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Exploring the role of endocrine factors in sensitive parenting in men

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ABSTRACT

Parental sensitivity has been studied extensively in parenting research. Recently, there has been increasing attention to endocrine factors that may be related to parental sensitivity, such as oxytocin, vasopressin, testosterone, and cortisol. Although hormones do not act in isolation, few studies integrated multiple hormones and examined their combined associations with parental sensitivity. The current study aimed to explore the hormonal correlates of paternal sensitivity by examining in 79 first-time fathers of young infants (2–4 months old) (1) the separate and combined associations of basal oxytocin, vasopressin, testosterone, and cortisol levels with sensitivity, and (2) the associations between paternal sensitivity and oxytocin, vasopressin, testosterone, and cortisol reactivity following father-infant interactions. We additionally explored whether interactions between the various basal hormone levels could predict paternal sensitivity. Saliva for the quantification of fathers' hormone levels was sampled before and after an interaction with their infant to determine basal levels and reactivity. Results revealed no significant associations between sensitivity and basal hormone levels or reactivity. However, results indicated that cortisol and testosterone interacted in their effects on paternal sensitive parenting. Namely, fathers with low basal cortisol levels showed more sensitivity with increasing T levels, but fathers with high cortisol levels were less sensitive with increasing T levels. However, it should be noted that the latter slope was not significantly different from zero. These findings suggest that variations in parental sensitivity might be better explained by interactions between hormones than by single hormone levels.

1. Exploring the role of endocrine factors in paternal sensitive parenting

Parental sensitivity, defined as parents' ability to perceive, accurately interpret, and appropriately and promptly react to infants' signals (Ainsworth et al., 1974), has been studied extensively in parenting research, using a variety of behavioral observation settings and coding systems. The interest in parental sensitivity is not remarkable, as sensitive parenting behavior is related to positive child outcomes such as cognitive development, socio-emotional functioning (Deans, 2020; Rodrigues et al., 2021) and infant attachment security, both with mothers (De Wolff and van IJzendoorn, 1997; Posada et al., 2016) and fathers (Brown et al., 2012; Lucassen et al., 2011). Recently, there has been increasing attention to endocrine factors that may be related to parental sensitivity (e.g., Feldman and Bakermans-Kranenburg, 2017). Moreover, research suggests that several hormones, including oxytocin (OT), vasopressin (AVP), testosterone (T) and cortisol (CORT) are associated with human paternal caregiving behavior (e.g., Bos, 2017; Rajhans et al., 2019; Rilling and Mascaro, 2017). However, few studies integrate multiple hormones and examine their simultaneous associations with parental sensitivity. The current study aimed to explore the hormonal correlates of paternal sensitivity by (1) examining the separate and combined associations of basal OT, AVP, T, and CORT levels with sensitivity in fathers of young infants, and (2) studying associations between paternal sensitivity and OT, AVP, T, and CORT reactivity following father-infant interaction. In a post-hoc analysis, it was additionally explored whether interactions between the various basal hormone levels could predict paternal sensitivity.

A widely studied hormone in the context of the study of parental sensitivity is OT (Feldman and Bakermans-Kranenburg, 2017). Concerning basal OT levels, several studies showed that OT positively relates to sensitive parenting behavior. For example, higher basal OT

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levels have been associated with more parental affectionate contact, but not stimulatory contact, towards infants during a parent-infant interaction task (Apter-Levi et al., 2014). Interestingly, studies that distinguish between mothers and fathers show that basal OT levels are positively related to affectionate contact in mothers (Feldman et al., 2010), whereas in fathers, OT levels are positively related to stimulatory contact (Feldman et al., 2010, but see Gordon et al., 2017 for non-significant findings in fathers). Higher paternal basal OT levels have also been associated with more positive engagement, affect synchrony and positive communicative sequences between father and infant (Feldman et al., 2011). Moreover, studies that focused on intranasal OT administration, showed that OT administration led to higher paternal responsive structuring and less hostility towards the infants (Naber et al., 2010; Naber et al., 2013), although no effects were observed on paternal sensitivity and non-intrusiveness. Less is known about the relation between paternal sensitivity and OT reactivity to interaction with infants, but one study found that for fathers who showed higher levels of stimulatory contact, OT increased after father-infant interaction (Feldman et al., 2010). This finding suggests that paternal sensitive behavior may be positively related to OT reactivity.

A neuropeptide that is biologically related to OT is AVP (Carter, 2017; Carter et al., 2020). Research on AVP in relation to parental caregiving behavior is scarce, however, some research indicates that AVP is involved in specific parental behaviors during parent-infant interactions. Apter-Levi et al. (2014) showed that, in contrast to their observation for OT, mothers' and fathers' basal AVP levels were positively associated with observed stimulatory touch, although not with affectionate touch. Moreover, parents with high basal AVP levels, compared to low basal AVP levels, provided more stimulatory touch and tended to respond more to infant social cues with gaze at an object or stimulatory touch. These results might suggest that basal AVP might have a similar role in positive parenting behavior as paternal OT, however, to draw firm conclusions further research is needed. Focusing on fathers specifically, previous studies showed that AVP might be linked to the processing of infant cues in fathers (to be) (Alyousefi-Van Dijk et al., 2019; Atzil et al., 2012; Cohen-Bendahan et al., 2015; Thijssen et al., 2018; but see Li et al., 2017 for non-significant neural findings), however, not to the thoughts and feelings fathers have about their unborn child (Lotz et al., 2020a). Interestingly, no previous studies have focused on AVP reactivity. However, as AVP is biologically related to OT (Carter, 2017; Carter et al., 2020) and previous literature indicates that father-infant interaction may lead to changes in OT, it is important to study whether fathers' sensitivity is associated with changes in AVP during interaction with their infant.

