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Adaption of cardio-respiratory balance during day-rest compared to deep sleep—An indicator for quality of life?

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ABSTRACTS

Heart rate and breathing rate fluctuations represent interacting physiological oscillations. These interactions are commonly studied using respiratory sinus arrhythmia (RSA) of heart rate variability (HRV) or analyzing cardiorespiratory synchronization. Earlier work has focused on a third type of relationship, the temporal ratio of respiration rate and heart rate (HRR). Each method seems to reveal a specific aspect of cardiorespiratory interaction and may be suitable for assessing states of arousal and relaxation of the organism. We used HRR in a study with 87 healthy subjects to determine the ability to relax during 5 day-resting periods in comparison to deep sleep relaxation. The degree to which a person during waking state could relax was compared to somatic complaints, health-related quality of life, anxiety and depression. Our results show, that HRR is barely connected to balance (LF/HF) in HRV, but significantly correlates to the perception of general health and mental well-being as well as to depression. If relaxation, as expressed in HRR, during day-resting is near to deep sleep relaxation, the subjects felt healthier, indicated better mental well-being and less depressive moods.

1. Introduction

Beat-to-beat changes of heart rate (HR), i.e. heart rate variability (HRV), can be analyzed in the "time domain" by statistical measures (e.g. average, standard deviation) or in the "frequency domain" using spectral analysis. In the frequency domain different frequency bands have been defined (high frequency—HF, low frequency—LF, very low frequency—VLF), ultra low frequency—ULF) and it has been shown that they may be used as indicators of autonomic nervous system (ANS) activity (Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology, 1996). The high frequency band (HF) reflects vagal activity, whereas low frequency (LF) is an indicator of both sympathical and parasympathical influences on HR and captures baroreflex rhythm. VLF expresses vagal and renin-angiotensin system effects and ULF circadian influences on HRV (Stein and Pu, 2012).

Respiratory activity modulates cardiac action, giving rise to respiratory sinus arrhythmia (RSA). By analyzing beat-to-beat changes of the RR-interval, i.e. the RR interval series, using a single channel ECG with a sufficiently high sampling rate and without artifacts from physical activity, it is possible to obtain clinically reliable respiration frequency from RSA during resting periods. In addition, as a consequence of respiration induced diaphragm movements, changes of the electrical axis of the heart can be used to derive respiration frequency from the ECG (Cysarz et al., 2008b; Moody et al., 1986).

Heart rate and breathing rate represent two weakly coupled physiological oscillations. Analysis of this interaction has been a challenge for decades (Pessenhofer and Kenner, 1975). Recent work focused e.g. on cardio-respiratory phase synchronization. This type of coordination represents the occurrence of heartbeats at the same phase of consecutive respiration cycles and changes significantly during sleep stage transitions, but seems to be hardly correlated with RSA (Bartsch et al., 2012). Further methods to determine synchronization of the two rhythms have been used (Hamann et al., 2009; Moser et al., 1995; Schafer et al., 1998). Recently, cardiorespiratory coordination has been suggested as an indicator of general health (Cabiddu et al., 2012).

However, some recent scientific work analyzing the temporal ratio of respiration and heart rate regardless of synchronization or coordination (heart respiration ratio, HRR) has not gained

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much attention although this ratio is the basis for the analysis of cardiorespiratory synchronization. HRR exhibits a circadian rhythm (Bettermann et al., 2002) which varies considerably during the day in the same individual and between different individuals. HRR is particularly influenced by physical activity (Moser et al., 1995) and possesses the unique feature of approaching a median of four (4) heart beats per breathing cycle during night sleep among larger samples. This ratio seems to be independent of the individual's heart rate pattern during day and at night and even of the study population being examined (Cysarz et al., 2008a; Hildebrandt, 1999). The decrease of heart rate is primarily attributed to the change of posture from upright to the supine position during nocturnal sleep, whereas the reduction of respiration rate is mainly a consequence of the transition from waking to sleeping (Naifeh et al., 1987).

HRR can be used as a simple measure of cardio-respiratory coordination (Hoyer et al., 2004) and to assess the ability to recover after physical activity (Hildebrandt, 1999; Matthiolius et al., 1995). Even if HRV and HRR detection uses the same source of physiological information from the basic data of an ECG, HRR and all other HRV parameters barely correlate during night sleep and there is only a weak correlation of HRR and HRV observed during the day (Cysarz et al., 2008a).

Accordingly, the information contained in HRR differs from the information contained in HRV and its relationship with physiological and psychological parameters is still unsatisfactorily explained.

