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Adolescent Personality: Associations With Basal, Awakening, and Stress-Induced Cortisol Responses

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Abstract

The purpose of the present study was to investigate the associations between personality facets and hypothalamic-pituitary-adrenal (HPA) axis functioning. Previous studies have mainly focussed on stress-induced HPA-axis activation. We hypothesized that other characteristics of HPA-axis functioning would have a stronger association with personality based on the neuroendocrine literature. Data ($n = 343$) were used from the TRacking Adolescents' Individual Lives Survey (TRAILS), a large prospective cohort study of Dutch adolescents. We studied the association between facets of Neuroticism, Extraversion, and Conscientiousness and basal cortisol, the cortisol awakening response (CAR), and four measures of stress-induced HPA-axis activity. Basal cortisol levels were related to facets of all three personality traits. The CAR and stress-induced cortisol were not related to personality. Possibly due to its more trait-like nature, basal cortisol seems more informative than stress-induced cortisol when investigating trait-like characteristics such as personality facets.

The hypothalamic-pituitary-adrenal (HPA) axis is a key component in the body's neuroendocrine stress response, and its end product, cortisol, has been implicated in the transduction of psychosocial stress into psychopathology (Herbert, 1997; Susman, 1998). Functioning of the HPA axis has become increasingly popular in the study of mechanisms underlying the development of psychopathology. Although the associations are complex, atypical HPA-axis functioning has been suggested to be related to psychopathology (e.g., Burke, Davis, Otte, & Mohr, 2005). Parallel to the study of cortisol and psychopathology is the study of personality and psychopathology. Similar to atypical HPA-axis functioning, atypical personality profiles have been posited to predispose to psychopathology (Khan, Jacobson, Gardner, Prescott, & Kendler, 2005; Kotov, Gamez, Schmidt, & Watson, 2010; Ormel, Rosmalen, & Farmer, 2004). Despite the complexity of the respective relationships, it seems clear that some people are at increased risk for psychopathology by virtue of their personality traits and/or HPA-axis functioning. The question that remains is whether and how functioning of the HPA axis and personality are related to each other. The current study aims to investigate associations between various measures of HPA-axis functioning and personality facets during adolescence.

This research is part of the TRacking Adolescents' Individual Lives Survey (TRAILS). Participating centers of TRAILS include various departments of the University Medical Center and University of Groningen, the Erasmus University Medical Center Rotterdam, Utrecht University, the Radboud Medical Center Nijmegen, and the Parnassia Bavo group, all in the Netherlands. TRAILS has been financially supported by various grants from the Netherlands Organization for Scientific Research NWO (Medical Research Council program grant GB-MW 940-38-011; ZonMW Brainpower grant 100-001-004; ZonMw Risk Behavior and Dependence grants 60-60600-97-118; ZonMw Culture and Health grant 261-98-710; Social Sciences Council medium-sized investment grants GB-MaGW 480-01-006 and GB-MaGW 480-07-001; Social Sciences Council project grants GB-MaGW 452-04-314 and GB-MaGW 452-06-004; NWO large-sized investment grant 175.010.2003.005; NWO Longitudinal Survey and Panel Funding 481-08-013), the Dutch Ministry of Justice (WODC), the European Science Foundation (EuroSTRESS project FP-006), Biobanking and Biomolecular Resources Research Infrastructure BBMRI-NL (CP 32), the participating universities, and Accare Center for Child and Adolescent Psychiatry. We are grateful to all adolescents, their parents and teachers who participated in this research, and everyone who worked on this project and made it possible. This article has benefited from thoughtful comments by Jaap Koolhaas, Harriette Riese, Judith Rosmalen, and Elizabeth Shirtcliff on the conceptual definitions of the various cortisol indices.

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Measures of HPA-Axis Functioning

HPA-axis functioning can be studied at different levels. An important distinction can be made between basal levels of HPA-axis activity and changes in HPA-axis activity. The basal HPA-axis activity level reflects the basal or resting metabolism of an organism (Hellhammer et al., 2007). Basal HPA-axis functioning can be operationalized as a (series of) cortisol sample(s) taken at a fixed moment during the day, for example, in the morning (Pruessner, Kirschbaum, Meinlschmid, & Hellhammer, 2003). In healthy humans, HPA-axis activity follows a circadian rhythm (e.g., Fries, Dettenborn, & Kirschbaum, 2009; Kudielka, Schommer, Hellhammer, & Kirschbaum, 2004). Cortisol, the main effector of the HPA axis, is excreted in a pulsatile fashion (Young, Abelson, & Cameron, 2004), and concentrations start to rise during the second half of the night and reach a peak in the early morning hours, gradually decreasing throughout the day (Dallman, 2000; Fries et al., 2009; Tsigos & Chrousos, 2002). Cortisol concentrations are relatively stable when assessed at the same time on subsequent days (Hellhammer et al., 2007) and have a substantial genetic component (.62; Bartels, Van den Berg, Sluyter, Boomsma, & de Geus, 2003). Basal HPA-axis functioning is therefore suggested to be a trait-like characteristic.

In contrast, HPA-axis reactivity is an indicator of the sensitivity of the HPA axis to specific situations (Hellhammer et al., 2007). The HPA axis plays a crucial role in preparing the body for performing a specific task (Koolhaas et al., 2011); in other words, changes in HPA-axis activity might be an indicator of the amount of energy or effort an individual is willing or able to invest in performing the task, more than perceived stress. HPA-axis reactivity can be studied in terms of *cortisol awakening responses* (CAR) or in terms of *cortisol responses induced by a (social) stress task*. The CAR reflects HPA-axis reactivity to the anticipated stress load of the upcoming day (Fries et al., 2009; Hellhammer et al., 2007). The CAR has generally been operationalized as the area under the cortisol curve with respect to the increase (AUCi) of the various assessments from wakening up to an hour after wakening (Pruessner et al., 2003; although see, e.g., Adam, 2006, and Adam & Kumari, 2009, for proposed alternative methods), during the first half hour of which cortisol concentrations increase sharply (Kudielka et al., 2004). The CAR has a modest heritable component (e.g., .40–.48: Wüst, Federenko, Hellhammer, & Kirschbaum, 2000; .52: Riese, Rijsdijk, Rosmalen, Snieder, & Ormel, 2009) for the increase in the first hour after awakening, and might therefore be considered more state-like than basal HPA-axis functioning.

