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Fathers: The interplay between testosterone levels and self-control in relation to parenting quality☆

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ABSTRACT

In this study, we examined the potential interaction effect between fathers' basal testosterone levels and their ability to control their impulses in relation to their quality of parenting. Participants included 159 fathers and their preschoolers. Evening and morning salivary samples were analyzed with isotope dilution-liquid chromatography–tandem mass spectrometry (ID-LC-MS/MS) to determine basal testosterone (T) levels. During a home-visit, fathers' self-control was measured with a computerized Go/NoGo task, and their sensitivity and respect for child autonomy was observed in a free-play session. We found that higher T levels in the evening were related to less respect for child autonomy, but *only* in fathers with low self-control. Further, higher T in the evening was related to more sensitive parenting, yet *only* in fathers with high self-control. These findings indicate that different aspects of fathers' quality of parenting are differently affected by the interaction between T and self-control. Further research is needed to clarify the interplay between fathers' neuro-endocrine system functioning and their trait characteristics in relation to the development of father-child relationships.

1. Introduction

One of the most salient biomarkers of male social behavior is Testosterone (T). Focusing on fathers' parenting behavior, the challenge hypothesis proposes that the association between T and parenting is reciprocal with higher T levels inhibiting parenting, while cues associated with children, child care, or parenting are suggested to down-regulate T (Wingfield et al., 1990). In addition, the more recently developed steroid/peptide theory of social bonds, a theory based on a critical evaluation of a large body of research on T and social behavior in animals and humans, associates high T with dominant and competitive behaviors and low T with nurturing behaviors, including parenting (Van Anders, 2013). In line with both theoretical frameworks, there is evidence for the proposition that variations in basal T predict the amount of time fathers spend with their children and the level of father involvement in daily family life (e.g., Alvergne et al., 2009; Kuzawa et al., 2009; Lawson et al., 2017; Muller et al., 2009). For example, fathers with lower T levels have been found to provide more direct care for their children as well as to provide more financial support for their family compared to fathers with higher T levels (Alvergne et al., 2009). Regarding the second part of the challenge hypothesis on the down-regulating effects of child-related cues on T, studies have shown that fatherhood and more involvement in child care are indeed associated with subsequent lower T levels in men (Gettler et al., 2011a). Further, in a recent study by Edelstein et al. (2017) expectant fathers showed a decline in T in response to their partner's pregnancy. Moreover, fathers who showed relatively greater declines in prenatal T, reported higher postpartum family investment, commitment, and satisfaction than other fathers. These findings offer support for the challenge hypothesis by indicating a down-regulating effect of child-related cues (i.e., a partner's pregnancy, becoming a parent) on T and, subsequently, this change in T allowing for more optimal parenting. However, according to the steroid/peptide theory of social bonds, child-related cues may not always have a downregulating, rather than an upregulating, effect on fathers' T (Van Anders et al., 2012). More specifically, challenging social signals are thought to stimulate men's T. Indeed, baby cries, that can be considered as a challenge, have been found to increase T levels in men (Fleming et al., 2002; Storey et al., 2000). This was especially the case when baby cries could not be terminated with nurturing behaviors (Van Anders et al., 2012).

