-, 12-, and 18-months old. Next, we hypothesized that mothers who reported higher satisfaction with their partner would: (i) have greater cortisol attunement to their infant; and (ii) have infants with lower overall cortisol levels. Lastly, we hypothesized that mothers' progesterone would be associated with fathers' progesterone.

Method

Participants

A total of 55 families were recruited from obstetrics clinics to participate in the 18-month study prior to infant birth. The final sample included 32 families (32 mothers; 21 fathers, 32 infants). Mothers in the sample completed individual and household demographic information for their family. Women reported a mean age of 29 years old ($M_{age} = 29.32$, $SD = 6.37$); 59.26% of mothers identified as White, while 22.22% identified as Native American/Indigenous, 14.81% identified as Hispanic/Latino, and 7.41% identified as Black. Over half of the sample (i.e., 51.8%) reported an annual income of less than \$20,000, with 29.6% reporting their annual income in between \$20,000–60,000, and 11.1% of the households reporting an income between \$60,000–100,000 each year. Two families chose not to disclose their income.

Monthly Survey Materials

Mothers and fathers completed one prenatal questionnaire; mothers completed eight postnatal questionnaires at months 1–6, 12, and 18 to measure infant development and mother relationship status and quality. For the present analyses we only used mother responses regarding couple satisfaction.

Couple Satisfaction. To assess mother relationship status and relationship quality we used the Couple Satisfaction Index (Funk & Rogge, 2007). This scale assesses the presence and severity of 29 common problems (i.e., communication, support) between individuals in cohabitating, dating, or married relationships. Items are measured on a 1–6 Likert-type scale such that responses of “1” indicate low couple satisfaction and responses of “6” indicate maximum couple satisfaction. Responses were computed as a sum variable and possible scores could range from 29 to 174; the measure has good internal consistency ($\alpha = 0.94$).

Home Visit Procedure

Home visits were conducted when the infant reached 4-, 12-, and 18-months. Visits included a semi-structured parent-child interaction lasting approximately 70 min. At 4-months, these activities included semi-structured play, feeding, a diaper change, and parents reading to the infant. At 12- and 18-months, these activities included semi-structured play, parents reading to the infant, and developmentally challenging activities, such as playing with shape sorters and puzzles. These tasks were chosen based on established protocols that assessed behavioral interactions between parents and infants that intended to model naturalistic interactions (Ainsworth, 1974; Brown, Thoynre et al., 2009; Rowe & Goldin-Meadow, 2009).

During activities, one parent participated with the child at a time, alternating activities. The other parent was out of the child’s sight to ensure that the participating parent and child were focused on one another during the activity. If only the mother was present, then she completed all the activities herself. All activities lasted approximately five minutes.

Saliva samples were collected from the mother, infant, and partner three times across each visit, approximately 5 min after arrival (Time 1), then 20 min (Time 2, at the end of the interaction tasks), and 45 min (Time 3). Research assistants facilitated saliva collections and activities but were not involved in interactions with the infants.

All materials and procedures were approved by the Institutional Review Board.

COVID-19

Data collection started before the pandemic and required research assistants to be in close proximity with the families for extended periods of time during home visits. Modifications were made to the protocol to minimize the families' exposure, but resulted in the inability to collect (and code) observational data. Eighteen of the 32 families completed a 4-month visit prior to the pandemic; modifications primarily applied to protocols for the 12- and 18-month visits. Research assistants dropped off supplies outside the families' homes and all instructions were delivered and monitored over the phone. After the visit, parents placed all materials in a sealed bag outside to be retrieved by research assistants.

All materials and procedure modifications were approved by the Institutional Review Board.

Saliva Collection

Adults were provided with SalivaBio collection tubes (Salimetrics, LLC) and saliva collection aids for each collection. Infant samples were collected using absorbent swabs (SalivaBio's Infant's Swab, Salimetrics, LLC). Families were instructed to not eat or drink anything besides water the hour before the visit started, but they rinsed their mouth with water prior to the visit. Research assistants documented collection duration for each family member and stored the samples in a Styrofoam cooler with icepacks until samples could be transferred to a -80 °C freezer.

Salivary Assays

Saliva samples were stored at -80 °C after collection. On the day of assay, they were thawed for 1 h and 30 min, centrifuged at 3000RPM, and assayed using the Salimetrics protocol for Cortisol and Progesterone using Enzyme Immunoassay Saliva Kits (ELISA). Salivary assays were conducted by trained research assistants at Oklahoma State University. The intra- and inter-assay coefficients for Cortisol were, 3.16 and 11.20 and for Progesterone, 2.47 and 2.35.

Results

Data Analyses

Thirty-two families provided saliva samples at month 4, 28 at month 12, and 14 at month 18. Table 1 provides bivariate correlations for all study variables of interest.

