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Physiological and Emotional Stress Reactions: The Effects of Temperament and Exhaustion

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Physiological and emotional stress reactions: The effects of temperament and exhaustion

Abstract

The aim of the present study was to examine whether innate temperament and an individual’s sense of vital exhaustion were associated with emotional and physiological reactions during laboratory induced stress among 95 healthy men (n = 49) and women (n = 46) aged 22-37 years. Gray`s temperament theory was used to define behavioral inhibition system (BIS) sensitivity and behavioral approach system (BAS) sensitivity. We measured heart rate, respiratory sinus arrhythmia, and pre-ejection period during an aversive startle probe, an appetitive mental arithmetic task, an aversive reaction time task, and a speech task. Larsen and Diener’s circumplex model of affect was used to structure the self-reported affects. Results revealed that BAS sensitivity was related to heart rate reactivity and parasympathetic withdrawal during the tasks, but was unrelated to baseline levels. In addition, BAS sensitivity was generally associated with pleasant affects, with an especially large increase of *Activated pleasant affect* during the appetitive mental arithmetic task. On the other hand, BIS sensitivity was associated with unpleasant affects, with a especially great increase of *Activated unpleasant affect* during aversive tasks. BIS sensitivity was unrelated to both reactivity and baseline levels of cardiac measures. The results for feelings of exhaustion showed that the level of vital exhaustion among healthy persons is related to unpleasant state affects (other than *Unactivated unpleasant* affect) and to parasympathetic withdrawal. Temperament also modified the association of vital exhaustion with affects and physiological reactions. In addition, vital exhaustion was related to a tendency to behavioral inhibition (harm avoidance). Overall, our results suggest that temperament and sense of exhaustion are associated with physiological and emotional reactions during acute stress and should thus be taken into account in stress management.

Fysiologinen reaktiivisuus ja emootiot stressitilanteissa: tempperamentin ja uupumuksen vaikutukset

Tiivistelmä

Tutkimuksessa tarkasteltiin tempperamentin ja uupumuksen tunteen vaikutuksia fysiologisiin ja emotionaalisiin stressireaktioihin 95 terveellä naisella (*n* = 46) ja miehellä (*n* = 49), jotka olivat tutkimushetkellä 22-37 vuotiaita. Laboratoriokokeessa koehenkilöiden fysiologisia (syke, sykeperäinen parasympaattisen autonomisen hermoston toiminnan mittari ja sykeperäinen sympaattisen autonomisen hermoston toiminnan mittari) ja emotionaalisia reaktioita seurattiin voimakkaan startle-äänen, päässälaskutehtävän, reaktioaikakokeen ja puhetehtävän aikana. Tempperamenttipiirteinä käytettiin Grayn teorian mukaisesti taipumusta välttämiskäyttäytymiseen ja taipumusta lähestymiskäyttäytymiseen. Uupumuksen tunnetta mitattiin Maastricht-kyselyllä. Tulokset osoittivat, että taipumus lähestymiskäyttäytymiseen oli yhteydessä voimakkaampaan tehtävien aikaiseen sykereaktiivisuuteen, joka oli parasympaattisen hermoston kontrolloimaa. Lisäksi taipumus lähestymiskäyttäytymiseen oli yhteydessä positiivisiin emootioihin koko kokeen ajan (levot ja tehtävät). Taipumus lähestymiskäyttäytymiseen oli yhteydessä erityisen voimakkaisiin reaktioihin (sekä emotionaalisiin että fysiologisiin) positiivisia palkintoja sisältävien tehtävien aikana (päässälasku ja puhe). Sen sijaan taipumus välttämiskäyttäytymiseen ei ollut yhteydessä fysiologiaan mutta kylläkin negatiivisiin emootioihin koko kokeen ajan. Erityisen voimakkaisiin negatiivisiin emotionaalisiin reaktioihin välttämiskäyttäytyminen oli yhteydessä tehtävien aikana jotka sisälsivät negatiivisia vahvisteita (startle ja reaktioaikakoe). Myös uupumuksen tunne oli yhteydessä negatiivisiin emootioihin kokeen ja lepojen aikana. Uupumus ei kuitenkaan ollut yhteydessä matalan aktivaatiotason negatiivisiin tunteisiin kuten väsymykseen, uneliaisuuteen tai torkkuvaisuuteen vaan esimerkiksi suruun, pettymykseen, pelokkuuteen, levottomuuteen, vihaisuuteen ja suuttuneisuuteen. Tutkimus osoittaa, että synnynnäisellä tempperamentilla kuten myös uupumuksella on vaikutusta sekä fysiologisiin että emotionaalisiin reaktioihin stressitilanteissa. Nämä erot olisi hyvä huomioida sekä valistuksessa että kuntoutuksessa.

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Helsinki, August 2004

CONTENTS

LIST OF ORIGINAL PUBLICATIONS

ABBREVIATIONS

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The thesis is based on the following publications, which are referred to by Roman numerals ***I-IV***.

Study I

Heponiemi, T., Keltikangas-Järvinen, L., Puttonen, S., & Ravaja, N. (2003). BIS-BAS sensitivity and self-rated affects during experimentally induced stress. *Personality and Individual Differences* 34: 943-957.

Study II

Heponiemi, T., Keltikangas-Järvinen, L., Kettunen, J., Puttonen, S., & Ravaja, N. (2004). BIS-BAS sensitivity and cardiac autonomic stress profiles. *Psychophysiology* 41: 37-45.

Study III

Heponiemi, T., Keltikangas-Järvinen, L., Puttonen, S., & Ravaja, N. (in press). Vital exhaustion, temperament, and the circumplex model of affect during laboratory induced stress. *Cognition and Emotion*

Study IV

Keltikangas-Järvinen, L. & Heponiemi, T. (2004). Vital exhaustion, temperament, and cardiac reactivity in task-induced stress. *Biological Psychology* 65: 121-135.

ABBREVIATIONS

ACTH	Adrenocorticotrophic hormone
ANS	Autonomic nervous system
BAS	Behavioral approach system
BIS	Behavioral inhibition system
CD/ADHD	Attention-deficit/hyperactivity disorder plus conduct disorder
CHD	Coronary heart disease
CNS	Central nervous system
CRF	Corticotrophin-releasing factor
CRYF	Cardiovascular Risk in Young Finns
dZ/dt	First derivative of the pulsatile impedance signal
ECG	Electrocardiogram
EDA	Electrodermal activity
FFS	Fight/flight system
GLM	General Linear Model
HPA	Hypothalamic-pituitary-adrenocortical
HR	Heart rate
IBI	Interbeat intervals
MQ	Maastricht Questionnaire
NA	Negative affectivity
PEP	Pre-ejection period
RSA	Respiratory sinus arrhythmia
SAM	Sympathetic-adrenal-medullary
TCI	Temperament and Character Inventory

1 INTRODUCTION

1.1 The concept of stress

Stress is an ambiguous concept; it applies to many different phenomena and eludes precise definition. Stress may have very different meanings for each individual, and even scientists have widely varying definitions of it. For example, Selye (1973) defines stress as a function of elevated corticosteroid levels and uses the term to refer to the effects of any agent that threatens the homeostasis of the organism. Cannon (1935) used the term homeostasis to refer to the process of maintaining internal stability in the face of environmental change. Cannon argued that human beings can respond to deviations from normal conditions by invoking behavioral changes, thus altering metabolic and other bodily processes to reachieve optimal conditions. Selye also introduced the term general adaptation syndrome, which refers to physiological changes that are non-specific in a sense that a diverse range of stimuli, called stressors, are able to trigger the general adaptation syndrome. Selye considers stress responses as necessary for survival and hence adaptive, and he recognizes that severe, prolonged stress responses can result in tissue damage and disease. Lovallo (1997) states that stress implies a level of challenge that is severe enough to require major readjustments to meet the challenge or that is prolonged enough to alter system function. He suggests that a stress response is the compensatory reaction the body makes to the disturbance caused by the stressor. Sapolsky (1994) defines a stressor as anything that throws the body out of homeostatic balance. According to Sapolsky, even a prolonged pleasant stimulation could be stressful if it involves deviation from homeostasis. Another way of defining stress is to see it as a more chronic state that arises only when defense mechanisms are either being chronically stretched or are actually failing (Toates, 1995).

McEwen (1998) introduced the term allostasis to refer to the ability to achieve stability through change. When physiological stress systems are activated frequently in response to a lot of stress, allostatic load occurs, and the body is damaged. There are four main causes of allostatic load: (a) frequent stress, (b) lack of adaptation to a repeating stress, (c) inability to turn off the allostatic response when the stress is over, and (d) inadequate responses by some stress systems so that other systems have to compensate by increasing their activity.

According to Lazarus and Folkman's (1984) cognitive appraisal model of stress, cognitive appraisals are thought to shape emotional, physiological, and behavioral responses to potentially stressful situations. Primary appraisal reflects perceptions of the nature of risk and the potential threat that a situation presents. Secondary appraisal reflects perceptions of the resources or abilities to cope with the situation. A situation is considered as a threat when the perception of danger exceeds the perception of resources, whereas a situation is considered a challenge when the perception of danger does not exceed the perception of abilities.

Stress response can be seen, in fact, as a "whole-body" compensatory reaction to the disturbance caused by the stressor. Stress responses are meant to support maximal strength and vigilance. The effects of stress are manifest in four distinct domains: physiology, behavior, subjective experience, and cognitive functions. Physiological effects include alterations in neuroendocrine, the autonomic nervous system, and immune functions, such as heightened cardiovascular and respiratory activity, as well as changes in blood flow, digestion, and skeletal muscle tone. Behavioral effects are manifested in aggressive responses, freezing, deficits in task performance, and changes in health related behaviors, such as in smoking and in alcohol consumption. Subjective experiences include distress, dissatisfaction, anger, anxiety, alertness, and depression, among others. The cognitive manifestations of stress include alterations in memory and attention.

Changes that occur as part of stress response have negative side-effects and can cause harm if stress is prolonged or very intense. Thus, stress responses have consequences for health and well-being. For example, prolonged physiological arousal or frequent increases in arousal can cause wear and tear on arteries and coronary vessels, formation of thrombi, suppression of host resistance, and other direct biological effects (Baum & Cohen, 1998). In addition, consequences of stress, such as poorer problem-solving and task performance, disrupted social relationships, and poorer quality of life, could affect decisions involving health risks and affect health indirectly (Baum & Cohen, 1998).

1.2 Physiological reactions to stress

The brain uses two systems to regulate in challenges, the nervous system and the endocrine system. One branch of the nervous system is called the autonomic nervous system (ANS), which plays a central role in homeostatic functions of the body and the stress response. Present studies focused on cardiac control of the ANS. ANS is composed of two major subsystems, (a) the parasympathetic system, which is catabolic, energy restoring and, for example, generally slows the heart and (b) sympathetic nervous system, which is anabolic, energy expending and, for example, generally accelerates the heart. Heart rate (HR) is largely an expression of the balance of the autonomic regulation of these two systems. An increase in HR due to stress can, for instance, be determined by the simultaneous activity of cardiac sympathetic activation and reciprocal cardiac parasympathetic withdrawal. However, HR reactivity can also be derived from other than reciprocal modes of autonomic control as well, namely by coactive and independent changes of autonomic systems (Berntson, Cacioppo, & Quigley, 1991).

Parasympathetic activation promotes the digestion and absorption of food from the alimentary tract. Normal parasympathetic influences on the heart serve to promote good health, self-regulation, and calm behavioral states, and they may protect the heart and serve to dampen the sympathetic reactions to stress (Eckberg, 1980; Porges, 1992). Instead, low parasympathetic control of HR has been shown to be related to cardiovascular diseases (Tsuji et al., 1996), increased mortality (Kleiger, Miller, Bigger, & Moss, 1987), and hypertension (Singh et al., 1998). Porges (1992) has suggested that chronically low parasympathetic tone accompanied by low parasympathetic reactivity indicates a person's vulnerability to stress. In contrast, persons with high parasympathetic tone having an ability to dampen parasympathetic activity in challenging situations (i.e., capacity to react) and return to a high baseline afterwards (i.e., self-regulation) exhibit an appropriate stress response and will be less susceptible to stress. Similarly, Friedman and Thayer (1998) have suggested that a low resting parasympathetic control may be associated with ineffective emotional regulation and behavioral inflexibility. Respiratory sinus arrhythmia (RSA), a widely used index of parasympathetic activity, has been found to be an accurate noninvasive indicator of parasympathetic regulation of HR when respiration falls within the usual respiratory frequencies (e.g., Porges & Bohrer, 1990). It is often measured by quantifying the amplitude of rhythmic fluctuations in HR, which are associated with breathing frequencies.

Sympathetic activation serves in emergencies to mobilize bodily resources to cope with threats. Sympathetic activation initiates physiological changes that prepare the body for "fight or flight". As a result of activation, cardiac activity is increased and blood is diverted from the stomach and intestine to the muscles. Sympathetic activation is mediated via both direct and indirect pathways. The direct pathway comprises neurons that release noradrenaline and terminate on target organs. The indirect pathway refers to neurons that release adrenaline and noradrenaline (which are carried in the bloodstream and distributed to a variety of target organs) from the adrenal medulla. Pre-ejection period (PEP), derived from systolic time intervals, is a reliable noninvasive marker of cardiac sympathetic activity as long as variations in preload and afterload are small (e.g., Allen, Obrist, Sherwood, & Crowell, 1987; Cacioppo, Berntson et al., 1994; Cacioppo, Uchino, & Berntson, 1994).

It has been suggested that cardiovascular reactivity mediated through sympathetic activation has more relevance for disease pathogenesis than reactivity mediated through parasympathetic withdrawal (e.g., Blascovich & Katkin, 1993). For instance, endocrinological and immune functions have been shown to be more closely related to HR reactivity mediated by sympathetic reactivity than to that mediated by parasympathetic reactivity (Cacioppo, 1994; Cacioppo et al., 1995). In addition, several studies have highlighted the importance of sympathetic activation for disease susceptibility (e.g., Rozanski, Blumenthal, & Kaplan, 1999) and the pathogenesis of hypertension, for example (Greenwood, Stoker, & Mary, 1999).