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Recently, attention has shifted from T-driven effects on *quantitative* aspects of parenting, such as amount of time spent with children or level of financial support for the family, to the effects of T on *qualitative* aspects of parenting as these characteristics are central to the promotion of optimal social-emotional development of children. Two important qualitative aspects of parenting in early childhood are sensitive responsiveness (sensitivity) and respect for children's autonomy. Sensitivity refers to the adult's ability to notice child signals (e.g., crying, smiling, outstretched arms, looking at an object), to interpret these signals correctly, and to respond to them promptly and appropriately (Ainsworth et al., 1974). For example, comforting a distressed child soon after the child starts crying up until the child relaxes and is ready to continue his or her activities, is a sensitive response. Another example is helping a frustrated child who is trying something that he or she cannot do yet. A large body of research has emphasized the important role of both paternal and maternal sensitivity in children's adaptive social-emotional development (e.g., Bakermans-Kranenburg et al., 2003; Biringen et al., 2014; Lucassen et al., 2011; Tamis-LeMonda et al., 2004). For instance, parents who respond in a sensitive manner to negative child emotions like anxiety, have been found to directly foster an optimal level of arousal in their children as evidenced by a decrease in heart rate and smooth return to positive affect (e.g., Conradt and Ablow, 2010; Haley and Stansbury, 2003). Further, studies on parental sensitivity during enjoyable activities such as play suggest that parents' awareness of positive feelings in their children and their warm and supportive reactions to such feelings stimulate children's emotion regulation skills in stressful situations (e.g., Leerkes et al., 2009). Respect for the child's autonomy refers to the parent's ability to refrain from behaviors that are over-directing, over-stimulating, or interfering with the child's flow of activities (Biringen et al., 2014). An example of respect for child autonomy in a parent-child play situation is letting the child decide what to play with and how (within commonsense boundaries), and following the child's lead. Examples of lack of respect for autonomy (i.e., intrusiveness) during play are picking up the child unexpectedly, taking toys away when the child is in the middle of playing with them, or posing a string of directive questions or play initiatives, thereby limiting the child's space to play as he or she likes. A lack of respect for the child's autonomy has been associated with less optimal outcomes in young children, including externalizing behaviors and lower academic achievement (e.g., Cabrera et al., 2007; Egeland et al., 1993; Ispa et al., 2004).

To date, research on the association between fathers' T and *quality* of parenting, as compared to studies focusing on *quantity* of parenting, is limited. The few studies that did focus on T in relation to parenting quality do not reveal a clear picture. There is some evidence that lower T predicts higher quality parenting in fathers. For example, in an experimental study in which expectant fathers and mothers were asked to hold a test baby doll on their shoulders while being confronted with a variety of infant stimuli (e.g., listening to a tape of newborn cries), men with relatively low T levels tended to hold the doll longer than men with higher T levels (Storey et al., 2000). In another study, fathers with lower basal T showed more affectionate touch, gaze, and vocalization during interaction with their infants (Weisman et al., 2014). However, other studies found no link between basal T and fathers' qualitative parenting characteristics, including sensitivity and respect for the child's autonomy (e.g., Endendijk et al., 2016; Gray et al., 2002).

These inconsistent results thus far may be due to the fact that the existing studies only focused on the direct link between T and parenting, interaction effects between T and other father characteristics have not yet been considered (for a review see Bos, 2017). From a biopsychosocial perspective on parenting, it is likely that androgens interact with one's trait characteristics and contextual factors to shape unique parental responses. For example, regarding trait characteristics, studies on the relation between T and aggression suggest that individual differences in trait anxiety moderate this relation, with higher T responses to competition being associated with more aggression, but only among men with low anxiety (Carré et al., 2011; Carré and Olmstead, 2015; Norman et al., 2015). In addition to anxiety, the ability to exert self-control may play a key role in the way individual variations in basal T manifest in men's social behavior. According to I^3 theory (pronounced as "I-cubed theory"), a theoretical model on the manifestation of human aggression, both external factors like provocation and internal forces like T can stimulate aggressive impulses, but these may not translate into actual behavior in people who are able to suppress such impulses (Carré et al., 2016; Slotter and Finkel, 2011). Indeed, there is ample evidence that self-control inhibits aggressive responses (Bettencourt et al., 2006; Denson, 2015; Denson et al., 2012), and one recent experimental study found that the administration of T stimulated male aggressive behavior but only in men low on self-control (Carré et al., 2016).

Turning to parenting, it could be that self-control not only inhibits T-driven aggression in men, but it could also modulate T-driven effects on their quality of parenting. This may be specifically true for fathers' sensitivity and respect for their child's autonomy. These aspects of parenting require fathers to inhibit dominant and self-oriented behaviors, which both have been linked to higher T in men (e.g., Eisenegger et al., 2011; Guin Sellers et al., 2007; Pfattheicher, 2016). In line with the steroid/peptide theory of social bonds, according to which high T links to dominance and competition (Van Anders, 2013), it is conceivable that higher T hinders fathers' ability to be sensitive and responsive to their child's signals and to give their children room to explore the environment at their own pace, but only in men low on self-control because these fathers lack the ability to override their (T-driven) dominant and self-oriented impulses.

