Biological Psychology 80 (2009) 325–332

Contents lists available at ScienceDirect

Biological Psychology

journal homepage: www.elsevier.com/locate/biopsycho

Effects of stress on heart rate complexity—A comparison between short-term and chronic stress

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ARTICLE INFO

Article history:
Received 13 September 2006
Accepted 21 November 2008
Available online 3 December 2008

Keywords:
Heart rate variability
Non-linear
Correlation dimension
Chronic stress
Short-term stress stressor

ABSTRACT

This study examined chronic and short-term stress effects on heart rate variability (HRV), comparing time, frequency and phase domain (complexity) measures in 50 healthy adults. The hassles frequency subscale of the combined hassles and uplifts scale (CHUS) was used to measure chronic stress. Short-term stressor reactivity was assessed with a speech task. HRV measures were determined via surface electrocardiogram (ECG). Because respiration rate decreased during the speech task ($p < .001$), this study assessed the influence of respiration rate changes on the effects of interest. A series of repeated-measures analyses of covariance (ANCOVA) with Bonferroni adjustment revealed that short-term stress decreased HR D2 (calculated via the pointwise correlation dimension PD2) ($p < .001$), but increased HR mean ($p < .001$), standard deviation of R–R (SD_{RR}) intervals ($p < .001$), low (LF) ($p < .001$) and high frequency band power (HF) ($p = .009$). Respiratory sinus arrhythmia (RSA) and LF/HF ratio did not change under short-term stress. Partial correlation adjusting for respiration rate showed that HR D2 was associated with chronic stress ($r = -.35$, $p = .019$). Differential effects of chronic and short-term stress were observed on several HRV measures. HR D2 decreased under both stress conditions reflecting lowered functionality of the cardiac pacemaker. The results confirm the importance of complexity metrics in modern stress research on HRV.

1. Introduction

For millennia we have understood that heart rate (HR) responds to stress. Two recent developments allow one to examine measures of this linkage more precisely. The first development differentiates between chronic stress exposure and responses to short-term stressors, i.e., reactivity. The second development deals with different ways of characterizing the fundamental properties of the HR itself and different ways of measuring its variability. This study examines how short-term stressors and long-term stress exposure relate to measures of HR and HR variability (HRV).

Exposure to chronic stress is a good predictor of cardiovascular disease. Ongoing troubles and the failure to resolve negative emotional states such as anger and anxiety generate imbalance between the sympathetic (SNS) and the parasympathetic nervous system (PNS), the two branches of the autonomic nervous system (ANS). An increase in the sympathetic-to-parasympathetic ratio (SPR) is now being linked to increased cardiovascular morbidity and mortality (Piccirillo et al., 1997; Gorman and Sloan, 2000; Rozanski and Kubzansky, 2005).

There are two major approaches how chronic psychosocial stress can be conceptualized in research on HRV. One is based on the measurement of major life events and assumes that experiencing major events such as divorce or death of a loved one requires adjustment that leads to psychological and/or physical symptoms (Selye, 1956; Moss, 1973). The other approach focuses on measures of minor incidents and hassles (e.g., argument with partner); that approach suggests that minor events are more common than major events and, thus, may be more salient for the individual at a single point in time (Kanner et al., 1981; DeLongis et al., 1982; Weinberger et al., 1987).

Research on HRV has generally focused on acute, laboratory stressors as opposed to chronic stress. Assessment of the impact of acute stress on HRV has been done utilizing cognitive (e.g., mental arithmetic), psychomotor (e.g., mirror tracing), or physical (e.g., cold pressor) challenges. Moreover, as standard laboratory stressors do not always engage subjects' affective response, social interaction stressors such as public speaking tasks are often

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doi:10.1016/j.biopsycho.2008.11.005

applied to provide a more appropriate social context in which negative emotions might be elicited (Waldstein et al., 1998).

Continuous changes in sympathetic and parasympathetic neural impulses exhibit alterations in HR and cause oscillation of the R–R interval around its mean value (HRV). Increasingly refined calculations have been developed to measure HRV. One of the more global and simple measures of HRV is the standard deviation of the mean R–R interval (SD_{RR}) (Berntson et al., 1997). When healthy subjects are acutely stressed, HR increases and SD_{RR} decreases transiently (De Geus et al., 1990; Boutcher and Stocker, 1996). Chronically stressed individuals, on the other hand, show decreased HR (Furlan et al., 2000; Lucini et al., 2005). Respiration has a strong influence on HR changes and is commonly included as a covariate in statistical analysis of the relation between stress and HRV changes (Berntson et al., 1997). Respiratory sinus arrhythmia (RSA) is the HRV in synchrony with respiration and represents the difference between the longest and the shortest heart period within the respiratory cycle (Berntson et al., 1997). RSA is known as an index of cardiac parasympathetic activity and usually decreases under acute psychological stress (Task force of ESC and NAPE, 1996; Houtveen et al., 2002). However, despite their value in estimating overall HRV or components of HRV related to respiration, these "time domain" measures have only limited application in cases requiring a more precise parsing of HRV pattern (Berntson et al., 1997).