In addition to the CAR, changes in HPA-axis functioning can also be studied in terms of responses to stress, such as during a social stress task. Following the same argument as for the CAR, that changes in HPA-axis activity reflect an individual's physiological preparation, task-induced HPA-axis reactivity reflects the extent to which an individual physiologically invests in performing a certain task (Koolhaas et al., 2011; Sapolsky, Romero, & Munck, 2000) and thus might be an indicator of the amount of energy or effort an individual needs for performing the task, such as the Trier Social Stress Test (Benschop et al., 1998; Kirschbaum, Pirke, & Hellhammer, 1993), more than perceived stress. Task-induced HPA-axis reactivity is operationalized as the increase in cortisol concentrations from resting, usually measured prior to the task, compared to during the task. It is often calculated as a difference score, or as the residual of cortisol during the task regressed on resting cortisol (Burt & Obradović, 2012). For measurement of HPA-axis reactivity, it is important to keep in mind that there is a delay of approximately 20 min between the onset of HPA-axis activity and detectability of increases in salivary cortisol (Kirschbaum & Hellhammer, 1992). This means that saliva samples do not need to be taken during the task, but can be taken immediately after the task. Heritability of stress-induced cortisol has also been found to be rather low (.33; Federenko, Nagamine, Hellhammer, Wadhwa, & Wüst, 2004). Nonetheless, this heritability of stress-induced cortisol has been found to increase substantially with repetition of the stressor, suggesting that whereas first-time stress-induced cortisol reflects a state characteristic, habituation to the task may be more trait-like (Federenko et al., 2004). Moreover, this seems to indicate that whereas the (empirical) basis for basal cortisol as a trait characteristic is substantial, CAR and stress-induced cortisol are probably not exclusively state-like.

Although almost all studies examining the association between personality and stress-induced HPA-axis functioning have focussed on stress-induced HPA-axis reactivity, HPA-axis reactivity may not be the most informative measure of stress-induced HPA-axis functioning (Koolhaas et al., 2011). Research in rats showed that sexual behavior elicited the largest increase in cortisol, not an adverse stimulus (Koolhaas, de Boer, de Ruiter, Meerlo, & Sgoifo, 1997). This suggests that HPA-axis reactivity is indeed primarily a marker for energy mobilization, and not stress, but effort related (Koolhaas et al., 2011; Sapolsky et al., 2000). Moreover, when investigating HPA-axis responses to behaviors that differed in perceived stress (e.g., winning vs. losing a fight, naïve vs. experienced swimming), the increase in cortisol (HPA-axis reactivity) was the same, whereas rats differed in recovery of the HPA axis after the task (i.e., the decrease in cortisol). These findings suggest that recovery rate is a more informative index of stress than reactivity (Koolhaas et al., 2011; Nederhof et al., 2013) and, thus, that recovery after stress might be an interesting cortisol index to study in addition to the more frequently studied reactivity.

Recovery of the HPA axis after a task is determined by the strength of the negative feedback loop and might reflect perceived control over, or perceived stress in, a specific situation (Koolhaas et al., 2011; Sapolsky et al., 2000). HPA-axis recovery can be operationalized as the decline in cortisol concen-

trations during the task to after the task and can be calculated as either a difference score, a residual score, or a slope when more than one recovery measure is taken (Burt & Obradović, 2012). As salivary cortisol concentrations reflect HPA-axis activity 20 min earlier, a recovery measure should be taken approximately 40 min after the end of the task.

Although not directly an index of change, another interesting measure of HPA-axis functioning in the context of stress may be anticipation. *Anticipatory HPA-axis activity* reflects an individual's arousal in expectation of an event. Anticipatory HPA-axis activity can be operationalized as cortisol concentration preceding an event, such as after coming into the lab before the start of the experiments. Apparently, in humans, HPA-axis activity in expectation of an event with unknown content is associated with mental health. Mikolajczak and Luminet (2008) found that lower anticipatory cortisol was associated with higher scores on a resilience questionnaire. Likewise, although not tested for significance, results from Young and colleagues suggested that anticipatory cortisol concentrations were lower in healthy participants compared to participants with affective and/or anxiety disorders (Young et al., 2004). In the present study, we will explore whether anticipatory HPA-axis activity is also associated with personality.

A final measure of HPA-axis functioning we will investigate is the total cortisol output during the stress task (STAUCg). In contrast to measures of stress-induced cortisol, emphasizing changes over time and, in particular in the case of stress reactivity, sensitivity of the system, *total HPA-axis activity during a task* primarily reflects the magnitude of a response, including both sensitivity (i.e., the difference between the single measurements) and intensity (i.e., the distance of these measures from ground; Fekedulegn et al., 2007; Pruessner et al., 2003). Total cortisol output during a task can be operationalized as the area under the curve with respect to the ground (AUCg); the sum of changes in cortisol concentrations (Pruessner et al., 2003) are superimposed on the diurnal rhythm. The stress task AUCg (STAUCg) can be seen as a measure of stress-induced cortisol that is influenced both by state and trait components.

Measures of Personality

Whereas research has barely focused on different measures of HPA-axis functioning, personality literature has traditionally distinguished various facets, or traits. The focus on different personality traits has resulted in several slightly different three- and five-factor measures (De Raad & Perugini, 2002). Together, the (three or five) factors are widely accepted as facilitating a comprehensive and detailed picture of an individual's personality profile. The broad factors Neuroticism, Extraversion, Openness to Experience, Agreeableness, and Conscientiousness have appeared to explain most of the common variance among normal personality traits (Digman, 1990). For the current study, we have focused on facets of Neuroticism, Extraversion, and Conscientiousness, the three personality traits that have been most consistently linked to psychopathology (Kotov et al., 2010). With regard to Neuroticism, we distinguish between vulnerability (i.e., general susceptibility to stress), angry/hostility (i.e., tendency to experience anger and related states such as frustration and bitterness), and impulsivity (i.e., tendency to act on cravings and urges rather than reining them in and delaying gratification). Two facets of Extraversion are distinguished: assertiveness (i.e., social ascendancy and forcefulness of expression) and excitement seeking (i.e., need for environmental stimulation). Regarding Conscientiousness, we will focus on self-discipline (i.e, capacity to begin tasks and follow through to completion despite boredom or distractions; Costa & McCrae, 1992).