In the current study we examined the links between basal T levels, self-control and parenting quality in Dutch fathers. In the Netherlands, like other West-European and Scandinavian countries, gender equality has become an increasingly important value in the past decades. Fathers and mothers are stimulated by social movements and policy makers to share the financial and childcare responsibilities in the family (Sigle-Rushton et al., 2013). For example, Dutch fathers (and mothers) are given the opportunity to take up to 26 weeks of unpaid parental leave until their children reach the age of eight years (www.rijksoverheid.nl). Although fathers have indeed become more involved in early childrearing, mothers are still the primary caregivers in many families and they spent substantially more time with the children than fathers (Sociaal Cultureel Planbureau, 2011).

The aim of this study was to examine the potential interaction effect between fathers' T, measured in saliva, and their ability to exert self-control in relation to their observed quality of parenting. Specifically, this study focuses on fathers' sensitivity and respect for autonomy while playing with their preschoolers. Based on I^3 theory and research on the links between T, self-control, and aggression, we hypothesized that higher T levels in fathers would be associated with lower sensitivity and less respect for autonomy toward their preschoolers, but only in fathers with lower levels of self-control. For fathers relatively high on self-control, we expected no relation between T and quality of parenting as these fathers are thought to be better able at inhibiting their T-driven impulses in favor of more optimal parenting behavior.

2. Method

2.1. Sample

This study is part of the longitudinal research project *Boys will be boys?*, which examines the influence of parents' gender-differentiated socialization on child social-emotional development in the first years of life. The current paper focuses on the associations between fathers' circulating T, their ability to exert self-control, and quality of parenting while interacting with their preschoolers during the fourth wave of the study. During this wave, fathers' salivary T samples were collected from a subsample of the participating families. The preschoolers were on average 4 years old ($SD = 0.1$) (second-born, 52% boys).

Families with two children in the Western region of the Netherlands were selected from municipality records. In this study, we focus on the second-born children in the family as data on parental sensitivity and respect for autonomy were only available for these children. Families were eligible for participation if the second-born child was around 12 months of age at the time of recruitment and the oldest child was around 2 years older. Exclusion criteria were single parenthood, severe physical or intellectual impairments of parent or child, and having been born outside the Netherlands and/or not speaking the Dutch language. Between April 2010 and May 2011, eligible families were invited by mail to participate in the study. Both parents were asked to participate in one home visit each per year for a period of four years. In addition to the home observations, participation in the study included computer testing and filling in questionnaires. Of the 1249 eligible families, 31% ($n = 390$) agreed to participate. The participating families did not differ from the non-participating families with respect to fathers' age ($p = .13$) and their educational level ($p = .10$), and the degree of urbanization of the family's place of residence ($p = .77$). At the time of Wave 4, 20 families had dropped out due to family issues ($n = 12$), considering participation as too demanding ($n = 4$), or because they could not be reached by phone or mail ($n = 4$). This resulted in a total of 370 participating families (95% of the original sample). During Wave 4, parents were asked if they were willing to provide saliva for hormone level analysis, and 212 fathers agreed.

For the current study, fathers were excluded when they had missing data on any of the pertinent variables ($n = 42$) or when they used medication that is known to affect hormone levels (e.g., antidepressants, $n = 11$). This resulted in a total of 159 fathers. The fathers were between 28.8 and 53.4 years of age ($M = 39.3$, $SD = 4.7$), and most of them had finished academic or higher vocational schooling (75%). The majority of fathers was married or had a registered partnership or cohabitation agreement with the mother of the target child (92%). At the time of the fourth wave, 3 fathers (2%) were divorced. The 159 included fathers did not differ from the excluded fathers on educational level and the degree of urbanization of the place of residence ($ps > .33$). However, participating fathers were slightly younger than the excluded fathers ($M = 40.3$, $SD = 5.2$), $t(367) = 2.02$, $p < .05$.