A steroid hormone that has been linked to paternal behavior is T. T has been previously studied in the context of paternal involvement and parenting quality, and lower levels of basal T were found to be associated with higher involvement and parenting quality, with small to medium combined effect sizes (see for meta-analyses Grebe et al., 2019; Meijer et al., 2019). Observational studies that focused specifically on sensitivity during father-infant interactions found negative associations between basal T levels of fathers and their affectionate and stimulatory touch, and between basal T levels and the average duration of infant-directed vocalization, i.e., motherese (Gordon et al., 2017; Weisman et al., 2014). In the same vein, the delay in infant-directed speech was positively associated with basal T levels of fathers (Weisman et al., 2014). In the context of hormonal reactivity, one study found that paternal salivary T levels decrease after a caregiving interaction with their infant (Bos et al., 2018). A similar decrease in T of fathers was observed in reaction to an infant doll's cries when coupled with nurturing responses (van Anders et al., 2012). This might indicate that T reactivity is related to paternal caregiving behavior. Moreover, there is some evidence that hormone reactivity induced by father-infant interactions might predict positive parenting behavior in a subsequent task (de Vries et al., 2019; Kuo et al., 2016).

Another steroid hormone that is associated with parenting behavior is CORT. For example, it was shown that in both fathers and mothers basal CORT measured a few days after the birth of their infant was positively associated with parental behavior (Fleming et al., 1987; Kuo et al., 2018). Specifically for fathers, higher basal CORT levels in the early postnatal period, i.e., first two days after birth, predicted greater involvement in direct and indirect infant care measured a few months later (Kuo et al., 2018). Interestingly, the relation between basal CORT levels and positive parenting seems to be reversed (i.e., negative) when CORT is measured several months after birth in both fathers (Bos et al., 2018) and mothers (Finegood et al., 2016; Gonzalez et al., 2012). As the infants in the current study are around eight weeks old, we expect to observe a negative association between basal CORT levels and paternal sensitivity. Concerning CORT reactivity, a significant decline in paternal CORT was observed after holding or interacting with their infant (Bos et al., 2018; Kuo et al., 2018; Storey et al., 2011). However, how this decline in CORT is related to the quality of paternal behavior is still unclear.

There are many indications that hormones act in concert, rather than acting in isolation (Feldman and Bakermans-Kranenburg, 2017; Rajhans et al., 2019). For example, OT might interact with T and AVP, as OT nasal spray administration increased salivary T levels (Weisman et al., 2014) and salivary AVP levels (Weisman et al., 2013). In addition, salivary T and CORT are found to be positively associated (Bos et al., 2018; Gettler et al., 2011). Moreover, hormones may interact in their effects on paternal behavior. For instance, OT and T may interact in their effect on paternal sensitivity as it was shown that T levels moderated the association between OT and affectionate touch (Gordon et al., 2017). In addition, salivary T and CORT might interact in their effects on behavior. For instance, the dual hormone hypothesis states that associations of T with behavior depend on individuals' CORT levels (Mehta and Prasad, 2015). In the context of parenting behavior, Bos et al. (2018) found a stronger negative association between CORT and sensitivity for fathers high in T, suggesting that a combination of high T and high CORT levels is associated with lower sensitivity scores. Taken together, previous research and theory suggest that studies of hormonal correlates of parenting behavior may be more informative when examining several hormones simultaneously, as the combined associations and interplay between these hormones may be more informative in their associations with parenting than each of them separately.

In the current study, we explored whether baseline levels of OT, AVP, T and CORT were associated with paternal sensitivity in first-time fathers. Moreover, we studied whether paternal sensitivity during observed father-infant interaction was associated with changes in OT, AVP, T and CORT. Finally, we explored whether interactions between the various basal hormone levels could predict paternal sensitivity. By focusing on multiple hormones and their combined associations with paternal sensitivity, rather than only studying parenting hormones in isolation, we aimed to enhance our knowledge on the role of endocrine factors in sensitive parenting behavior in fathers.

2. Methods

2.1. Participants

Seventy-nine first-time fathers were recruited via municipal records, infant welfare centers, midwife practices and social media (See Supplementary Material Fig. 1 for a recruitment overview). Participants were first-time fathers in the early postnatal phase of parenthood, all but one were the biological father of their child, spoke Dutch fluently, and cohabitated with their partner (and biological mother of the child). Children were healthy full-born infants (except for one infant that was born at 36 weeks and six days, but was considered healthy). See Table 1 for an overview of demographic variables.

Before inclusion, fathers were screened for psychiatric, endocrine, neurological diagnosis, medication use, alcohol/and or drug abuse, and possible MRI contraindications (e.g., metallic foreign objects in

Table 1
Sample characteristics.

$N = 79$		$M(SD)/N$ (%)	Range		
Participant age (years)		33.10 (5.36)	25.06	–	56.50
Education (years past primary education)[a]		8.28 (1.85)	3.00	–	10.00
Country of birth[a]	The Netherlands	72(92)			
	Other	6(8)			
Race	Caucasian	73(92)			
	Other	6(8)			
Infant age (weeks)		11.62 (3.37)	7.57	–	21.57
Infant sex	Male	42(53)			
Baseline oxytocin[a] (pg/mL)		1.38 (0.45)	0.00	–	2.18
Baseline vasopressin[a] (pg/mL)		1.62 (0.47)	0.87	–	2.67
Baseline cortisol[b] (nmol/L)		1.75 (2.28)	0.09	–	15.40
Baseline testosterone[b] (pg/mL)		45.42 (35.91)	2.14	–	216.96
Post-interaction oxytocin (pg/mL)		1.37 (0.45)	0.65	–	2.80
Post-interaction vasopressin (pg/mL)		1.64 (0.50)	0.80	–	2.52
Post-interaction cortisol (nmol/L)		1.28 (1.46)	0.17	–	10.13
Post-interaction testosterone (pg/mL)		44.30 (39.18)	2.88	–	196.14
Oxytocin reactivity[a]		0.00 (0.99)	−2.38	–	3.52
Vasopressin reactivity[a]		0.00 (0.99)	−2.55	–	2.35
Cortisol reactivity[b]		0.00 (0.99)	−2.76	–	4.15
Testosterone reactivity[b]		0.00 (0.99)	−2.25	–	5.12
Observed sensitivity		5.73 (1.48)	3.00	–	8.50
Observed cooperation		4.47 (1.56)	2.00	–	8.00

