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Relationships between features of autonomic cardiovascular control and cognitive performance

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ABSTRACT

The study investigated relationships between autonomic cardiovascular control and attentional performance. In 60 healthy subjects R-wave to pulse interval (RPI), respiratory sinus arrhythmia (RSA), heart rate variability in the mid-frequency (MF) band and sensitivity of the cardiac baroreflex (BRS) were assessed at rest and during a visual attention test. All parameters decreased markedly during test execution. Lower values of resting BRS predicted increased performance. On-task RPI, RSA, MF power and BRS were inversely related to attentional functioning, with RSA accounting for the largest portion of test score variance. The inverse association between resting BRS and performance is discussed as reflecting the bottom-up modulation of cerebral function by baroreceptor activity. The results concerning the on-task measures suggest that a pattern of cardiovascular adjustment including enhanced sympathetic and reduced vagal cardiovascular influences, as well as baroreflex inhibition may induce an adaptive state associated with improved cognitive-attentional functioning.

1. Introduction

Interactions between states of the autonomic nervous system and cognitive performance have a long tradition as a topic of psychological research. Classic concepts from motivational psychology suggested an inverted u-shaped association between unspecific activation and mental functioning (Hebb, 1955; Yerkes and Dodson, 1908). According to this, best functional conditions are expected at midrange arousal, and both overarousal and underarousal are accompanied by declines in performance. Cardiovascular psychophysiology has also contributed to this line of research, the respective models relating changes in cardiovascular activity to facilitation or inhibition of information processing (Lacey and Lacey, 1970) or energetic mobilization of the organism when faced with a situation requiring behavioral adjustment (Obrist, 1981). However, although this certainly constitutes a beneficial approach, empirical work in this field remains relatively sparse (cf. Hansen et al., 2003).

Both the sympathetic and parasympathetic systems contribute to cardiovascular regulation (Levy and Pappano, 2007). Sympathetic influences are transmitted through efferent fibres to the sinus node, the myocardium and the vascular musculature, their activation leading to increases in heart rate, cardiac contractility and vascular tone. Parasympathetic influences are widely, but not completely, restricted to the modulation of heart rate through inhibiting sinus node activity. In addition, the cardiac baroreflex is involved. In this negative feedback loop changes in the activity of the arterial baroreceptors due to fluctuations in blood pressure are responded to with compensatory changes in heart rate and contractility. A complex network of brain stem units subserve cardiovascular autonomic control including, e.g. the nucleus of the solitary tract (NTS), the dorsal motor nucleus (DMN), the nucleus ambiguus (NA) and the rostral ventrolateral medulla (RVLM) (van Roon et al., 2004). Bilateral direct and indirect connections exist between this network and cortical areas, which form an important link between cardiovascular regulation and cognition (Dembowsky and Seller, 1995; Rau and Elbert, 2001).

The present study aimed at investigating relationships between features of sympathetic, parasympathetic and baroreflex cardiovascular control and attentional performance. Hypotheses concerning the role of the sympathetic system may be derived from findings supporting the traditional view of an inverted u-shaped association between unspecific arousal and mental capacity. For instance, sympathetic activation induced by moderate physical exercise led to increased performance on attention tasks, whereas a reduction in performance was observed during higher workload (e.g. Chmura et al., 1994; Yagi et al., 1999). The degree of exercise-induced catecholamine release was also reported to be associated with attentional functioning, the relationship between plasma catecholamine level and performance being inversely u-shaped (Chmura et al., 1994; Peyrin et al., 1987). Memory processes are

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also sensitive to modulations in sympathetic arousal, adrenergic stimulation and blockade produced memory improvement and impairment, respectively (Cahill et al., 1994; Cahill and Alkire, 2003; Maheu et al., 2004). Sympathetic cardiovascular tone may be estimated based on the measurement of R-wave to pulse interval (RPI) (Contrada et al., 1995; Hugdahl, 2001). RPI is given by the time interval between the occurrence of the R-wave and arrival of the pulse at a peripheral location (Marie et al., 1984; Obrist, 1981). Despite not being a pure sympathetic parameter, RPI decreases subject to increasing beta-adrenergic influences on myocardial contractility (Contrada et al., 1995). To the best of our knowledge, RPI has not as yet been related to cognitive performance.

More theoretical and empirical contributions are available concerning the interaction between parasympathetic cardiovascular control and attentional performance. Parasympathetic influences on heart rate can be reliably quantified by respiratory sinus arrhythmia (RSA), the variation in heart rate that occurs during a breathing cycle. The RSA is mediated through inhibitory vagal fibres to the sinus node (Berntson et al., 1997; Task Force, 1996) and may be derived from the high frequency (HF) band of the heart rate variability spectrum that is habitually associated with respiration. Porges (1992) proposed a theoretical framework on the link between cardiac vagal tone and interindividual differences in attention. Building on earlier models (Lacey, 1967; Obrist et al., 1970), he postulated that higher resting levels of cardiac vagal tone are associated with improved attentional capacity. This is consistent, for instance, with Richards' (1987) observation of reduced distractibility in infants with high baseline RSA. Suess et al. (1994) presented school children with a continuous performance task and found perceptual sensibility to be positively related to resting RSA. In young adults, levels of cardiac vagal tone indexed by heart rate variability were associated with better reaction time performance (Porges, 1972, 1973). A group of sailors with higher heart rate variability displayed better performance on working memory and continuous performance tests than those with lower heart rate variability (Hansen et al., 2003).

