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Autonomic and hypothalamic–pituitary–adrenal stress resilience: Impact of cardiac vagal tone

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ABSTRACT

Resilience refers to the ability to cope with stressful events. Variation in the activity of the stress-responsive sympatho–adrenal–medullary and hypothalamic–pituitary–adrenal axes is particularly important for adaptive stress responses and thus may give rise to individual differences in resilience. Here, we investigated whether cardiac vagal tone and adult attachment style are related to psychophysiological stress resilience by exposing a sample of healthy young men and women ($n = 68$) to a laboratory stress test while monitoring autonomic (heart rate, salivary alpha-amylase), hypothalamic–pituitary–adrenal (salivary cortisol), and psychological stress levels. Our results demonstrate that adult attachment style did not influence autonomic, hypothalamic–pituitary–adrenal, or psychological stress responses. In contrast, higher resting cardiac vagal tone was associated with stress-induced increases in cortisol. This suggests a role for sympathetic influences on heart rate regulation in hypothalamic–pituitary–adrenal stress responses, and extends previous observations of a link between vagal tone and stress resilience.

1. Introduction

Unfortunately, the incidence of stressful life events that may lead to various psychological and physical health problems is high. Most people however are resilient in the face of stressful events in that they are able to adapt and respond remarkably well to trauma, tragedy, or other sources of adversity (Bonanno, 2004; Masten, 2001). One important aspect of such resilience is the ability to psychophysiologically cope with stressful events. That is, differences in the excretion and function of the many hormones, neuropeptides, and neurotransmitters that are implicated in the neuroendocrine stress response may give rise to individual differences in stress resilience (for a recent review see Feder et al., 2009).

Activity of the stress-responsive sympatho–adrenal–medullary (SAM) and hypothalamic–pituitary–adrenal (HPA) axes following stress exposure, for example, is particularly important for adaptive stress responses. In short, when encountering a stressor the organism almost immediately responds with the activation of the sympathetic branch of the nervous system (SNS) while the parasympathetic part is simultaneously suppressed. This rapid SAM response causes the release of adrenalin and noradrenalin, which in turn produces increases in heart rate, blood pressure, and respiration frequency. Adrenalin and noradrenalin cannot readily pass the blood brain barrier and thus cannot affect brain regions directly. However, they can stimulate the vagus nerve via the locus coeruleus and the nucleus of the solitary tract, which results in increased noradrenergic tone in the brain (de Kloet et al., 2005). A second slower response is orchestrated by the HPA axis. Here, corticotropin releasing hormone (CRH) is secreted by the hypothalamus and subsequently triggers the secretion of adrenocorticotropic hormone (ACTH) by the pituitary gland. Upon reaching the adrenal glands, ACTH instigates the release of glucocorticoids (GCs; i.e., cortisol in humans and monkeys; corticosterone in rodents) by the adrenal cortex into the bloodstream. These GCs together with the sympathetic nervous system and glucagons released by the pancreas are then responsible for raising blood glucose levels, in turn producing more energy for the body to react to the stressor. A negative feedback system in which cortisol returns to the pituitary and hypothalamus to inhibit additional secretion of CRH and ACTH prevents the HPA axis from overshooting (de Kloet et al., 2005).

Despite their vital role for understanding successful adaptation to stress, only a handful of studies focused on the psychophysiological markers of resilience (Souza et al., 2007; Simeon et al., 2007). Souza et al. (2007), for example, showed that individuals with higher resting cardiac vagal tone (i.e., parasympathetic input to the heart) displayed faster cardiac recovery from stress relative to those with lower resting vagal tone (see also Porges, 1992), while Simeon et al. (2007) recently showed that secure attachment is associated with resilience. The latter, of course, is not entirely new, as research has shown that attachment in humans is critical for the ability to modulate physiological stress responses (Gunnar et al., 1996; Gunnar and Donzella, 2002; Stansbury and Gunnar, 1994).