2.2. Procedure

All fathers gave written informed consent for their participation in the study at each Wave. Each father participated in a 2-hour home-visit per year with his firstborn and second-born child. The participating families received a yearly gift of 30 Euros and small presents for the children. During the home visit, parent-child interactions and sibling interactions were filmed and children performed a computer task. At the end of the home-visit, fathers completed several computer tasks, one of which to measure self-control. The order in which fathers interacted with their two children was counterbalanced between families. All visits were conducted by pairs of trained students. At Wave 4, fathers were asked to collect two saliva samples by passive drool in polypropylene tubes within two weeks before or after their home visit, once before going to bed (PM) and once at waking (AM), with one night in between (e.g., Monday evening and Tuesday morning) for the measurement of parental T. Fathers were also asked to fill in a questionnaire to establish basic background information that could be associated with hormone levels (e.g., weight, exercise). Saliva samples were stored in the father's freezer until pick-up and were then stored at −80 °C until analysis. Ethical approval for this research was provided by the Research Ethics Committee of the Institute of Education and Child Studies of Leiden University.

2.3. Measures

2.3.1. Circulating T

Testosterone concentrations in fathers' salivary samples were analyzed in duplicate at the Endocrine Laboratory, Department of Clinical Chemistry of the VU University Medical Center Amsterdam. Measurements of samples of which the duplicate measurement had a difference N 15% were repeated. Salivary testosterone was determined by isotope dilution-liquid chromatography–tandem mass spectrometry (ID-LC-MS/MS). This method has been described in detail earlier and is calibrated on an LC–MS/MS method for serum testosterone, which was found to be concordant with a reference method (Bui et al., 2013; Macdonald et al., 2011). In short, after thawing and centrifugation (30 min at 1900*g*), 200 μL saliva was pipetted in duplicate. After addition of internal standard ([2H5]-testosterone) and derivatization using methoxylamine hydrochloride, the samples were injected into a Symbiosis online solid phase extraction (SPE) and liquid chromatography system (Spark Holland, Emmen, the Netherlands) coupled to a Quattro Premier XE tandem mass spectrometer (Waters Corp., Milford, MA). Intra-assay coefficient of variation (CV) was 11%, 4%, and 2% at 10, 140, and 900 pmol/L respectively, and inter-assay CV was 5% at 200 and 2000 pmol/L respectively. Mean recovery was 93% (*SD* 7%).

2.3.2. Self-control

To measure fathers' ability to exert self-control, an adapted version of the KX-task (Kiehl et al., 2000), a computerized Go/NoGo task, was administered during the home visits on a laptop computer. Go/NoGo tasks require participants to perform quick motor responses (e.g., pressing a button) to specific visual stimuli (i.e., the go signal), while on some trials participants are presented with a stop signal, instructing the participant to inhibit his or her habituated go response (Eagle and Robbins, 2008). Previous research has demonstrated adequate construct validity of Go/NoGo tasks in the measurement of executive functioning skills, including the ability to exert self-control (e.g., Duckworth and Kern, 2011; Langenecker et al., 2007; Votruba and Langenecker, 2013). For example, in a study by Votruba and Langenecker (2013), participants' efficiency scores on a Go/NoGo task were strongly related to other commonly administered neuropsychological tests such as the Wisconsin Card Sort (measuring cognitive flexibility) and the Stroop Color-Word test (selective attention and cognitive flexibility). In addition, participants with high self-reported impulsivity have been found to score low on Go/NoGo tasks (e.g., Weidacker et al., 2017). Also, adequate response inhibition on Go/NoGo tasks has repeatedly been associated with activation of brain regions (including the interior cingulate cortex), which are known to play a central role in monitoring conflicting responses to both internal and external stimuli (Hester et al., 2004).

In the KX-task, fathers were asked to respond as quickly and accurately as possible by pressing a red button every time an X appeared on the screen (Go-stimuli), and not to respond to a K (NoGo-stimuli). The stimuli were presented for 50 ms each and the interstimulus time interval varied randomly between 1000, 2000, and 3000 ms. The task consisted of a practice session, in which 10 X's and 10 K's were presented in alternating order, and a test session, in which 80 X's and 20 K's were presented at random. Correct rejections, i.e., the number of non-responses to NoGo-stimuli, were taken as a measure of self-control.

