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RESEARCH ARTICLE

Fathering behavior, attachment, and engagement in childcare predict testosterone and cortisol

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Abstract

The present study examined testosterone (T) and cortisol (Cort) in fathers engaged with caregiving. We collected saliva samples in the mornings and evenings of two consecutive days in 150 fathers of 1- to 5-year-old children. Fathers completed questionnaires on socioeconomic status, family structure and life, sleep characteristics and body mass index (BMI), and reported on their engagement in childcare. Fathers used smartphone-based experience sampling throughout 1 week to sample ongoing activities with their children, including times of *supervision*, *joint play*, *rough-and-tumble play*, and *cuddling* episodes. External observers rated *father–child attachment* during a home visit.

We began by testing for widely characterized covariates of T and excluded seasonal variations and known predictors associated with lowered T, such as older fathers and those with multiple and young children, lower BMI, shorter sleep duration, and sexual activity before sampling. Most interestingly, however, fathers' *engagement* in childcare and *attachment* to the child appeared more pronounced the greater the diurnal decline in T. *Cuddling* predicted a similar negative association, whereas *joint play* and *rough-and-tumble play* (RTP) showed enhancing effects on declining T. Interestingly, all fathering behaviors (except *RTP*) were positively related to lower Cort. In contrast, *supervision* was ineffective on both Cort and T.

KEYWORDS

Attachment-Q Sort, Parental Behavioral Inventory, quality of father–child relationship, seasonal variation in testosterone and cortisol, timetable interview

1 | INTRODUCTION

Inspired by findings that among some male birds, pair-bonding and paternal care are associated with lower testosterone (T) levels, while searching for and acquiring mating partners are associated with higher T (Wingfield et al., 1990), a growing body of research examined the role of T in humans during the past decades. A meta-analysis of around 66 studies by Grebe et al. (2019) recently summarized evidence that (1) partnered men have lower T than single men, (2) men more committed in their current pair-bonded relationship have lower T than those less involved, and (3) fathers have lower T levels than nonfathers. However, the study found substantial heterogeneity across studies on the question whether fathers' T varies with the degree of their involvement in childcare (see also Meijer et al., 2019).

The increased interest in the psychobiology of fathers, and how hormonal responses might be linked to fathering behaviors, was paralleled by the growing attention to fathers in social science. From the mid-1970s onwards, scholars became interested in both quantifiable dimensions of paternal care, such as the amount of time fathers spent with their children, as well as qualitative dimensions, which, for example, describe types and quality of father–child activities and of the father–child relationship (e.g., Cabrera & Tamis-LeMonda, 2013; Lamb, 2000, 2010; Ahnert & Schoppe-Sullivan, 2020). The intent of the present study was to combine quantitative and qualitative dimensions of paternal care and to shed more light upon their hormonal correlates. We mainly focused on the gonadal system, but strengthened the study by additionally exploring fathers' cortisol (Cort) responses. The reason for this approach was that the hypothalamic–pituitary–gonadal (HPG) axis, which is the primary source of T in males, and the hypothalamic–pituitary–adrenal (HPA) axis, which releases Cort, are conceptualized as mutually inhibitory systems and are particularly sensitive in males (e.g., Oyola & Handa, 2017; Toufexis et al., 2014).

In previous research, however, Cort was also related to parenting, where new mothers and fathers already showed higher concentrations of baseline cortisol before the birth and even more postpartum (e.g., Almanza-Sepulveda et al., 2020; Storey et al., 2000; Kuo et al., 2018). These studies demonstrated that greater levels of postpartum Cort were associated with greater sensitive care. With growing stabilization of the parent–child relationship, however, the association of Cort and parenting fluctuated and even reversed (with low Cort in sensitive parents), depending on changing care and play contexts (Bos et al., 2018; Gonzalez et al., 2012). With child maturation, however, the parent and the child increasingly show correlated patterns of Cort release, both concurrently and over time. This coregulation of cortisol can be positively coupled, despite the finding of inverse relations in the Cort responses of mother and child during challenge tasks. This implies that the child's Cort goes up with the stressor while the mother downregulates her Cort release, perhaps calming herself and consequently her child. This mechanism has been interpreted as a way to permit adaptation to threat and protect the child from overexposure to corticosteroids (Atkinson et al., 2013).

1.1 | Fathers' time spent with children

Research on fatherhood initially focused on time fathers spent with their children and showed mixed results when associated with fathers' T levels. Gettler and colleagues found that Filipino fathers who considered themselves as one of the individuals who had responsibility for taking care of children in the household, and spent 3 hrs or more daily on childcare, had lower T compared to fathers not involved in childcare (Gettler et al., 2011b; Kuzawa et al., 2009). Likewise, T levels in Dutch fathers were lower on days with a greater amount of time spent with the child than on the fathers' working days (de Vries et al., 2019). In contrast, when fathers were away from their children for several hours ("without-child" day) as compared to days when they remained with their children ("with-child" day), T levels for "with-child" and "without-child" days did not differ (Storey et al., 2011). Similarly, Gray and colleagues (Gray et al., 2004) evaluated fathers' T levels on days spent mostly with their young children as opposed to days spent mostly away from their children and failed to find significant differences in testosterone. Levels of T did not significantly differ, even when fathers who resided away from their children were compared to fathers who were classified as engaged with paternal care (Gray et al., 2007). Overall, researchers concluded that the qualitative aspects of the father–child activities may be more important in determining hormonal responses to fathering than the pure extent of time that fathers invest in childcare.

1.2 | Differences in fathering behaviors

Fathering behaviors are central to the multifaceted concept of fatherhood. Different types of real-life interactions, which are likely to represent fathering behaviors, were therefore reproduced in the laboratories, videotaped, and microanalyzed. For example, Feldman and her colleagues (e.g., Weisman et al., 2014; Gordon et al., 2017) investigated fathers' interactions with their 1–6-month-old infants. They demonstrated that T was negatively related to the amount of father's affectionate touch (e.g., kissing, stroking, hugging) and his vocalization, which resembled the high-pitched speech with repetitive rhythm usually observed in sensitive mother–infant dyads. Overall, however, fathers' T levels showed very little fluctuation across the father–child activities, similar to other studies that hypothesized T would decrease during fathers' encounters with their children. In these studies, interaction sessions differed greatly: they ranged from 8 to 30-min play sessions with fathers at home in the early afternoon (Endendijk et al., 2016; Gettler et al., 2011a) to a 20-min session with fathers and the child's mother jointly interacting with the child at the university hospital at a random time between morning and afternoon (Gray et al., 2007), and a 30-min father–child test interaction at home in the late afternoon (Storey et al., 2011) when the fathers had either already spent the day with the child ("with-child day") or were only available for the test interaction ("without-child day"). None of these studies found that T significantly changed over the sessions.

In order to conceptualize the effect of T during father–child encounters, researchers thus called for both a stricter consideration of the sampling times, given the natural diurnal decline in T, and a division of the contexts if disparate functional entities are contained. For example, while listening to baby's cries, fathers' perception might lead to decreased or increased T levels depending on whether the listening test had been designed as a nurturing (T decreasing) or competitive-related (T increasing) context (van Anders et al., 2012). To avoid contradictory interpretations of the fathers' hormonal responses, it is therefore necessary to split a heterogeneous context into clearly defined situations and test them separately (see van Anders et al., 2014). However, when de Vries et al. (2019) observed the fathers during two opposing situations, which were designed as a play versus a discipline session (15 min each), T levels did not differ, nor was there a difference in T across Kuo et al. (2016)'s 15 min teaching situation.