Associations Between Personality and HPA-Axis Functioning

Given the various facets of both HPA-axis functioning and personality, it should not be surprising that there is no easy-to-view picture of the association between the two. Some hypotheses regarding the associations might be formulated based on both theoretical arguments and previous research. First, personality has traditionally been assumed to be a trait-like characteristic. Although a recent behavioral genetic study has provided evidence for both a state component and a trait component in Neuroticism (Kandler et al., 2010; Laceulle, Ormel, Aggen, Neale, & Kendler, 2013), the substantial heritability of personality (Bouchard & McGue, 2003; Heath, Neale, Kessler, Eaves, & Kendler, 1992) suggests that all facets of personality traits have a stronger relation with trait aspects of HPA-axis functioning compared to state aspects. Consequently, it seems plausible that personality traits have the strongest association with trait components of HPA-axis functioning (basal cortisol and to some extent also STAUCg).

Surprisingly, trait aspects of HPA-axis functioning have only incidentally been studied in relation to personality. In only one published study has the association between basal cortisol and personality been investigated. Using a sample of 81 male and female students, Schommer and colleagues found that basal cortisol did not distinguish between subjects with high or low scores on either Extraversion or Neuroticism (nor did they find an association for psychoticism, a third trait assessed in their study; Schommer, Kudielka, Hellhammer, & Kirschbaum, 1999). To the best of our knowledge, no studies have been performed on associations between stress task AUCg and personality. Nonetheless, a study on associations between cognitive "personality" traits and cortisol stress responses showed that situation-specific cognitive traits (e.g., anticipatory cognitive appraisal) explained a substantial amount of variance in STAUCg (up to 35%; Gaab, Rohleder, Nater, & Ehlert, 2005). More general cognitive "personality" traits (e.g., self-concept of own competence) were only weakly related to STAUCg (up to 8%). The authors suggest that situation-specific factors are more interesting to study in the

context of a stress task than broader personality traits, possibly because they have comparable conceptual levels.

With regard to the more state-like aspects of HPA-axis functioning, some studies have assessed associations between personality traits and both cortisol awakening response and stress reactivity. Interestingly, all studies examining personality and cortisol awakening response have focused on Neuroticism, whereas no studies seem to have assessed associations with other personality traits. The focus on Neuroticism might be a result of the presumed link between Neuroticism and low tolerance for stress or aversive stimuli (e.g., Norris, Larsen, & Cacioppo, 2007). Nonetheless, research into associations between Neuroticism and cortisol awakening responses has resulted in inconsistent findings. Although most studies reported no significant associations (Chan, Goodwin, & Harmer, 2007; Riese et al., 2009; Wirtz et al., 2007), others found that individuals who scored extremely high on Neuroticism had a higher CAR than individuals with an extremely low Neuroticism score (Portella et al., 2005; Schommer et al., 1999).

Without a doubt, most research has been performed on the association between personality traits and reactivity to a stress task. Some studies did not find any association (Kirschbaum, Bartussek, & Strasburger, 1992; Schommer et al., 1999). For example, although Kirschbaum and colleagues examined many different personality traits and investigated with a number of questionnaires (i.e., the Eysenck Personality Questionnaire, the Zuckerman Sensation Seeking Scale, and the Strelau Temperament Inventory) no significant correlation was observed between stress reactivity and any of the personality measures studied. Pruessner and colleagues (1997) reported negative associations between reactivity and facets of Extraversion and Conscientiousness, but only after data aggregation. Other studies reported associations between high levels of Extraversion and a blunted cortisol response to stress (Kirschbaum et al., 1995; Oswald et al., 2006) or to elevated cortisol responses (LeBlanc & Ducharme, 2005). Similarly, high levels of Neuroticism have been associated both with increased responses (Habra, Linden, Anderson, & Weinberg, 2003; Houtman & Bakker, 1991) and with blunted cortisol responses (LeBlanc & Ducharme, 2005; Oswald et al., 2006; Phillips, Carroll, Burns, & Drayson, 2005). With regard to Conscientiousness, associations seem to be a bit more consistent: Either no consistent association was found (e.g., Oldehinkel, Hartman, Nederhof, Riese, & Ormel, 2011; Oswald et al., 2006) or higher Conscientiousness was related to enhanced cortisol responses (Garcia-Banda et al., 2011; Oldehinkel et al., 2011). Given our earlier argument that HPA-axis reactivity reflects effort, it may be plausible that the previously reported inconsistent findings between stress reactivity and personality traits (i.e., the positive as well as the negative associations that have been reported for various traits) mainly reflect some fluctuation around the nonsignificant relation between personality and stress-induced HPA-axis reactivity.

Current Study

In this project, we investigated the associations between HPA-axis functioning and personality in a large population-based sample of adolescents. In contrast to previous studies, we included various aspects of HPA-axis functioning as well as various facets of broader personality traits.

Measures included were three different but often studied aspects of HPA-axis functioning (i.e., basal cortisol, the CAR, and reactivity to a stress task). Basal cortisol was operationalized as cortisol concentration at awakening. In addition to basal cortisol, the CAR and reactivity, anticipation and recovery elicited by a social stress task, and STAUCg were included because those have been proposed as highly informative (Koolhaas et al., 2011; Pruessner et al., 2003) but have never been reported in the context of personality. Personality characteristics under study were facets of Neuroticism, Extraversion, and Conscientiousness, the three personality traits that have been consistently linked to psychopathology (Kotov et al., 2010).

In a large sample of adolescents, we tested the hypothesis that trait aspects of HPA-axis functioning, basal cortisol, and possibly STAUCg are more strongly related to personality than the more state-like aspects of HPA-axis functioning, the CAR, and stress task–induced anticipation, reactivity, and recovery. Consequently, we hypothesize that none of our personality facets is substantially related to stress reactivity.