2.3.3. Sensitivity and respect for autonomy

The fourth edition of the Emotional Availability Scales (EAS; Biringen, 2008) was used to measure fathers' sensitivity and respect for autonomy while interacting with their preschoolers during free play. Each dyad received a bag with toys and was invited to play for 8 min. In the EAS, sensitivity is operationalized as parents' ability to show warmth and appropriate responsiveness to the child. Important aspects are the expression and appropriateness of positive affect, and clarity in perception of the child's signals as well as the ability and willingness to respond timely and adequately to these signals. Respect for autonomy (in the EAS, this scale is labeled as nonintrusiveness) refers to parents' ability to refrain from any unnecessary physical or verbal intrusions and to give the child space to explore things at his or her own pace and in his or her own way (within commonsense boundaries to prevent harm to the child or his or her environment). Important aspects in a play situation are following the child's lead and adequate timing of contact initiatives. Both sensitivity and respect for autonomy are divided into seven subscales; the first two subscales are coded on 7-point Likert scales and the other subscales are coded using 3-point Likert scales (potential score range 7–29). For every subscale, a global rating was given for the entire free play session. Subscale 7 of the dimension respect for autonomy (The adult is made to 'feel' or 'seem' intrusive) was excluded because it refers to child behavior rather than parental behavior, leading to a potential score range of 6–26.

Seven coders rated the videotapes on the EAS dimensions. The sixth author, who is an experienced coder of parent-child interactions, completed the online training provided by Zeneyp Biringen and then trained a team of coders. During the team training, some subscales led to persistent interpretation problems and some alterations were made to improve intercoder agreement (for more information see Hallers-Haalboom et al., 2014). Intercoder reliability was adequate, with intraclass correlation coefficients (single measure, absolute agreement) being higher than 0.70 for both sensitivity and respect for autonomy. During the coding process, the first 100 videotapes of every coder were coded twice independently by separate coders and regular meetings were organized to prevent coder drift.

2.4. Data analysis

All measures were inspected for possible outliers that were defined as values > 3.29 *SD* above or below the mean (Tabachnick and Fidell, 2012). Outliers were winsorized, meaning that they were given a score that was no more extreme than the most extreme value that fell within the accepted range of a normal distribution. All variables were normally distributed.

To control for the effect of age and weight on fathers' T, which have been robustly related to basal T in the literature, residualized scores were computed based on linear regression. Because no significant differences were found between boys and girls regarding fathers' sensitivity and respect for the child's autonomy (p's > .32), child gender was not included as a covariate in the analyses. Pearson correlation coefficients were computed to examine the associations between fathers' evening and morning T level, self-control, and fathers' sensitivity and respect for autonomy while interacting with their preschoolers. To examine interaction effects between fathers' T and self-control on the degree to which they interacted in a sensitive and nonintrusive manner with their preschoolers, four hierarchical regression analyses were conducted; two for sensitivity (one with evening T as endocrine predictor, one with morning T) and two for respect for autonomy (again one with evening T, one with morning T). In the first step, fathers' morning or evening T level and self-control were entered. In the second step, the two-way interaction between fathers' self-control and their evening or morning T was entered. Variables were centered before computing interaction effects.

3. Results

Table 1 displays the means, standard deviations, and bivariate correlations for fathers' T levels in the evening and morning, self-control, and their sensitivity and respect for the child's autonomy during free play with their preschoolers. Consistent with previous research, fathers' evening and morning T levels were correlated, but their morning T was significantly higher than their evening T, $t(158) = -26.73, p < .01, d = -1.91$. Further, fathers' sensitivity was positively related to their level of respect for autonomy while interacting with their preschooler.

Table 1
Summary of means, standard deviations, and correlations for all study variables ($n = 159$).