One might conclude that neither such short-term situations involving varied fathering behaviors nor different comparisons of long-term day-to-day encounters of a father with his child (Gray et al., 2004; Storey et al., 2011) were able to systematically document fluctuations of the HPG axis. We thus decided to explore fathers' childcare across an entire week, divided father–child activities into relevant categories (beside a complex evaluation of the fathers' quality of childcare based on an inquiry and an observation) in order to link them to fathers' T and Cort levels.

1.3 | Fathering behaviors and the quality of paternal care

Father–child play has become a salient focus in fatherhood research, in the United States and Europe. Scholars have examined various forms of father–child play ranging from joint play activities to extreme physical forms of rough-and-tumble play (RTP). From this research, it seems clear that RTP demonstrates fathers' physical activation and stimulation of risk taking, encouraging child competitive skills (e.g., Ahnert et al., 2017; Paquette, 2004; Paquette & Dumont, 2013; Teufl & Ahnert, submitted). In contrast, joint play activities foremost challenge children's mental and language skills (e.g., Teufl et al., 2020), support child exploration (Grossmann et al., 2002), and regulate emotions when the child copes with frustration (e.g. Deichmann & Ahnert, 2021).

Another focus in current fatherhood research is the intimate side of fathering behaviors dealing with affection and close proximity as, for example, the practice of cosleeping in the Philippines demonstrated. Gettler and his colleagues (Gettler et al., 2012) explored T levels of those fathers who slept on the same surface as their children (same surface cosleepers), slept on a different surface but in the same room (room-sharers), or slept separately to their children (solitary sleepers). As a result, same surface cosleeping fathers had lower evening T than fathers who slept solitarily.

In general, close proximity in parent–child relationships has been most comprehensively explored from the perspective of attachment theory with emotional security as a central construct. Attachment involves tender loving care, comfort and consolation, and external help with emotion regulation when children explore to gain knowledge and skills (see Ahnert & Schoppe-Sullivan, 2020; Bretherton, 2010). A conventional understanding of this construct may also guide questionnaires on parental care. Significant parts of the items are often in line with characteristics of parental attachment behaviors, such as being responsive to the child's needs, enthusiastic about the child's accomplishments, and sensitive to the child's emotional states in order to make the child feel comfortable, accepted and loved (e.g., Abidin, 1995; Lovejoy et al., 1999).

1.4 | Methodological considerations

The present paper built on past research on the association of fathering behaviors and fathers' testosterone, aiming for a better understanding of the hormonal involvement in paternal care. We first oriented the study toward common qualitative aspects of paternal care and examined fathers' engagement in childcare and father–child attachment relationships. In addition, we focused on the time fathers spent with their children over a typical week and divided the amount of time into typical fathering behaviors which focused either on emotionally (e.g., cuddling), mentally (e.g., joint play), or physically (e.g., rough-and-tumble) activating types of father–child activities.

To investigate the diurnal decline of T and to reduce unwanted variation of T, we collected saliva from each father in the mornings and evenings of two consecutive days, as suggested by previous research (e.g., Dabbs, 1990; van Cauter, 1990). We also supported the idea that fathers' engaged parenting might be related to the evening nadir in T, which might be particularly sensitively associated with paternal care (e.g., Kuzawa et al., 2009; Gettler et al., 2011b). We therefore paid particular attention to the sampling times and transformed each time to hours since waking.

Furthermore, we analyzed cortisol from the same saliva samples. Researchers found evidence for a mutually inhibitory interface between T and Cort (see Bedgood et al., 2014; Bos et al., 2018; Harden et al., 2016; Gettler et al., 2011c). In particular, animal research provided detailed insights into the reciprocal relationship between the HPG and the HPA axis in males, wherein the activation of one affects the function of the other and vice versa, demonstrating a dose-dependent and reciprocal crosstalk between the gonadal and adrenal systems (Viau, 2002). However, the synergistic effects which T and Cort exert on human behavior are not well understood (Storey et al., 2020).

We thus broadened the study through a dual endocrine approach, added analyses of Cort and compared them with T to better understand fathers' hormonal responses in the context of childcare. As suggested by van Anders et al. (2014), we eventually examined age and BMI of the fathers as well as age of the target child and the number of children and investigated seasonality effects on T and Cort levels as the sampling took place over 2 years. We thus aimed to control for all those influences to be able to exclude them from effects that related the fathers' engagement, attachment, and parenting behavior to their T and Cort levels.

1.5 | Research questions and hypotheses

The present study followed five major research goals. *First*, we evaluated fathers' T levels as well as the diurnal decline in T. We presumed that fathers' engagement and attachment, which stand for a broad array of affectionate aspects of parenting, would be negatively associated with fathers' T levels and show suppressive effects on the decline of T throughout the day. *Second*, we captured four typical fathering behaviors, namely *supervision*, *joint play*, *RTP*, and *cuddling*, during a week and linked them to fathers' T. We hypothesized that fathering behaviors with affectionate characteristics (like *cuddling*) were related to low T levels, whereas behaviors with mentally challenging and physically activating characteristics (like *joint play* and *RTP*) would show enhancing effects on T. *Third*, we also inspected fathers' Cort levels as well as the diurnal decline in Cort. We proposed that father's engagement and attachment, which reflect interest in the child's world and empathy towards the child, were positively linked to father's Cort and showed enhancing effects on the diurnal decline of Cort. *Fourth*, we presumed for similar reasons that pronounced *joint-play* and *cuddling* episodes throughout a day would be positively related to father's Cort, as many studies showed that increases in Cort in response to the child were predictive of greater paternal involvement in childcare and play (e.g., Kuo et al., 2018). In contrast, fathers who like to engage in *RTP* might downregulate their Cort levels, presumably then calming the child (Atkinson et al., 2013). This implies *RTP* has suppressive effects on father's Cort. *Fifth*, the inhibitory nature by which testosterone regulates HPA functioning led us to expect that the reciprocal crosstalk between HPG and HPA activities are paralleled by fathers' engagement, attachment, and parenting behaviors. We thus expected simultaneous negative associations with T levels and positive associations with Cort levels, and vice versa, which might be consistent with the possibility of suppressive effects on T and enhancing effects on Cort, triggered by fathers' engagement, attachment, and parenting behaviors.

2 | METHODS

2.1 | Participants

Recruitment of $N = 150$ fathers of two-parent families, with target children ($n = 79$ girls) ranging in ages from 12–65; 6 months ($M = 25;10$; $SD = 16;3$), occurred in Vienna/Austria and the surrounding state of Lower Austria. Fathers were on average 38; 5 years (SD = 6;6) old, with a broad range between 22 and 67 years. Fifty-two percent of the fathers were first-time fathers, 39% had one to two older children, and 9% were fathers of an additional younger child (newborn or infant), who was fully nursed and cared for mainly by the mother. Fathers' BMI ranged from 17.7 to 41.9 ($M = 25.45$; $SD = 3.55$). Furthermore, families were representative of the highly educated middle class. Of the fathers, 58.7% held a university degree and 22.1% had finished high school, whereas only 19.2% had completed primary education and/or vocational training. Fathers reported an average income of 2680.60 Euro (SD = 1539.39) per month.