Linear mixed-effects models (LMEs) with maximum likelihood estimation were conducted to test the relationships between mother-infant cortisol attunement, the role of couple satisfaction on attunement, and mother-father progesterone attunement. LMEs were used to account for time varying covariates (i.e., salivary hormones), missing observations across time (4-, 12-, and 18 months), and to measure hormone attunement of dyads (mother-infant, mother-father, father-infant) across multiple time points throughout the study. Mixed-effect models are recommended for analyzing changes in hormones across dyads rather than collapsing hormone measures into one variable (Hendrix et al., 2018). For hypothesis 1 and 2, mothers' and fathers' cortisol, couple satisfaction, and the interaction between mothers' cortisol and month of visit, and mothers' cortisol and couple satisfaction were entered as fixed effects, while infants' cortisol was the dependent variable. For hypothesis 3, mothers' progesterone, and couple satisfaction were entered as fixed effects, while fathers' progesterone was the dependent variable. All analyses included a random intercept for participants, sample collection (3 per visit) and time of saliva collection for each month were entered as control variables to account for diurnal response. To account for a slight positive skew, cortisol and progesterone were log transformed.

Mother-infant Cortisol Attunement

Our first hypothesis predicted mother-infant cortisol attunement across the three time points. The effect of mothers' cortisol on infants' cortisol was not significant, ($b = -0.14$, $SE = 0.16$, $95\%CI [-0.46, 0.16]$, $p = .36$). However, there was a significant interaction between maternal cortisol and visit timepoint at 18 months compared to 4 months ($b = 1.41$, $SE = 0.40$, $95\%CI [0.61, 2.19]$, $p < .001$), but not at 12 months compared to 4 months ($b = -0.09$, $SE = 0.30$, $95\%CI [-0.68, 0.49]$, $p = .75$), see Fig. 1. To

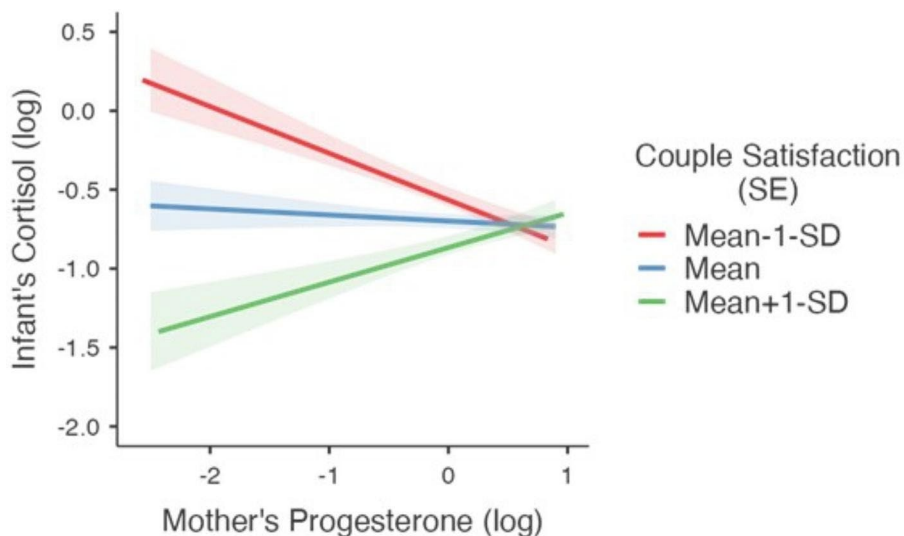


Fig. 1 The relationship between mother's cortisol and infant's cortisol across the 4-, 12-, and 18-month visits

further understand this interaction, we performed a simple effects analysis for each time point. Mothers' cortisol positively predicted infants' cortisol at the 18-month visit ($b=1.26$, $SE=0.46$, 95%CI [0.34, 2.17], $p=.007$), but not at the 4-month visit ($b=-0.14$, $SE=0.19$, 95%CI [-0.53, 0.24], $p=.45$) or 12-month visit ($b=-0.24$, $SE=0.33$, 95%CI [-0.90, 0.42], $p=.47$). Additional analyses showed a significant positive association between maternal and paternal cortisol overall, irrespective of visit timepoint ($b=0.28$, $SE=0.08$, 95%CI [0.12, 0.44], $p<.001$). That is, cortisol attunement between partners was consistent at each timepoint.

Couple Satisfaction and Attunement

Our second hypothesis predicted mothers' self-reported couple satisfaction would be associated with lower cortisol in infants and overall mother-infant attunement. We tested the relationship between maternal couple satisfaction and its association with infant cortisol levels, and then tested the interaction between maternal cortisol and couple satisfaction predicting infant cortisol. The effect of couple satisfaction ($b=-0.003$, $SE=0.001$, 95%CI [-0.007, 0.004], $p=.08$), and the interaction between maternal cortisol and couple satisfaction was not significant ($b=0.006$, $SE=0.004$, 95%CI [-0.003, 0.03], $p=.10$).