1.1. Heart rate variability, sleep and health

HRV shows a significant 24 h circadian variation. It has been suggested that deep sleep is an optimal condition for determining HRV (Brandenberger et al., 2005). Among all, the first deep sleep phase is usually the longest and therefore particularly suitable for investigating cardio-respiratory variables. HRV can be used to differentiate between REM sleep and NREM sleep. Heart rate decreases in association with decreased variability in sleep stages 1–4, whereas HR increases in REM sleep. HF increases in deep sleep, peaking in stages 3 and 4 (Zemaityte et al., 1984). During deep sleep, the LF/HF quotient is low and also the interbeat autocorrelation coefficient decreases (Otzenberger et al., 1998). Before and during REM sleep phases, sympathetic activity increases and likewise LF/HF (Cabiddu et al., 2012). Spectral bands in the electroencephalogram (EEG) are closely linked to cardiac autonomic activity in the LF and HF-bands of HRV. Among the EEG bands, the delta power band varies mostly in response to HF variability, reflecting vagal cardiac autonomic regulation. It has also been observed, that changes in cardiac autonomic activity precede changes in the EEG power bands during sleep (Jurysta et al., 2003). Deep sleep is characterized by long-wavelength EEG activity (Slow-Wave-Activity, SWA). SWA peaks during the first hours of sleep and diminishes evenly during a sleep cycle.

Cardio-respiratory phase-synchronization is high during deep sleep and low during REM sleep. Episodes of n:m synchronization occur in all sleep stages with a dominance of n:1 synchronization. There is a consistent decrease in synchronization observed in stage transitions from deep sleep to REM (Bartsch et al., 2007; Bartsch et al., 2012).

Cardio-respiratory phase synchronization changes in accordance with the state of health and is more pronounced in athletes than in non-athletes (Cabiddu et al., 2012). Deep sleep deprivation had a substantial effect on sleepiness, motor and cognitive performance, and mood during the following day (Ferrara et al., 1999). In conclusion, a sufficient duration of deep sleep seems to be important for physical recovery, alertness and concentration ability.

A short resting period during the day of <30 min improved alertness and learning ability. In contrast, longer resting periods have been associated with less favorable mental performance and are correlated to higher morbidity and mortality, particularly in the elderly (Dhand and Sohal, 2006). Little is known of how much the duration of a resting period influences HRR and HRV.

In an earlier study (von Bonin et al., 2001) we found indications for a correlation between the state of health and the ratio of HRR during day-resting (D-HRR) and HRR during the first deep sleep phase (NREM-HRR). This ratio D-HRR/NREM-HRR was defined as day-night-index-HRR (DNI-HRR). Thus, it might represent a persons' ability to quickly achieve a parasympathetic state during the day and could be used as an indicator for adaptation and recovery ability. In this exploratory case study, we investigated the behaviors of HRV and HRR of healthy individuals under normal life conditions in relation to physical health and well-being, using five short resting-periods during the day and the first deep sleep phase of the night for assessment.

We hypothesize that HRV and HRR contain different information. Second, a DNI-HRR close to 1 corresponds to a better state of physical health and better well-being than a DNI-HRR considerably higher than 1. The more HRR (and possibly the HRV-variables) during a day-rest corresponds to the same values during the first phase of deep sleep, the better the regenerative ability of the organism will be.

2. Methods

2.1. Study participants

All holders of a life insurance policy (in one company) of $>200{,}000$ Swiss Francs in the canton of Berne, Switzerland, born between 1954 and 1968 ($n=300$) received a postal invitation to participate in the study. Out of these, 167 persons announced interest in participating. They received a detailed description of the study, including an informed consent. On receiving written consent, a first consultation was arranged with the study physician. Of those interested ($n=167$), 140 persons fulfilled the entry criteria and were enrolled in the study. They received a second appointment at the Insel Hospital Berne for a detailed physical examination, taking of blood sample, and instructions. Final inclusion criteria were good physical health and mental well-being (see Tables 2 and 3). Exclusion criteria were heart disease, hyper- or hypotension, diabetes mellitus, obesity, smoking, menopause, as well as treatment at the time with beta-blockers, other antiarrhythmics, antibiotics and psycho-active medication and severe sleep disorders. The study was approved by the local ethics committee (KEK 21/04). No remuneration was provided to the participants.

2.2. Examination sequence

A medical intern collected a structured history, performed a physical examination and draw a blood sample of the subjects. To assess subjective somatic complaints, health-related quality of life and the most frequent mental impairments, the Freiburg List of Complaints FBL, the Short-Form-12 Health Questionnaire SF-12 and the Hospital Anxiety and Depression Scale HADS-D were applied (Laederach-Hofmann et al., 2007). The participants then received instructions and a Holter ECG was attached. The participants had to fill in an activity protocol (diary) to note activities and sleeping times during the recording. They were instructed to lie down and relax at their home or work place for 15 min at 9 a.m., 11 a.m., 1 p.m., 3 p.m., and 7 p.m. For this purpose, they were given a resting-set, containing pillow, blanket and a portable mat. On the following day, the participants returned the Holter ECG and materials and completed the study.

2.3. Calculation of HRV and HRR

HRV data were extracted from a single channel Holter ECG (Medikorder MK3, TOM-Medical, Graz, Austria). The sampling rate for obtaining the RR-tachogramm to calculate HRV was 4096 Hz. The ECG was saved at a sampling rate of 128 Hz to reduce memory consumption of the Holter recorder. Before analysis, the ECG was visually inspected for artifacts and analyzed with MATLAB Software (The Mathworks, Natick, MA, USA). HRV parameters in the time and frequency domains were calculated according to the standards of the Task Force (Anonymous, 1996). In the time domain, the standard deviation of normal-to-normal intervals (SDNN) reflects