1.3 Stress-induced emotional experiences

Emotion theories generally suggest that an emotion has three components: nonverbal expressions, physiological arousal, and subjective experience. The studies presented in this thesis focus on physiological arousal (discussed in the previous section) and subjective experience.

Emotions are important for human welfare. Emotional processes are identified as one possible mediator of the associations between psychosocial variables and health outcomes (Taylor & Aspinwall, 1993). For example, negative affectivity (NA) has been associated with negative health outcomes (Denollet, 1998; Denollet, Vaes, & Brutsaert, 2000). In addition, it has been found that stressors without a negative affective component do not produce the basic stress response (Baum, Davidson, Singer, & Street, 1987; Mason, 1975).

Generally, research suggests that people feel more negative when stressed; symptom reporting increases, a negative emotional tone is reported more frequently, and general mood suffers (Baum et al., 1987). In addition, anxiety and depression are common forms of affective experience in stressful settings. Lazarus (1999) has identified anger, envy, jealousy, anxiety, fright, guilt, shame, and sadness, among others, as stress emotions. Indeed, Watson and Clark, (1984) have suggested that stress reactivity can most appropriately be measured by the increase in distress that occurs as the subject moves from normal situation to a stressful situation.

Emotions can be structured in terms of basic distinct emotions, such as anger, fear, and happiness. Alternatively, a dimensional view suggests that all emotions can be located in a two (or more)-dimensional space, for example, as coordinates of valence and arousal. In other words, emotions form a structure that can be divided by two axes, one representing the valence (positive - negative) and the second representing intensity (activation). The circumplex model of affect, which was originally proposed by Schlosberg (1941, 1952), and elaborated, for example, by Russell (1980) and Larsen and Diener (1992), represents one useful way to structure affects in a two-dimensional space. Larsen and Diener suggested that the circumplex structure can be carved up into eight sections, which are called octants (Figure 1). The circumplex model implies that the similarity between affective states is a function of their distance from one another. As a result, adjacent octants should have positive correlations, orthogonal (90°) octants should be uncorrelated, and as separation approaches 180°, octants should have increasing negative correlations with one another. Substantial evidence supports this model: for example, principal-components analyses of self-reported affects, multidimensional-scaling analyses of similarity judgments of affective states, emotional ratings of environment, anticipated reactions to events, and judgments of facial expressions have suggested a circular structure (Larsen & Diener, 1992; Remington, Fabrigar, & Visser, 2000). The use of the circumplex model in present studies was reasonable because, as Larsen and Diener have stated, it suggests how affects may combine, the dynamics by which a stimulus will change one emotion into another, and a clear structure for the effects emotion will have on behavior, cognition, and physiology. In addition, Larsen and Diener suggested that circumplex of affect may allow bridges to personality.

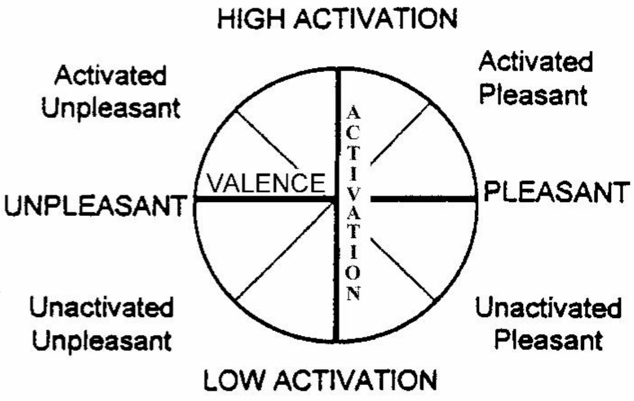

Figure 1**.** Larsen and Diener’s (1992) two-dimensional circumplex model of affect.

1.4 Inducing stress in the laboratory

Physical stressors, such as cold, heat, infection, and the like, are threats based on their physical ability to cause harm and destroy life. Psychological stressors, such as failure to achieve a highly valued goal in life, are challenges that can alter bodily functions because of their meaning to a person (Lovallo, 1997). Psychological stressors usually induce physiological responses that exceed the metabolic needs of somatic activity.

Considering psychological stressors, the nature of the task is an important determinant of whether the reaction will be positive or negative. Important aspects are the emotional valence of the task, the degree of personal control over the performance, and the degree of activity invested in the task. Financial rewards, social pride, and other rewards can highlight the appetitive nature of the task, whereas loud noise punishments, mild shocks and social punishments can emphasize the aversiveness of the task. The degree of personal control over the stressful situation may help explain whether the experience has debilitating or facilitating consequences for the individual. A considerable degree of control by the individual seems to be characteristic for stressful situations that produce positive affective responses. By contrast, situations over which an individual can exercise very little personal control seem to create negative consequences (Allen, 1985). The stressor is passive, when subjects are given no opportunity to control or perform in the situation and can thus be considered as relatively passive recipients of external stimuli. On the other hand, in active tasks subjects are required to actively engage in the performance.

Typical psychological stressors used in laboratory settings are an acoustic startle probe, a mental arithmetic task, a reaction time task, and a public speaking task, among others. Lang and his colleagues (Lang, Bradley, & Cuthbert, 1990) proposed startle reflex as a measure of emotion. A startle reflex occurs as a response to an onset of an intense stimulus, such as a loud noise, a bright light, or an electric shock. An important part of the human startle reflex is the reflexive eyeblink, which is rapid (typically within 50 ms of the stimulus onset) and almost impossible to inhibit. An acoustic (loud noise) startle probe requires passive coping with no personal control and is experienced as aversive (e.g., Cook & Turpin, 1997). Acoustic startle probes have been found to elicit, for example, HR acceleration (Turpin, Schaefer, & Boucsein, 1999).

A mental arithmetic task requires the volunteer to calculate answers to arithmetic problems without the benefit of a paper and pencil and to provide answers as a check on performance. For example, the subject is given a three-digit number and is asked to add or subtract a certain number from it repeatedly. This task is active, requires sensory rejection, and the subject has to devote significant processing resources to working memory. The characteristics of the mental arithmetic can be manipulated to change the level of difficulty and the emotional valence of the task. For example, an appetitive mental arithmetic task with a monetary reward has been demonstrated to elicit large increases in HR with concomitant large parasympathetic withdrawal, but relatively small beta-adrenergic activation (Allen & Crowell, 1989).

Reaction time task protocols can vary widely, but they usually involve a discrimination of a stimulus (for example a tone), after which subjects are supposed to respond as quickly as possible, by pressing a computer key, for example. As a punishment for a wrong answer, loud noises or mild shocks are usually used, whereas in most cases money is used as an appetitive reward. To increase the frustrativeness of the task, it can become progressively more difficult, and subjects can be misled into believing that they have control over punishments. However, control progressively declines so that everybody receives the same amount of punishment irrespective of the performance. Reaction time tasks require sensory intake. Aversive reaction time tasks have been shown to elicit mainly beta-adrenergically mediated low or moderate HR increase; (Allen & Crowell, 1989; Langer et al., 1985; Sherwood, Allen, Obrist, & Langer, 1986).

Public speaking tasks usually involve a preparation time during which subjects plan their speech over the topic they have been given and a delivery period. To enhance the degree of involvement, the speech can be videotaped, evaluated, and presented in front of an audience. The speech task offers social awards and threats, but money awards can also be offered. It usually elicits high HR reactivity, which appears to be subserved by both sympathetic activation and parasympathetic withdrawal (Burleson et al., 1998; Cacioppo, 1994; Cacioppo, Uchino et al., 1994).

1.5 Individual differences in reactions to stress

Individual differences are all-important in the study of stress; a great amount of variation exists in stress responses and in the consequences that stress has for different individuals. Even though the nature of the stressor is an important determinant of the outcome, the sole stimulus tells us very little about the subjective reaction of the person to whom the stimulus is applied. Identical stimuli may be evaluated as anxiety-provoking, neutral, or even pleasant by different persons. The same situation can evoke different responses interindividually (between-subjects), when there are differences between individuals experiencing the same stressful situation. The differences can also be intraindividual (within-subject), when the response or behavior of an individual varies across different situations. Of course, there are stimuli that are almost universally found to produce stress in most people. An important part of the variety is probably derived from differences in temperament. Additionally, other factors affect on brain structure and physiology as well. For example, experiences early in life (e.g., gentle handling or maternal separation) are associated with alterations in neuroendocrine responses to stress in adulthood (Steptoe, 2000). Childhood trauma and abuse can also sensitize an individual to subsequent stress (Steptoe, 2000). In addition, an individual’s appraisal of the stress situation is an important source of variety.

1.5.1 The role of temperament

One important source of variety in stress reactions is temperament. Temperament takes part in regulating the relationship between a person and his/her external world (Strelau, 1996). For instance, temperament is considered to be a moderator of what one identifies as a stressor, a state of stress, efforts to cope with stress, and the psychophysiological costs of the states of stress (Strelau, 1996). Gilboa and Revelle (1994) have stated that the structure of an individual’s response to stressful events is to some extent a consistent and coherent feature of temperament. Temperament arises from our genetic endowment. Rothbart and Derryberry (1981) have defined temperament as individual differences in reactivity and self-regulation, which are assumed to have a constitutional basis. Thomas and Chess (1977) defined temperament as the "how" of behavior.

1.5.1.1 Gray´s temperament model

Gray's (1982, 1991) temperament theory has a strong basis in physiology, as he explains the basic temperamental dimensions in terms of biologically based constructs. Gray's temperament model assumes the existence of three fundamental systems with independent neurobiological mechanisms in the mammalian central nervous system (CNS): the behavioral inhibition system (BIS), the behavioral approach system (BAS), and the fight/flight system (FFS). FFS is omitted in the present studies because it is a lot less examined and discussed in temperament context than the BIS and BAS. Gray has proposed that the individual differences in the functioning of these systems and their interaction underlie differences in human temperament.

The BIS is activated primarily by aversive stimuli (punishment, non-reward) causing behavioral inhibition, an increase in arousal and attention levels, and negative affective experiences. In addition, the BIS is the proposed causal basis of trait anxiety. Gray has proposed that the BIS comprises the septohippocampal system, its monoaminergic afferents from the brainstem, and its cortical projection in the frontal lobe. Fowles (1980) has suggested that the activation of the BIS is associated with increased electrodermal activity (EDA). Recent revision of the original theory suggests that the BIS does not mediate reaction to aversive reaction per se , but is responsible for resolving approach-avoidance conflict (Gray & McNaughton, 2000). The BAS is activated primarily by appetitive stimuli (reward, termination of punishment) causing approach behavior or activation and positive affective experiences. In addition, the BAS is the proposed causal basis of trait impulsivity. Gray proposed that the neural basis of the BAS is activity in the mesolimbic dopamine system focused on the nucleus accumbens. Fowles has suggested that the activation of the BAS is associated with increased HR. In Gray and McNaughton’s (2000) revised theory, BAS mediates reactions to both conditioned and unconditioned (added) appetitive stimuli. There are individual differences in the sensitivity or strength of these systems. Thus, some people are prone to react to incentives and to have positive emotional reactions (BAS sensitive individuals), whereas others are fixed on threats or dangers in the environment and to negative emotional reactions (BIS sensitive individuals).

Gray's theory is based on physiological evidence derived mainly from animal studies and lesion research. The theory has been supported by, for instance, procedural learning studies (Corr, Pickering, & Gray, 1997), computerized go/no-go tasks (Gomez & McLaren, 1997; Hagopian & Ollendick, 1994), and EEG-studies (De Pascalis, Fiore, & Sparita, 1996; Harmon-Jones & Allen, 1997; Sutton & Davidson, 1997), but conflicting findings have also been reported (for a review see Matthews & Gilliland, 1999). Corr (2001) suggested that these inconsistencies might be partially explained by, for example, the imprecise operational definition of reinforcement, diversity of psychometric measurements of BIS/BAS measures, and incomplete characterization of BIS/BAS effects. Corr (2002) has also emphasized the importance of comparing actual reinforcement with expected reinforcement. That is, only actual reward/punishment equal to, or greater than, expected reward/punishment serves as an adequate input to the BAS/BIS.

In terms of emotions, recent evidence supports the connection between the BIS and negative affects, and the BAS and positive affects. Gable, Reis, and Elliot (2000) found that BIS sensitive persons reported more negative affects and BAS sensitive persons more positive affects in everyday life when measured with diaries. Furthermore, the BIS also had a moderator effect, that is, persons with a sensitive BIS experienced more negative affects after negative life events than persons with less sensitive BIS. In addition, BIS sensitivity has been found to correlate positively with negative affect and BAS sensitivity positively with positive affect when measured with questionnaires asking how participants generally felt (Heubeck, Wilkinson, & Cologon, 1998; Jorm et al., 1999).

In laboratory settings the BIS scores predicted negative emotions, whereas the BAS scale predicted positive emotions when participants viewed emotional public service announcements (Dillard & Peck, 2001). Also, BAS sensitivity predicted happiness to cues of impending reward (a chance for students to earn extra experiment points), whereas BIS sensitivity predicted the level of nervousness in response to impending punishment (ice water; Carver & White, 1994).

In terms of physiology, significant increases in heart rate have been found when the BAS has been activated by reward or active avoidance cues (Arnett & Newman, 2000; Tranel, Fisher, & Fowles, 1982), although some studies have not found similar results (Gomez & McLaren, 1997; Sosnowski, Nurzynska, & Polec, 1991). Furthermore, Knyazev, Slobodskaya and Wilson (2002) have found that BAS sensitivity scores were associated with lower baseline RSA and, unexpectedly, lower HR reactivity during a mental arithmetic test. In addition, a socially relevant stimulus (talking facial image) has been found to elicit greater RSA withdrawal among high BAS individuals than among low BAS individuals (Ravaja, 2004). Beauchaine (2001) has, in turn, suggested that both the BIS and the BAS are mediated peripherally by the sympathetic nervous system.