2.2 | Overall procedure

The Ethics Committee of the Medical University of Vienna approved the present study (ECS 1710/2013), and parents provided written informed consent before participation. Data collection took place between July 2013 and June 2015. At the fathers' convenience, two research assistants visited the homes twice during 1 week. During the first visit, they interviewed the fathers on their curriculum vitae, current life situation, and income. Fathers also reported on daily routines in order to tailor the sampling scheme for the father–child activity assessment. A two-hours observation of the father–child attachment followed (via Attachment Q-Sort [AQS]), which both assistants carried out simultaneously. They also left the father with a questionnaire on engagement in paternal care (via Parental Behavior Inventory [PBI]). During the second visit, research assistants picked up the completed questionnaire, and instructed the fathers on the saliva collection which later served to analyze T and Cort. The assistants eventually introduced the fathers to the experience sampling method (ESM) for assessing father–child activities on the smartphones, which would commence the following day. Together with the fathers, the assistants went through the short surveys of ESM and explained the items, which appeared in a multiple-choice format and required yes/no answers. Encrypted data on the smartphones was sent to a secure server, downloaded, and decrypted from its web console, and prepared for further analysis. Saliva probes were picked up from homes.

2.3 | Measures

2.3.1 | Fathers' engagement

In order to assess the engagement in childcare, we asked the fathers to complete the PBI (Lovejoy et al., 1999). For the present study, we used the *Supportive-Engaged Scale*, which consists of 10 six-point rating scales, starting from *0 "not at all true (I do not do this)"* to *6 "very true (I often do this)"*. The scale considers positive, sensitive, and warm behaviors that ultimately lead to feelings of love, acceptance, and comfort for the benefit of child's welfare; with items such as "*I listen to my child's feelings and try to understand them*" (item 11) or "*I comfort my child when s/he seems scared, upset, or unsure*" (item 17). Scores ranged from 2.8 to 5.0 ($M = 4.4$; SD = 0.4). The scale indicated strong internal consistency with Cronbach's alpha = 0.80 [0.75; 0.84].

2.3.2 | Fathers' attachment

We evaluated the relationship quality between the father and his target child with the German version of the AQS (Ahnert et al., 2012; Waters, 1995). The AQS captures parent–child attachment in home environments and allows for an ecological examination of parent–child relationships. A group of research assistants received intensive training for the AQS procedure using video training and live observations in preparation for the study. As a rule, two research assistants observed the father–child dyads simultaneously and for at least 2 hrs, but rated the observation individually afterwards. According to the test construction, the observer must sort 90 items into nine piles (with 10 cards each) from "most descriptive" to "least descriptive" of the dyad. Items describe situations when the child searches for proximity to the father (e.g., *Child keeps track of father's location when he plays around the house*; item 21), enjoys proximity (e.g., *Child often hugs or cuddles against father, without asking or inviting him to do so*; item 11), likes to share and obey (e.g., *Child follows father's suggestions readily, even when they are clearly suggestions rather than orders*; item 18), etc. The sorting of all items was then correlated with an expert's sorting provided for secure parent–child dyads. The correlation resulted in AQS scores ranging from −1.0 to +1.0, with scores representing the extent of attachment security. The higher the AQS score, the better the father–child attachment. In the present study, AQS scores ranged from −0.46 to 1.00 ($M = 0.43$; $SD = 0.28$). Furthermore, the intraclass coefficient (ICC) between the AQS scores of the two research assistants was high (ICC = .87), indicating excellent reliability. Fisher's r-to-z transformation (Fisher, 1915) served to ensure linearity across the distribution of AQS scores for later statistical analyses.

2.3.3 | Fathering behaviors

To sample relevant fathering behaviors, we conducted a two-step approach, in which a *Timetable interview* was used to set up an ESM for all days throughout an entire week, applying defined *surveys*.

Timetable interview

In order to tailor the ESM for each individual father and the target child, fathers were interviewed regarding their everyday routines throughout an entire week. To calculate the total time fathers were available for the child, the following time frames were excluded from consideration: father's paid working hours, the child's out-of-home hours (e.g., in public child care), and sleeping hours, leaving only overlapping time frames in which father and child were able to engage in activities with one another. Within these time frames, surveys (see below), including the name of the target child, were sent out.

Experience sampling method

The software movisensXS (2014) was employed for an ESM on the Android operating system and installed on either the father's own smartphone or on a provided device. We instructed fathers to carry the smartphones everywhere and to respond reliably to a set of questions. These surveys were to be answered across the individualized time frames derived from the timetable interview. The ESM randomly sent out eight to 15 sets of questions per day. Thus, it was possible to detect the relative time fathers invested in specific father–child activities during the weekdays of the same week as the T assessment took place. However, 28 fathers did not engage in the sampling procedure; but there were no differences in age, education, or income between fathers that participated and fathers that did not participate in the study.

Survey and response rates

The survey was kept as short as possible (less than half a minute) to not interfere with the father's ongoing activities. The ESM sent out the main set multiple times over the entire time frame to obtain detailed information on a father's immediate location, anyone in his vicinity, and his current activities. Questions were organized hierarchically, worded generally at first and then followed by increasingly detailed questions regarding father's activities. For example, Where are you? —at home/in the street/shopping/etc. —Is someone with you? (yes/no) —if yes: Who? —partner/<name of child>/etc. —if child: Are you doing something with <name of child>? (yes/no) —if yes: What are you doing? Here, the fathers were offered four conceptually similar categories of father–child encounters to allocate their concrete behaviors to. The four categories were: *supervision* (e.g., looking after the child, taking the child to the playground, watching TV with the child), *joint play* (e.g., barrier tasks, shared book reading, card and board games), *RTP*(e.g., throwing an infant/toddler in the air, romping around), and *cuddling* (e.g., kissing, stroking, hugging). Fathers' response rates were calculated from the number of questions sent out within the individually determined time frames as the proportion of responses relative to total questions asked (percentage of responses). Days with response rates lower than 25% were excluded (5.9%). The response rates also yielded a duration time relative to the time frame in which they occurred. As a result, each category of father–child activities yielded a measure of duration (in minutes), which was aggregated and later used in statistical analyses (for more details, see Piskernik & Ahnert, 2019).

The duration of the four categories of fathering behaviors were provided separately for workdays and days off work, as suggested by Yeung et al. (2001), who demonstrated huge differences between these days. In the present study, however, fathering behaviors on weekdays were significantly positively related to fathering behaviors on days off work (except *RTP*: $r = .15$, $p = .100$) with *supervision*: $r = .40$, $p < .001$, *joint play*: $r = .34$, $p < .001$, and *cuddling*: $r = .29$, $p = .001$, though we only presented fathering behaviors during the week.

2.3.4 | Testosterone and cortisol

Fathers collected saliva immediately after waking up in the morning and in the evening, on two consecutive weekdays when the activities with the target children were also documented. Thus, fathers' T and Cort levels corresponded with fathers' activities in the same time frame.

Measurement protocols

We asked the fathers to refrain from strenuous bodily activities and sexual activities for 12 h prior to saliva sampling, as well as from brushing teeth, chewing gum, drinking alcoholic and caffeinated beverages, and smoking for 1 h prior to saliva sampling. We also inquired about sleep duration, disturbances, the nights before sampling, and registered weight (kg) and height (m) in order to calculate the body mass index (BMI) as the ratio of weight and height. We then instructed the fathers to rinse their mouth with pure water before sampling approximately 1.5 mL of saliva using ultra-pure polypropylene collecting devices (SaliCaps: IBL International GmbH, Hamburg, Germany). Fathers filled in a protocol of all this information during the 12 h prior to saliva sampling, including the exact times of waking as well as of sampling. Sampling times in the morning ranged from 4:15 to 12:00 p.m. with $M = 0{:}22$ h ($SD = 0{:}23$) from waking time and in the evening from 5:45 to 11:59 p.m. with $M = 14{:}35$ h ($SD = 1{:}15$) after waking time. Fathers stored the saliva probes in the freezer at 18°F until the final pickup.

