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Children's heart rate variability as stress indicator: Association with reported stress and cortisol

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ABSTRACT

Stress is a complex phenomenon coordinated by two main neural systems: the hypothalamic–pituitary–adrenal system with cortisol as classical stress biomarker and the autonomic nervous system with heart rate variability (HRV) as recently suggested stress marker. To test low HRV (5 minute measurements) as stress indicator in young children (5-10y), associations with self-reported chronic stress aspects (events, emotions and problems) ($N = 334$) and salivary cortisol ($N = 293$) were performed. Peer problems, anger, anxiety and sadness were associated with lower root mean square of successive differences (RMSSD) and high frequency power (i.e. lower parasympathetic activity). Anxiety and anger were also related to a higher low frequency to high frequency ratio. Using multilevel modelling, higher cortisol levels, a larger cortisol awakening response and steeper diurnal decline were also associated with these HRV patterns of lower parasympathetic activity. *Conclusion:* Low HRV (lower parasympathetic activity) might serve as stress indicator in children.

1. Introduction

Chronic stress is linked to psychological and physiological health complaints through behavioural responses and changes in the neuroendocrine system (Cohen, Janicki-Deverts, & Miller, 2007). Consequently, an adequate measurement of chronic stress is necessary. Stress is an adaptive, dynamic state that is composed of several aspects. The initiating stimulus is the 'stressor'. This is the environmental demand, challenge or event. When being confronted with these stressors, people evaluate whether this is a potential threat. This is the stress appraisal or perceiving phase. When homeostasis is threatened i.e. when there is a discrepancy between what is expected or the 'normal' situation and what is happening in reality, a physiological and psychological coping response will be initiated that induces arousal. Only if the person is unable to handle the persistent situation (chronic and uncontrollable stress), the sustained, chronic arousal can trigger long-term physiological, emotional, and behavioural disturbances (Koolhaas et al., 2011; Ursin & Eriksen, 2004).

Next to subjective reports (by questionnaires), also biomarkers can be used to measure stress. Two major neuroendocrine systems have been shown to adapt the organism to stress situations: the hypothalamus–pituitary–adrenal axis and the autonomic nervous system (Charmandari, Tsigos, & Chrousos, 2005). The first system starts in the hypothalamus by secretion of the corticotropin-releasing hormone that stimulates the pituitary which eventually stimulates the adrenal cortex to secrete cortisol as hormonal end product. The autonomic nervous system starts in the spinal-cord/brainstem, results in secretion of adrenaline/noradrenaline as main hormonal end products and can be divided in the sympathetic system that prepares the body for a fight or flight and the parasympathetic system that brings the body back from an emergency status to a resting status. In times of stress, this autonomic system will give priority to cardiovascular tone and high blood pressure, respiration and release of energy substrates, while it will temporarily suppress digestion, growth, reproduction and immunity. These two major pathways can be reflected by the biomarker cortisol and heart rate variability (HRV), respectively.

Abbreviations: CAR, cortisol awakening response; ChiBS, children's body composition and stress; HF, high frequency; HRV, heart rate variability; LF, low frequency; nu, normalized units; PA, parasympathetic activity; pNN50, percentage of consecutive normal RR intervals differing more than 50 ms; RMSSD, root mean square of successive differences; SA, sympathetic activity.

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Cortisol is the most commonly used biomarker for stress. Salivary cortisol sampling is stress-free and allows multiple sampling throughout the day in a natural environment. The secretion has a circadian rhythm with lowest levels around midnight and peak production in the early morning. Apart from this circadian rhythm, a cortisol awakening response (CAR) is elicited by a quick cortisol increase within 30 min after wake up (Fries, Dettenborn, & Kirschbaum, 2009). In general, the CAR reflects the anticipation of the upcoming day by activation of memory representation and by orientation in time and space. Next to the single cortisol values, these cortisol patterns (CAR and the diurnal slope) may serve as an index of adrenocortical activity on longer term. The reported associations between stress-exposure and cortisol levels are quite complex. A hyper-/hypo-cortisolism hypothesis suggested that recent exposure to a stressor may initially elevate cortisol levels (hypercortisolism with high morning cortisol and steep diurnal slope), while the axis may develop a counter-regulatory response of cortisol lowering after extended stress exposure (Heim, Ehlert, & Hellhammer, 2000). In a previous analysis, evidence for hypercortisolism was found in our young population since negative events and emotional problems were related to a steeper diurnal slope and low happiness with a higher overall, morning and evening cortisol, although peer problems were associated with lower overall cortisol levels in girls (Michels, Clays, et al., 2012).