Gray's constructs can be applied to a wide range of traits, affective disorders, and psychopathology. To date, only a few studies have been done on the relationship between cardiac autonomic activity and direct measures of BIS and BAS sensitivity. However, some research has been done on cardiac reactions and constructs closely linked to the BIS and BAS. According to Gray (1982, 1991), anxiety is directly related to high BIS sensitivity, and anxiety has also been associated with low resting cardiac parasympathetic tone (Thayer, Friedman, & Borkovec, 1996; Watkins, Grossman, Krishnan, & Sherwood, 1998). Furthermore, depression has been suggested to be characterized by low BAS and high BIS activity (Fowles, 1988; Kasch, Rottenberg, Arnow, & Gotlib, 2002). Decreased parasympathetic activity and increased sympathetic activity have been found in depressed subjects during rest and a speech task (Light, Kothandapani, & Allen, 1998; Yeragani et al., 2002).

1.5.1.2 Cloninger´s temperament model

Cloninger´s (1987) theory of temperament originally assumed three independent dimensions of temperament with specific central nervous system neurotransmitter systems: novelty seeking, harm avoidance, and reward dependence. Later Cloninger and his colleagues (Cloninger, Svrakic, & Przybeck, 1993) added persistence, which was originally a component of reward dependence, to this model. Novelty seeking, which has been linked to dopaminergic activity, is a tendency to respond strongly to novelty and to actively avoid monotony and potential punishment. Harm avoidance is a tendency to react intensely to aversive stimuli leading to inhibition of behavior; it is linked to serotonergic activity. Reward dependence, which is related to norephinephrine activity, is a tendency to maintain behavior that has previously been associated with reward, including a dependence on social pride and approval of others. Persistence reflects a tendency towards perfectionism and perseverance despite frustration and fatigue.

Cloninger has suggested that individuals high in novelty seeking tend to be exploratory, enthusiastic, easily bored, and impulsive, whereas individuals high in reward dependence tend to be eager to please and help others, sentimental, and sensitive to social cues. Individuals high in harm avoidance tend to be tense, nervous, negativistic and fearful. In addition, Cloninger and his co-workers (Svrakic, Svrakic, & Cloninger, 1996) have stated that one’s emotional state depends on the interaction of the temperament and the valence of the stimulus. For example, they have suggested that harm avoidance is associated with anxiety when the emotional experience is positive and with depression when the experience is negative. Reward dependence they associated with affection when the emotional experience is positive and with disgust when the experience is negative. Novelty seeking they associated with euphoria when the emotional experience is positive and with anger when the experience is negative. Persistence they associated with enthusiasm when the emotional experience is positive and with steadfastness when the experience is negative. In previous studies, harm avoidance has been found to be related to depression and negative emotions, whereas the results of studies on the relationship between other temperament dimensions and emotions have not been consistent (Chien & Dunner, 1996; Cloninger, Bayon, & Svrakic, 1998; Krebs, Weyers, & Janke, 1998; Peirson & Heuchert, 2001; Svrakic, Przybeck, Whitehead, & Cloninger, 1999).

1.6 Vital exhaustion

Vital exhaustion is a state characterized by lack of energy, increased irritability, and demoralization (Appels, 1990). Vital exhaustion has remarkable health consequences. It has been shown to be a risk factor for myocardial infarction (MI; Appels & Mulder, 1988) and to predict the onset and progress of coronary heart disease (CHD; Appels, 1997). Exhaustion has also been related to reduced fibrinolytic capacity (Räikkonen, Lassila, Keltikangas-Järvinen, & Hautanen, 1996) and HPA axis hypoactivity, that is, a decreased capacity to cope with stress (Keltikangas-Järvinen, Räikkonen, Hautanen, & Adlercreutz, 1996; Nicolson & van Diest, 2000).

Typically, vital exhaustion has been seen as a consequence of prolonged stress resulting from environmental overload. Indeed, long-term overtime work, family conflicts, and financial problems have been found to predict exhaustion (Appels, 1989). It has been shown that vital exhaustion is related to personality type D (Pedersen & Middel, 2001), which is defined as a tendency towards negative affectivity and a tendency to inhibit the expression of this affect in social interplay. Also, fatigue (construct closely related to exhaustion) has been found to be related to negative affect (Denollet, 1993). In addition, exhaustion has been found to correlate with depression (Kristenson et al., 1998; Wojciechowski, Strik, Falger, Lousberg, & Honig, 2000).

1.7 Aims of the present studies

The main aim of the present series of studies was to examine whether innate temperament (sensitivity to reward or punishment) and an individual’s sense of vital exhaustion are associated with emotional and physiological reactions to laboratory tasks. In addition, we wanted to examine how the nature of the task influences the above-mentioned associations by using several well-known tasks (i.e., widely documented in previous literature) with varying reinforcements. Emotions were assessed by using the circumplex model proposed by Larsen and Diener (1992;

see Figure 1). The physiological parameters used were HR, RSA and PEP. The detailed objectives and hypotheses of each paper are listed below:

Study I. Study ***I*** focused on dispositional BIS and BAS sensitivities, measured with Carver and White's (1994) BIS/BAS questionnaire, and their relations to emotions evoked by different experimental stressors in laboratory settings. Specifically, our aim was to elucidate inter-individual differences in affects between BIS and BAS sensitive persons during different stressors, and intra-individual differences among BIS or BAS sensitive persons evoked by different stressors. Two aversive tasks (the startle probe and the choice-deadline reaction time task with loud noises) and one appetitive task (the mental arithmetic task with monetary reward) were used as stressors.

We hypothesized that, generally, BIS sensitive persons would experience more unpleasant affects, whereas pleasant affects would be typical of BAS sensitive persons. In addition, we hypothesized that BIS sensitive persons would be more reactive to cues of impending punishment and therefore have more extensive increment of unpleasant affects (especially activated ones) during aversive tasks when compared with persons with less sensitive BIS. Similarly, BAS sensitive persons were expected to be more reactive to cues of reward, and therefore to have a more extensive increment of pleasant affects (especially activated ones) during an appetitive task when compared with persons with a less sensitive BAS.

Study II . Study ***II*** focused on the associations of BIS and BAS sensitivities with HR, RSA, and PEP at baseline and in response to different stressors. We used an appetitive task (the mental arithmetic task), an aversive task (the reaction time task), and a task offering social awards and threats (the public speech task). Speech was considered mainly as an appetitive task, given that (a) social interactions may be intrinsically rewarding (Aitken & Trevarthen, 1997) and (b) a monetary reward was offered

Based on previous findings with depression, we expected that high BIS sensitivity would be associated with high sympathetic baseline activity and reactivity, whereas high BAS sensitivity would be associated with low sympathetic baseline activity and reactivity. Alternatively, based on findings with anxiety and depression, we expected that high BIS sensitivity would be associated with low parasympathetic baseline tone, whereas high BAS sensitivity would be associated with high parasympathetic tone. The association of neuroticism and negative affectivity (high BIS sensitivity) with CHD (Denollet, 2000; Goebel, Peter, Mueller, & Hand, 1998), risk factors of which are sympathetic arousal and low parasympathetic tone, also supports the hypotheses above regarding the BIS. On the other hand, Beauchaine's (2001) suggestion that both the BIS and the BAS are mediated peripherally by the sympathetic nervous system would lead us to expect that high BIS and high BAS sensitivity would be associated with increased sympathetic activity. In addition, in line with Fowles (1980), we would expect that BAS sensitivity would be associated with increased HR reactivity, whereas subjects with high BIS sensitivity would exhibit pronounced sympathetic reactivity. Overall, we expected that subjects with high BIS sensitivity would be drawn to punishment signals and would exhibit greater reactions during aversive reaction time task, whereas BAS sensitive subjects would be fixed on reacting to incentives and would exhibit greater reactions during appetitive tasks. In addition, BAS sensitive subjects were expected to be especially sensitive to a socially relevant speech task, because Gray's BAS dimension is closely aligned (30º) with extraversion, the essential feature of which is the tendency to enjoy social situations (Matthews & Gilliland, 1999).

Study III. The focus of study ***III*** was on three concepts and their interactions: vital exhaustion, innate temperament, and emotional reactions to stress. This study was undertaken in order to examine the relationship between vital exhaustion and state affects evoked by the tasks and the moderating effect of Cloninger´s temperament dimensions (as measured by the Temperament and Character Inventory; TCI) on this relationship. The stressors used were the startle probe, the mental arithmetic task, and the reaction time task.

We hypothesized that vital exhaustion would be associated with state affects from the unpleasant octants and inversely associated with *Activated pleasant affect*. Especially strong associations with *Unactivated unpleasant affect* (inasmuch as fatigue is a typical characteristic of exhaustion) and with *Activated unpleasant affect* (anger; increased irritability being a typical characteristic of exhaustion) were expected. In addition, we expected that Cloninger´s temperament dimensions would modify the association between vital exhaustion and affects. Especially harm avoidance and/or persistence were expected to strengthen the relationship between exhaustion and affects from the unpleasant octants. Based on previous literature, no specific a priori hypotheses regarding reward dependence and novelty seeking were posed. In addition, we expected that the association between vital exhaustion and affects from unpleasant octants would be especially apparent during the aversive tasks.

Study IV. The aim of the study ***IV*** was to determine whether there is an association between vital exhaustion and cardiac autonomic (HR, RSA, and PEP) baseline activity or reactivity during a task-induced stress. Additional aims of this study were to determine whether Cloninger´s temperament dimensions modify this association and to examine the role of the different tasks. The tasks used were the mental arithmetic task, the reaction time task, and the speech task. It was hypothesized that vital exhaustion impairs one’s ability to cope physiologically with acute stress.

2 METHODS

2.1 Subjects

The subjects were 95 healthy men (*n* = 49) and women (*n* = 46) aged 22-37 years, who were participating in the ongoing prospective epidemiological Cardiovascular Risk in Young Finns (CRYF) study (Åkerblom et al., 1991). Since 1980, the CRYF study has been monitoring the development of risk factors for CHD at intervals of 3 or 5 years. The subjects of the CRYF study, a total of 3,596 healthy Finnish children, adolescents and young adults, were a randomly selected sample of 360 rural and 360 urban girls and boys in the age cohorts of 3, 6, 9, 12, 15, and 18 years at baseline in 1980. The design of the study and the sample have been described previously (Åkerblom et al., 1991). The present subjects are a sample from those subjects who participated in the 5th follow-up of the CRYF study (in 1997) and were living within a 100 km radius of Helsinki (*n* = 343). Due to missing data, technical problems, and some dropouts during the experiment, *n* varies in different papers.

2.2 Physiological Measures and data treatment (studies *II* and *IV*)

Electrocardiogram (ECG) and the first derivative of the pulsatile impedance signal (dZ/dt) were measured continuously during the experiment with a Minnesota Impedance Cardiograph Model 304B (Surcom Inc., Minneapolis, MN). A tetrapolar aluminum/mylar tape electrode configuration was used, with four electrodes completely encircling the body, following guidelines set by Sherwood et al. (1990). ECG and dZ/dt signals were sampled continuously at the rate of 500 Hz, digitized with a 12-bit 8-channel A/D converter, and stored on the hard disk of a PC microcomputer for later analysis. On-line data reduction was performed with custom-programmed Labview data acquisition software (National Instruments Co., Austin, TX).

Cardiac interbeat intervals (IBIs), in ms, were determined from the ECG signal. Deviant IBI values were identified using a 20% change from the previous IBI as a criterion. If needed, they were corrected following the guidelines of Porges and Byrne (1992). The beat-to-beat IBI data were transformed to equidistant IBI time series with 200 ms intervals using the weighted-average interpolation method of Cheung and Porges (1977). To conduct a time series analysis, IBI series were divided into separate 60-s blocks. The mean and trend were removed from each IBI segment to exclude long-term changes in the time series. RSA was computed separately for each data segment. The total variance (in ms^2) within the respiratory range (0.12 to 0.40 Hz) was summed in order to index RSA (see Berntson et al., 1997; Grossman, van Beek, & Wientjes, 1990). RSA was logarithm-transformed to reduce positive skewness. The impedance data were ensemble averaged within 60-s blocks. The Q wave and the B-point were determinated by careful visual examination with the aid of a self-programmed computer program similar to that described by Kelsey and Guethlein (1990). Pre-ejection period (PEP), in ms, was calculated as the interval between the Q wave of the ECG and the B-point of the dZ/dt waveform. In addition, HR, in bpm, was computed for each subject in 60-s intervals from the mean IBI.

One-minute means for baseline HR, RSA, and PEP were averaged across minutes 6, 7, and 8 during B1 and B2. Task HR, RSA, and PEP data were averaged across the first 3 min of each task. Data were analyzed from the speech delivery that was presented first, because it elicited the largest physiological reactions regardless of the topic of the scenario. Only the first 3 minutes of each task were used, because several studies have shown that cardiac reactivity peaks early when novelty and uncertainty are greatest and then declines with continuous exposure (e.g., Kelsey et al., 1999). Change (Δ) scores were computed by subtracting the initial baseline average value from each average task value.

2.3 Psychological Measures

2.3.1 BIS and BAS sensitivity (studies *I*, *II*)

The BIS and BAS sensitivities of the subjects were measured using Carver and White's (1994) BIS-BAS scales based on a self-administered questionnaire with 20 items rated on 5-point Likert scales. The questionnaire was sent to the participants before the laboratory experiment in 1999 to be completed at home and returned at their laboratory visit or shortly after it by mail. The questionnaire comprised the BIS scale (seven items; e.g., "I worry about making mistakes," "I have very few fears compared to my friends" [reverse scored]) and the BAS scale, which consisted of following subscales; Reward Responsiveness (five items; e.g., "It would excite me to win a contest," "When I get something I want, I feel excited and energized"), Drive (four items; e.g., "I go out of my way to get things I want," "When I want something, I usually go all-out to get it"), and Fun Seeking (four items; e.g., "I crave excitement and new sensations," "I often act on the spur of the moment"). Reliabilities of the scales, as assessed by Cronbach`s α, were .82 and .83 for the BIS and BAS, respectively.

The internal consistency of the BIS scale has been reported to be 0.74. Internal consistencies of Reward Responsiveness, Drive, and Fun Seeking subscales have been reported to be 0.73, 0.76, and 0.66, respectively (Carver & White, 1994). In regard to validity, the BIS scale has been found to predict level of nervousness in response to impending punishment, and the BAS scale has been found to predict happiness in response to an impending reward (Carver & White, 1994). Jorm and his colleagues (Jorm et al., 1999) have evaluated the psychometric properties of the BIS/BAS scales and concluded that they are valid and practical measures of the BIS and BAS.