Assays

Salivary T (pg/mL) and Cort (nmol/L) assays were run at the Biolaboratory of the University of Zurich, Switzerland. Concentrations of T were determined using a testosterone luminescence immunoassay (IBL International GMBH, Hamburg, Kit: RE62039) with interassay coefficients of testosterone variation between 4.04% and 6.96% for high and low control samples. Concentrations of Cort were determined using a cortisol luminescence immunoassay (IBL International GMBH, Hamburg, Kit: RE62019) with interassay coefficients of cortisol variation between 4.30% and 3.60% for high and low control samples. Sample and standard reactions were run in duplicate, and values were averaged. Unfortunately, assays of one morning and seven evening probes (2.7%) were not possible due to the small amount of saliva.

2.4 | Data handling and data analysis

In order to select adequate statistic modeling for testing the research hypotheses, we first inspected the T and Cort data, examined their distribution and stability across the two days. Because certain distributional characteristics might strongly impact the results if left unattended, we (1) identified and removed outliers in T and Cort, (2) recognized the Poisson distribution of the remaining data, and (3) checked the distributions of all other study variables which ought to serve either as covariates (i.e., *sampling time*, *sleep duration* and *disruption*, and *sexual* and *bodily activities* prior to sampling), or as general predictors (i.e., fathers' *age*, *BMI*, *child age*, *number of children*, *fathers' engagement and attachment*), or as behavior-specific predictors (i.e., *supervision*, *joint play*, *RTP*, and *cuddling*) for T and Cort. We included *seasonality* as one additional covariate. Variations in T and Cort across two years of the sampling were tested with one-factorial repeated measurement ANOVAs and were significant. We therefore created two variables (*seasonality (T)* and *seasonality (Cort)*), which mapped the seasonal oscillation in T and Cort.

The present study required multilevel modeling for repeated measures, as T and Cort had been collected for each father four times, that is, in the mornings and evenings of two days, and displayed Poisson distribution. For this reason, we utilized *generalized linear mixed models* (GLMMs), which can (a) take the nature of repeated measurement structures into account, (b) model datasets of different distributions, and (c) divide and test the influences of the study variables separately. We carried out *two sets of GLMMs* (for T and Cort) and conducted them consecutively in a three-Block design using the package lme4 (Bates et al., 2015; R package version 1.1-21) in R (R Core Team, 2017). Block 1 consisted of all control variables, such as *sampling time*, *seasonality*, *sleep duration* and *disruption*, and *sexual* and *bodily activities*. We kept theses controls in all three blocks. We additionally included all general predictors, such as fathers' *age*, *BMI*, *engagement*, and *attachment* as well as *number of children* and *age of the target child*, in Block 2. Given the importance of fathers' hormonal levels in the evenings and that the evening nadir seemed most sensitively connected with parenting, we added the interaction of *sampling time* × *father's* age, *BMI*, *engagement*, and *attachment*, as well as *number of children* and *age of the target child*, not only to test the impact of these predictors on T and Cort levels but also on their slopes. In Block 3, we added the four distinct fathering behaviors (i.e., *supervision*, *joint play*, *RTP*, and *cuddling*) as predictors and included an interaction with sampling time.

GLMMs deliver the proportion of explained variance by the marginal and conditional R^2, which improve across the blocks and are better the closer R^2 is to 1.0 (see also Nakagawa & Schielzeth, 2013).

TABLE 1 Description of testosterone (in pg/mL) and cortisol (nmol/L) in the mornings and evenings of two consecutive days[a]

	Day 1		Day 2			
	M	*SD*	*M*	*SD*	t^a	*p*
Testosterone (T)						
Morning	53.22	42.99	56.05	46.16	−0.54	.589
Evening	20.01	18.53	24.29	23.94	−1.68	.094
Slope	33.36		31.82		0.33	.740
Cortisol (Cort)						
Morning	37.65	39.55	39.47	40.63	−0.39	.697
Evening	16.18	24.56	18.62	27.04	−0.79	.428
Slope	22.88		21.66		0.35	.729

Notes. M = mean; *SD* = standard deviation; Slope = difference between morning and evening values.[a]Outliers were excluded.

While marginal R^2 describes the proportion of variance explained by the included study variables alone, the conditional R^2 depicts the proportion of variance explained by both study variables and random factors. Furthermore, effect sizes of the study variables can be demonstrated by Exp(*b*), which represent the incidence rate ratios (IRR). For each study variable, IRR can be interpreted as an increase above 1.0 and as a decrease below 1.0 in percent of T or Cort for each unit (e.g., in hours, years, or scores) on the respective variable.

3 | RESULTS

3.1 | Preliminary analyses on testosterone and cortisol

3.1.1 | T and Cort across two consecutive days

We first investigated T and Cort levels of the two consecutive days. To identify and remove outliers, we normalized the right-skewed distributions of T and Cort by applying a square root transformation and utilized Tukey's standard method (Tukey, 1977). The method searched one and a half of the interquartile range from the upper or lower quartile and found five outliers for T with levels larger than 173 pg/mL, and five outliers for Cort with levels larger than 150 nmol/L. Distributions of T and Cort data were still highly skewed to the right, even after removing the outliers, with skewness for *T* = 1.30 and for Cort = 1.47. Means and standard deviations are shown in Table 1, demonstrating stable levels between the first and second day of sampling as well as stable slopes of the two days.

3.1.2 | T and Cort across the season

To explore the seasonal variations in T and Cort, respectively, we applied two one-factorial repeated measurement ANOVAs (factor: *month* of the year, repetition: *morning vs. evening* /*Day 1 vs. Day 2*) to the

TABLE 2 Seasonal variations of testosterone and cortisol across the two-year sampling

	SS	*df*	MS	*F*	*p*	partial η^2
Testosterone (T)						
(Intercept)	42286.89	1	42286.89	59.94	.000	
Morning vs. evening	132571.08	1	132571.08	187.92	.000	.26
Day 1 vs. Day 2	1038.24	1	1038.24	1.47	.226	.00
Month	115936.65	11	10539.70	14.94	.000	.23
Error	383070.38	543	705.47			
Cortisol (Cort)						
(Intercept)	161.77	1	161.77	0.28	.595	
Morning vs. evening	43341.70	1	43341.70	75.63	.000	.12
Day 1 vs. Day 2	609.29	1	609.29	1.06	.303	.00
Month	176775.49	11	16070.50	28.04	.000	.36
Error	311772.52	544	573.11			

Note. df, degree of freedom; MS, mean square; partial η^2, effect size; SS, sum of squares.

data. For T, results showed a main effect of the two time windows of the sampling (morning vs. evening) on T as expected, $F(1,543) = 187.92$, $p < .001$, $\eta^2 = .26$. There was no effect for the repeated measures on Day 1 and 2. Most importantly, however, a main effect of seasonal changes across the months of the year was detected, $F(11,543) = 14.94$, $p < .001$, $\eta^2 = .23$. As follows, T levels were highest in January ($M = 55.22$ pg/mL; $SD = 39.94$), and lowest in August ($M = 12.5$ pg/mL; $SD = 9.93$); see Table 2 and Figure 1.