An exploratory analysis was run on the relationship between mothers' progesterone and infants' cortisol levels, and whether it was moderated by couple satisfaction. The relationship between mothers' progesterone and infants' cortisol was not significant ($b=-0.05$, $SE=0.06$, 95%CI [-0.17, 0.06], $p=.39$), but the interaction between mothers' progesterone and couple satisfaction was significant ($b=0.006$, $SE=0.001$, 95%CI [0.003, 0.009], $p<.001$). We probed this interaction by running a simple slopes analysis across couple satisfaction at -1SD from the mean, the mean, and +1SD from the mean. The relationship was significant at lower levels of couple satisfaction (-1SD), where mothers' progesterone negatively predicted infants' cortisol levels ($b=-0.26$, $SE=0.08$, 95%CI [-0.43, -0.09], $p=.001$). At the mean of couple satisfaction, the relationship was not significant ($b=-0.07$, $SE=0.08$, 95%CI [-0.23, 0.07], $p=.32$). At higher levels of couple satisfaction, the relationship was marginally significant ($b=0.11$, $SE=0.10$, 95%CI [-0.09, 0.32], $p=.28$), see Fig. 2. Fathers' progesterone levels were not associated with infants' cortisol ($b=0.06$, $SE=0.07$, 95%CI [-0.07, 0.20], $p=.34$).

Progesterone Attunement

The third hypothesis predicted that mothers' progesterone would be associated with fathers' progesterone. Maternal progesterone significantly predicted paternal progesterone, irrespective of visit timepoint ($b=0.27$, $SE=0.13$, 95%CI [0.01, 0.53], $p=.03$), indicating attunement at each visit. The relationship between mothers' self-reported couple satisfaction and paternal progesterone ($b=-0.001$, $SE=0.002$, 95%CI [-0.006, 0.003], $p=.61$), was not significant.

Considering our sample size decreased over time, we ran an additional analysis comparing participants who completed all three time visits (4-, 12-, and 18-months) on their hormone measures to participants who only completed the first visit (4-months).

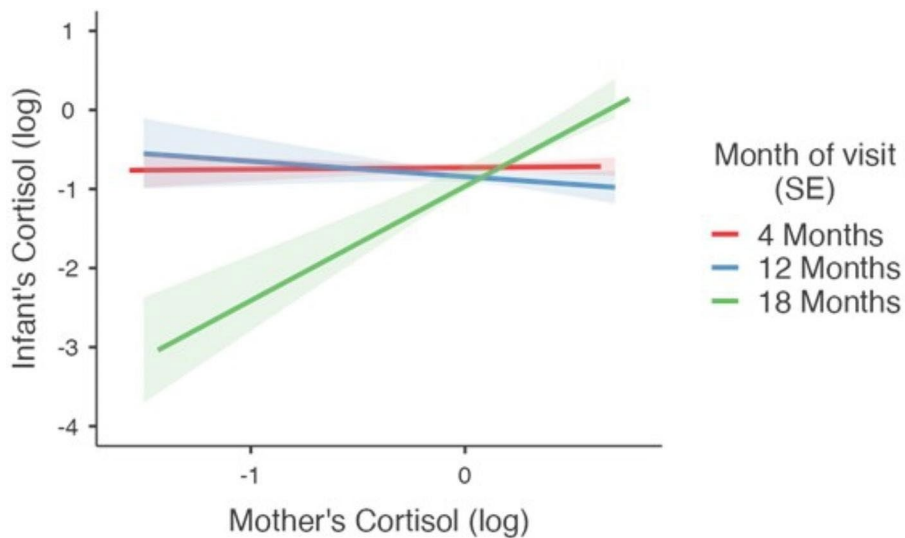


Fig. 2 Moderating effects of couple satisfaction on the relationship between maternal progesterone and infant cortisol

There were no significant differences in infants ($b = -0.11$, $SE = 0.11$, $95\%CI[-0.35, 0.11]$, $p = .33$), fathers ($b = -0.12$, $SE = 0.13$, $95\%CI[-0.38, 0.14]$, $p = .37$), and mothers ($b = -0.001$, $SE = 0.08$, $95\%CI[-0.16, 0.15]$, $p = .98$) who completed all three visits compared to those who did not on cortisol and progesterone. This suggests that in regard to their hormone profile, participants who dropped out of the study over time were not different from participants who completed the study.