Note. Sample characteristics are calculated based on non-transformed complete cases data. Participants' race was coded by researchers based on videotapes of fathers and was defined as Caucasian or other. Hormonal reactivity was calculated with a residualized change score, i.e., post-interaction samples were residualized by corresponding baseline samples.
[a] $N = 78$.
[b] $N = 77$.

participant's body). Moreover, fathers were excluded when they had an upper torso injury that could affect the use of a baby carrier or reported to use a baby carrier more than 5 h per week, which was relevant for the full study procedure that included the use of a baby carrier (Bakermans-Kranenburg, 2014; Riem et al., 2021). To maximize the sample size, we decided to deviate from a priori stated inclusion criteria in seven cases (Birth <37 weeks $n = 1$, endocrine disorder $n = 1$, cardiovascular disease $n = 1$, neurodevelopmental disorder and psychotropic medication use $n = 1$, and MRI contraindications $n = 3$). The study was approved by the Ethics Committees of the Leiden University Medical Centre (LUMC) and of the Department of Education and Child studies at Leiden University. The study was carried out in accordance with the declaration of Helsinki and all participants gave written informed consent.

2.2. Procedure

Depending on participant's preference and possible MRI contraindications, the data reported in the current paper was collected either at the Leiden University Medical Centre ($n = 65$) or at the participant's home ($n = 14$). Each assessment consisted of the following measures: saliva and hair sampling for hormonal measurements (Lotz et al., 2020b; Manenschijn et al., 2011); behavioral measurements, including a 10-minute Free play; a handgrip force paradigm (Alyousefi-Van Dijk et al., 2019); the Five Minute Speech Sample (Lotz et al., 2020a); and questionnaires about e.g., health, medication use and current mental state. Additionally, when the assessment took place at the LUMC, the Free Play was immediately followed by the Auditory Startling Task (AST; Lotz et al., 2020b) and neural measurements were conducted (Alyousefi-van Dijk et al., 2020; Horstman et al, 2022; Riem et al., 2021). Following the assessments, participants and partners completed online questionnaires at home.

2.3. Measures

2.3.1. Paternal sensitive parenting

Paternal positive parenting behavior was observed from a video-taped 10-minute free play session. Before the start of the recordings, fathers were instructed to play with their infant as they would normally do. To ensure that both father and infant were visible on the video at the start of the recording, participants were asked to lay their infant on a play mat and take a seat next to their infant. During the first 5 min, father and infant played without toys, after which the experimenter provided a standard set of age-appropriate toys (e.g., a ball and a music toy) to play with for another 5 min. Videos were rated for paternal sensitivity and cooperation using the 9-point Ainsworth Sensitivity Scales (Ainsworth et al., 1974), in which higher scores indicate higher levels of sensitivity and cooperation. Five coders were trained by an expert coder (MBK) and interrater reliability with the expert coder was established. ICCs (single measure, absolute agreement) based on 20 videos were adequate, ranging between 0.68 and 0.76 ($M = 0.73$) for sensitivity and between 0.64 and 0.79 ($M = 0.70$) for cooperation.

2.3.2. Hormones

Hormones were measured in saliva. Salivary samples were obtained at the beginning of the assessment (Baseline, $M = 03{:}25$ pm, $SD = 3{:}13$ h, range = 09:15 am–07:39 pm) and 10 min after the end of the free play (post-interaction sample, $M = 04{:}11$ pm, $SD = 3{:}14$ h, range = 09:50 am–08:29 pm). Participants were instructed not to engage in physical exercise or consume any alcoholic drinks during the 24 h prior to the assessment. Moreover, participants were instructed not to drink any caffeinated drinks on the day of the assessment, and not to smoke, chew gum, eat or drink (other than water) 30 min before the start of the appointment. Before the start of each saliva collection participants rinsed their mouth with water. After collection, samples were stored at −20 °C as soon as possible. When samples could not be stored in the freezer immediately, samples were placed on ice. Baseline samples of one participant were not stored adequately immediately after collection, and they were therefore excluded from further analyses. Hormonal reactivity was calculated with a residualized change score, i.e., post-interaction sample levels were residualized by baseline sample levels.

2.3.2.1. Steroid hormones. For the quantification of T and CORT, saliva was collected using the passive drool method. Participants collected approximately 1.5 mL saliva in a 2 mL cryogenic vial (SalivaBio, Salimetrics), either by drooling directly into the vial or by using a saliva collection aid (SalivaBio, Salimetrics). Before drooling, participants were asked to swallow once and to bent slightly forward. To stimulate saliva production, participants were recommended to move their jaws, to look at pictures of food, or to think about something sweet or sour. On average, it took 9.29 ($SD = 5.71$) min to complete the collection. T and CORT levels were quantified at Dresden LabService GmbH (Germany) by Luminscence immunoassay (IBL International GMBH), e.g., see Alvergne et al. (2009) for a detailed description of the procedure for T. All samples, except six, were analyzed in the same assay run (14 plates total) and 30% of the samples were randomly selected and analyzed in

duplicate for the calculation of the intra-assay variability. For the samples ran in duplicate, a mean value was calculated and used in further analyses. Fifty μL of each sample was used for the quantification of T. The limit of detection was 1.8 pg/mL. Inter-assay variability was ≤10% and intra-assay variability was 5%. Cross-reactivity with other substances tested ≤0.01%. T values are reported in pg/mL. For the quantification of CORT, 20 μL of each sample was used. Detection limit was 0.012 μg/dL. Inter-assay variability was ≤8% and intra-assay variability was 8%. Cross-reactivity with other substances tested ≤1%. CORT values are reported in nmol/L.