2.3.2 Cloninger's Temperament (studies *III* and *IV*)

Cloninger´s temperament was measured by the TCI (Cloninger, 1987; Cloninger et al., 1993), a 240-item, self-administered questionnaire for the assessment of four temperament (reward dependence, harm avoidance, novelty seeking and persistence) and three character dimensions. Only temperament dimensions were used in the present study. Instead of using the original true-false response format, each of the items was rated on a 5-point scale, ranging from 1 (*not true for me at all*) to 5 (*true for me*). The modification of the response format increases the number of response options, permitting greater latitude and finer distinctions by the respondent. This has frequently resulted in higher item validity and higher item reliability in other personality inventory applications (Comrey & Montag, 1982). The inventory was sent to the participants in the context of the fifth follow-up in 1997 to be completed at home and returned by mail.

In Cloninger´s (Cloninger et al., 1993) original study, Cronbach´s alpha reliabilities were 0.78, 0.87, 0.76, and 0.65 for novelty seeking, harm avoidance, reward dependence, and persistence, respectively. In addition, the content, construct, and predictive validity as well as reliabilities (i.e., 0.85, 0.87, 0.76, and 0.65, respectively) of the TCI scales in a Finnish sample have previously been shown to be acceptably high (Puttonen, 1998).

2.3.3 Vital exhaustion (studies *III* and *IV*)

Vital exhaustion, a state characterized by excessive fatigue, irritability, and demoralization was assessed with the Maastricht Questionnaire (MQ), a 21-item checklist of signs and symptoms of exhaustion (Appels, Höppener, & Mulder, 1987). Cronbach´s alpha was 0.91, indicating good reliability. Instead of the original true-false response format, each of the items was rated on a 5-point scale, ranging from 1 (*never true for me*) to 5 (*always true for me*). This questionnaire was sent to the participants before the present laboratory experiment in 1999 to be completed at home and returned at their laboratory visit or shortly thereafter by mail.

2.3.4 State affects *(*studie*s I* and *III)*

Before and after the experiment, the subjects were asked to describe how they felt at that moment, using a certain list of adjectives (circumplex model). In addition, after three tasks (a startle probe, a mental arithmetic task, and a reaction time task) they were asked to describe how they felt during the task using the same list. All items were rated using a category-ratio scale (CR-10) developed by Borg (1982) to allow maximum precision in the between-individual comparison of the intensity of perception and experience. The range of the scale varied from 0 (*nothing at all*) to 11 (*more than ever before*).

The adjectives were chosen to represent the eight octants of the affective circumplex presented by Larsen and Diener (1992). In this model, affects form a circular structure that can be divided by two axes, that is, the valence (pleasant - unpleasant) of an affect and the intensity (activation) of an affect. Figure 1 shows the labeling of the eight octants. Three- or 4-item scales (means) were formed as follows: (a) *High activation*: aroused, intense, quiet (reverse scored), and inert (reverse scored; α = .69; a separate low activation scale was not formed; kiihtynyt, kiihkeä, hiljentynyt, ja veltto in Finnish); (b) *Activated pleasant affect*: vigorous, peppy, and lively (α = .92; tarmokas, energinen ja pirteä); (c) *Pleasant affect*: happy, satisfied, and delighted (α = .86; onnellinen, tyytyväinen ja riemukas); (d) *Unactivated pleasant affect*: at rest, serene, and calm (α = .92; levollinen, rauhallinen ja tyyni); (e) *Unactivated unpleasant affect*: dull, tired, drowsy, and sleepy (α = .87, tylsistynyt, torkkuva, väsynyt ja unelias); (f) *Unpleasant affect*: sad, disappointed, depressed, and gloomy (α = .90;surullinen, pettynyt, masentunut ja synkkä); and (g) *Activated unpleasant affect characterized by low dominance*: anxious, fearful, uneasy, and tense (α = .91; ahdistunut, pelokas ja levoton); and (h) *Activated unpleasant affect characterized by high dominance*: annoyed, angry, aggressive and irritated (α = .94; suuttunut, vihainen ja aggressiivinen).

2.4 Procedure

Each subject underwent a standardized computer-controlled experimental session of about 180 min. The procedure started at the same time of the day (9:00 a.m.) for all subjects, preceded by similar instructions concerning a light breakfast, smoking, etc. The experiment was carried out in a room equipped with a computer with a large screen for stimulus presentation, as well as with a video camera for monitoring the subject. Subjects were seated in an upholstered chair during all procedures. An initial 10-min resting period preceded a series of 5 tasks, each of which was followed by a resting period. However, in the present studies results considering emotion evoking picture viewing were not included. The tasks were presented in the following order: (a) emotion-evoking picture viewing, which was followed by a resting period of 5 min, (b) an acoustic startle probe, which was followed by a resting period of 5 min, (c) a mental arithmetic task, which was followed by a resting period of 8 min, (d) a choice-deadline reaction time task, which was followed by a resting period of 8 min, and (e) a speech task, which was followed by a last resting period of 10 min.

The startle probe. Subjects were presented three trials of intense auditory stimulation in the form of a distorted sound of 400 Hz frequency, 109 dB intensity, 0.5 s duration, and a virtually instantaneous risetime. The inter-stimulus interval was 110 s, and the task ended 100 s after the third sound. The startle is an aversive/defensive task (e.g., Cook & Turpin, 1997).

The mental arithmetic task. During the mental arithmetic task, the subjects were asked to perform continuously six 1-minute serial subtraction problems adjusted for individual differences in mathematical skills (see Cacioppo et al., 1995). The minuend was 297, 688, 955, 593, 1200, and 1741 for minutes 1, 2, 3, 4, 5, and 6, respectively. The subtrahend in minute 1 was 3. To maintain maximal task involvement and moderate task difficulty (i.e., approximately 10 correct answers/minute), the subtrahend specified for each subsequent minute was contingent on the subject's performance during the preceding minute (the subtrahends specified as a function of prior performance can be found in Cacioppo et al., 1995). The minuend and the subtrahends were presented on the computer screen, and subjects gave their answers using the keyboard. The subject was told that the three best subjects would be awarded a prize of $40, which made mental arithmetic mainly an appetitive task requiring sensory rejection (e.g., Turner, 1994).

The reaction time task. The reaction time task was a 2-choice tone discrimination task. During the task, three increasingly difficult 3-min blocks of 10 trials were presented to each subject. Each trial included a stimulus presentation, during which a 1000 Hz or 2000 Hz tone was presented through headphones. This was followed by a response period with a deadline, during which the subject was to push one of two buttons according to which tone was presented. If the response was incorrect or too slow, an unpleasant distorted sound (400 Hz, 100 dB, instantaneous risetime, and 0.5 s duration) was presented. Finally, a feedback period was included, during which performance feedback for that trial as well as the percentage of correct responses up to that point in the test were displayed on the screen. The reaction time deadline was altered to correspond to the subject's own reaction time. The deadline was equal to the mean response time of the last three trials multiplied by a constant factor of 1.15, 1.00, and 0.85 for the first, second, and third blocks, respectively. Thus, the blocks became increasingly difficult. This is a typical aversive reaction time task in an avoidance paradigm and it requires sensory intake (e.g., Turner, 1994).

The speech task. The speech task involved three scenarios in which the subject was asked to construct and deliver a 3-min public speech after a 3-min silent preparation period. Two experimenters (one male and one female) were sitting in the room during the task as an audience and the speech was videotaped. The subjects were told that the speech would be evaluated later and that the best-rated speeches would be awarded a prize of $40. Three scenarios were presented in a counterbalanced order: (a) a presentation based on a *Reader`s Digest* article about the need for sleep (high in informational content but lacking emotional content); (b) the subject's own reasoned opinion about homosexuals' rights to marry and adopt children (at that time a much discussed topic in the media); and (c) a speech in which the subjects were to defend themselves in a hypothetical scenario in which they were wrongly accused of shoplifting. Similar scenarios have previously been used by al`Absi et al. (1997), among others.

2.5 Statistical Analyses

Study I. The data were analyzed by the General Linear Model (GLM) Repeated measures procedure in SPSS, with the categorical independent variable (i.e., gender) as the between subjects factor and continuous independent variables (i.e., BIS and BAS scores) as covariates. BIS and BAS scores were not dichotomized (also in study ***II***), which is warranted for several reasons: (a) these variables are by their nature continuous variables, and, when dichotomizing them, arbitrary cutoff-points are used, and (b) a considerable amount of information is lost when dichotomizing a continuous variable. Analyses of each affect scale (a total of seven) included one within-subject factor, i.e., task (5 levels: initial baseline, the startle probe, the mental arithmetic task, the reaction time task, and last baseline). We specified a custom model that initially contained (a) main effects of gender, BIS, and BAS; (b) all possible 2-way interactions; and (c) one 3-way interaction (Gender x BIS x BAS). We then deleted all nonsignificant interactions and main effects that were not included in a significant higher-order interaction to develop a final model. Multivariate analyses were used for the repeated measures data. To compare the appropriate categories of the task within-subject factor, we created special contrasts, i.e., (a) initial baseline and last baseline vs. the startle probe, the mental arithmetic task, and the reaction time task (bases vs. tasks); (b) initial baseline vs. last baseline; (c) the startle probe vs. the mental arithmetic task; (d) the reaction time task vs. the mental arithmetic task; and (e) the startle probe vs. the reaction time task. Temperament variables were centered to reduce possible multicollinearity among them. In the graphs (also in study ***II***), given that the BIS and BAS variables were continuous, the high BAS and low BAS subjects are abstractions. Graphs for subjects receiving low (1 *SD* below the mean) and high (1 *SD* above the mean) BAS scores were derived from the GLM equation. This method to graphically present an effect (involving continuous variables) has been recommended by several authors (e.g., Aiken & West, 1991).

Study II. GLM Repeated Measures analyses were performed for each physiological variable (delta scores), with gender as the between-subjects factor and with the continuous independent variables (i.e., BIS, BAS, and age) as covariates. Age was included as a covariate in these analyses because it tended to correlate with physiological change scores. Analyses included one within-subjects factor, i.e., task (3 levels: the mental arithmetic task, the reaction time task, and the speech task). In order to be able to compare the different levels of the task within-subjects factor, we used polynomial contrasts. We specified a custom model that contained (a) main effects of age, gender, the BIS score, and the BAS score; (b) 2-way interactions, i.e., Gender × BIS, Gender × BAS, and BIS × BAS. Multivariate analyses were used for the repeated measures data. In addition, analyses of variance (with the same custom model as above) were performed to analyze the initial baseline level and the last resting level of the physiological parameters. Temperament variables were centered to reduce possible multicollinearity among them.

Study III. The data were analyzed by GLM Repeated Measures procedure, with the continuous independent variables (i.e., vital exhaustion and temperament variables) as covariates. Vital exhaustion and temperament variables were centered to reduce possible multicollinearity among them. Analyses of each affect octant included one within-subject factor, i.e., task (5 levels: initial baseline, the startle probe, the mental arithmetic task, the reaction time task, and last baseline). In order to be able to compare the different levels of the within-subject factor, we created special contrasts, i.e., (a) baselines vs. tasks; (b) initial baseline vs. last baseline; (c) the startle probe and the reaction time task (aversive tasks) vs. the mental arithmetic task (appetitive task); and (d) the reaction time task vs. the startle probe. Analyses were conducted according to the hypotheses to minimize the number of analyses. We evaluated the main effect of vital exhaustion on *Activated pleasant affect*, *Unactivated unpleasant affect*, *Unpleasant affect*, and *Activated unpleasant affect* (both fear/anxiety and anger). We evaluated the effects of the interaction of vital exhaustion with harm avoidance and with persistence (in separate analyses) on *Unactivated unpleasant affect*, *Unpleasant affect*, and *Activated unpleasant affect* (both fear/anxiety and anger). We examined the effects of the interaction of vital exhaustion with reward dependence and with novelty seeking (in separate analyses) on all affect octants. The probability value associated with the Greenhouse-Geisser correction (ε) procedure for repeated measures (Greenhouse & Geisser, 1959) was used to obtain a more conservative test due to possible violations of the homogeneity of variance assumption. In the graphs, given that the vital exhaustion variable was continuous, the high vital exhaustion and low vital exhaustion subjects are abstractions (see study ***I***).

Study IV. GLM Repeated measures analyses were performed for each cardiac variable (delta scores), with gender, vital exhaustion (low, high), and temperament variables (low, high) as the between subjects factors (vital exhaustion and temperament groups were based on median splits), and with continuous variables age and initial baseline level as covariates. Analyses included one within-subject factor, i.e., task (3 levels: the mental arithmetic task, the reaction time task, and the speech task). In order to be able to compare the different tasks of the within-subject factor, we created special contrasts, i.e., (a) the mental arithmetic task vs. the reaction time task, (b) the mental arithmetic task vs. the speech task, and (c) the reaction time task vs. the speech task. Analyses were conducted in two phases. First, we evaluated the pure effect of vital exhaustion with a custom model that contained (a) main effects of the covariates, gender, and vital exhaustion score, and (b) all possible 2-way interactions. In order to develop a final model, we then deleted all nonsignificant interactions and main effects (except covariates) that were not included in a significant higher-order interaction. Second, we evaluated the effects of interactions of vital exhaustion and temperament variables with the custom model that initially contained (a) main effects of the physiological baseline value, age, gender, vital exhaustion score, and temperament scores; (b) all 2-way interactions including gender and temperament variables; (c) all 2-way interactions including vital exhaustion; and (d) all 3-way interactions involving gender and vital exhaustion with temperament variables (e.g., Gender x vital exhaustion x reward dependence). In order to develop a final model, we then deleted all nonsignificant interactions and main effects (except covariates) that were not included in a significant higher-order interaction. The probability value associated with the Greenhouse-Geisser correction (ε) procedure for repeated measures (Greenhouse & Geisser, 1959) was used to obtain a more conservative test due to possible violations of the homogeneity of variance assumption. In addition, analyses of variance (with the same custom model as above, but without initial baseline as covariate) were performed to analyze the initial baseline level and last resting level of the physiological parameters.