	1	2	3	4	*M*	*SD*
1. Evening T					124.18	46.13
2. Morning T	0.65**				239.53	72.00
3. Self-control	0.12	−0.04			16.50	2.38
4. Sensitivity	0.08	0.09	0.04		23.78	2.82
5. Respect for autonomy	−0.08	−0.07	0.00	0.49**	21.15	3.14

Note. Correlations with T levels are based on residualized scores for T. Means and standard deviations for T represent raw data. *$p < .05$, **$p < .01$.

Table 2
Fathers' Circulating Testosterone and Inhibitory Control in Relation to their Sensitivity and Respect for Autonomy (n = 159).

		Sensitivity		Respect for autonomy	
		β	R^2	*β*	R^2
Evening T	Step 1		0.01		0.01
	T	0.07		−0.08	
	Self-control	0.03		0.01	
	Step 2		0.05		0.07*
	T * Self-control	0.20*		0.25**	
Morning T	Step 1		0.01		0.00
	T	0.09		−0.07	
	Self-control	0.04		0.00	
	Step 2		0.02		0.02
	T * Self-control	0.07		0.11	

Note. Separate regression analyses for fathers' evening and morning T and for fathers' sensitivity and respect for child autonomy. * $p < .05$, ** $p < .01$.

Both the bivariate correlations and the multivariate regression analyses revealed no significant relations between fathers' T levels and their self-control or parenting quality (sensitivity and respect for autonomy) during free play (Table 1 and Table 2). Likewise, fathers' self-control was not related to either aspect of parenting quality during free play. However, we did find significant interaction effects between fathers' evening T and self-control with respect to their sensitivity and respect for autonomy (Table 2). To explore these interaction effects, we conducted simple slopes analyses (Aiken and West, 1991) for both aspects of parenting, see Fig. 1. In fathers with relatively high self-control, higher T in the evening was related to more sensitivity toward preschoolers. In contrast, in fathers with low self-control, higher T was associated with less respect for the child's autonomy during free play. Exclusion of outliers on the variables under investigation (resulting $n = 155$), yielded the same results. In addition, examining fathers' evening and morning T in the same regression models (one model for sensitivity and one model for respect for autonomy), gave the same results.

4. Discussion

To our knowledge, this study is the first to examine the interplay between fathers' T and their ability to exert self-control in relation to the quality of their parenting. In line with our hypothesis, we found that fathers' higher T levels in the evening were related to less respect for their child's autonomy, but *only* in fathers with low self-control. Furthermore, higher T in the evening was related to more sensitive parenting *only* in fathers with high self-control.

Our finding that higher evening T levels were associated with less respect for preschoolers' autonomy during parent-child interaction in fathers with relatively low self-control is not only consistent with I^3 theory, but also extends this theory from human aggression to parenting quality. I^3 theory states that internal characteristics such as T can

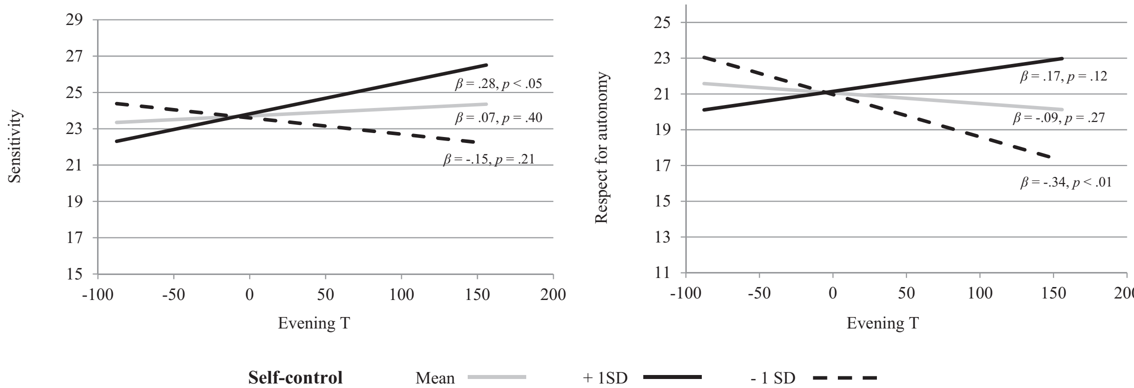

Fig. 1. Associations between fathers' testosterone and (a) sensitivity and (b) respect for autonomy by self-control (n = 159).