With regard to the personality facets under study, we expect that facets of Neuroticism show stronger associations with basal cortisol than facets of Extraversion and Conscientiousness. However, given the previously reported nonsignificant association between basal cortisol and either Extraversion or Neuroticism (Schommer et al., 1999), it might be that only some, but not all, facets of Neuroticism are related to basal cortisol. In particular, the Neuroticism facet vulnerability is hypothesized to be related to basal cortisol, given the previously mentioned presumed link with sensitivity to stress (e.g., Norris et al., 2007).

METHODS

Sample

Data were used from the TRacking Adolescents' Individual Lives Survey (TRAILS), a large prospective cohort study of Dutch adolescents who are followed biennially or triennially from 11 to at least 25 years of age (Ormel et al., 2012). The present study involves data from the third assessment wave, which ran from September 2005 to December 2007. At Wave 1, 2,230 preadolescents (50.8% girls) enrolled in the study (response rate: 76.0%), of whom 1,816 (response rate: 81.4%; 45.3% girls) participated in Wave 3. At Wave 3, the mean age was 16.13 years ($SD = 0.59$). A detailed description of the sample selection, procedures, and methods can be found in de Winter and colleagues (2005).

During T3, 744 of the 1,816 adolescents participating at Wave 3 were invited to participate in a series of experiments in addition to the usual assessments. Of these, 715 (96.1%) agreed to do so. Adolescents with an increased risk of mental health problems had a greater chance of being selected for the experimental session. Increased risk was defined based on T1 temperament (high frustration and fearfulness, low effortful control), lifetime parental psychopathology, and environmental risk (living in a single-parent family). In total, 66.0% of the sample had one of the above-described risk factors; the remaining 34.0% were selected randomly from the total TRAILS sample (Bouma, Riese, Ormel, Verhulst, & Oldehinkel, 2009). A previous study in the same sample by Bouma and colleagues (2009) on the effects of gender, menstrual phase, and oral contraceptive use indicated that the use of oral contraceptive affects the cortisol awakening response as well as responses to the social stress test. Moreover, HPA-axis functioning in girls using oral contraceptives was so severely distorted (i.e., these girls did not show any cortisol response) that we could not consider oral contraceptives as a simple confounder. Therefore, these girls, as well as girls with missing data on oral contraceptive use, were excluded from all analyses ($n = 126$).

Other reasons for exclusion were smoking and use of coffee in the 2 hr before the behavioral experiments ($n = 4$), as well as the use of steroid-containing medication and selective serotonin reuptake inhibitors ($n = 24$). Further reduction of the sample was due to completely ($n = 48$) and partly ($n = 170$) missing cortisol samples and personality data. Final analyses were performed on complete cases ($n = 343$).

Procedure

TRAILS participants filled out questionnaires at school, in the classroom, supervised by one or more test assistants. In addition, a subsample of adolescents (see above) was invited to participate in the experimental session. The experimental session consisted of a number of different challenges, including orthostatic stress (from supine to standing), a spatial orienting task, a gambling task, a startle reflex task, and a social stress test, preceded and followed by a 40-min period of rest. For the current study, we focused on the social stress task. During the experimental challenges, we assessed participants' psychophysiological responses (i.e., cardiovascular, cortisol, and subjective experiences). Measures that were used in the present study are described more extensively below. The experimental sessions took place in soundproof rooms with blinded windows at selected locations in the participants' residence towns. The total session lasted about 3.5 hr and started between 8:00 and 9:30 a.m. (morning sessions, 50%) or between 1:00 and 2:30 p.m. (afternoon sessions). Adolescents were asked to refrain from smoking and from using coffee, milk, chocolate, and other sugar-containing foods in the 2 hr before the session. At the start of the session, the test assistant explained the procedure and administered a short checklist on current medication use, oral contraceptives (OC), menstrual cycle, quality of sleep, and physical activity in the last 24 hr. The protocol was approved by the Central Committee on Research Involving Human Subjects.

The Social Stress Test

This test was the final challenge of the experimental session. It involves a standardized protocol including public speaking and mental arithmetic, inspired by the Trier Social Stress Task (TSST; Kirschbaum et al., 1993), for the induction of moderate performance-related social stress. The TSST has been found to elicit significant changes in heart rate and in the HPA system (Benschop et al., 1998). The participants were instructed to prepare a 6-min speech about themselves and their lives and to deliver this speech in front of a video camera. They were told that their videotaped performance would be judged on content of speech as well as on use of voice and posture, and rank-ordered by a panel of peers after the experiment. The participants had to speak continuously for the whole period of 6 min. The test assistant watched the performance critically and showed no empathy or encouragement. The speech was followed by a 3-min interlude in which the participants were not allowed to speak. After the interlude, participants were instructed to subtract 17 repeatedly, starting with 13,278. This difficult task was meant to induce a sense of uncontrollability. Uncontrollability was further provoked by negative feedback by the test assistant, including remarks such as "No, wrong again, begin at 13,278," "Stop wiggling your hands," or "You are too slow, be as fast as possible, we are running out of schedule."

Measures

Personality Facets. The Revised NEO Personality Inventory (NEO PI-R; Costa & McCrae, 1992; Hoekstra, de Fruyt, & Ormel, 2003) is a 240-item personality questionnaire that measures 30 personality facets, a selection of which were assessed in our study. For the present analyses, we included all scales that were assessed in the TRAILS study: angry/hostility, impulsiveness, and vulnerability (all facets of Neuroticism); assertiveness and excitement seeking (both facets of Extraversion); and self-discipline (a facet of Conscientiousness). All scales consisted of eight items, which could be scored on a 5-point scale ranging from 1 (*totally disagree*) to 5 (*totally agree*). Internal consistency (Cronbach's α) ranged from .51 (impulsivity) to .77 (vulnerability).