3 RESULTS

Before presenting the results of the four studies, the mean affective and physiological reactions evoked by the different tasks are presented below. The meaning of showing these results is to clarify whether the present stressors activated expected reactions (for example, that the mental arithmetic task operated as an appetitive stimulus, whereas startle probe and the reaction time task as aversive ones).

Table 1 presents the mean affect scores during the different tasks and baselines (***I*** and ***III***). *High activation* scores were higher during the tasks than during baselines, higher during the last baseline than during the first baseline, and higher during appetitive mental arithmetic than during the aversive tasks. *Activated pleasant affect* scores were higher during the tasks than during baselines and higher during math than during the aversive tasks. *Pleasant affect* scores were highest during the baselines and lowest during startle and the reaction time task. *Unactivated pleasant affect* scores were higher during the baselines than during the tasks. *Unactivated unpleasant affect* scores were higher during the baselines than during the tasks, higher during the first baseline than during the last baseline, higher during the aversive tasks compared to mental arithmetic, and higher during startle than during the reaction time task. *Unpleasant affect* scores were higher during the tasks than during baselines and highest during the reaction time task. *Activated unpleasant affect (fear/anxiety)* scores were higher during the tasks than during baselines, higher during the first baseline than during the last baseline, and highest during startle. *Activated unpleasant affect (anger)* scores were higher during the tasks than during baselines and higher during the aversive tasks than during appetitive mental arithmetic.

Table 2 presents the mean levels and standard deviations of HR, RSA, and PEP during the different phases of the experiment (***II*** and ***IV***). HR was significantly higher during the tasks than during the rests and startle, whereas RSA and PEP were significantly lower during the tasks than during the rests and startle. During startle, in contrast to other tasks, HR decreased and RSA increased. HR increased most during speech and least during the reaction time task. Correspondingly, PEP shortened most during the speech task and least during the reaction time task. RSA decreased most during the speech task and the mental arithmetic task, and least during the reaction time task.

Table 1. The Means and Standard Deviations of Affect Octants during the Different Phases of the Experiment

	Base 1	S	MA	RT	Base 2
1. High activation	3.7 (0.9)	5.7 (1.9)	6.1 (1.2)	5.8 (1.5)	4.2 (1.3)
2. Activated pleasant	3.0 (1.8)	3.7 (2.1)	5.4 (2.1)	4.0 (2.2)	3.4 (1.9)
3. Pleasant	3.9 (1.6)	1.7 (1.7)	2.9 (2.1)	1.9 (1.6)	3.8 (2.2)
4. Unactivated pleasant	5.4 (1.8)	2.2 (1.9)	2.4 (1.8)	2.3 (1.9)	5.3 (2.4)
5. Unactivated unpleasant	3.0 (1.7)	1.8 (1.7)	0.8 (1.0)	1.3 (1.5)	2.0 (1.8)
6. Unpleasant	0.6 (0.8)	1.0 (1.5)	1.0 (1.2)	1.6 (1.8)	0.6 (1.0)
7. Activated unpleasant (fear)	1.0 (0.9)	3.2 (2.4)	1.8 (1.2)	2.0 (1.7)	0.6 (0.9)
8. Activated unpleasant (anger)	0.3 (0.6)	2.2 (2.4)	1.0 (1.4)	2.4 (2.7)	0.3 (0.6)

Note. Base 1 = initial baseline; S = the startle probe; MA = the mental arithmetic task; RT = the reaction time task; Base 2 = last baseline

Table 2. Means and Standard Deviations of Cardiac Variables during Different Phases of the Experiment

	Mean values (*SD*s in parenthesis)					
	B1	S	MA	RT	speech	B2
HR	71.7(9.5)	68.0(10.4)	84.9(16.0)	74.1(13.0)	98.2(18.6)	70.9(11.4)
RSA	2.83(0.22)	2.90(0.21)	2.65(0.27)	2.86(0.20)	2.67(0.31)	2.82(0.26)
PEP	96.6(11.1)	[a]	80.8(17.4)	85.4(15.8)	74.7(16.3)	100.8(10.2)

Note. HR = heart rate (bpm); RSA = respiratory sinus arrhythmia (log ms^2); PEP = pre-ejection period (ms); B1 = initial baseline; S = the startle probe; MA = the mental arithmetic task; RT = the reaction time task; B2 = last rest.

[a] Owing to technical problems, ΔPEP scores were not obtained from the startle.

3.1 BIS/BAS sensitivity and the Circumplex Model of affect (*I*)

The results considering BIS/BAS sensitivity and affects are summarized in Table 3 (upper part). A more detailed description of results is presented below.

High activation. BIS was positively associated with *High activation* scores, F (1, 66) = 4.40, p = .040, η^2 = .06. The Multivariate analysis showed also a significant Task x BIS interaction for *High activation*, F (4, 63) = 4.44, p = .004, η^2 = .21. Contrasts showed that BIS was associated with *High activation* during the tasks, but not during the baselines. In addition, BIS was associated with *High activation* especially during startle, whereas during the mental arithmetic task the association was weaker (Figure 2a). BAS had no significant effects for *High activation*.

Activated pleasant affect. BAS was positively associated with *Activated pleasant affect* scores, F(1,67) = 7.22, p = .009, η^2 = .10. In addition, there was a significant Task x BAS interaction, F(4,64) = 3.53, p = .012, η^2 = .18; the association between BAS and *Activated pleasant affect* was especially strong during the mental arithmetic task, and less so during the reaction time task (Figure 3a). BIS had no significant effects for *Activated pleasant affect*.

Pleasant affect. BAS was positively associated with *Pleasant affect* during the whole experiment, F(1,66) = 16.14, p < .001, η^2 = .20 (Figure 3b). BIS had no significant effects for *Pleasant affect*.

Unactivated pleasant affect. BAS was positively associated with the *Unactivated pleasant affect* during the whole experiment, F(1,66) = 4.64, p = .035, η^2 = .07 (Figure 3c). BIS had no significant effects for *Unactivated pleasant affect*.

Unactivated unpleasant affect. There was a significant Gender x BIS interaction when predicting *Unactivated unpleasant affect* during the whole experiment, F(1,64) = 8.03, p = .006, η^2 = .11; that is, BIS was positively correlated with *Unactivated unpleasant affect* among men, but not among women (Figure 2b). BAS had no significant effects for *Unactivated unpleasant affect*.

Unpleasant affect. The main effect of BIS and a Gender x BIS interaction were significant when predicting *Unpleasant affect* scores, *F*s(1,64) = 15.95 and 8.15, *p*s < .001 and = .006, η^2s = .20 and .11; that is, BIS was associated with *Unpleasant affect* (Figure 2c), association being stronger among men than among women. BAS had no significant effects for *Unpleasant affect*.

Activated unpleasant affect. BIS was positively associated with *Activated unpleasant affect*, $F(1,65) = 22.67$, $p < .001$, $\eta^2 = .26$. In addition, the Task x BIS interaction was significant, $F(4,62) = 8.49$, $p < .000$, $\eta^2 = .35$. BIS was associated with *Activated unpleasant affect* scores more strongly during the tasks than during the baselines. In addition, BIS had a stronger association with *Activated unpleasant affect* scores during the aversive startle and the reaction time task than during the appetitive mental arithmetic task. The association was strongest during startle task (Figure 2d). BAS had no significant effects for *Activated unpleasant affect*.

The BIS x BAS and Gender x BIS x BAS interactions were nonsignificant for all affect octants.

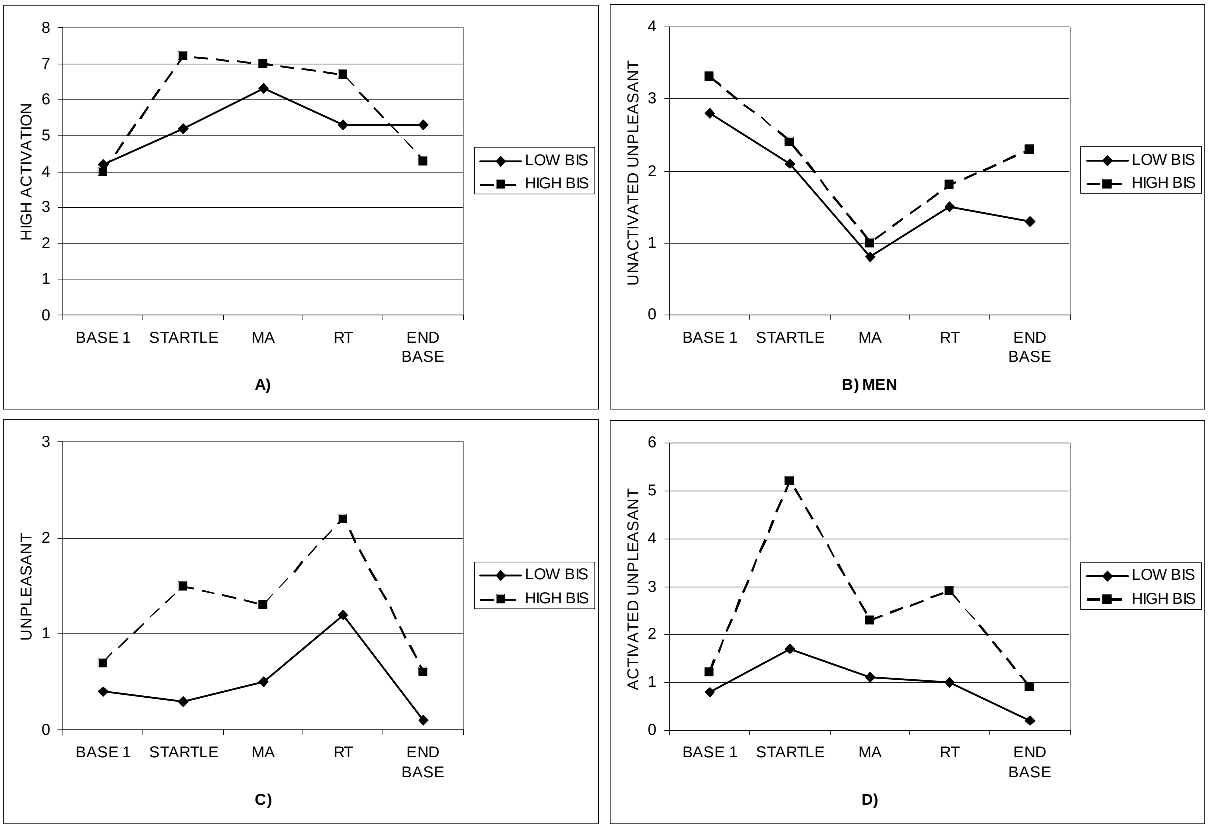

Figure 2. Mean (A) *High activation*, (B) *Unactivated unpleasant affect* (among men), (C) *Unpleasant affect*, and (D) *Activated unpleasant affect* (item) scores during different phases of the experiment in low and high BIS subjects. Low = 1 *SD* below the mean; High = 1 *SD* above the mean; MA = the mental arithmetic task; RT = the reaction time task.

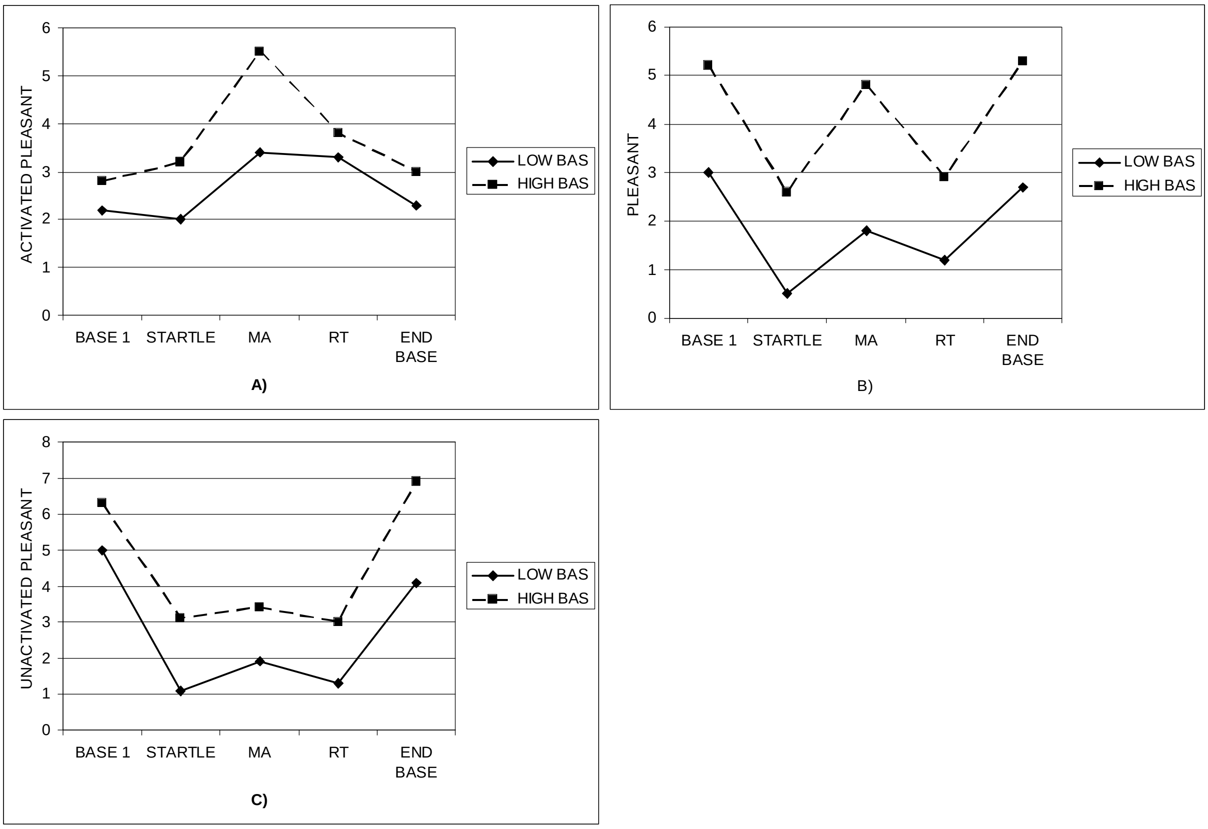

Figure 3. Mean (A) *Activated pleasant affect*, (B) *pleasant affect*, and (C) Unactivated pleasant affect scores during different phases of the experiment in low and high BAS subjects. Low = 1 *SD* below the mean; High = 1 *SD* above the mean; MA = the mental arithmetic task; RT = the reaction time task.