For Cort, similar results were obtained with a main effect of the morning versus evening measures, $F(1,544) = 75.63$, $p < .001$, $\eta^2 = .12$, but no effect for the repeated measures across the two days. Most importantly, the main effect of the season across the year was highly significant; $F(11,544) = 28.04$, $p < .001$, $\eta^2 = .36$. Cort levels were highest in September ($M = 46.94$ nmol/L; $SD = 33.49$), and lowest in March ($M = 8.12$ nmol/L; $SD = 8.79$); see Table 2 and Figure 1.

TABLE 3 Descriptive statistics of fathering behaviors

	Nonoccurrence	*M*	*SD*
Supervision	47.5	1:11	1:04
Joint play	30.3	0:43	0:33
Rough-and-tumble play	77.0	0:24	0:16
Cuddling	65.6	0:28	0:15

Note. M, means; *SD*, standard deviations. Nonoccurrences were omitted for *M* and *SD* which are presented in h:mm; Nonoccurrence is shown in percentages.

To control for these seasonal changes in the GLMMs, we derived a *seasonality* variable for T and Cort, respectively, by subtracting each months' mean (of T or Cort) from the overall mean (of T or Cort) of the whole year. Thus, *seasonality* was defined as monthly mean deviation in T or Cort levels from the yearly mean level of T or Cort.

3.2 | Preliminary analyses on fathering behaviors

Not all fathers reported on all four fathering behaviors in the ESM. Therefore, nonoccurrence of the behaviors varied with *joint play* resulting in the lowest and *RTP* the highest percentage. In addition, durations of these behaviors varied greatly, that is, fathers spent the longest time period supervising the child, whereas a RTP only lasted briefly (see Table 3).

3.3 | Predicting fathers' testosterone levels across typical working days

Utilizing a GLMM on fathers' T with a three-Block design (see Table 4), we first included the controls in all three Blocks. There were significant main effects for *sampling time* and *seasonality (T)* in predicting father's T levels across all three blocks. Sleep duration was negatively associated with T, indicating that T levels declined around 6% with each additional

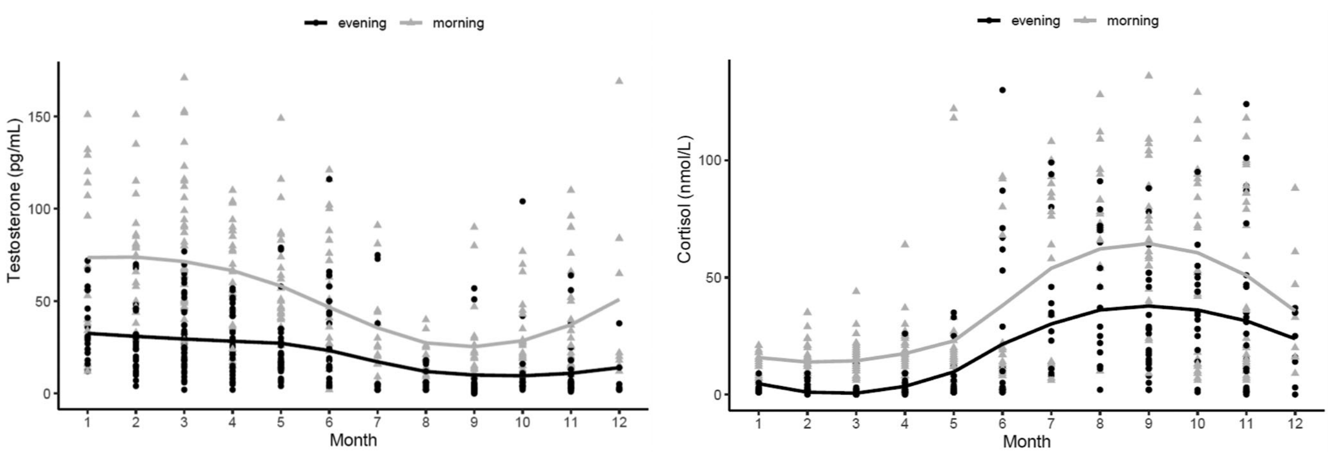

FIGURE 1 Seasonal variations of testosterone and cortisol ((Is it possible to enlarge the figures ?))

TABLE 4 Predicting fathers' testosterone levels across a typical working day

	Block 1				Block 2				Block 3			
	b	*Exp(b)*	*SE b*	*p*	*b*	*Exp(b)*	*SE b*	*p*	*b*	*Exp(b)*	*SE b*	*p*
Intercept	4.126	61.92	0.183	<.001	4.284	72.52	0.815	<.001	4.078	59.02	0.921	<.001
Sampling time (h)[a]	−0.063	0.94	0.001	<.001	−0.016	0.98	0.020	.440	−0.042	0.96	0.030	.160
Seasonality (T)[b]	−0.033	0.97	0.004	<.001	−0.036	0.96	0.004	<.001	−0.034	0.97	0.004	<.001
Sleep duration (h)	−0.061	0.94	0.025	.013	−0.057	0.94	0.027	.034	−0.027	0.97	0.031	.384
Sleep disruption (yes)	0.073	1.08	0.060	.224	0.083	1.09	0.067	.219	0.074	1.08	0.075	.320
Sexual activity (yes)[c]	−0.214	0.81	0.110	.051	−0.201	0.82	0.112	.073	−0.217	0.81	0.114	.058
Bodily activity (yes)	−0.047	0.95	0.030	.121	−0.035	0.97	0.032	.280	0.005	1.00	0.037	.903
Age father (years)					0.006	1.01	0.009	.511	0.007	1.01	0.010	.460
BMI (scores)					−0.024	0.98	0.014	.094	−0.027	0.97	0.017	.111
Age child (years)					0.007	1.01	0.041	.873	0.009	1.01	0.045	.838
Number of children					0.065	1.07	0.094	.488	0.113	1.12	0.101	.263
Attachment (AQS scores)					−0.002	1.00	0.183	.993	0.131	1.14	0.206	.525
Engagement (PBI scores)					0.032	1.03	0.138	.818	0.007	1.01	0.154	.963
Sampling time × Age father					−0.002	1.00	0.001	<.001	−0.002	1.00	0.001	<.001
Sampling time × BMI					0.002	1.00	0.001	<.001	0.002	1.00	0.001	<.001
Sampling time × Age child					0.006	1.01	0.001	<.001	0.003	1.00	0.001	.012
Sampling time × Number of children					−0.011	0.99	0.002	<.001	−0.009	0.99	0.003	.001
Sampling time × Attachment					−0.015	0.99	0.004	<.001	−0.009	0.99	0.005	.069
Sampling time × Engagement					−0.009	0.99	0.004	.015	−0.003	1.00	0.005	.564
Sampling time × Rough-and-tumble play									0.083	1.09	0.027	.002
Sampling time × Cuddling									−0.278	0.76	0.032	<.001
Sampling time × Joint play									0.030	1.03	0.012	.014
Sampling time × Supervision									−0.001	1.00	0.008	.879
Marginal R^2/Conditional R^2	0.504/0.958				0.539/0.961				0.553/0.963			

[a]Hours from waking time to sampling time.
[b]Monthly deviation in T from the yearly mean level of T.
[c]Within 12 h before sampling.

hour of sleep (Block 1: p = .013; Block 2: p = .034). Moreover, T levels of fathers who were sexually active prior to sampling were around 21% lower than fathers who were not sexually active (Block 1: $p = .051$).