elicit aggressive behavior, but only (or mostly) in people who are less able to suppress their impulses (Carré et al., 2016; Slotter and Finkel, 2011). A lack of respect for child autonomy reflects a constellation of intrusive behaviors, including excessive stimulation, over-directive behavior, and unnecessary interference in the child's flow of activities (Biringen et al., 2014). These intrusive characteristics are rooted in parents prioritizing their own agenda and goals while interacting with their children, rather than prioritizing understanding and following their child's lead (Ispa et al., 2004). As such, intrusiveness (or a lack of respect for child autonomy) and aggression have components of dominance and self-centeredness in common, which are robust behavioral correlates of higher T levels in animal research (Aitken Harris, 1999). Furthermore, according to the steroid/peptide theory of social bonds, higher T co-occurs with more dominant and competitive behavior in both animals and humans (van Anders, 2013). To a much larger degree than other mammals, humans have the ability to modulate social behaviors that stem from internal forces such as basal T (MacDonald, 2008). Our study shows a moderating effect of self-control that determines the degree to which men are susceptible to the impact of T on their ability to follow their child's lead instead of overruling the child's perspective in favor of their own.

The finding that higher T in the evening was related to more sensitive parenting only in fathers with high self-control, whereas for fathers with relatively low self-control no clear relation between T and sensitivity was found, appears to contradict our hypothesis and the previously discussed results on respect for child autonomy. Based on I^3 theory we would expect a negative association between T and sensitivity in fathers with low self-control. Although empirically and conceptually parental sensitivity and respect for child autonomy are often seen as closely related aspects of parenting quality, it is conceivable that sensitivity taps into another spectrum of social behavior than respect for autonomy when it comes to T-driven responses. That is, a lack of respect for others' autonomy, like aggression, clearly encompasses dominance as a central characteristic. Sensitivity, on the other hand, refers to the investment and ability to see things from the child's point of view and, consequently, to respond to the child's signals in such a way that it is (age-) appropriate and fits the direct needs of the child (Ainsworth et al., 1974). From that perspective, parental sensitivity is more closely related to the domain of warm, nurturing, and supportive parenting. The moderately high correlation between fathers' sensitivity and respect for child autonomy in this study supports the idea that the two have several characteristics in common, but still reflect distinct and unique features of parenting quality. Although further research on basal T levels in fathers is needed, a certain level of T could be beneficial for nurturing parenting behaviors, including sensitivity (Endendijk et al., 2016). The rationale behind this is that the enzyme aromatase leads to the conversion of T to estradiol in the central nervous system, which is essential for the synthesis of oxytocin (Cornil et al., 2006). Both estradiol and oxytocin are known to stimulate parent-infant bonding and nurturing parenting in various species (e.g., Insel and Young, 2001; Kendrick, 2000). This positive effect of T on sensitive parenting could be particularly true for fathers who are able to inhibit other impulses that might otherwise cloud the potentially positive effects of T on fathers' responsiveness to their child's signals. In addition, the combination of relatively high T and high self-control may be ideal for seeing things from the other's point of view, a central aspect of sensitivity. That is, high T has been suggested to promote goal-oriented behavior (Booth et al., 2006) and high self-control thwarts the distraction by both internal and external stimuli. During dyadic parent-child interactions, this blend may help fathers to focus on their preschooler and his or her activities, needs, desires, and emotions.

In this study we only found interaction effects between fathers' self-control and their T levels in the *evening* on parenting quality, while no effects were found for fathers' T in the *morning*. The diurnal rhythm of T is characterized by highest T levels in the morning, steeply declining levels before noon, followed by a slower decline in the afternoon and early evening, reaching the lowest levels in the evening (Booth et al., 2006; Cooke et al., 1993). This diurnal rhythm of T appears to be more pronounced in males than in females (Granger et al., 2002). A group of researchers in the field of T-driven social and physical responses propose that the overnight rise in T, reflected in the highest T levels at wakening, facilitates muscle anabolism (Kuzawa et al., 2016). The dramatic drop in T after wakening, particularly among fathers, may then help calibrating T in favor of social demands. Although this hypothesis requires further investigation, it could be that T level at wakening is less informative when examining social responses than T level later during the day.