3.2 Effects of BIS/BAS sensitivity on Cardiac Autonomic Activity (*II*)

The results considering BIS/BAS sensitivity and cardiac activity are summarized in Table 3 (bottom part). A more detailed description of results is presented below.

Baseline levels. BIS and BAS scores were unrelated to mean initial baseline and last resting baseline levels of HR, RSA, and PEP.

Heart rate reactivity. Higher BAS scores were associated with greater increases in HR, *F*(1,57) = 9.13, *p* = .004, $\eta^2 = .14$ (Figure 4). BIS was unrelated to HR reactivity.

Respiratory sinus arrhythmia reactivity. Higher BAS scores were associated with greater decreases in RSA during the tasks, $F(1,57) = 7.09$, $p = .010$, $\eta^2 = .11$. In addition, the Task x BAS interaction was significant, $F(2,56) = 3.62$, $p = .033$, $\eta^2 = .12$. The association between BAS and RSA reactivity was more evident during the mental arithmetic task and the speech task (appetitive tasks) than during the aversive reaction time task. The association was most evident during the speech task (Figure 4). BIS was unrelated to RSA reactivity.

Pre-ejection period reactivity. BIS and BAS scores were unrelated to ΔPEP.

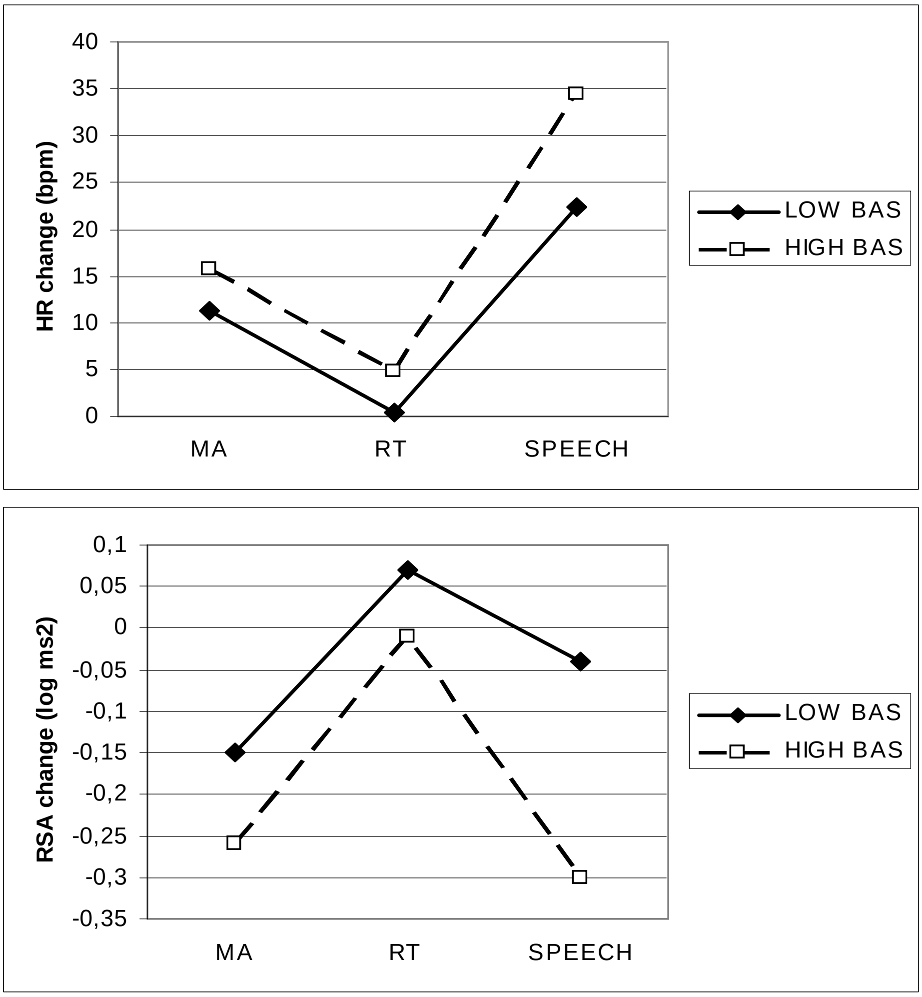

Figure 4. The means of heart rate (HR; bpm) change and respiratory sinus arrhythmia (RSA; log ms^2) change during the tasks (the mental arithmetic task, the reaction time task, and the speech task) in low BAS sensitive and high BAS sensitive subjects. Low = 1 *SD* below the mean; high = 1 *SD* above the mean; BAS = Behavioral approach system; MA = the mental arithmetic task; RT = the reaction time task.

Table 3. Summarized results for the effect of BIS/BAS sensitivity when predicting state affects and cardiac activity.

	BIS	BIS x Gender	Task x BIS	BAS	BAS x Gender	Task x BAS	BIS x BAS
High activation	**4.40***	ns.	**4.44****	ns.	ns.	ns.	ns.
Activated pleasant	ns.	ns.	ns.	**7.22****	ns.	**3.53***	ns.
Pleasant	ns.	ns.	ns.	**16.14****	ns.	ns.	ns.
Unactivated pleasant	ns.	ns.	ns.	**4.64***	ns.	ns.	ns.
Unactivated unpleasant	ns.	**8.03****	ns.	ns.	ns.	ns.	ns.
Unpleasant	**15.95****	**8.15****	ns.	ns.	ns.	ns.	ns.
Activated unpleasant	**22.67****	ns.	**8.49****	ns.	ns.	ns.	ns.
HR (bpm) initial baseline	ns.	ns.	-	ns.	ns.	-	ns.
HR (bpm) change	ns.	ns.	ns.	**9.13****	ns.	ns.	ns.
RSA (log ms^2) initial baseline	ns.	ns.	-	ns.	ns.	-	ns.
RSA (log ms^2) change	ns.	ns.	ns.	**7.09***	ns.	**3.62***	ns.
PEP (ms) initial baseline	ns.	ns.	-	ns.	ns.	-	ns.
PEP (ms) change	ns.	ns.	ns.	ns.	ns.	ns.	ns.

Note. Table 3 presents the *F* values from the GLM Repeated Measures procedure or from analyses of variance (baseline levels of cardiac variables). ns. = not significant; - = not studied; BIS = behavioral inhibition system sensitivity; BAS = behavioral approach system sensitivity; HR = heart rate; RSA = respiratory sinus arrhythmia; PEP = pre-ejection period.
* < .05
** < .01

3.3 The Correlations between Vital Exhaustion and Cloninger’s Temperament Variables (*III*)

The correlation between vital exhaustion and harm avoidance was significant, $r = .54$, $p <$ 001, whereas there were nonsignificant correlations between vital exhaustion and reward dependence, $r = -.16$, vital exhaustion and novelty seeking, $\underline{r} = -.16$, and vital exhaustion and persistence, $r =-.05$. We also explored the correlations between vital exhaustion and harm avoidance subscales. Vital exhaustion correlated significantly with all subscales, that is, with "anticipatory worry & pessimism", $r = .52$, $p <$ 001, "fear of uncertainty", $r = .40$, $p <$ 001, "shyness with strangers", $r = .46$, $p <$ 001, and "fatigability", $r = .34$, $p =$ 002.

3.4 The Effects of Vital Exhaustion and Temperament Variables on Affects (*III*)

The results for vital exhaustion, Cloninger’s temperament variables, and affects are summarized in Table 4 (upper part). A more detailed description of results is presented below.

The interactions of Vital exhaustion with Harm avoidance and Reward dependence were nonsignificant for all studied affect octants.

High activation. The main effect of Vital exhaustion for *High activation* was not hypothesized, and therefore not tested. The Vital exhaustion × Novelty seeking interaction was significant for *High activation*, $F(1,62) = 4.80$, $p = .032$, $\eta^2 = .08$. Vital exhaustion was negatively related to *High activation* scores among subjects scoring low on novelty seeking, whereas the reverse was true among subjects scoring high on novelty seeking. The combination of low vital exhaustion and low novelty seeking was associated with the highest levels of *High activation*.

Activated pleasant affect. The main effect of Vital exhaustion (and Vital exhaustion x Novelty seeking interaction) for *Activated pleasant affect* (liveliness) was not significant. However, there was a significant Task x Vital exhaustion interaction, $F(4,60, \underline{\varepsilon} = .91) = 3.48$, $p = .011$, $\eta^2 = .05$.

Contrasts indicated that, during the baselines, vital exhaustion was inversely related to *Activated pleasant affect* (liveliness).

Pleasant affect. The main effect of Vital exhaustion for *Pleasant affect* was not hypothesized, and therefore not tested. The Vital exhaustion x Novelty seeking interaction was nonsignificant.

Unactivated pleasant affect. The main effect of Vital exhaustion for *Unactivated pleasant affect* was not hypothesized, and therefore not tested. When interactions with temperament variables were included there was a significant Vital exhaustion × Novelty seeking interaction for *Unactivated pleasant affect*, $F(1,62) = 6.03$, $p = .017$, $\eta^2 = .09$. Vital exhaustion was positively associated with *Unactivated pleasant affect* scores among subjects scoring low on novelty seeking. That is, the combination of low vital exhaustion and low novelty seeking was associated with the lowest level of *Unactivated pleasant affect*, whereas the combination of high vital exhaustion and low novelty seeking was associated with the highest levels of *Unactivated pleasant affect*.

Unactivated unpleasant affect. Vital exhaustion was unrelated to *Unactivated unpleasant affect*. When interactions with temperament variables were included the Task x Vital exhaustion x Persistence interaction was significant, $F(4,59, \underline{\varepsilon} = .82) = 6.40$, $p < .001$, $\eta^2 = .09$. Most subjects experienced more *Unactivated unpleasant affect* during the baselines than during the tasks, but the contrasts showed that a combination of high vital exhaustion and high persistence was associated with an almost equal level of *Unactivated unpleasant affect* during the baselines and tasks. This was because a combination of high vital exhaustion and high persistence was associated with a high level of *Unactivated unpleasant affect* scores during the tasks, especially during the aversive tasks. The Vital exhaustion x Novelty seeking interaction was nonsignificant.

Unpleasant affect. Vital exhaustion was positively associated with *Unpleasant affect* during the experiment, $F(1,64) = 20.82$, $p < .001$, $\eta^2 = .25$ (Figure 5a). When interactions with temperament variables were included, there was a significant Vital exhaustion × Novelty seeking interaction for *Unpleasant affect* (sadness), $F(1,62) = 10.18$, $p = .002$, $\eta^2 = .14$. A combination of high novelty seeking and high vital exhaustion was associated with the highest levels of *Unpleasant affect*. The Vital exhaustion x Persistence interaction was nonsignificant.

Activated unpleasant affect (fear/ anxiety). Vital exhaustion was positively associated with *Activated unpleasant affect*s (fear/anxiety), $F(1,64) = 9.98$, $p = .002$, $\eta^2 = .14$. In addition, the Task x Vital exhaustion interaction was significant, $F(4,61, \underline{\varepsilon} = .57) = 3.33$, $p = .033$, $\eta^2 = .05$. Contrasts indicated that the association between vital exhaustion and *Activated unpleasant affect* (fear/anxiety) was stronger during the tasks than during the baselines (Figure 5b). The Vital exhaustion x Novelty seeking and Vital exhaustion x Persistence interactions were nonsignificant.

Activated unpleasant affect (anger). Vital exhaustion was positively associated with *Activated unpleasant affect*s (anger) during the experiment, $F(1,64) = 7.64$, $p = .007$, $\eta^2 = .11$ (Figure 5c). The Vital exhaustion x Novelty seeking and Vital exhaustion x Persistence interactions were nonsignificant.

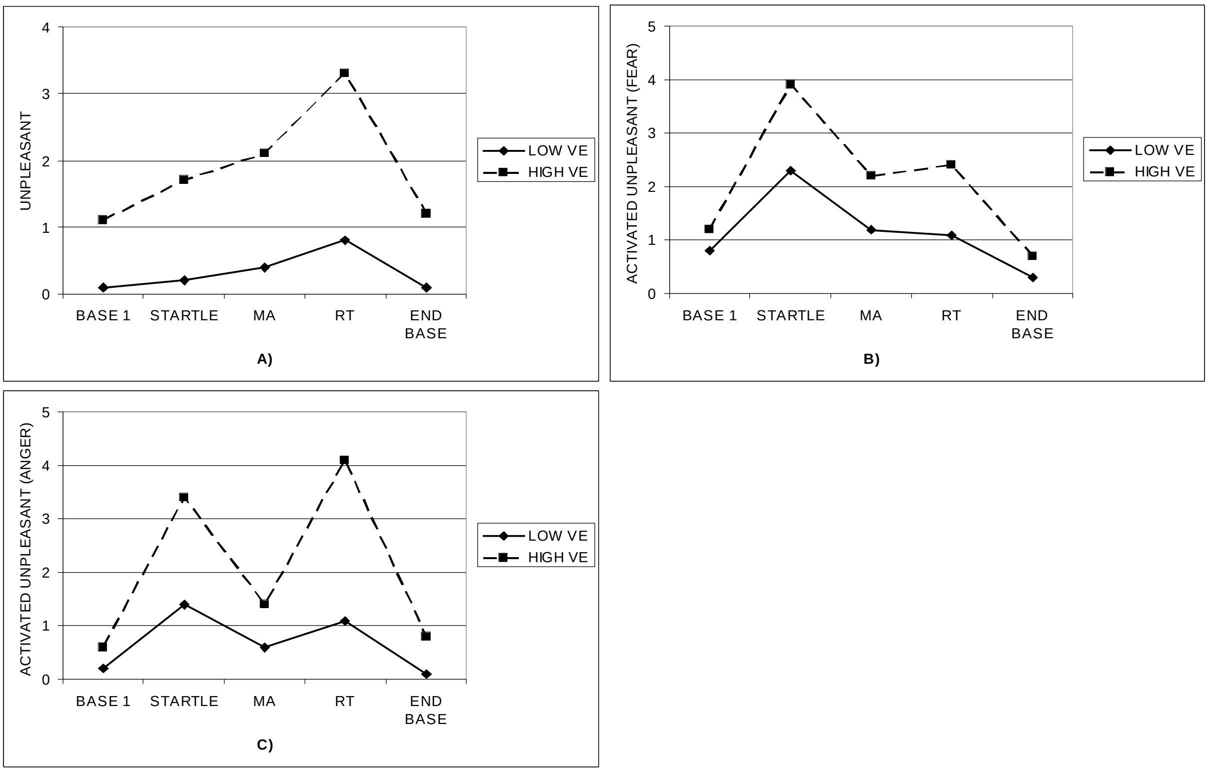

Figure 5. Mean (A) *Unpleasant affect*, (B) *Activated unpleasant affect* (fear), and (C) *Activated unpleasant affect* (anger) scores during different phases of the experiment in low and high vital exhaustion subjects. Low = 1 *SD* below the mean; High = 1 *SD* above the mean; MA = the mental arithmetic task; RT = the reaction time task.