Functional features of the cardiac baroreflex, particularly its sensitivity expressed as change in heart cycle duration per unit of blood pressure change, have also been related to cognitive performance. Baroreflex sensitivity (BRS) can be determined in the time domain using sequence analysis of spontaneously occurring covariation between systolic blood pressure and heart cycle duration (Duschek and Reyes del Paso, 2007; Parati et al., 2000). Yasumasu et al. (2006) reported an inverse association between BRS assessed during the execution of serial subtractions and task performance. Reyes del Paso et al. (in press) also found better arithmetic performance (addition of three-digit numbers) in individuals with lower on-task BRS. Yasumasu et al. (2006) interpreted their finding in the context of the intake rejection hypothesis (Lacey and Lacey, 1970), according to which increased heart rate due to baroreflex inhibition facilitates internal cognitive elaboration such as required by an arithmetic task. Alternatively, they considered that the inverse association may reflect interindividual differences in mental effort invested in the task. BRS was shown to decrease with increasing mental load (Reyes del Paso et al., 1996; Robbe et al., 1987). Assuming a positive relationship between mental effort and task performance, it may be expected that lower on-task BRS is accompanied by better performance. However, it should not be overlooked that the findings of Yasumasu et al. (2006) and Reyes del Paso et al. (in press), though certainly promising, are restricted to arithmetic processing and thus cannot be generalized to other domains of cognitive functioning.

Spectral power in the mid-frequency (MF) band of the heart rate variability spectrum is another parameter of cardiac autonomic regulation, which may more accurately represent mental load than BRS. Oscillations in this so-called 0.10 Hz component reflect both sympathetic and parasympathetic effects on sinus node activity (van Roon et al., 2004). A number of studies indicated that their magnitude is inversely related to the individual degree of effort during execution of a cognitive task (Boucsein and Backs, 2000; van Roon et al., 2004). On account of this, it seemed useful also to include MF power in the present analysis.

As a secondary aim, the study investigated interindividual differences in task induced cardiovascular modulations. Porges (1992) postulated an association between resting cardiac vagal tone and the extent of cardiovascular reactivity. This is consistent with studies that have revealed more pronounced heart rate responses to various stimuli in children and adults with higher baseline heart rate variability (DeGangi et al., 1991; Porges, 1972; Porter et al., 1988). Cardiovascular reactivity to cognitive demands may also relate to task performance. Duschek (2005) found a positive correlation between systolic and diastolic blood pressure increases during the execution of five attention tasks and performance on each of them. In infants, greater decreases of RSA during mental testing were related to higher functional levels (DeGangi et al., 1991). Interindividual differences in cardiovascular modulation possibly reflect different degrees of autonomic adjustment as well as motivation on a task, both of which may contribute to performance. However, inconsistent findings, i.e. missing or even inverse associations between cardiovascular reactivity and mental performance, were also reported (Backs and Seljos, 1994; Wright et al., 2005). Thus, the current state of research does not allow definite conclusions.

In the present study, attentional capacity was assessed using a classic letter cancellation test ("Attentional Performance Test", Test d2, Brickenkamp, 1994). Tasks of this type address the cognitive components of selective and sustained attention that are undoubtedly of vast importance in everyday life (Johnson and Proctor, 2004; Posner and Rafal, 1987). In the test subjects have to select and mark as many target stimuli as possible in a given amount of time, hence it also has certain load on speed of information processing. Autonomic parameters were recorded under resting conditions and during execution of the task. One may assume that features of autonomic control assessed during cognitive processing show the closest link to performance. On the other hand, on-task measures are influenced by factors such as mental effort, emotional stress or subjectively experienced task difficulty. In contrast, baseline measures are free of these confounding variables.

The following predictions were made: (1) Taking an inverted u-shaped association between unspecific sympathetic arousal and mental performance into account, and assuming an experimental situation in which sympathetic overactivity is unlikely to occur, an inverse relationship between RPI and attentional performance may be expected. (2) On account of Porges' (1992) model, we predicted a positive correlation between resting RSA and performance. (3) Our findings on baroreflex function (Reyes del Paso et al., in press; Yasumasu et al., 2006) suggest that individuals with increased BRS should exhibit poorer performance. (4) Given the inverse association between oscillations in the MF band and mental effort load, and supposing better performance in the case of higher effort, MF power assessed during task execution should correlate negatively with performance. (5) Considering Porges' (1992) hypothesis, we expected higher cardiovascular reactivity in individuals with higher resting RSA. (6) Even though the available database is somewhat controversial, the likely association between mental effort and autonomic reactivity suggests stronger reactivity to be related to increased performance.

2. Methods

2.1. Participants

Sixty university students (28 men, 32 women) with a mean age of 24.5 years (SD = 3.7) participated. Exclusion criteria comprised severe physical diseases, psychiatric disorders, as well as the use of psychoactive drugs or medication