HPA-Axis Functioning. To collect data on basal and awakening cortisol, we provided participants with verbal and written instructions to collect saliva at home immediately after waking up as they were still lying in bed (CM1; awakening/basal) and 30 min after awakening (CM2; awakening + 30), using the

Sarstedt Salivette device (Nümbrecht, Germany). Directly after sampling, participants stored saliva samples in their freezer. We assessed HPA-axis responses toward the social stress test by four cortisol samples (referred to as CE1, CE2, CE3, and CE5). There is a delay of approximately 20 min between the production of cortisol by the adrenal glands and the detectability of representative levels of cortisol in saliva. CE1 (preexperiment), reflecting cortisol levels induced by anticipation stress, was taken at the start of the experimental session. CE2 (prestress) was collected just before the social stress test, reflecting HPA-axis activity 20 min earlier, when the participants filled out a rating scale, not related to the present study, and is considered a pretest measure. CE3 (stress, speech) was collected directly after the end of the social stress test and reflects cortisol levels during speech. CE4 (stress, arithmetic) was collected 20 min after CE3 and reflects cortisol levels immediately after the social stress test. CE5 (poststress), collected 40 min after the end of the social stress test, reflects posttest cortisol levels.

After the experimental session, the samples were placed in a refrigerator at 4°C, and within a few days, they were stored at −20°C until analysis. All samples were analyzed with the same reagent, and all samples from a participant were assayed in the same batch. Cortisol was measured directly in duplicate in 100 ml of saliva using an in-house radioimmunoassay applying a polyclonal rabbit cortisol antibody and 1,2,6,7 ^{3}H cortisol (Amersham, Arlington Heights, Illinois) as the tracer. After incubation for 30 min at 60°C, the bound and free fractions were separated using activated charcoal. The intra-assay coefficient of variation was 8.2% for concentrations of 1.5 nM, 4.1% for concentrations of 15 nM, and 5.4% for concentrations of 30 nM. The inter-assay coefficients of variation were 12.6%, 5.6%, and 6.0%, respectively. The detection border was 0.9 nM. Missing samples were due to detection failures in the lab (60%) or insufficient saliva in the tubes (40%). Cortisol levels five standard deviations above the mean were considered outliers and recoded into missing values.

Other Variables. Experiment time, sex, and habitual smoking were included as potential confounders of the associations under study. Smoking was assessed by questions on past and current smoking in a questionnaire that was filled out at school, on average 3.07 months ($SD = 5.12$) before the experimental session. We distinguished between nonsmokers ($n = 376$) and habitual smokers (i.e., at least one cigarette a day; $n = 123$).

Statistical Analyses

All analyses were performed in SPSS (Version 18.0). We first calculated descriptive statistics of the variables used in this study. Differences between boys and girls were tested by means of *t* tests.

The standardized score of CM1, the cortisol measure immediately after awakening, was used as a measure of basal HPA-axis activity. With respect to awakening responses, we subtracted CM1 from CM2 (when only two measures are available, calculating the formula proposed by Pruessner comes down to subtracting cortisol at awakening from cortisol 30 min after awakening, a method that has consistently been used in different studies; Pruessner et al., 2003). Anticipation before the experimental session, reactivity to the social stress test, and recovery from the social stress test were used as indices of stress-induced HPA-axis functioning. Anticipatory HPA-axis activity was operationalized as the first cortisol sample (CE1) taken at the start of the experimental session, approximately 1 hr before the start of the social stress test. Reactivity and recovery were calculated by saving the standardized residuals of regression analyses: For reactivity, stress task cortisol (CE3, for most participants the highest cortisol level) was predicted by the pretest measure (CE2), and for recovery, posttest cortisol (CE5) was predicted by the task measure (CE3). Standardized residuals are commonly used in studies on stress reactivity and are the residuals divided by an estimate of their standard deviation. Similar to normal *z*-scores, they have a mean of 0 and a standard deviation of 1. Scores reflect the distance to the regression line and can consequently be used as a measure of change; that is, positive scores represent relatively high HPA-axis activation compared to other adolescents (Burt & Obradović, 2012). Finally, the area under the curve with respect to the ground of the social stress task (STAUCg), reflecting total cortisol output during the test, was calculated using the following formula for AUCg recommended by Pruessner and colleagues (2003): ((CE3 + CE2) × 12.5) + ((CE4 + CE3) × 10) + ((CE5 + CE4) × 10). Basal cortisol, the CAR, anticipation, and STAUCg scores were standardized into *z*-scores. Standardized residuals are already similar to normal *z*-scores; they have a mean of 0 and a standard deviation of 1.

Using Fisher's *Z*-test, we compared the bivariate correlation coefficients of cortisol measures and personality traits between boys and girls. If no consistent sex differences were found, we performed further analyses for boys and girls together. Subsequently, associations between HPA-axis functioning and personality traits were assessed in more detail by means of partial correlations. Smoking, sex, and experiment time were included as covariates. Analyses were performed on complete cases ($n = 343$). Effects were marked as significant if $p \leq .05$ (two-tailed).

Finally, we ran three additional analyses with alternative operationalizations of cortisol measures. For the CAR, we examined whether associations with personality traits were the same when the CAR was operationalized as a standardized residual (suggested as the most reliable operationalization for stress-induced reactivity; Obradović, Bush, Stamperdahl, Adler, & Boyce, 2010) instead of the commonly used difference score (Pruessner et al., 2003). For reactivity and recovery, we examined whether associations with personality traits were the same when they were assessed operationalized as difference scores instead of standardized residuals.

RESULTS

Descriptive Statistics

Means and standard deviations of all variables are reported in Table 1. Boys were higher on assertiveness, on excitement seeking, on cortisol levels prior to (CE2) and during (CE3) the stress task, and with regard to reactivity to the stress task. Girls were higher with respect to vulnerability, impulsivity, and cortisol levels 30 min after awakening and recovery after the stress task. They were also slightly higher on basal cortisol. A detailed description of cortisol responses to awakening and social stress in our sample (e.g., with regard to gender differences) can be found in Bouma and colleagues (2009). Bivariate correlations between single cortisol measures and personality traits are reported in Table 2.