All other predictors did not directly predict fathers' T levels, but were significantly related to the diurnal slope. Block 2 and 3 demonstrated that men had steeper declines of T across the day if they were older (*ps* < .001), had lower BMI, had more children, and if the target child was younger (*ps* < .001). Furthermore, fathers' engagement and attachment were negatively associated with the slope, suggesting lower evening T levels with higher engagement (Block 2: $p = .015$) and better attachment between father and child (Block 2: $p < .001$); see also Figure 2.

Regarding the fathering behaviors, all but *supervision* had a significant effect on the slope as shown in Block 3. While *joint play* ($p = .014$) and *RTP* ($p < .002$) were positively related to the declining T levels (see Figure 3), *Cuddling* was negatively linked, suggesting that the more the fathers cuddled the child throughout the week, the more T lowered in the evenings (p < .001); see Figure 3. Overall, the GLMM on T excellently explained 50–55% (marginal R^2) and 96% (conditional R^2) of the variance in fathers' T during typical working days.

3.4 | Predicting fathers' cortisol levels across typical working days

Because the GLMM on fathers' Cort was to complement the results on fathers' T, we followed similar modeling strategies and first explored the controls across all three Blocks (see Table 5). *Sampling time* and *seasonality (Cort)* were the only predictors that were associated with fathers' Cort levels (all *ps* < .01). *Sampling time* displayed the same effect on the diurnal decline of Cort as shown in T, the same goes for *seasonality* (see Figure 1). All other covariates were not significant. However, the age of the target child was positively associated with Cort, indicating that Cort levels rose around 10% with each additional year (Block 2: $p = .039$).

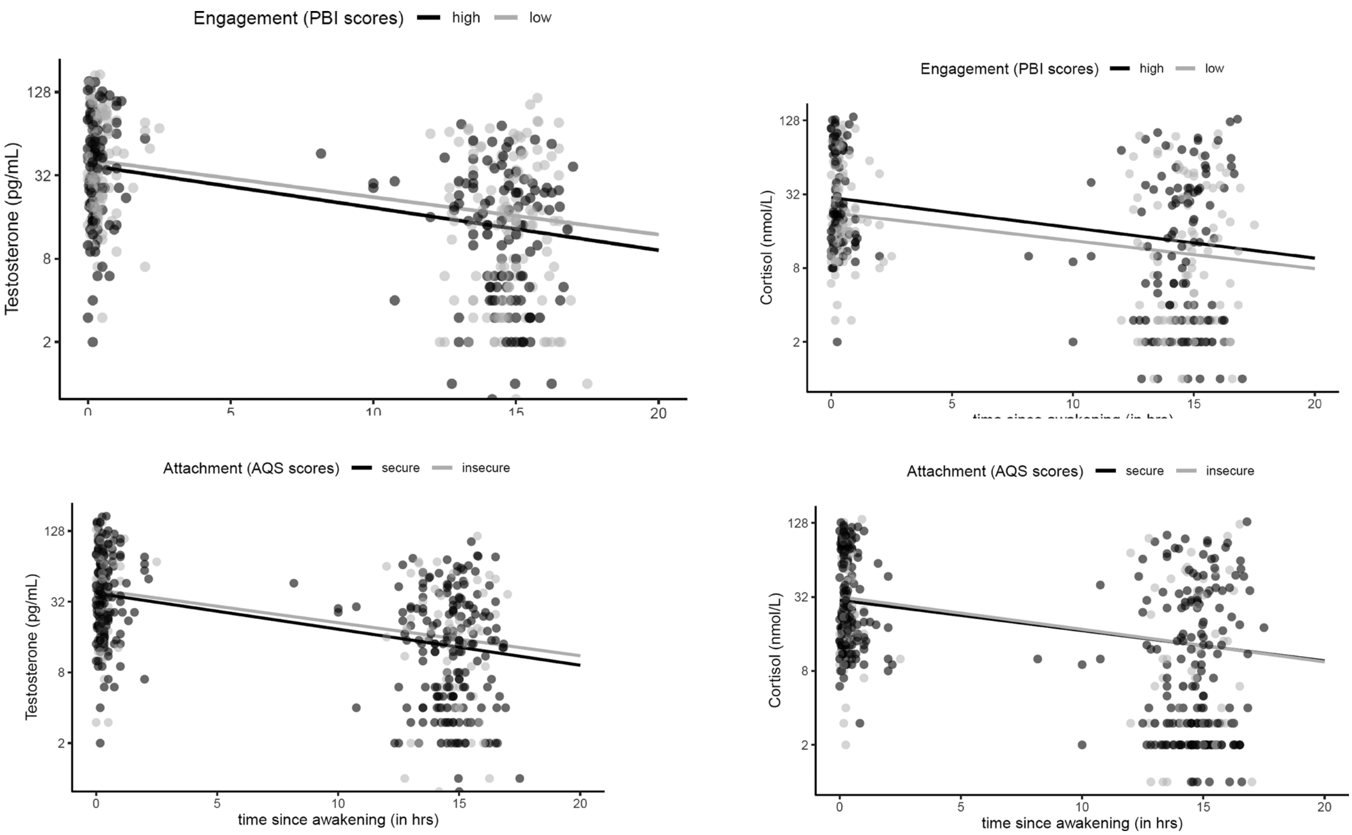

FIGURE 2 Engagement and attachment in relation to testosterone and cortisol ((Is it possible to enlarge the figures ? above/right figure is not in line with the above/left figure))

Regarding the diurnal slope of Cort, significant negative effects could be revealed for father's *age* (Block 2: $p < .002$), *age of the target child* (Block 2: $p < .012$; Block 3: $p < .010$) and *number of children* (Block 2: $p < .004$; Block 3: $p < .007$). Attachment showed an enhancing effect on the declining Cort (Block 2: $p < .012$; Block 3: $p < .001$), whereas *Engagement* failed to reach significance.

Finally (in Block 3), all fathering behaviors (except *supervision*) were significantly associated with the slope of Cort (*p*s between .001 and .039). That is, *joint play* ($p = .039$) and *cuddling* ($p = .039$) showed an enhancing effect on the declining Cort levels. Most interestingly, however, *RTP* ($p < .001$) was negatively linked to evening Cort, suggesting that the more the father engaged in such play with the child during the week, the more his Cort levels lowered in the evenings ($p < .001$); see Figures 2 and 3). Overall, the GLMM on Cort excellently explained 50–57% (marginal R^2) and 96% (conditional R^2) of the variance in fathers' Cort during typical working days.

4 | DISCUSSION

The present study explored the question of how fathers' T and Cort vary with the degree of fathers' engagement in childcare. As past research has indicated mixed findings on this question, we studied the qualitative dimensions of paternal care corresponding to father's time investment in care. For this, we *first* analyzed self-reports of fathers' engagement and external evaluations of fathers' attachment to the child. Moreover, we investigated fathers' smartphone-based experience sampling throughout 1 week, which sampled ongoing father–child activities including *supervision*, *joint play*, *RTP*, and *cuddling* episodes. These fathering behaviors were indicated by frequencies and accumulated time measures, where *supervision* lasted the longest and *RTP* only briefly. Furthermore, *supervision* and *joint play* were most frequent and *RTP* relatively seldom. *Second*, we inspected father's T and Cort responses in the mornings and evenings of two consecutive days and across 2 years. Hence, we revealed stable levels and diurnal declines of the 2 days and also significant fluctuations in T and Cort depending on the season. The highest and lowest T levels were shown in January and August and highest and lowest Cort levels in September and March.