3.5 Effects of Vital Exhaustion and Temperament Variables on Cardiac Autonomic Activity (*IV*)

The results for vital exhaustion, Cloninger’s temperament variables, and cardiac activity are summarized in Table 4 (bottom part). A more detailed description of these results is presented below.

Baseline levels. Vital exhaustion and its interactions with temperament were nonsignificant when predicting initial baseline levels of HR, RSA, and PEP.

Heart rate reactivity. The main effect of Vital exhaustion was nonsignificant when predicting ΔHR. When interactions with temperament variables were included, there was a significant Task x Gender x Vital exhaustion x Persistence interaction, $F(2{,}50, \underline{\varepsilon} = .76) = 8.05$, $p = .001$, $\eta^2 = .14$. Contrasts indicated that during the speech task, women with high vital exhaustion and high persistence exhibited highest HR reactivity, whereas women with high persistence and low vital exhaustion exhibited the lowest HR reactivity. There were no significant differences among men.

Respiratory sinus arrhythmia reactivity. Initial baseline level x Vital exhaustion interaction, $F(1{,}52) = 11.08$, $p = .002$, $\eta^2 = .18$ modified the main effect of Vital exhaustion, $F(1{,}52) = 11.38$, $p = .001$, $\eta^2 = .18$ when predicting ΔRSA. Vital exhaustion was associated with higher RSA reactivity, but the highest reactivity was among low vital exhaustion subjects with high initial baseline RSA. That is, among high vital exhaustion subjects, initial baseline level had no effect on RSA reactivity, whereas among low vital exhaustion subjects, RSA reactivity was highest when initial baseline level was high (Figure 6). When interactions with vital exhaustion and temperament variables were included, there was also a significant Task x Gender x Vital exhaustion x Persistence interaction, $F(2{,}50, \underline{\varepsilon} = .82) = 5.25$, $p = .011$, $\eta^2 = .09$. Contrasts indicated that women with high persistence and high vital exhaustion had the highest RSA reactivity during the speech task, whereas women with high persistence and low vital exhaustion had the lowest RSA reactivity during the speech task. There were no significant differences among men.

***Pre-ejection period reactivity*.** The main effect of Vital exhaustion was nonsignificant when predicting ΔPEP. When interactions with Vital exhaustion and temperament variables were included, there was a significant Task x Vital exhaustion x Persistence interaction, $F(2{,}52) = 3.48$, $p = .034$, $\eta^2 = .06$. Contrasts indicated that High Persistence/low Vital exhaustion and low Persistence/high Vital exhaustion subjects had greater PEP reactivity than low Persistence/low Vital exhaustion and high Persistence/ high Vital exhaustion subjects during the reaction time and speech tasks.

The interactions of Vital exhaustion with Harm avoidance, Reward dependence, and Novelty seeking were nonsignificant for all cardiac measures.

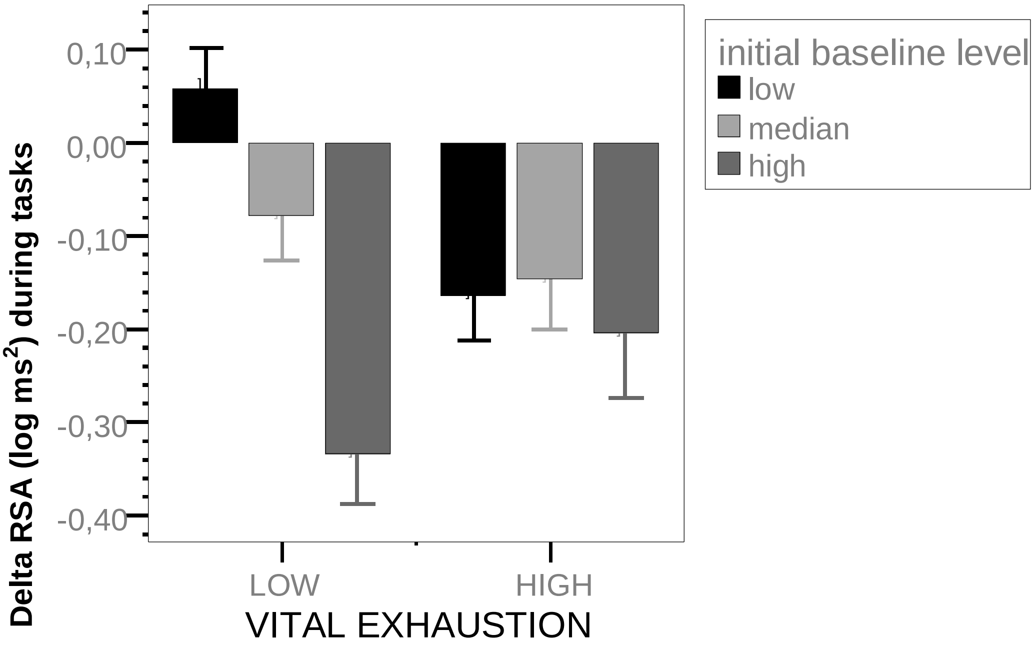

Figure 6. Mean respiratory sinus arrhythmia (RSA) change during the tasks (the mental arithmetic task, the reaction time task, and the speech task) in subjects with high/low vital exhaustion and high/median/low initial baseline RSA value. Error bars show mean +/- 1 SEM.

Table 4. Summarized results for vital exhaustion and its interactions with Cloninger's temperament variables when predicting state affects and cardiac activity.

	VE	Task x VE	VE x HA	Task x VE x HA	VE x P	Task x VE x P	VE x RD	Task x VE x RD	VE x NS	Task x VE x NS
High activation	-	-	-	-	-	-	ns.	ns.	4.80*	ns.
Activated pleasant	ns.	3.48*	-	-	-	-	ns.	ns.	ns.	ns.
Pleasant	-	-	-	-	-	-	ns.	ns.	ns.	ns.
Unactivated pleasant	-	-	-	-	-	-	ns.	ns.	6.03*	ns.
Unactivated unpleasant	ns.	ns.	ns.	ns.	ns.	6.40**	ns.	ns.	ns.	ns.
Unpleasant	20.82**	ns.	ns.	ns.	ns.	ns.	ns.	ns.	10.18**	ns.
Activated unpleasant (fear)	9.98**	3.33*	ns.	ns.	ns.	ns.	ns.	ns.	ns.	ns.
Activated unpleasant (anger)	7.64**	ns.	ns.	ns.	ns.	ns.	ns.	ns.	ns.	ns.
HR (bpm) initial baseline	ns	-	ns.	-	ns.	-	ns.	-	ns.	-
HR (bpm) change	ns.	ns.	ns.	ns.	ns.	[a] (x Gender) 8.05**	ns.	ns.	ns.	ns.
RSA (log ms^2) initial baseline	ns	-	ns.	-	ns.	-	ns.	-	ns.	-
RSA (log ms^2) change	11.38**	ns.	ns.	ns.	ns.	[a] (x Gender) 5.25*	ns.	ns.	ns.	ns.
PEP (ms) initial baseline	ns	-	ns.	-	ns.	-	ns.	-	ns.	-
PEP (ms) change	ns.	ns.	ns.	ns.	ns.	3.48*	ns.	ns.	ns.	ns.

Note. Table 4 presents the *F* values from the GLM Repeated Measures procedure or from analyses of variance (baseline levels of cardiac variables). ns. = not significant; - = not studied; VE = vital exhaustion; HA = harm avoidance; P = persistence; RD = reward dependence; NS = novelty seeking; HR = heart rate; RSA = respiratory sinus arrhythmia; PEP = pre-ejection period.

[a] In these cases the VE x Gender x Task x P x interaction was significant

* < .05; ** < .01

4. DISCUSSION

4.1 How BIS/BAS sensitivity is related to emotional and physiological reactions (*I* and *II*)

BIS sensitivity was associated with unpleasant affects irrespective of the activation level, with the exception of *Unactivated unpleasant affect* among women. In addition, BIS sensitive persons seemed to be especially sensitive to aversive stressors. However, BIS sensitivity was unrelated to cardiac autonomic reactions. In contrast, BAS sensitivity was, in general, associated with pleasant affects in all levels of emotional activation. Further, BAS sensitive persons seemed to be especially sensitive to appetitive stressors. In addition, we found that BAS sensitivity was associated with parasympathetically mediated HR reactivity.

More specifically, our results suggest that persons with high BIS sensitivity, compared to those with low BIS sensitivity, experience more unpleasant affects at all levels of activation in general. Furthermore, they experience a greater increase of unpleasant affects with high activation during situations including punishment cues; that is, we found that BIS sensitivity was related to an increase of *Activated unpleasant affect* (anxious, fearful, uneasy, and tense) particularly during aversive tasks and especially during the startle probe. In contrast, our findings imply that persons with high BAS sensitivity, compared to those with a less sensitive BAS, experience more pleasant affects at all levels of activation in general. Furthermore, they experience a greater increase of pleasant affects with high activation during situations including incentives; that is, we found that BAS sensitivity was related to an increase of *Activated pleasant affect* (vigorous, peppy, and lively) especially during the appetitive math task. These findings are completely in line with Gray’s (1982, 1994) theory and with Larsen and Diener’s (1992) suggestion that

Activated unpleasant affect is associated with biologically based sensitivity to conditioned signals of punishment, whereas *Activated pleasant affect* is associated with biologically based sensitivity to reward. However, these suggestions have not been previously so consistently tested. Generally, BIS persons have been found to be more negative, whereas BAS persons have been found to be more positive; that is, BIS and BAS scales have been found to be associated with negative and positive affects, respectively, in everyday diaries (Gable, Reis, & Elliot, 2000), in questionnaires asking how a person generally feels (Heubeck et al., 1998; Jorm et al., 1999), and when viewing emotional announcements (Dillard & Peck, 2001). In addition, previous studies have found some evidence supporting the suggestion that BIS persons are more sensitive to aversive situations, and BAS persons are more sensitive to appetitive situations. Carver and White (1994) found that BAS sensitivity predicts positive emotional reactions to cues of impending reward, whereas BIS sensitivity predicts a level of nervousness in response to impending punishment. However, the influence of varying stressors on the same participants was not included, and thus the intra-individual aspect was not taken into account. Gable et al. (2000) found an association between BIS sensitivity and increased frequency of negative affects after negative life events, but not with BAS sensitivity and increased frequency of positive affects after positive life events.

The association between BAS scores and HR reactivity found here is in line with Fowles' (1980) suggestion that BAS activity is strongly associated with HR activity. There was no association with baseline HR, however. BAS-related pronounced HR reactivity is consistent with previous findings showing that HR increases when the BAS is activated by reward or active avoidance cues (Arnett & Newman, 2000; Tranel et al., 1982). However, Knyazev et al. (2002) found that BAS scores (measured with Gray-Wilson Personality Questionnaire; Wilson, Barret, & Gray, 1989) were negatively related to HR acceleration during the mental arithmetic task. As they did not include incentives, it is possible that the task did not produce changes in BAS activation (see Corr, 2001). In addition, the aforementioned study seems to have induced only mild reactivity, whereas our tasks evoked large physiological reactions. Furthermore, the discrepancy in the results may be due to the use of different BIS/BAS measures.

Persons with high BAS sensitivity exhibited higher HR reactivity independently of the nature of the stressors (i.e., during all tasks). Consequently, persons who are sensitive to incentive signals seem to have strong HR reaction to diverse active coping tasks that include incentives. Our results imply that persons with high BAS sensitivity react to incentive signals by initiating goal-directed behavior and by focusing attention on incentive-related cues, perhaps discounting or neglecting cues for punishment or frustration, as Patterson and Newman (1993) have suggested.

The pronounced HR reactivity of our subjects with high BAS scores seems to have been mediated by parasympathetic withdrawal. BAS sensitivity was associated with stronger parasympathetic withdrawal during the tasks, whereas there was no association with baseline parasympathetic tone. The association between BAS sensitivity and parasympathetic withdrawal was stronger during appetitive tasks (the mental arithmetic task and the speech task) than during the aversive reaction time task. The association was most evident during the socially relevant speech task. This finding is of importance, because the public speech task is known to have a great deal of social relevance and ecological validity; thus, it corresponds well to stresses of daily life.

Our expectations considering cardiac measures based on anxiety and depression studies were not confirmed. There are at least two possible explanations for this. First, these measures assess somewhat different qualities. Carver and White (1994) have claimed that the BIS scale is not so closely aligned with other anxiety measures because its items reflect the propensity to anxiety in a given situation rather than how often anxiety is experienced or the general affective tone. Depression questionnaires mainly focus on depressed mood, lack of goals, and boredom, whereas BIS and BAS items concentrate on threat and incentive responsiveness, respectively. Second, it may be that more extreme BIS or BAS sensitivities in clinical samples would yield different results.