Using Fisher's *Z*-test, we compared all the bivariate correlation coefficients for boys with the correlation coefficients for girls. Significant differences were found for only three of the correlation coefficients. Correlations between, respectively, assertiveness and anticipation ($Z = 1.99$, $p = .047$), assertiveness and STAUCg ($Z = 3.14$, $p = .002$), and self-discipline and recovery ($Z = 1.97$, $p = .049$) were slightly stronger in girls than in boys. All other 33 differences in correlations were nonsignificant. Consequently, further analyses were performed for boys and girls together.

Personality Traits and Cortisol Responses to Awakening and Stress

Analyses presented were performed on complete cases. However, it should be noted that results of analyses excluding cases pairwise showed the same picture. Partial correlations between personality traits and cortisol responses are reported in Table 3. All correlations were controlled for smoking, experiment time, and sex (see Bouma et al., 2009, for more

Table 1 Descriptive Statistics

	N	Mean (*SD*)	Sex Differences
Vulnerability (N-facet)	502	2.37 (.52)	$t(1, 500) = 6.76$, $\mathbf{p = .000}$
Impulsivity (N-facet)	502	2.90 (.46)	$t(1, 500) = 2.02$, $\mathbf{p = .044}$
Angry/hostility (N-facet)	502	2.45 (.53)	$t(1, 500) = -.79$, $p = .431$
Assertiveness (E-facet)	502	3.02 (.55)	$t(1, 500) = -2.25$, $\mathbf{p = .025}$
Excitement seeking (E-facet)	502	3.54 (.51)	$t(1, 500) = -4.85$, $\mathbf{p = .000}$
Self-discipline (C-facet)	502	3.26 (.54)	$t(1, 500) = .02$, $p = .987$
Awakening (CM1)	417	7.82 (4.22)	$t(1, 412) = 1.98$, $\mathbf{p = .049}$
Awakening + 30 min (CM2)	417	13.34 (5.55)	$t(1, 412) = 2.84$, $\mathbf{p = .005}$
Preexperiments (CE1)	504	5.07 (4.33)	$t(1, 502) = -.89$, $p = .889$
Prestress task (CE2)	506	3.67 (4.02)	$t(1, 504) = -.81$, $p = .421$
During stress task (CE3)	513	4.83 (4.16)	$t(1, 511) = -2.77$, $\mathbf{p = .006}$
Poststress task (CE4)	506	4.72 (4.25)	$t(1, 504) = -1.08$, $p = .280$
20-min poststress task (CE5)	505	3.93 (3.57)	$t(1, 503) = -.15$, $p = .879$
Basal (*Z*-score CM1)	417	0 (1)	$t(1, 412) = 1.98$, $\mathbf{p = .049}$
CAR (CM2 – CM1)	403	0 (1)	$t(1, 398) = 1.24$, $p = .216$
Anticipation (*Z*-score CE1)	504	0 (1)	$t(1, 502) = -.89$, $p = .466$
Reactivity (SR CE3 on CE2)	504	0 (1)	$t(1, 502) = -3.52$, $\mathbf{p = .000}$
Recovery (SR CE5 on CE3)	505	0 (1)	$t(1, 503) = 3.05$, $\mathbf{p = .002}$
STAUCg (*Z*-score)	352	0 (1)	$t(1, 350) = .01$, $p = .998$

Note. N = Neuroticism; E = Extraversion; C = Conscientiousness; CM = cortisol concentration in the morning; CE = experimental cortisol concentration; CAR = cortisol awakening response; SR = standardized residuals; STAUCg = stress task area under the curve with respect to the ground. Basal and anticipation are the standardized values of CM1 and CE1. All cortisol measures are in nmol/l. Boldfaced *p*-values are significant at $p < .05$.

Table 2 Correlations Between Single Cortisol Measures and Personality Traits

	Vulnerability	Impulsiveness	Angry/Hostility	Assertiveness	Excitement Seeking	Self-Discipline
CM1	**.237**	**.173**	.053	**−.135**	−.029	**−.214**
CM2	**.148**	.066	.032	−.088	−.029	**−.196**
CE1	−.047	−.051	.053	.052	−.016	.015
CE2	−.086	−.064	.016	.082	.039	.064
CE3	−.062	−.006	−.044	−.006	.058	.023
CE4	−.012	−.011	−.024	−.042	.006	.000
CE5	−.009	.059	.002	−.007	.001	−.034

Note. CM = cortisol concentration in the morning; CE = experimental cortisol concentration. Boldfaced values are significant at $p < .05$.

Table 3 Partial Correlation Analyses

	Vulnerability	Impulsiveness	Angry/Hostility	Assertiveness	Excitement Seeking	Self-Discipline
Basal	**.206**	**.174**	.072	**−.119**	.022	**−.226**
CAR	.023	−.012	.034	.006	−.032	−.109
Anticipation	−.002	−.036	.060	.029	−.050	.018
Reactivity	.035	.054	−.044	−.072	.019	.019
Recovery	.022	.074	.055	.004	−.042	−.070
STAUCg	.015	.016	−.011	−.035	.004	.015

Note. CAR = cortisol awakening response; STAUCg = stress task area under the curve with respect to the ground. Results reflect partial correlations. Smoking, experiment time, and sex were included in all analyses as covariates. Boldfaced *p*-values are significant at $p < .05$.