Discussion

This study is among the first to examine the establishment and coordination of the family biorhythm. Previous research has found that neuroendocrine responses reflect allocation of resources such as energy and attention and are one biological mechanism through which bonding and social learning occur (Hibel et al., 2018). Consistent with previous research, we report that mothers are to some degree physiologically attuned to their infants (Ruttle et al., 2011), as well as to their partners. In contrast to previous work (Clauss et al., 2018; Saxbe et al., 2019), we did not find an association between satisfaction within the parental relationship and maternal-infant adrenocortical attunement. We did find, however, that maternal progesterone moderates the relationship between couple satisfaction and infant cortisol such that mothers with lower couple satisfaction but higher progesterone had infants with lower cortisol. This suggests that progesterone may play a role in regulating affiliative behavior in the context of lower social support to promote dyadic cortisol attunement.

Although there is a paucity of research assessing progesterone coordination in the context of family relationships, and the role of progesterone has been largely underexplored, previous research has asserted that this hormone may be important

for affiliation and social support (Brown, Frederickson et al., 2009b; Rankin et al., 2021; Schultheiss et al., 2004). Our findings may provide evidence that progesterone attunement within the parental dyad may be related to mothers' greater ability to establish adrenocortical attunement with her infant. The inverse pattern of mothers' progesterone and infant's cortisol for those with low levels of satisfaction and perceived support provides further evidence for this assertion. In other words, gaps in important relationships may interfere with mothers' ability to sensitively respond to infant cues. Though this study lacks the behavioral assessment necessary to firmly establish that mother-infant behavioral coordination is mediated by these neuroendocrine responses, other work has suggested this is the case (Feldman, 2007, 2012). Additionally, mother-father progesterone attunement may indicate that fathers may play an indirect role in the establishment of mother-infant attunement.

Although the conclusions of this study may be limited by the small sample lacking diversity, the findings of this present study are fairly novel and rich due to the repeated measures design of the current study. Repeated measures not only increased the statistical power of our study (Quené & van den Bergh, 2004), but it also aided in our assessment of the establishment of the *family biorhythm*. Further, the use of a multilevel model approach allowed us to assess synchrony across dyads (mother-infant, mother-father), rather than running multiple tests on individual hormone measurements across multiple samples over months. Additionally, this is one of the first studies to include fathers in assessments of infant attunement, allowing us to gain insight to the unique contributions fathers may have on the development of the family biorhythm. Yet, while the present study may indicate that father support can promote mother-infant attunement, and presumably caregiving sensitivity, more research is needed to understand if the support provided by fathers is unique when compared to other sources of social support (e.g., grandparents, alloparents). Furthermore, future work with a more diverse sample will allow for comparisons between different family structures. Nonetheless, it is important to acknowledge that sample size did decrease over time, and conclusions on hormone synchrony specific to the 18-month visit should be taken with caution.

This study provides valuable insight into the interrelationships among multiple systems involved in the development of the neuroendocrine system occurring early in life. By providing a series of physiological snapshots into the family landscape, we have provided evidence of a role for the HPGa in the initiation of individual differences in developmental outcomes as they relate to dyadic and triadic family interactions. While external and internal factors that regulate the development of the HPAA are still being identified, quality caregiving appears to play a significant role (Hibel et al., 2018). These findings reinforce the idea that increasing supportive parental relationships can bolster optimal developmental outcomes.

Supplementary Information The online version contains supplementary material available at <https://doi.org/10.1007/s40750-023-00215-0>.

Acknowledgements The authors would like to make a special acknowledgement to the individuals without whom this project would not have been possible: Shelia Kennison, Ph.D, Samantha Addante, Erin Harrington, Ph.D, Mira Armans, Ph.D, Gina Erato, Ashley Quigley, Brandi Sheppard, Danya Brewer, Dylan Rodriguez, Erin Cusak, Garrin Williams, Hayley Barnes, Imani Bluiett, Jordan Cazenave, Katie

Billings, Lauren Koetting, Lauren Warr, Makalie Ogletree, Melanie Sokolowski, Mikayla Tolliver, Sophie Harston, Thao Stapleton.

Author Contribution E.W., and J.B.-C. wrote the main manuscript text. E.W., prepared tables. R.G. conducted and prepared analyses, summarized research findings, and prepared figures. All authors reviewed the manuscript and provided feedback on final manuscript.

Funding Funding for this project was received from Oklahoma Center for the Advancement of Science and Technology (OCAST) (HR17-003) and the Center for Integrative Research on Childhood Adversity (CIRCA) (P20GM109097).

Data Availability The data collected and analyzed in the present study are not publicly available due to continuing research in progress. Please contact the corresponding author for inquiries about the availability of the data.

Declarations

Ethical Approval All procedures were approved by the Oklahoma State University Institutional Review Board (IRB application number: AS-17-42).

Competing Interests The authors have no competing interests or conflicts of interests to declare.

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