2.3.2.2. Neuropeptides. For the quantification of AVP and OT, saliva was collected using a cotton swab (Salivette, Sarstedt). Participants were instructed to chew lightly on a cotton swab for 60 s and slightly move the swab around in their mouth. AVP and OT were quantified using radioimunnoassay at RIAgnosis (Sinzing, Germany, see for detailed description Kagerbauer et al., 2019). Salivettes were centrifuged at 4 degrees Celsius for 30 min with ca. 5000*g* centrifugal force, after which 0.6 mL of saliva was pipetted into a vial (0.3 mL for the analysis of AVP and 0.3 mL for the analysis of OT). All samples were analyzed simultaneously in the same assay run. The detection limit for AVP and OT was in the 0.1 pg sample range. Intra-assay and inter-assay variability were <10%. There was no significant cross-reactivity with other neuropeptides (< 0.7%). AVP and OT values are reported in pg/mL.

2.4. Data-analyses

2.4.1. Data distribution

Distribution of the data was inspected in SPSS version 24. Shapiro Wilk tests showed that the distribution of all collected variables, except for baseline OT levels, did deviate significantly from a normal distribution. However, based on the skewness and kurtosis of the distributions, only baseline and the post-interaction samples of CORT and T levels did not approach normal distributions. Baseline CORT and T variables were Log-transformed for further analyses. Hormone reactivity was calculated based on the untransformed baseline and post-interaction values. Next, outliers were inspected. Inspection of Z-values revealed six outliers ($Z < -3.29$ or $Z > 3.29$): one for OT reactivity, one for CORT reactivity, one for T reactivity, one for the participants' age, and two for participants' BMI. All outliers were winsorized (Tabachnick and Fidell, 2007). After winsorizing, all four hormonal reactivity variables approached a normal distribution. Lastly, assumptions for multiple linear regressions were inspected. Variance inflation factors (VIF) ranged between 1.03 and 1.73, indicating absence of multicollinearity. Scatterplots revealed that the data was homoscedastic and normal P-P plots indicated that residuals were normally distributed. Durbin-Watson tests ranged between 2.19 and 2.23 and indicated independent error-terms. Visual inspection of Cook Distances indicated multivariate normality of the data and Mahalanobis Distances indicated the absence of multivariate outliers.

2.4.2. Covariates

We examined whether baseline hormone levels, hormone reactivity, and observed sensitivity and cooperation were significantly different between lab and home assessments. Moreover, we tested if time of saliva collection (e.g., Berg and Wynne-Edwards, 2001; Dabbs, 1990), participant age (van Anders et al., 2014), and recent caffeine intake (e.g., Lovallo et al., 2006) were significantly related with baseline levels of all four hormones. Additionally, age of the infant was an examined as a significant covariate for both T and CORT baseline levels. Specifically for CORT baseline levels, BMI was examined as possible covariate (Fraser et al., 1999). As the Free Play was immediately followed by the AST (Lotz et al., 2020b) during LUMC visits but not the home visits, the possible relation between the administration of the AST and hormone reactivity levels was tested. For observed sensitivity and cooperation, the age of the infant was explored as possible covariate because infant development might affect the interaction between father and infant. Significance was set at $p < .05$. For baseline hormone levels, significant differences were observed between lab and home samples (AVP: $t(27.19) = 3.25$, $p = .00$; CORT: $t(14.91) = -2.52$, $p = .02$; T: $t(21.82) = -2.29$, $p = .03$). Moreover, baseline hormone levels were significantly associated with infant age (CORT: $r = 0.32$, $p = .01$; T: $r = 0.33$, $p < .01$), and time of collection (CORT: $r = -0.38$, $p = .00$; T: $r = -0.24$, $p = .04$). Pearson and Spearman correlations revealed similar outcomes.

2.4.3. Analyses

Firstly, bivariate Pearson correlations were computed for the associations between baseline hormone levels, hormone reactivity, observed sensitivity, and observed cooperation based on the full cases dataset. Significance was set at $p < .05$. Secondly, Structural Equation Model (SEM) analyses were computed to explore the main research questions (see supplemental material for the R code). In a first step, a SEM was computed that explored whether baseline hormone levels together predicted the latent construct Sensitivity (i.e., based on observed sensitivity and cooperation). A second SEM was computed to explore whether Sensitivity predicted hormonal reactivity (i.e., OT, AVP, CORT, and T). In a final SEM, it was explored whether hormonal reactivity predicted Sensitivity. SEM analyses were performed with the package Lavaan (Rosseel, 2012) in R (R Development Core Team, 2013). The location of the assessment was included as a covariate for baseline AVP, baseline CORT, and baseline T. Infant age was included as a covariate for baseline CORT and baseline T, and time of saliva collection was included as a covariate for baseline CORT and baseline T. For each model, the Robust Maximum Likelihood Estimation (MLR) was used. Moreover, the fit was checked with the robust χ^2-statistic, the Comparative Fit Index (CFI), and the Root Mean Square Error of Approximation (RMSEA). CFI values greater than 0.90 and RMSEA values smaller than 0.08 indicate acceptable model fit (Hu and Bentler, 1999). One percent of the data was missing (range = 0–2.5). Little's MCAR test (Little, 1988) indicated that the data was missing completely at random ($\chi^2(26) = 23{,}64$, $p = .60$). Therefore, Full Information Maximum Likelihood (FIML) was used to handle missing data.