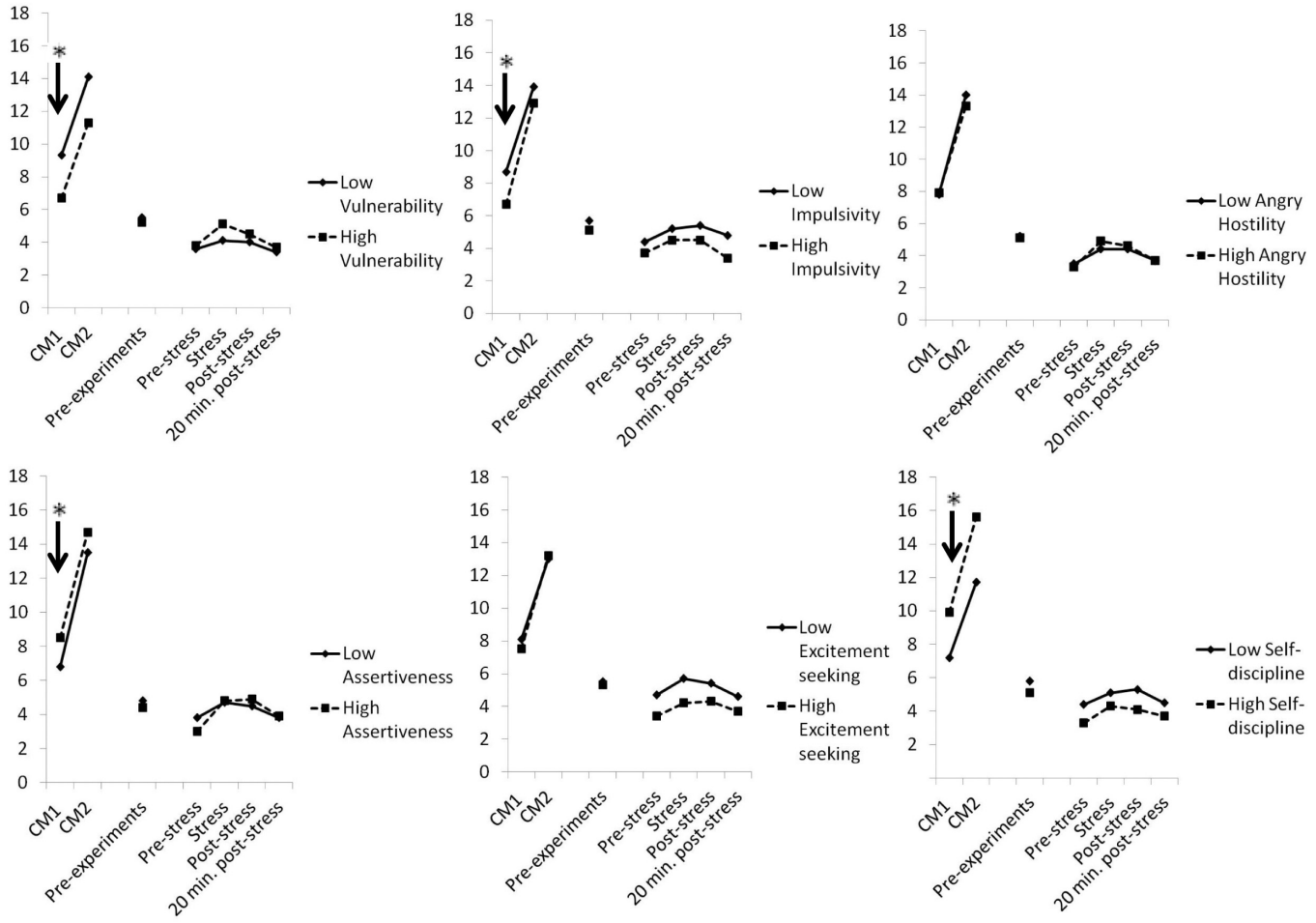

Figure 1 Graphic representation of the unadjusted associations between the various cortisol measures and the six personality facets. Low on a personality facet was defined as a score of ≤ 1SD below the mean of the trait, high as ≥ 1SD above the mean. Significant associations represent results from partial correlation analyses, adjusted for sex, experiment time, and habitual smoking and are indicated with asterisks (*). All cortisol values are in nmol/l. CM = cortisol concentration in the morning.

details). Basal cortisol was significantly related to four out of six personality facets. Adolescents with higher levels of basal cortisol were higher on both impulsivity and vulnerability but lower on assertiveness and self-discipline (see Figure 1). No significant associations were found between basal cortisol and either angry/hostility and excitement seeking. CAR, anticipation, reactivity, recovery, and STAUCg were not related to any of the personality facets.

Additionally, we tested whether the results hold when the CAR was operationalized as a standardized residual and reactivity and recovery were operationalized as change scores. Partial correlations showed that associations with personality

traits were the same as for the original operationalizations; that is, none of the associations with temperament traits was significant.

DISCUSSION

The aim of this study was to examine whether and how various aspects of HPA-axis functioning were associated with facets of personality in a large population sample of adolescents. In line with our hypothesis, our results showed that individual differences in basal cortisol levels were related to individual differences in certain personality facets. Adolescents with high basal cortisol levels were higher on impulsivity and vulnerability, and lower on assertiveness and self-discipline. We found no association with the other cortisol measures, nor did we find an association between HPA-axis functioning and either angry/hostility or excitement seeking.

Basal Cortisol and Personality

As expected, we found that basal cortisol levels were related to several facets of personality, probably because of the more trait-like nature of basal cortisol (Bartels et al., 2003; Federenko et al., 2004; Hellhammer et al., 2007; Wüst et al., 2000). Moreover, the strength of the effects is probably an underestimation of the real associations, since previous research has suggested that basal cortisol levels fluctuate across days due to situational factors like waking time and subjective stress load for the prior and upcoming day (Hellhammer et al., 2007). In our sample, situational variability between participants was relatively small since morning cortisol measures were collected on the same day as the behavioral experiments in 95% of the adolescents, resulting in large similarity between adolescents with respect to the upcoming day. Additionally, the relatively low internal consistency of the personality facets is also likely to suppress the correlations between personality and HPA-axis functioning, resulting in an even stronger underestimation of the associations.

The theoretical basis for the association between basal cortisol levels and personality seems to be substantial, but what does the direction of the effects mean? From a meta-analysis on HPA-axis functioning and depression in children, we know that higher basal cortisol levels are related to higher levels of depression (Lopez-Duran, Kovacs, & George, 2009). We found that higher basal cortisol levels were associated with higher levels of two facets of Neuroticism: impulsivity and vulnerability. Taking into account the strong relation between Neuroticism and depression, our results seem reasonable. In addition, previous research has emphasized the adaptive value of self-discipline (e.g., Oldehinkel, Hartman, de Winter, Veenstra, & Ormel, 2004). We found that high basal cortisol levels were associated with low levels of self-discipline. Taken together, the findings on impulsivity, vulnerability, and self-discipline seem to suggest that high basal cortisol is an indication of dysfunctioning of the HPA axis, and subsequently for vulnerability to psychopathology

From our findings, it is not clear how to interpret the negative association between basal cortisol and assertiveness. The literature on Extraversion, a concept closely related to assertiveness, has provided evidence for an association with externalizing behavior problems (John, Caspi, Robins, Moffitt, & Stouthamer-Loeber, 1994). However, not only low but also high levels of basal cortisol have been related to externalizing behavior problems (Ryan, 1998). From a person-centered approach, these contradicting results might not be surprising, given the finding that high scores on Extraversion are mostly related to behavioral problems in the presence of other characteristics, such as low self-discipline (e.g., Mervielde, De Clercq, de Fruyt, & Van Leeuwen, 2005). More research is needed to improve our understanding of different mechanisms underlying the associations with respectively low and high basal cortisol.