"Frequency domain" methods such as spectral analysis and autoregressive techniques are applied to analyze an R–R interval time series on the basis of its frequency distribution. It is proposed that the instantaneous balance between sympathetic and parasympathetic activities can be captured by the ratio between low frequency band power (LF, 0.05–0.15 Hz) and high frequency band power (HF, >0.15 Hz); the latter represents primarily respiratory components. This ratio of LF/HF is sometimes referred to as a measure of "sympathovagal balance" (Pagani et al., 1986; Malliani et al., 1991; Task force of ESC and NAPE, 1996). Studies on healthy individuals show that acute stress increases LF/HF and decreases HF, suggesting activation of the SNS as well as withdrawal of PNS activity under stress (Pagani et al., 1997). However, data are far from being unequivocal that the LF/HF ratio represents a relative sympathetic modulation (Eckberg, 1997). Moreover, a major proportion of HRV occurs over a large frequency span showing broad, noise-like, irregular variability (Kobayashi and Musha, 1982). Such evidence supports critics who argue that the proposed rigid scheme of the frequency bands cannot cope with the complex and variable interactions between the different rhythms (Koepchen, 1991; Grasso et al., 1997; Lambertz and Langhorst, 1998; Cammann and Michel, 2002; Perlitz et al., 2004).

The interactions between multiple autonomic influences (e.g., PNS, SNS, hormones, preload, and afterload) causes the output from the cardiac pacemaker to fluctuate in an apparently random, i.e., chaotic manner (Denton et al., 1990). Moreover, under normal conditions, the HR generating system tends to be homeokinetic (rather than homeostatic), i.e., it fluctuates between a set of metastable states or attractors (Lipsitz and Goldberger, 1992; Lipsitz, 1995). Such structural and functional diversity of the sinus node leads to a large repertoire of responses and enables the heart to switch from one state to another quickly, perhaps a needed requirement for adaptation to external and internal challenges of everyday life (Goldberger et al., 2002). In this respect, a stronger regularity and decreased responsiveness of the cardiac pacemaker to changing circumstances may be associated with increased risk of disease (Pincus, 1994).

In recent years, a third class of HRV measures, the "phase domain" methods, has been developed in order to grasp the complex properties of the HR dynamics. These measures are derived from chaos theory and non-linear system theory and differ from the conventional HRV methods because they are not designed to assess the magnitude of variability but rather the quality, scaling, and correlation properties of the HR dynamics (Beckers et al., 2006). No strict definition of complexity exists (Kanters et al., 1997), and although irregularity and unpredictability are important characteristics, they alone are not sufficient to comprehensively describe complexity. The most widely applied complexity measure of HRV is the approximate entropy (ApEntr). The ApEntr measures the amount of *information* needed to predict the future state of a system thus providing an index of randomness or unpredictability of a system (Pincus, 1991). The higher the ApEntr, the smaller the likelihood that runs of patterns which are close remain close on the next incremental comparisons (Mäkikallio et al., 1996). A decrease in HR ApEntr has been found to be predictive of ventricular and atrial fibrillation and to correlate with the risk of sudden infant death syndrome (Pincus, 2001). A second measure, the largest Lyapunov exponent (LLE), captures the *dynamical* properties of the system orbiting within the attractor (Elbert et al., 1994). The LLE quantifies the sensitivity of a system to initial conditions, which manifests itself graphically as adjacent trajectories that diverge widely from their initial close position. A positive LLE indicates sensitive dependence on initial conditions and thus loss of predictability (Ruelle, 1979). Patients with major depression and no heart disease have a significantly decreased LLE which may be related to the higher risk of cardiovascular mortality in this group (Yeragani et al., 2002).

A third measure, the correlation dimension D2, focuses on the system's *geometric* (static) structure (Elbert et al., 1994). The D2 gives information about the number of independent functional components necessary to describe the underlying system and the degree of non-linear coupling between these components (Grassberger and Procaccia, 1983). The higher the D2 is, the more degrees of freedom of a system and, therefore, the greater the range of possible adaptive responses. However, as the D2 cannot be validly applied to non-stationary data which are typical for long epochs of biological data (e.g., ECG, electroencephalogram, EEG) the pointwise correlation dimension (PD2) is often alternatively used (Skinner et al., 1991, 1993). The PD2 is based on the presumption that the variability of a time series is determined and patterned. It provides a series of "point" dimensions irrespective of whether the system is stochastic or deterministic or is stationary in time (Nahshoni et al., 2004). Skinner et al. (1993) found in high-risk cardiac patients that PD2 reduction preceded lethal arrhythmias by hours, but was not reduced in high-risk controls having only non-sustained ventricular tachycardia. However, when the SD_{RR} was used to characterize HRV, no difference was detected between the two groups.

As yet, only a few studies have investigated the impact of acute stressors on various HR complexity measures in healthy individuals. Anishchenko et al. (2001) showed in healthy young subjects that short-term psychological stress was associated with both decreases and increases in HR complexity (i.e., normalized entropy) regardless of the type of stressor (i.e., noise exposure, mental arithmetic, arithmetic against noise, and examination stress). Moreover, Hagerman et al. (1996) demonstrated in ten healthy individuals (33–51 years of age) that the dominant LLE of HR significantly decreased during exercise stress. Finally, other authors showed decreases in the fractal dimension of HR after subjects had been stressed by prolonged exercise (Nakamura et al., 1993) and orthostatic hypotension (i.e., head-up tilt and lower body negative pressure) (Butler et al., 1994). To date, no study has investigated the influence of chronic psychosocial stress on HR complexity.