Certain issues need to be taken into account in the interpretation of the results. First, the sample in this study consisted predominantly of highly educated Caucasian Dutch families. As a result, our findings are not necessarily generalizable to lower educated non-Caucasian fathers. Specifically, there is ample evidence that cultural background of the family plays an important role in both the level of father involvement in everyday family life, and type and quality of interactions fathers engage in with their children (e.g., Doucet, 2013). Although the negative association between T and overall father involvement has been found in various cultural contexts, much remains unclear about the underlying mechanisms causing this negative association as well as the specific aspects of father involvement that relate to T (Gettler, 2016). Are these mechanisms the same, and is T in a similar fashion related to type and quality of parenting in fathers across cultures? To what extent do cultural norms shape fathers' responses to T? In future research this type of questions can be addressed by adopting a cross-cultural approach. A second limitation of this study is that only two saliva samples were used to infer fathers' basal T; one sample collected in the evening and one in the morning. Because T is susceptible to various internal and external conditions (e.g., daily activities, hassles, hours of sleep) (e.g., Bancroft, 1993; Leproult and Van Cauter, 2017), and as discussed previously, T follows a distinct diurnal curve, it would have been more informative to estimate fathers' basal T levels using multiple saliva samples from different parts of the day across various days. In addition, in the current study only T levels were measured in fathers' saliva, while researchers increasingly stress the importance of examining the interaction between various endocrine factors in relation to human social-emotional behavior, including qualitative aspects of parenting. For instance, several studies suggest that high levels of both T and cortisol in men are detrimental for their parenting efforts (e.g., Bos et al., 2018; Gettler et al., 2011b). Examining the interplay between different aspects of the neuroendocrine system may be particularly helpful in understanding individual variations in parenting by providing insight in how and when (i.e., under which conditions) hormones such as T affect parenting. Third, we cannot draw firm conclusions about the direction of the found interaction effects because fathers' T, self-control, and parenting quality were measured roughly at the same time. Specifically, self-control and parenting were measured during a single home visit and fathers were asked to collect saliva samples within two weeks before or after this visit to establish basal T. According to the challenge hypothesis the association between T and parenting is reciprocal, with high T levels inhibiting parenting, and cues associated with children, child care, or parenting relating to decreased T levels (Wingfield et al., 1990). A number of studies have found support for this hypothesis (Gettler et al., 2011a, b; Kuzawa et al., 2009; Wingfield et al., 1990). However, as mentioned above, little is known about the mechanisms that underlie the negative link between T and parenting, leaving open many questions about the direction of the effects found to date (Gettler, 2016). Similarly, alternative explanations for the combined effects of T and self-control on parenting quality call for further research on both physical (e.g., fatigue) and social-emotional (e.g., fathers' priorities during parent-child interaction) mediators. In sum, we need cross-lagged longitudinal designs (i.e., both T levels and parenting measured across time) and experiments to gain more insight in the possible bidirectionality and the causal mechanisms underlying the relation between fathers' endocrine system functioning and the quality of their parenting.

To conclude, this study sheds new light on the puzzling findings thus far regarding the role of basal T levels in fathers' parenting quality and offers an interesting extension for I^3 theory on the link between T and human aggression. In contrast with other mammals, the impact of T on parenting in humans is likely to be modulated by trait characteristics such as the ability to exert self-control. Interestingly, our findings suggest that different aspects of fathers' parenting are differently affected by the interaction between T and self-control. Whereas higher T levels may stimulate dominant parenting behavior in fathers who are less able to inhibit their immediate responses, higher T may also promote paternal sensitivity in fathers who do have ample ability to inhibit their impulses and to focus on their child's signals. In sum, this study emphasizes the importance of examining the interplay between fathers' neuro-endocrine functioning and trait characteristics in the development of unique father-child interaction patterns.

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