Basal cortisol was related to most, but not all, of the personality facets in our study. For example, the Neuroticism facet angry/hostility was not related to cortisol, in contrast to the Neuroticism facets impulsivity and vulnerability, which were positively associated with basal cortisol. This finding seems in line with literature on personality facets suggesting that facets within the same domain may vary in the extent to which they are related to psychopathology. For example, although Extraversion has previously been related to externalizing problem behaviors (John et al., 1994), the Extraversion facet excitement seeking has a lower threshold for maladaptivity than warmth, which is also a facet of Extraversion as measured with the NEO-PI (Widiger & Trull, 1992). This suggests that it is important to study facets instead of, or in addition to, the broader personality traits like the Big Three or Big Five. Unfortunately, not all facets of all NEO-PI personality traits were assessed in our sample due to constraints on the total number of items in the multidisciplinary TRAILS study. Nonetheless, by including the current facets, we could differentiate between facets of the personality traits that have been consistently found to be related to psychopathology (Kotov et al., 2010).

CAR and Stress-Induced Cortisol and Personality

The absence of associations between personality and both CAR and stress-induced cortisol seem to be in line with the literature. Consistent with our study, the few studies previously performed on the CAR generally found no evidence for an association (e.g., Chan et al., 2007). Portella and colleagues (2005) reported a positive association, but they selected participants who scored extremely high or low on Neuroticism, which makes comparison with other studies difficult (Portella et al., 2005). Previous studies investigating the association between reactivity to a laboratory social stress task and several personality traits yielded inconsistent results. For example,

high levels of Neuroticism have been related both to elevated (e.g., Habra et al., 2003) and blunted (Phillips et al., 2005) cortisol responses. As was pointed out in the introduction, CAR, anticipation, activation, and recovery may not be as trait-like as basal cortisol and therefore not be as strongly related to personality traits. As is evident from Table 2, it is unlikely that the main reason these measures are not linked with personality is that all of them (except anticipation) were operationalized as change scores or as standardized residuals. None of the single-time cortisol measures were correlated with our personality facets, except CM2, which was positively related to vulnerability and negatively to self-discipline. This is probably due to the relatively high correlation with cortisol concentrations at awakening (CM1, $r = .51$). For example, more vulnerable individuals wake up with higher cortisol concentrations but show similar cortisol awakening responses (CAR), resulting in similarly higher levels of CM2. No associations were found with either impulsivity or excitement seeking, and none of the single cortisol samples collected during the social stress task was related to (one or more) personality traits. This seems to bolster the argument that basal HPA-axis activity, but not reactivity, is inherently relevant to personality.

Sex differences in personality and HPA-axis functioning, as well as in the association between personality and HPA-axis functioning, were explored. With regard to personality, our findings are well in line with previous studies (for a meta-analysis, see Roberts, Walton, & Viechtbauer, 2006). Girls were higher on vulnerability and impulsivity, both facets of Emotional Instability, whereas boys tended to be higher on assertiveness and excitement seeking, both facets of Extraversion. Concerning HPA-axis functioning, sex differences in cortisol reactivity to stress have been found to be modest, reporting slightly stronger increases in boys (e.g., see Kudielka & Kirschbaum, 2005, for a review). The results of the current study were in line with these findings. Higher cortisol levels were found in boys both prior to the stress task and during the stress task, as well as a larger reactivity. Girls showed stronger recovery after the task. However, given that HPA-axis functioning has been suggested to be very sensitive to differences in task design (Burt & Obradović, 2012), caution is needed when comparing our findings with previous literature. Finally, we investigated sex differences regarding the bivariate correlations between personality and HPA-axis functioning. No consistent sex differences were found, and therefore our main analyses were performed for boys and girls together. Previous studies have usually not reported on sex differences. This may be a result of small samples and limited power. It may also be that sex differences were not reported because associations were simply the same for boys and girls, which would be in line with our findings. Future studies using adequate sample sizes should investigate and report on this.

Compared to other studies in this field, our sample was very large. Next to the advantage of higher power is the advantage of smaller influence of outliers. Furthermore, our study is the first investigating the association between personality facets and various indices of HPA-axis activity representing different physiological functions. The direct comparison of associations with various aspects of HPA-axis functioning is novel to the literature, as well as the inclusion of anticipation and recovery. We have attempted to maximize similarity between the operationalization of our cortisol indexes and operationalizations in the literature (e.g., difference scores for CAR and standardized residuals for reactivity). Interestingly, when using other operationalizations (i.e., standardized residuals for CAR, change scores for reactivity and recovery), our findings remained the same. Therefore, it seems plausible that operationalizations other than the ones used in the current study will result in findings similar to the ones we found. It should be noted, however, that the current sample was initially selected with a slightly elevated risk (e.g., for familial psychopathology) to gain statistical power in the "high-risk range" and, subsequently, to get more information on a relatively interesting subgroup of adolescents. Consequently, although this "focus sample" still represented the whole range of problems seen in a normal population (Oldehinkel & Bouma, 2011), replication in a fully representative cohort sample is needed.

In conclusion, our study is one of the first providing evidence that basal cortisol is related to facets of the personality traits Neuroticism, Extraversion, and Conscientiousness. In line with previous studies, stress-induced cortisol was not consistently related to personality. These findings suggest that, possibly due to its more trait-like nature, basal cortisol seems to be most informative when investigating more trait-like characteristics such as personality facets.

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