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Moreover, attachment theory contends that securely attached individuals may adapt to stressful events more easily than insecurely attached individuals. To be precise, already during childhood people develop cognitive structures through a biologically based system that regulates the proximity between children and their parents or caregivers so as to enhance chances of survival in the face of adversity (Maunder and Hunter, 2001). In adulthood then, these cognitive structures represent the extent to which people can rely on close friends or relatives in times of distress. Individual differences in the cognitive structures – or working models – parallel people's adult attachment style (i.e., whether they are relatively securely or insecurely attached). Adult attachment style is thought to remain connected to the psychological and biological systems that regulate stress reactivity (Maunder and Hunter, 2001; Maunder et al., 2006). Thus, it is conceivable that insecure attachment leads to increased activity of the stress system and may leave people vulnerable to the detrimental effects of stress. Experimental evidence for this is provided by a recent study by Quirin et al. (2008) who found that high levels of attachment anxiety were associated with elevated – albeit small – cortisol stress responses. In contrast, Ditzen et al. (2008) observed that while being related to decreases in anxiety secure attachment in and of it self did not influence cortisol responses following stress exposure. Intriguingly, attachment has also been linked to cardiac vagal tone (Oosterman and Schuengel, 2007; Porges, 2007). However, to date no studies have looked at whether attachment and cardiac vagal tone interactively affect psychological or physiological stress responses. The current study therefore was set out to investigate whether attachment and cardiac vagal tone independently or interactively predicted psychological (i.e., subjective stress) and physiological (heart rate, salivary alpha-amylase, and cortisol) stress responses.

2. Methods

2.1. Participants

Thirty-four male and 34 female undergraduates with a mean age of 22.29 years (SD = 3.05; range: 18–30) and a normal Body Mass Index (BMI; mean = 22.28; SD = 1.80; range: 19.2–26.0) participated in the current study. Study eligibility was assessed using a structured telephone interview, with cardiovascular diseases, severe physical illnesses (e.g., fibromyalgia), hypertension, endocrine disorders, current or lifetime psychopathology, substance abuse, heavy smoking (>10 cigarettes/day) or being on any kind of medication serving as exclusion criteria. Women using oral contraceptives were also excluded from participation. To limit the effects of menstrual cycle phase on CORT stress reactivity, women were tested in the late luteal phase of their menstrual cycle (based on self-report) when CORT responses of women appear to be similar to those of men (Kirschbaum et al., 1999; Kudielka and Kirschbaum, 2005). Due to scheduling problems, 5 of the 34 women were tested in the follicular instead of the late luteal phase. Test protocols were approved by the standing ethics committee of the Faculty of Psychology and Neuroscience, Maastricht University. All participants provided informed consent and received a financial reward (25€) in return for their participation.

2.2. Stress induction

Stress was elicited using the Trier Social Stress Test (TSST; Kirschbaum et al., 1993), a psychosocial challenge test that basically consists of a preparation period, a 5 min mental arithmetic task, and a 5 min free speech in front of an audience. In keeping with our previous work (Smeets et al., 2007, 2009), the TSST was rendered even more ego-threatening by asking participants to critically describe their own personality characteristics in English (i.e., a non-native language) while standing in front of a live audience and being audio- and video-taped. Even though the TSST elicits stress that is unrelated to attachment insecurity, it was chosen primarily based on the fact that it reliably induces strong psychological, cardiac, and neuroendocrine stress responses (e.g., in terms of cortisol output, see Dickerson and Kemeny, 2004).

2.3. Cardiac vagal tone

Centrally mediated cardiac vagal tone was indexed using high-frequency heart rate variability (HF-HRV), which is associated with respiratory sinus arrhythmia (Task Force, 1996). A Polar® RS800CX portable device using a transmitter consisting of a stable polyamide case with heart rate electrodes attached to an elastic belt was fixated to the chest of the subject at the level of the lower third of the sternum. R–R intervals were recorded from the Polar system during a 10 min rest period at a sampling frequency of 1000 Hz, providing a temporal resolution of 1 ms for each R–R interval. R–R recordings were transferred to a password-protected PC under ASCII format via Polar-specific software (Polar® ProTrainer 5 software version 5.35.161). HF-HRV with the parameter for the HF band set at 0.15–0.4 Hz was derived from a 600 s R–R interval segment, with power spectral analysis using an autoregressive modeling technique serving as the indicator of parasympathetic activity. The Polar measurement and analysis system has been shown to be a valid and highly reliable way to assess short-term HF-HRV at rest (Nunan et al., 2009; Radespiel-Tröger et al., 2003).