4.1 | Common influences on fathers' T and Cort

The present study mainly focused on the decline between morning and evening levels of T or Cort, and thus used the degree of these slopes for the key statistical models. We first examined common influences on the HPG and HPA axes (as suggested by van Anders et al., 2014) in order to control for them when later associations between different characteristics of paternal care and fathers' T and Cort were tested. Most of these common influences, such as *seasonality* and *sampling time* as well as *age of the father* or the *number of children*, were negatively related to

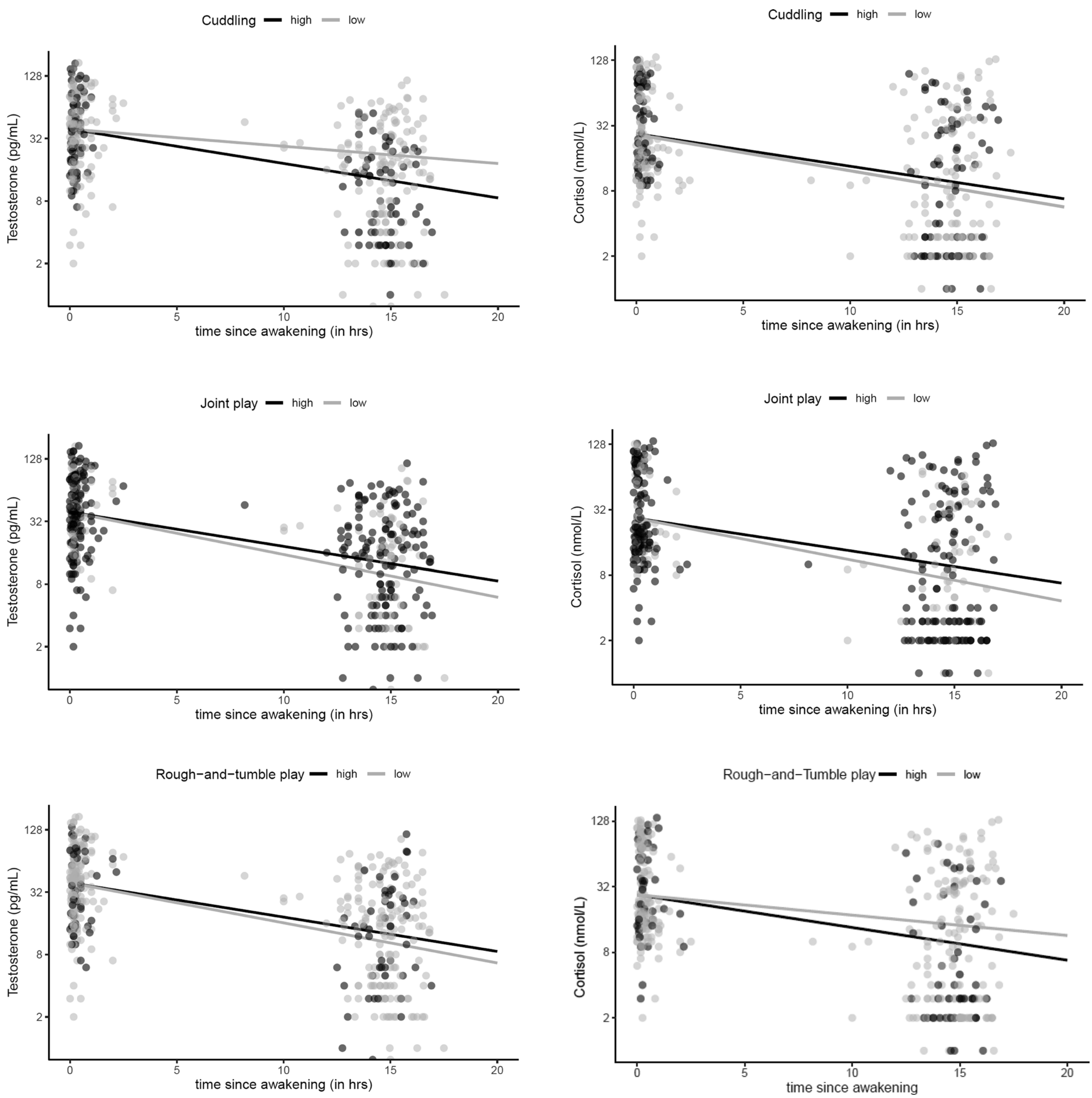

FIGURE 3 Fathering behaviors in relation to testosterone and cortisol ((Is it possible to enlarge the figures ?))

the declining T and Cort. Most interestingly, however, *sleep duration* and *sexual activities* shortly before sampling were negatively related only to T but not Cort, suggesting greater sensitivity of the HPG than the HPA axis for behavioral associations.

4.2 | Effects of fathers' engagement and attachment on T and Cort

We confirmed associations between self-reported engagement in childcare and lower evening T, as shown by Kuzawa et al. (2009) and others. That is, the more the fathers portrayed themselves as being engaged with their children and sensitive and attentive, the more their T levels lowered in the evenings. This confirmation is remarkable as administered self-reports are good at obtaining overall reports of parenting over long time periods when the fathers must rely on the recall of past events. Accuracy can diminish, however, and social desirability, wishful thinking or even a lack of insight in own parenting practices can distort the self-evaluation. Most importantly, however, external observations on the father–child relationship paralleled the self-evaluations on fathers' engagement and replicated the association with lowering T.

TABLE 5 Predicting fathers' cortisol levels across a typical working day

h	Block 1				Block 2				Block 3			
	b	*Exp(b)*	*SE b*	*p*	*b*	*Exp(b)*	*SE b*	*p*	*b*	*Exp(b)*	*SE b*	*p*
Intercept	3.181	24.07	0.200	<.001	2.282	9.80	0.966	.018	2.816	16.71	1.126	.012
Sampling time (h)[a]	−0.061	0.94	0.001	<.001	−0.059	0.94	0.031	.057	−0.134	0.87	0.037	<.001
Seasonality (T)[b]	−0.037	0.96	0.003	<.001	−0.040	0.96	0.003	<.001	−0.037	0.96	0.004	<.001
Sleep duration (h)	−0.007	0.99	0.027	.797	−0.014	0.99	0.028	.611	−0.023	0.98	0.032	.477
Sleep disruption (yes)	−0.015	0.99	0.059	.799	0.025	1.03	0.062	.689	0.017	1.02	0.070	.809
Sexual activity (yes) [c]	−0.007	0.99	0.079	.928	0.033	1.03	0.079	.677	0.014	1.01	0.079	.854
Bodily activity (yes)	0.021	1.02	0.039	.596	0.023	1.02	0.040	.576	−0.013	0.99	0.047	.783
Age father (years)					−0.003	1.00	0.010	.788	−0.005	0.99	0.012	.669
BMI (scores)					0.001	1.00	0.017	.933	−0.017	0.98	0.021	.404
Age child (years)					0.101	1.11	0.049	.039	0.092	1.10	0.055	.096
Number of children					−0.130	0.88	0.111	.239	−0.144	0.87	0.123	.242
Attachment (AQS scores)					0.007	1.01	0.218	.973	−0.040	0.96	0.254	.874
Engagement (PBI scores)					0.191	1.21	0.163	.243	0.231	1.26	0.188	.220
Sampling time × Age father					−0.001	1.00	0.001	.002	−0.001	1.00	0.001	.211
Sampling time × BMI					0.001	1.00	0.001	.361	0.002	1.00	0.006	<.001
Sampling time × Age child					−0.003	1.00	0.001	.012	−0.004	1.00	0.001	.010
Sampling time × Number of children					−0.007	0.99	0.003	.004	−0.008	0.99	0.003	.007
Sampling time × Attachment					0.009	1.01	0.005	.101	0.023	1.02	0.007	.001
Sampling time × Engagement					0.005	1.01	0.005	.268	0.006	1.01	0.006	.321
Sampling time × Rough-and-tumble play									-0.299	0.74	0.046	<.001
Sampling time × Cuddling									0.052	1.05	0.025	.039
Sampling time × Joint play									0.026	1.03	0.012	.039
Sampling time × Supervision									0.010	1.01	0.007	.159
Marginal R^2/Conditional R^2	0.507/0.954				0.569/0.954				0.567/0.957			

[a]Hours from waking time to sampling time.[b]Monthly deviation in Cort from the yearly mean level of Cort.[c]within 12 h before sampling.