Finally, we explored whether interactions between basal hormone levels predicted Sensitivity using the rFSA package (Lambert et al., 2018) in R (see supplemental material for the R code). The rFSA package identifies interaction terms that are most optimal solutions to explain variance in the dependent variable. The algorithm starts with a random combination of two predictors and then exchanges one of the two variables of the interaction term and the corresponding main effect. After each change, the fit of the model was evaluated based on *p*-values (Lambert et al., 2018). Baseline levels were centered and the analysis was based on 50 random starts. The average of the standardized scores for observed cooperation and sensitivity was used as dependent variable. The PROCESS macro for SPSS (version 3.5, Hayes, 2017) was used to further explore the best interaction term using multiple regression analysis.

3. Results

3.1. Preliminary results

As shown in Table 2, analyses revealed correlations with small to large effect sizes (Cohen, 1988). Pearson correlations indicated a strong positive association between the observed sensitivity and cooperation scales. Furthermore, baseline T was positively associated with baseline CORT. The negative correlation between baseline OT and baseline T felt short of significance, but showed small to medium effect size. Correlations between hormone reactivity levels indicated a trend-level correlation between T reactivity and CORT reactivity. Additionally, cooperation was negatively correlated with baseline OT levels. Finally, there was a trend for the negative association between baseline T levels

Table 2
Correlations between baseline hormone levels, hormone reactivity and observed sensitivity and cooperation.

Variable	Baseline OT	Baseline AVP	Baseline CORT	Baseline T	Reactivity OT	Reactivity AVP	Reactivity CORT	Reactivity T	Sensitivity	Cooperation
Baseline OT	x	–	–	–	–	–	–	–	–	–
Baseline AVP	−0.028	x	–	–	–	–	–	–	–	–
Baseline CORT	−0.188	−0.074	x	–	–	–	–	–	–	–
Baseline T	−0.216†	−0.080	0.556**	x	–	–	–	–	–	–
Reactivity OT	−0.010	−0.168	0.012	−0.206†	x	–	–	–	–	–
Reactivity AVP	0.062	0.000	0.020	0.042	−0.124	x	–	–	–	–
Reactivity CORT	−0.072	0.190†	−0.065	−0.205†	−0.113	0.037	X	–	–	–
Reactivity T	−0.115	0.116	−0.045	0.008	0.166	−0.116	0.202†	x	–	–
Sensitivity	−0.154	0.091	0.093	0.138	0.178	0.019	−0.030	−0.128	x	–
Cooperation	−0.234*	0.130	0.079	0.112	0.125	−0.010	−0.035	−0.099	0.667**	x

Note. Bivariate Pearson correlations are calculated on full cases dataset. Hormone reactivity is calculated by residualizing post-interaction hormone levels with baseline hormone levels. Baseline CORT and T levels are log-transformed.
** $p < .01$, * $p < .05$, † $p < .1$.

and OT reactivity, and for the positive association between basal AVP levels and CORT reactivity.

3.2. Structural models (SEM)

3.2.1. Baseline hormone levels and sensitivity

The first SEM with baseline hormone levels controlled for infant age and saliva collection time, as predictors of Sensitivity showed a perfect fit: χ^2 (6) = 2.21, p = .90; CFI = 1.00; RMSEA = 0.00 (Fig. 1). Standardized factor loadings were high, 0.68 and 0.99 for respectively observed sensitivity and cooperation, indicating an underlying latent variable Sensitivity. Parameter estimates revealed no significant associations with the latent construct Sensitivity. The observed perfect fit in combination with non-significant parameter estimates indicates that the power to reject the null hypothesis that the predicted model and observed data are equal was insufficient. As the correlation matrix revealed that baseline OT levels were significantly correlated with observed cooperation, we performed a multiple linear regression analysis with only cooperation as dependent variable. Results revealed no significant association between observed cooperation and baseline hormone levels, controlling for location of assessment, infant age and time of saliva collection (range β: −0.19–0.18; range SE: 0.00–0.58; $p \geq$ .11).

3.2.2. Sensitivity and hormonal reactivity

Next, we conducted a SEM examining the latent construct Sensitivity as a predictor of hormone reactivity levels. This model also indicated a perfect fit: $\chi^2(3) = 0.69$, p = .88; CFI = 1.00, RMSEA = 0.00 (Fig. 2).