2.4. Adult attachment style

Adult attachment style was assessed with the Experiences in Close Relationships scale (ECR; Brennan et al., 1998), a dimensional 36-item self-report instrument tapping attachment-related anxiety ($ECR_{ANXIETY}$; e.g., "I worry about being alone") and avoidance ($ECR_{AVOIDANCE}$, e.g., "I prefer not to be too close to romantic partners"). Participants were required to think about their close relationships without focusing on a specific partner and rate the appropriateness of each item on a 7-point scale (1 = disagree strongly; 7 = agree strongly). Higher scores on each subscale represent higher levels of attachment-related anxiety and avoidance (i.e., less secure attachment), respectively. The current study used a Dutch version of the ECR that has been validated elsewhere (Conradi et al., 2006). Note that in order to control for potential influences of trait anxiety on the ECR anxiety dimension, the State-Trait Anxiety Inventory-Trait version (STAI-T; Spielberger et al., 1970) was administered. This scale comprises 20 items (e.g., "I lack self-confidence") rated on 4-point scales (1 = almost never; 4 = almost always) and that measure trait anxiety.

2.5. Autonomic, hypothalamic–pituitary–adrenal, and psychological stress responses

2.5.1. Heart rate (HR)

The Polar® RS800CX was used to continuously record HR in real-time and is expressed as beats per minute (bpm). Three 5 min epochs were recorded prior to the TSST (t_{-15} to t_0), three during the TSST (t_0 to t_{+15}), and three post-stress (t_{+15} to t_{+30}).

2.5.2. Salivary alpha-amylase (sAA)

sAA was measured in response to the TSST as a measure of activity of the stress-responsive SAM axis. sAA data were obtained with cotton Salivette (Sarstedt®, Etten-Leur, The Netherlands) devices over a 65 min period at five assessment points: t_{-5}, t_{+20}, t_{+30}, t_{+45} and t_{+60} min with reference to the start of the stressor. Saliva samples were stored at −40 °C immediately on collection. sAA levels were determined from the saliva samples using a commercially available kinetic reaction assay (Salimetrics, Penn State, PA). Mean intra- and inter-assay coefficients of variation of the sAA analyses are typically less than 8% and 6%, respectively.

2.5.3. Cortisol (CORT)

CORT was also sampled using the Salivette devices to evaluate the stress-responsiveness of the HPA axis. Thus, CORT samples were collected at the same reference points as sAA. CORT levels were determined by a commercially available luminescence immunoassay with high sensitivity (IBL, Hamburg, Germany). Mean intra- and inter-assay coefficients of variation are typically less than 8% and 12%, respectively.

2.5.4. Psychological stress

Psychological stress was measured at baseline and immediately after the TSST using the Negative Affect subscale of the Positive and Negative Affect Schedule, state version (PANAS; Watson et al., 1988). The PANAS is a sound psychometric tool consisting of two subscales that quantify positive affect (PA) and negative affect (NA). The NA subscale comprises 10 items for which respondents indicate on a 5-point scale (anchors: 1 = *very slightly or not at all*; 5 = *extremely*) the extent to which certain feelings and emotions apply to them. Higher scores are indicative of higher levels of experienced NA.

2.6. Procedure

Participants were tested in individual sessions run between 09 h and 12 h. To allow for controlled saliva collection participants were asked not to brush their teeth and were deprived of food, drinks, and heavy exercise at least 1 h prior to the test phase. None of the participants reported to have violated these requirements. After arrival in the laboratory, the heart rate measurement device was connected and activated. In the following 40 min, participants were asked to relax and sit still in a comfortable chair during which time they completed the ECR and STAI-T. HF-HRV was assessed in the middle of the resting interval (i.e., from t_{-25} to t_{-15}). Prior to the start of the TSST as well as immediately afterwards, participants completed the PANAS NA. As stated above, the TSST consisted of a preparation phase (t_0 to t_{+5}), a mental arithmetic test (t_{+5} to t_{+10}), and a free speech (t_{+10} to t_{+15}). During the remainder of the session participants were asked to relax and engaged in non-stressful filler tasks (e.g., reading a neutral text).