To our knowledge, this is the first time that father–child attachment has been linked to testosterone. High quality of attachment represents relationships with close proximity, rewarding interactions and enjoyment of being together. Not surprisingly, the more pronounced fathers' attachment was, the lower the declining T, resembling Gettler et al. (2012)'s research on the same surface cosleeping Filipino fathers. In addition, associations between fathers' attachment and Cort were positive, confirming numerous studies that demonstrated greater sensitive care related to greater Cort levels (e.g., Almanza-Sepulveda et al., 2020; Storey et al., 2000; Kuo et al., 2018; cf., Bos et al., 2018; Gonzalez et al., 2012)

4.3 | Effects of affectionate fathering behaviors on T and Cort

While *Supervision* had no effect on fathers' T and Cort, more affectionate fathering behaviors were associated with the diurnal decline of T and Cort. That is, *cuddling* was negatively linked to the declining T but positively to declining Cort, so that the decreases in testosterone might have promoted empathic responses toward the child. This interpretation is in line with numerous research studies that videotaped and microanalyzed parent–child interactions (e.g. Almanza-Sepulveda et al., 2020; Weisman et al., 2014; Gordon et al., 2017). The suppression of fathers' T in relation to *cuddling* is especially notable in the present study, as we controlled for the effects of fathers' sexual activities beforehand. Past research did not always separate sexual activities from influences through parenting. Consequently, fathers' T levels associated with fatherhood were not found independently of pair-bonding status (e.g., Gray et al., 2004), which supported the belief that the same behavioral system that underlies parent closeness towards their children may underlie the dynamics of pair-bonding. In their pioneering work, Hazan and Shaver (1987) indeed suggested that romantic love involves many of the same behavioral patterns that characterize behaviors in parenting. In particular, fathering behaviors and the ways in which men facilitate pair-bonding, that is, enjoying the cuddly, affectionate aspects of intimacy besides the genital aspects of the sexual activity, resemble each other (see Fraley et al., 2005), even though positive feelings regarding cuddling across partner relationships may vary (Chopik et al., 2014; van Anders et al., 2012). As we disentangled conflation of intimacy between partners and between parents and their children, we managed to demonstrate that cuddling alone shows a suppressive effect on T, even if sexual activities occur close in time.

4.4 | Effects of activating fathering behaviors on T and Cort

We investigated two types of activation fathering behaviors, that is, *joint play and RTP*. Fathers' *joint play* showed enhancing effects on the sinking T and Cort levels throughout the day. Joint play is certainly one of the most frequent active fathering behaviors. Participating in a child's world, sharing knowledge with the child during play, storytelling, or shared book reading can be most challenging, in particular if fathers engage in such activities relatively infrequently. Infrequent involvement in child care might lead to difficult communication between the father and child (see Teufl et al., 2020; Ahnert et al., 2017) because the current level of mental and language performance of the child matures rapidly throughout the preschool years. As follows, fathers' communication needs to adapt to children's growing competence. *Joint play* seems to be a good opportunity to learn about the child's current abilities.

In contrast, RTP appeared as a type of play that is foremost physically activating. *RTP* research illustrates father–child activation that might play a role in exciting and destabilizing children, encourage them to test their physical skills (Paquette, 2004; Paquette & Dumont, 2013) and to resist internalizing behaviors (Ahnert et al., 2017). In the present study, *RTP* was positively associated with the diurnal decline in T, but was linked to a lowering diurnal decline of Cort. This supports the idea that fathers calm themselves, and consequently their children, so that the situation does not escalate (Atkinson et al., 2013).

4.5 | Final remarks

Although the present research successfully dealt with a complex dataset, the results must be discussed with regard to their limitations. *First*, fathering was explored only with children throughout the preschool years, in middle-to upper class families and during the week. This, however, can be quite different if the children have socially disadvantaged family backgrounds, are older and/or father–child activities are examined on days off work (e.g., weekends or holidays). Between those days, the amount of time and ways in which fathers spend time with their children can vary greatly, as shown in similar studies that demonstrate enriched as opposed to restricted parenting (see Piskernik & Ahnert, 2019). The present study, however, found positive correlations between the majority of fathering behaviors during the week and on days off work. This implies that fathers supervised and cuddled the children as well as played with them on days off work to a similar (or possibly greater) extent. Only rough-and tumbling followed its own situational-dependent patterns where weekday—day off work distinctions are unimportant. However, we cannot conclude that the relationship between fathering behaviors and T and Cort is similar on working days and days off work. On days off work, fathers' sleeping patterns and sexual activities, which have proven to be important for HPG axis activities, can noticeably change; what this means for the effect of fathering behaviors on T and Cort can be quite different and must be empirically investigated. *Second*, recent research on father–child relationships (Ahnert & Schoppe-Sullivan, 2020) point to the fact that fathering behaviors must be explored in broad contexts. Beside fathers' work centrality, work-life balance and numerous other factors (e.g., own childhood experience) might significantly shape fathering behaviors. Most importantly, the marital relationship may be central for paternal care, already starting during pregnancy. As Saxbe et al. (2017) demonstrated, fathers' declines in T predicted their postpartum investment in the couple's relationship; as follows, harmonious marital relations are best conditions for fathers' engagement in childcare (e.g., Schoppe-Sullivan et al., 2008). *Third*, past research suggested to include wide arrays of biological markers such as T, Cort, oxytocin, or prolactin to contribute to a broad understanding of the hormonal correlates of fatherhood (e.g., Neumann, 2008; Storey et al., 2000). We investigated two hormones, T and Cort, associated with fatherhood. Comparisons of these associations allowed interesting insights into the mechanisms of the two hormones: Affectionate fathering behaviors (*engagement*, *attachment*, *cuddling*) showed suppressive effects on the diurnal decline in T but enhancing effects on the decline in Cort throughout the day. Activating fathering behaviors (including mentally or physically activated facets of the behaviors) showed positive links to levels of both hormones in the evenings (except RTP on Cort), suggesting that the HPA axis corresponds less sensitively to the environment (of normal middle-class families) than the HPG axis. In any case, these findings contribute to a wider, multifaceted view about the role of fathers' hormonal responses during childcare, and might contribute to elucidating some inconsistent results of past research.

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CONFLICT OF INTEREST

No conflict of interest was reported by the authors

AUTHOR'S CONTRIBUTION

Lieselotte Ahnert made substantial contributions to conception and design and interpretation of data; she also drafted the manuscript and revised it during the revision process after discussions with all authors. Felix Deichmann made substantial contribution to analysis and interpretation of data. Markus Bauer, Barbara Supper, and Bernhard Piskernik collected and reworked data files, for example, smartphone-based experience sampling. All authors are accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

DATA ACCESSIBILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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