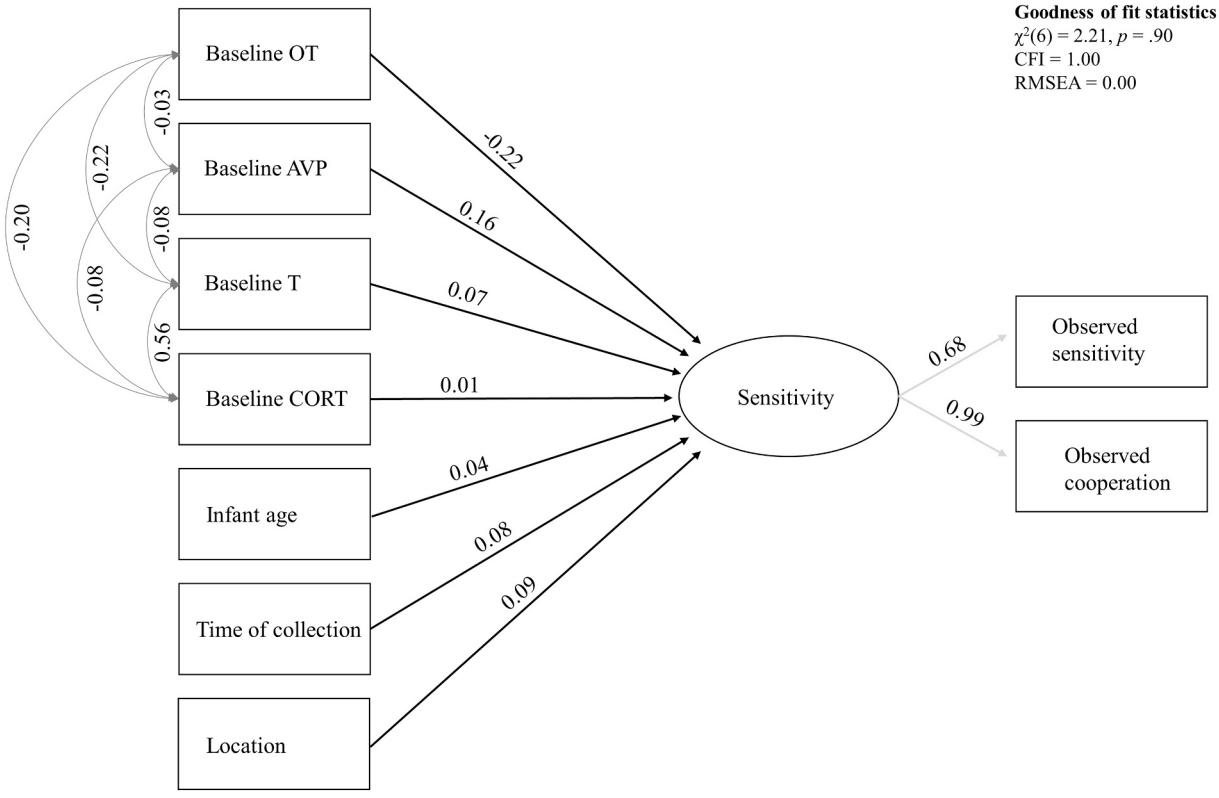

Fig. 1. SEM model with baseline hormone levels as predictors of sensitivity.
Note. Path coefficients are standardized parameter estimates. Black arrows indicate standardized β's. Dark grey arrows indicate correlation coefficients between the predictors. Light grey arrows indicate standardized factor loadings for latent construct sensitivity. Predictors are controlled for infant age, time of saliva collection and location.

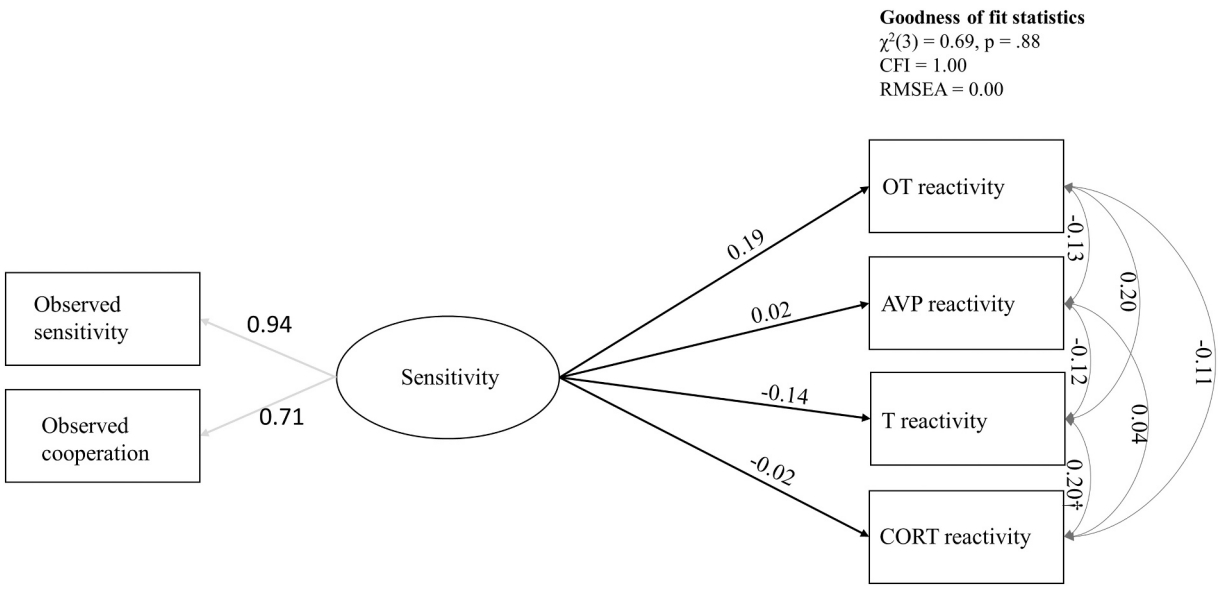

Fig. 2. SEM model with sensitivity as predictors of hormone reactivity.
Note. Path coefficients are standardized parameter estimates. Black arrows indicate standardized β's. Dark grey arrows indicate correlation coefficients between the dependent variables. Light grey arrows indicate standardized factor loadings for latent construct Sensitivity.
† $p < .1$.

Standardized factor loadings for the latent variable Sensitivity were high, 0.94 and 0.71 for respectively observed sensitivity and cooperation. There were no significant associations between Sensitivity and hormone reactivity, indicating that variation in sensitive parenting was not related to variation in hormonal reactivity. Additionally, we explored whether hormone reactivity levels predicted Sensitivity (see Supplementary material Fig. S2). Again, a perfect fit was observed $\chi^2(3) = 0.69$, $p = .88$; CFI = 1.00, RMSEA = 0.00 and factor loadings for the latent variable were high (above 0.71). No significant associations were observed between hormone reactivity levels and Sensitivity. Trends were observed for the associations of Sensitivity with OT reactivity and T reactivity (a stronger increase in OT or T was related to higher Sensitivity).