The hypothesis, based on Beauchaine's (2001) suggestion, that both high BIS sensitivity and high BAS sensitivity are associated with increased sympathetic activity was not confirmed. In contrast, our results and a previous study (Ravaja, 2004) suggest that the BAS is mediated peripherally by parasympathetic activity. In addition, prior studies with attention-deficit/hyperactivity disorder plus conduct disorder CD/ADHD subjects have found contradictory findings; that is, CD/ADHD (excessive BAS) subjects showed lower sympathetic baseline levels and reactivity (Beauchaine, Katkin, Strassberg, & Snarr, 2001).

As mentioned above, BAS sensitivity was related to HR reactivity, which seems to be mediated by parasympathetic withdrawal. Therefore, when considering only HR reactivity, as traditionally has been done, BAS sensitive persons could be assumed to be at a higher health risk, since higher HR reactivity has been associated with neuroendocrine responses (Lovallo, Pincomb, Brackett, & Wilson, 1990; Manuck, Cohen, Rabin, Muldoon, & Bachen, 1991; Sgoutas-Emch et al., 1994) and disease risk (e.g., Krantz & Manuck, 1984; Matthews et al., 1986). However, it has been suggested that cardiovascular reactivity mediated by sympathetic activation has more relevance for disease pathogenesis than reactivity mediated by parasympathetic withdrawal (e.g., Blascovich & Katkin, 1993; Cacioppo, 1994). Likewise, Porges (1992) suggested that parasympathetic withdrawal during stress is associated with behavioral flexibility. Given that high BAS individuals also experienced more pleasant affects during the experiment, it seems that high BAS persons may show an appropriate stress response, and their pronounced reactivity may be associated with goal-directed activation, positive arousal, enthusiasm, and physiological flexibility. Tomaka and his colleagues (Tomaka, Blascovich, Kelsey, & Leitten, 1993) have previously stated that cardiac arousal in response to situational demands is not an invariant marker of negatively toned emotional states such as those termed stress. Thus, cardiac reactivity may reflect positive enthusiasm as well.

In contrast, BIS sensitivity seems to predispose a person to emotional distress in stressful situations regardless of the nature of the stressor, particularly in aversive situations. Thus, high BIS sensitivity may predispose a person to higher stress vulnerability. However, we did not find an association between BIS sensitivity and our cardiac parameters. Nevertheless, there are several other physiological mechanisms via which BIS sensitivity might increase one’s stress vulnerability that our study did not cover. Besides physiological pathways, other mechanisms may also increase stress vulnerability among BIS persons. For example, behavioral inhibition and withdrawal may predispose a person to poor and inactive coping. Several studies have related the BIS to negative affectivity (NA; Carver, Sutton, & Scheier, 2000; Carver & White, 1994; Heubeck et al., 1998; Larsen & Ketelaar, 1991). High NA persons, in turn, have been shown to be not only easily distressed but also likely to cope poorly with stress (Watson & Clark, 1984; Watson, Clark, & Harkness, 1994).

4.2 How vital exhaustion is related to emotional and physiological reactions (*III* and *IV*)

We showed that enhanced sense of exhaustion, even though not reaching a clinical level, is related to emotional reactions and cardiac autonomic reactions. Vital exhaustion was associated with unpleasant affects in medium and high levels of activation but not with unpleasant affects in low levels of activation. In addition, vital exhaustion was associated with parasympathetic withdrawal during the stressors.

Vital exhaustion was associated with *Activated unpleasant affect* (both fear/ anxiety and anger) and *Unpleasant affect* during the whole experiment, that is, independently of the nature of the stimulus. In addition, vital exhaustion was inversely associated with *Activated pleasant affect* during baselines, but not during tasks. In other words, subjects with high levels of exhaustion felt more anxious, tense, fearful, sad, depressed, angry, irritated and disappointed during stress, as well as less vigorous, peppy, and lively in general (baselines), compared to subjects with low levels of exhaustion. Previously, vital exhaustion has been linked with depression (Kristenson et al., 1998; Wojciechowski et al., 2000) and type-D, which is characterized by negative affectivity and a tendency to inhibit the expression of this affect (Pedersen & Middel, 2001). In addition, fatigue has been linked with negative affects among patients with coronary heart disease (CHD; Denollet, 1993). Thus, exhaustion may increase the tendency to experience negative affects in situations that challenge a person and perhaps make one doubt one’s own strengths. For example, Wojciechowski et al. (2000) have suggested that vital exhaustion could be a possible pathway to depression. Alternatively, it might be that an innate tendency to experience negative affects and arousal predisposes a person to feelings of exhaustion. That is, exhaustion may reflect not only an outcome of long-term stress but also an intrinsic predisposition to negative affects in acute stress. The propensity to negative arousal found here might be one of the links between vital exhaustion and disease risk.

Interestingly and contrary to our hypothesis, vital exhaustion was not associated with unpleasant affect with low arousal (state fatigue), that is, with dullness, tiredness, and sleepiness, However, a lack of energy and fatigue have been defined as the most important aspects of vital exhaustion. Furthermore, the Maastricht Questionnaire includes some items (tiredness, weakness) that overlap with *Unactivated unpleasant affect*. Notably, the concept of vital exhaustion concerns chronic feelings, whereas our state affects correspond to short-term emotional reactions evoked by our stressors. Perhaps exhausted persons react with sadness, anger, fear and anxiety in stressful situations, experiencing fatigue and tiredness only when the acute stress situation is over.

Vital exhaustion was also associated with parasympathetic withdrawal, reactivity being highest among subjects with low scores on vital exhaustion and a high initial baseline parasympathetic tone. That is, among high vital exhaustion subjects, the initial baseline level had no effect on parasympathetic reactivity, whereas among low vital exhaustion subjects, parasympathetic reactivity was highest when initial baseline level was high. Porges (1992) has suggested that parasympathetic tone indexes stress and stress vulnerability; that is, persons with high parasympathetic tone who have an ability to dampen parasympathetic activity in challenging situations and return to high baseline afterwards exhibit an appropriate stress response and will be less susceptible to stress.

4.2.1 The moderating role of temperament

Our findings suggest that temperament may increase susceptibility to exhaustion and that particular temperament dimensions may predispose a person, in the presence of exhaustion, to negative affects and cardiac reactions, which, in turn, may lead to individual differences in stress vulnerability. Persons with high levels of exhaustion who exhibit a tendency to perseverance and perfectionism or to react with excitement to novelty and actively avoid monotony seem to be especially at risk.

Of the temperament dimensions, harm avoidance correlated highly with vital exhaustion. Previously, vital exhaustion has been linked with personality types A (hard driving, impatient, and hostile; Falger, 1989) and D (tendency to negative affect and to inhibit this affect; Pedersen & Middel, 2001). The harm avoidance subscale "fatigability" includes items that overlap with items in the Maastricht Questionnaire. However, vital exhaustion exhibited stronger correlations with other harm avoidance subscales than with "fatigability", that is, with "anticipatory worry and pessimism", "fear of uncertainty", and "shyness with strangers." This suggests that vital exhaustion is not only a final stage of prolonged stress but may also be predisposed by temperament. In other words, persons with a high sensitivity to behavioral inhibition are at higher risk of experiencing exhaustion. Notably, in study ***I***, we found an association between high sensitivity to behavioral inhibition and negative affects. Thus, it seems that a tendency to behavioral inhibition, negativity, and exhaustion are all associated.

Vital exhaustion was associated with *Unactivated unpleasant affect* (state fatigue) among subjects with high persistence scores during the tasks, especially during the aversive tasks. In addition, women with high scores on vital exhaustion and persistence also showed highest HR and parasympathetic reactivity during the speech task. Persons scoring high on persistence have been described as persistent and perfectionistic individuals who tend to be overachievers and workaholics (Cloninger et al., 1993). Our results imply that an innate tendency towards perseverance does not as such predispose to exhaustion (nonsignificant correlation). Instead, environmental factors, or a combination of environment and temperament, inducing exhaustion, may play an important role here. Hard driving, perfectionistic individuals may attempt to perform at the high levels that they achieved prior to their exhaustion and these attempts may fail in terms of their own perfectionistic standards. This may lead to critical evaluation and a sense of failure, leading to feelings of tiredness and fatigue, as our results suggest. For example, perfectionism has previously been related to negative state affects, self-criticism, and feelings of distress and depression (for a review, see Blatt, 1995).

The interaction of vital exhaustion and novelty seeking was also of importance. Subjects with high levels of both exhaustion and novelty seeking experienced more *Unpleasant affect* during the experiment compared to others. That is, they seemed more likely to feel sad, disappointed, and depressed. Novelty seeking scores as such were not associated with exhaustion scores; thus, novelty seeking does not predispose a person to exhaustion. Inability to meet previous unrealistic goals due to exhaustion may result in feelings of sadness, disappointment and depression in response to challenging situations among persons that prefer to live at the edge. Previously, novelty seeking has been found to be related, for example, to bipolar depression (Young et al., 1995), substance abuse (Howard, Kivlahan, & Walker, 1997), and suicidal behavior (van Heeringen, Audenaert, Van de Wiele, & Verstraete, 2000). Additionally, depressed persons with high novelty seeking have reported worse physical health than depressed persons with low novelty seeking (Sullivan, LaCroix, Russo, & Walker, 2001).

4.3 Limitations

The major limitation of our study concerns the use of self-report techniques to measure temperament and affective reactions, that is, the general problem of how well self-report measures cover the concepts of interest. For example, self-report measures of BIS and BAS are not direct measures of the underlying basic physiological processes. Nevertheless, the findings that BAS sensitivity is associated with greater relative left prefrontal activation and BIS sensitivity with greater relative right prefrontal activation, give some support for the possible biological basis of these scales (Harmon-Jones & Allen, 1997; Sutton & Davidson, 1997).
In addition, temperament may influence one´s focus of attention, which may cause that people interpret emotional terms differently. For example, BIS sensitive persons could be biased in favor of negative cues, whereas BAS sensitive persons could be biased in favor of incentive signals.

In addition, since the order of the tasks was fixed, order effects cannot definitely be ruled out. For example, the findings showing pronounced reactions during the speech task need to be viewed cautiously. It may be that stronger reactions have nothing to do with the specific characteristics of the speech task, but might instead reflect the effects of repeated stress exposure. Additionally, as the speech task was the only task involving vocalization, speech-related respiratory effects may also have confounded the results for RSA during the speech task. However, the levels of the cardiac measures (HR, RSA, and PEP) and affective ratings showed no trends during the experiment. The physiological reactions evoked by each task corresponded to those found in earlier studies (Allen & Crowell, 1989; Berntson, Cacioppo, & Fieldstone, 1996; Cacioppo, Berntson et al., 1994; Langer et al., 1985; Sherwood et al., 1986). The mental arithmetic task and the speech task evoked strong physiological reactions, whereas the reaction time task between these two tasks evoked only modest reactions. In addition, the stressors elicited the expected affective reactions, that is, the mental arithmetic task operated as an appetitive stimulus, whereas the startle probe and the reaction time task operated as aversive stimuli.

Another concern is whether our operationalization of reinforcements was successful. As we did not have experimental manipulations of incentive or punishment effects (the same task with incentive/punishment vs. no-incentive/punishment conditions), we cannot definitely determine whether the incentives or punishments were responsible for the observed effects.

In addition, as we did not measure respiration, we cannot be sure that respiration fell within the frequency band used to compute RSA estimates. However, it has recently been shown that it is acceptable to use uncorrected RSA to index within-subject changes in parasympathetic modulation of HR in most stress studies (Houtveen, Rietveld, & De Geus, 2002). Berntson et al. (1997) have suggested that the lack of respiratory measures may not preclude group contrasts in well-defined populations with known respiratory patterns and large-amplitude RSA and when experimental conditions do not alter respiratory parameters appreciably. In addition, several studies have found relations between invasively estimated parasympathetic cardiac activity and RSA that has not been controlled for respiration (e.g., Akselrod et al., 1981; McCabe, Yongue, Ackles, & Porges, 1985). However, owing to potential differences in respiratory parameters, biases may exist in our study in between-subject comparisons or across experimental conditions.

4.4 Conclusions

The present results have provided evidence that individual differences in sensitivities to reward and punishment are related to physiological and emotional reactions in challenging situations. Persons who are prone to focus on possible rewards and incentives (high BAS sensitivity) seem to have positive emotional reactions in varying challenges, especially when incentive cues are present. These persons become easily enthusiastic and have strong HR reactivity, which seems to be mediated by the parasympathetic nervous system. On the other hand, persons who focus on possible threats and punishments (high BIS sensitivity) seem to have negative emotional reactions during challenges, especially if punishment cues are present. Thus, we speculated that these persons might be more stress vulnerable. BIS-determined stress proneness might also predispose a person to somatic endpoints, as well. NA has, indeed, been found to be a non-specific risk factor for poor health outcomes in general, and a prognostic factor for cardiac events and for cancer (Denollet, 1998; Denollet et al., 2000). However, we did not find any associations between BIS sensitivity and our physiological measures (HR, RSA, and PEP). For this reason, future studies should examine the association between BIS sensitivity and other possible stress indicators. In addition, future studies should examine more precisely the effects of incentives and other manipulations known to activate the BAS or BIS.

Our findings also demonstrate that an individual's sense of exhaustion (even though not reaching a clinical level) is related to emotional and physiological reactions in acute stress as well as to temperament. More specifically, a high level of vital exhaustion among healthy persons is related to unpleasant state affects, excluding those with low arousal, and to parasympathetic reactivity evoked by stressful and challenging situations. In addition, we found that particular temperament dimensions might predispose a person, in the presence of exhaustion, to negative affects and to cardiac reactivity, which may lead to individual differences in stress vulnerability. Persons with high levels of exhaustion who exhibit a tendency to perseverance and perfectionism or to react with excitement to novelty and actively avoid monotony seem to be especially at risk. Taken together with the finding that vital exhaustion was related to a tendency toward behavioral inhibition (harm avoidance), our data suggest that there is an association between innate temperament, sense of exhaustion, and emotional and physiological reactions during a challenge. These findings might be relevant from the point of view of rehabilitation, and future studies should further examine the physiological and psychological variables that might predispose a person to vital exhaustion. Overall, our results suggest that innate temperament and sense of exhaustion are associated with physiological and emotional reactions during acute stress and should thus be taken into account in stress management.

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