Another promising and increasingly used stress marker is HRV. High HRV is defined as high variability of the distance between consecutive *R* peaks of the heart beat signal. This vital variability reflects the heart's ability to respond to physiological and environmental stimuli. Because of the specific autonomic nervous innervations of the heart, HRV is recognized as a quantitative marker of this autonomic nervous system: it is influenced by sympathetic activity (SA) and vagal parasympathetic activity (PA) (Task Force of, ESC/NASPE, 1996). These SA and PA innervations on the sinus node of the heart control the firing of electrical impulses that stimulate heart contraction. Importantly, the PA regularly sends inhibitory signals e.g. at expiration, with a temporary reduction of the heart rate as a result. When this PA innervations are pathologically attenuated, the sinus node will fire at its intrinsic rate, resulting in a lower variability of the heart rate i.e. low HRV. As stress influences this autonomic system, HRV can be used as an index of chronic stress, e.g. work related stress (Chandola, Heraclides, & Kumari, 2010). Low PA has previously been linked with poor emotion regulation, high stress, decreased stress reactivity and increased stress vulnerability, also in children (Porges, 1995; Porges, Doussard-Roosevelt, & Maiti, 1994). Moreover, a reduction of HRV (i.e. reduced PA due to changes in the innervations with or without increased SA) is a pathway linked to higher morbidity and mortality (Thayer, Yamamoto, & Brosschot, 2010) and consequently, HRV may be a potential pathway linking stress to ill health (Thayer & Brosschot, 2005).

The hypothesis of the present study is that 5-minute HRV parameters (especially low PA) could serve as chronic stress indicator. Since developmental changes have been shown in HRV with age-related wave-like increases in PA (Galeev, Igisheva, & Kazin, 2002), it is interesting to test this hypothesis also in children. After all, research on HRV as stress marker is very scarce in this population, although the prevalence of stress/mental health problems is already high in childhood (Kieling et al., 2011) and HRV has been shown to be a risk factor for disease also in children (Zhou, Xie, Wang, & Yang, 2012). Children's HRV will be tested as chronic stress indicator. Low HRV (=low PA) is hypothesized to be associated with (1) questionnaires on stress-related aspects and (2) hypersecretion patterns of the biomarker salivary cortisol. To cover several aspects of stress, different questionnaires will be used. Furthermore, measuring cortisol at several time points will enable the consideration of alternative cortisol parameters across the day (overall cortisol levels, the CAR and the diurnal decline). As studies on the basal cortisol–HRV relation are almost non-existing, this paper will broaden the knowledge on the equilibrium between these two homeostasis systems.

2. Methods

2.1. Participants and general procedures

Participating children were recruited from the Belgian ChiBS study (Children's Body composition and Stress) that examines the association between stress and body composition evolution over 2 years (2010–2012). Detailed aims, methods and population characteristics were described elsewhere (Michels, Vanaelst, et al., 2012). Children were selected by random cluster sampling (primary school children in the selected city of Aalter, Belgium). Data was collected from February till June 2010 (the ChiBS baseline survey) when the children were between 5 and 10 years old. The study was conducted according to the Declaration of Helsinki and the project protocol was approved by the Ethics Committee of the Ghent University Hospital. Written informed consent was obtained from the parents.

The different measurement modules (i.e. salivary cortisol, HRV, questionnaires) were optional and were performed under different conditions: parents had to make an appointment at the local sports park for the HRV measurement and questionnaire administration, while salivary cortisol was sampled at home. In total, 523 children participated in the ChiBS survey. To enable exclusion of unhealthy subjects, parents had to fill in a medical questionnaire. Concerning HRV related diseases, one child with a cardiovascular disease was excluded and no cases with diabetes were reported. Concerning cortisol, no Cushing or Addison patients were found in our population. No clinical psychopathologies were reported. Because of high quality control for HRV and cortisol data (see respective sections) and the different modules being optional, 432 children had complete HRV data, 310 had complete cortisol data and 484 had stress questionnaire data. Consequently, the analyses for HRV versus reported stress (questionnaire data) were performed in 334 children and for HRV versus salivary cortisol in 293 children. No difference in sex, parental education and physical activity was observed between children included and not included in these two sets of analyses, but those included were somewhat older.

Physical activity was studied as the parental reported hours of physical activity per week (both at sports club and outdoors) and was used as confounder of HRV. Parental education was used as proxy variable for the socio-economic status using the International Standard Classification of Education. Further categorization was done into 2 groups: low (=up to secondary education) and high (=tertiary education) status.

2.2. Heart rate variability

Inter-beat RR-intervals were recorded at a sampling rate of 1000 Hz with the elastic electrode belt Polar Wearlink 31 using a Windlink infrared computer transmitter. This low-cost device has been validated against an electrocardiogram device in children (Gamelin, Baquet, Berthoin, & Bosquet, 2008). Each child was individually examined in a quiet room in the supine position during 10 min. Children were asked to refrain from strenuous physical activity on the measurement day. The heart rate belt was fixed around the chest and measurements were started when the signal was stabilized. Each child was encouraged to breath normally and not to speak or move during the measurement. In the occasion of sudden irregular respiration, the registration was cancelled, as such minimizing breathing influences. Further data processing was done with the free, professional HRV Analysis Software of the University