3.3. Interaction between baseline hormone levels

rFSA analysis revealed that the interaction term between baseline CORT and T, in combination with the main effects of baseline CORT and T as predictors provided the optimal solution for the fit of the data (adjusted $R^2 = 0.07$, $F(3,73) = 2.98$, $p = .04$). A post-hoc multiple regression analysis revealed that the interaction between CORT and T significantly predicted the average of the standardized scores for cooperation and sensitivity ($\beta = -0.31$, SE = 0.59, $p = .01$). To further examine this interaction, we performed a simple slope analysis with low (−1 SD) and high (+1 SD) CORT groups (see Fig. 3). For fathers with low CORT levels, baseline T was positively related to Sensitivity (B = 0.83, SE = 0.38, $p = .03$). For fathers with high CORT levels, baseline T was negatively related to Sensitivity (B = −0.59, SE = 0.46, $p = .20$), although it should be noted that this slope was not significantly different from zero.

3.4. Sensitivity analyses

As we obtained perfect fit for each SEM model, suggesting a lack of statistical power to reject the null hypothesis, we performed sensitivity analyses to explore whether multiple linear regression analyses resulted in similar (standardized) estimates. For this purpose, standardized scores for sensitivity and cooperation were averaged. Sensitivity

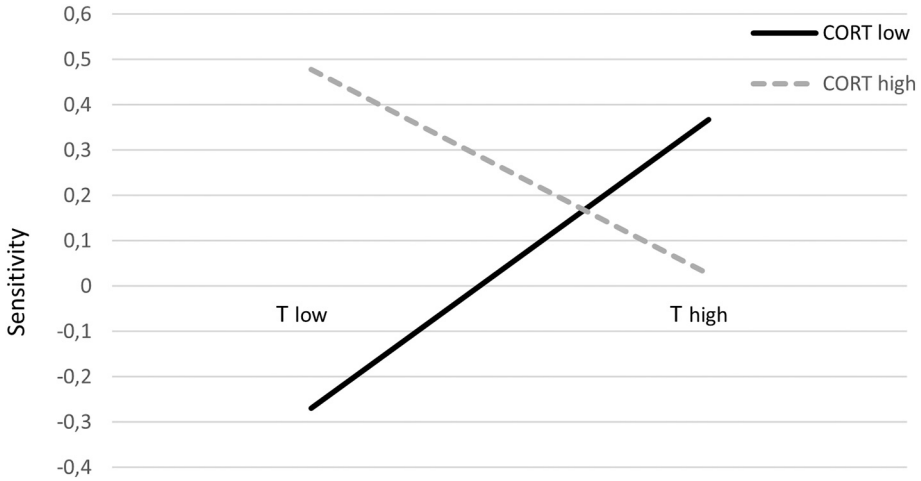

Fig. 3. The interaction between testosterone and cortisol on sensitivity.
Note. This figure demonstrates the interaction between testosterone and cortisol on sensitivity. A simple slope analyses was performed with low CORT (−1SD) and high CORT (+1SD) groups. Sensitivity was calculated by averaging the standardized scores for observed cooperation and sensitivity. All three variables are centered and cortisol and testosterone Log-transformed.

analyses with multiple linear regression analyses revealed similar (standardized) estimates for all three SEM models (see supplementary material Table S1a–c).

Moreover, sensitivity analyses were performed for the three SEM models excluding two participants that had an endocrine disorder or reported to have used medication potentially interfering with the endocrine system on the day of the assessment, as this might affect participants' hormone levels. The SEM with baseline hormone levels as predictors of the latent construct Sensitivity showed a perfect fit: χ^2 (6) = 2.27, p = .89; CFI = 1.00; RMSEA = 0.00. Parameter estimates revealed similar associations with the latent construct Sensitivity. The SEMs focusing on hormone reactivity levels indicated both perfect fit and revealed no significant associations, however, two associations now approached significance in the third SEM. The beta corresponding to the association between OT reactivity and Sensitivity was within the range of 10% from the beta from the main analyses. The beta corresponding to the association between T reactivity and Sensitivity was just outside the range of 10%.

4. Discussion

In the current study, the relation between parenting hormones and sensitive parenting behavior was studied in first-time fathers in the early postnatal phase. We explored associations between basal OT, AVP, T, and CORT (separate and combined) on the one hand and paternal sensitivity on the other hand, as well as associations between paternal sensitivity and OT, AVP, T, and CORT reactivity. Finally, we explored the interactions between various basal hormone levels in the prediction of paternal sensitivity. Results revealed no significant associations between sensitivity and hormone baseline levels or reactivity, however, analyses indicated that the interaction between CORT and T significantly predicted paternal sensitive parenting.

As possible correlates of paternal sensitive behavior, we focused on the baseline levels and hormone reactivity of two neuropeptides and two steroid hormones that have previously been associated with parental sensitivity, namely OT, AVP, T and CORT. To test whether baseline hormone levels together are proper predictors of paternal sensitivity, and whether paternal sensitivity predicts hormonal reactivity, we performed SEM analyses with observed sensitivity and cooperation as a latent construct (Sensitivity). Both the SEM model including basal hormone levels, and the SEM model including hormonal reactivity revealed a perfect fit, suggesting a lack of power to reject the null hypothesis that the predicted model and the observed data are equal (Muthen, 2013). Nonetheless, as multiple regression sensitivity analyses revealed similar regression parameter estimates, we are able to interpret the individual regression parameters. Concerning basal hormone levels, none of the bivariate associations between hormones and Sensitivity were significant, suggesting that basal hormones were no suitable correlates of paternal sensitivity in the current study. These findings are not in line with previous literature that reported significant associations between single baseline hormone levels and positive parenting behavior (see e.g., Apter-Levi et al., 2014; Feldman et al., 2010; Kuo et al., 2018; Meijer et al., 2019). Concerning hormone reactivity, no associations with Sensitivity were observed, suggesting that paternal sensitivity does not relate to fathers' hormonal responses to interacting with their infants. Although no previous research examined associations of AVP and CORT reactivity with paternal caregiving behavior, some previous studies did suggest an association between OT and T reactivity and quality of caregiving (Feldman et al., 2010; van Anders et al., 2012). The current findings did not confirm the limited available previous findings on the link between paternal sensitivity and hormone reactivity.

The discrepancy between the current non-significant associations and previously observed relations might be explained by several reasons. First, the perfect fit of the SEM analyses and the non-significant regression estimates might indicate that the current study was underpowered. This might be due to a relatively small sample size and on average low correlations between hormone levels and observed parenting behavior (Muthen, 2013). Notably, several effect sizes for the regression estimates were around 0.20 (i.e., the association between baseline OT and Sensitivity, Sensitivity and OT reactivity, and T reactivity and Sensitivity). These might indicate promising findings for further exploration in larger samples.

Second, differences between previous studies and the current study in the operationalization of parental sensitivity may have led to different findings. In the current study, we used the Ainsworth Sensitivity Scales (Ainsworth et al., 1974), reflecting parents' ability to perceive, accurately interpret, and appropriately and promptly react to infants' signals (sensitivity) and the extent to which parents' behavior interferes with the infants ongoing activity (cooperation). A different coding scheme that has been used in previous studies focusing on the endocrine correlates of parental sensitivity is the biobehavioral synchrony model (Feldman, 2012). This model includes amongst others the amount of parental affectionate contact and stimulatory contact (Feldman et al., 2010). Interestingly, although the synchrony model incorporates affectionate behavior that might sooth the infant, the aspect of prompt and appropriate responses to infant signals is not incorporated in the coding scheme. Moreover, stimulatory play can be more or less cooperative, depending on whether the action interferes with the baby's ongoing activity. This difference in coding schemes might explain that we observed reversed (negative) associations between the basal OT and cooperation and between OT and Sensitivity in the current dataset, compared to previous findings of Feldman et al. (2010). Future research is necessary to further examine the similarities and differences between the coding systems to be able to compare previous findings on the associations between fathering behavior and endocrine measurements.

Third, the discrepancy with previous findings might be explained by differences in sampling methods, for example, saliva vs. plasma, and lab analyses (Grumi et al., 2021). Moreover, for humans it is still unclear whether plasma and salivary OT measurements are reliable indicators of central OT levels (Grumi et al., 2021), although previous studies indicate moderate correlations between peripheral plasma and salivary OT and AVP (Feldman et al., 2010; Feldman et al., 2011; Weisman et al., 2013).

Last, contrary to previous research, we included four hormones that had been associated with parenting behavior, thereby incorporating their shared variance. Including several hormones might be a more suitable method as previous literature indicates that hormones act in concert rather than in isolation (e.g., Feldman and Bakermans-Kranenburg, 2017; Rajhans et al., 2019).

Indeed, exploratory analyses for interactions between basal hormone levels indicated that the interaction between CORT and T statistically predicted Sensitivity. In short, the association between T and sensitivity was dependent on accompanying CORT levels: fathers with low basal CORT levels showed more sensitivity with increasing T levels, but fathers with high CORT levels were less sensitive with increasing T levels. These results indicate that low levels of both T and CORT, as well as high levels of both T and CORT, were associated with lower parenting sensitivity. However, it should be noted that the observed relation in the high CORT group was not significantly different from zero and should be interpreted with caution. The current results might thus indicate that, conform the dual hormone hypothesis (Mehta and Prasad, 2015) and previous research (Bos et al., 2018), the interplay between CORT and T might provide a more relevant correlate of positive parenting behavior than hormone main effects. Future research is clearly needed to elaborate on the associations between hormone systems and parenting behavior.

The current study has several limitations that should be discussed. First, we have single measurements of basal hormone levels, reactivity, and paternal sensitivity. Future research is encouraged to use repeated measurements collected on several consecutive days as this approach may provide more robust indications about the associations between hormones and behavior. Second, we cannot draw conclusions about longitudinal or causal relations between hormones and behavior based

on the current study. Although there is time-ordering in the current measures (i.e., the basal hormone sample was collected before the father-infant interaction, and the post-interaction sample was collected 10 min after the interaction), the measures were assessed in close temporal proximity. Manipulation of hormones or parenting behavior may be needed to assess any causal effects. Third, the procedure was not completely standardized as the location of the assessment (lab vs home) and the administration of the Auditory Startling Task (Lotz et al., 2020b) after the free play episode differed across participants. As analyses indicated that baseline hormone levels were different at home and in the lab, we controlled for location in further analyses. Last, as already mentioned above, the current analyses might be underpowered due to the relatively modest sample size. Future research should aim for larger samples to test the associations between hormonal systems and sensitive parenting behavior.

In sum, the current study was the first to explore the separate and combined associations between OT, AVP, T and CORT, and fathers' sensitive parenting behavior. Our results indicate an absence of associations between paternal sensitivity on the one hand and basal levels of hormone activity and reactivity on the other hand. However, basal CORT and T interacted in their prediction of sensitive parenting behavior. This might indicate that variations in parental sensitivity might be better explained by interactions between hormones than by single hormone levels. As sensitive parenting behavior is related to a number of positive child outcomes including cognitive and socio-emotional development (Deans, 2020) and infant attachment security (Brown et al., 2012; Lucassen et al., 2011), further examination of the association between hormones and behavior might be important to better understand the contributing factors of paternal sensitivity.

CRediT authorship contribution statement

AML: Methodology, Validation, Formal analysis, Investigation, Data curation, Writing- original draft, Visualization, Project administration. RSMB: Methodology, Formal analysis, Writing – review & editing, Visualization, Supervision. KA-vD: Investigation, Writing – review & editing. AMW: Investigation, Writing- review & editing. MJB-K: Conceptualization, Methodology, Formal analysis, Data curation, Writing – review & editing, Supervision, Funding acquisition. MWFTV: Methodology, Formal analysis, Data curation, Writing – review & editing, Visualization, Supervision.

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Declaration of competing interest

None.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.yhbeh.2022.105118.

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