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Is slow wave sleep an appropriate recording condition for heart rate variability analysis?

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Abstract

Heart rate variability (HRV) analysis holds increasing interest but electrocardiographic (ECG) recordings are strongly disturbed by body movements, changes in environment and respiration. Here we give arguments for the use of slow wave sleep (SWS) as an appropriate recording condition. Sixteen healthy subjects aged 21–31 years (10 males, 6 females) underwent polygraphic sleep, ECG, and respiratory recordings during one experimental night. HRV was analyzed in 5-min SWS segments and compared to data collected during quiet wake in the morning with controlled breathing, using for each individual the same respiratory frequency as that recorded during SWS. SWS has two major advantages. First, it is a quiet sleep period, free of any external confounding events and is characterized by fewer body movements or arousals that cause abrupt heart rate (HR) increases which disrupt the ECG signal. Second, SWS avoids the deleterious effect of controlled breathing on HRV. Respiratory cycles were spontaneously more regular during SWS than during generally used wake (Standard deviation (SD) of the respiratory cycles was 0.27 ± 0.02 s during SWS vs 0.42 ± 0.07 s during wake under controlled breathing; $p < 0.01$). Compared to quiet wake, the SD of normal R–R intervals reflecting global variability was significantly lower during SWS (54.3 ± 4.7 vs 78.8 ± 6.1 ms; $p < 0.001$) and the normalized high frequency power was increased (0.57 ± 0.04 vs 0.51 ± 0.03; $p < 0.05$), suggesting a higher parasympathetic control of the heart. Thus, SWS offers a "self-controlled" and undisturbed moment of observation for assessing time and frequency domain HRV indexes. Its relevance as an optimal ECG recording condition has to be confirmed in various experimental conditions.

Keywords: Autonomic nervous system; Heart rate variability; Sleep

1. Introduction

Heart rate (HR) variability (HRV) holds growing interest for clinicians because of the predictive association between reduced HRV and higher cardiovascular risks and all-cause mortality (Bigger et al., 1993; Tsuji et al., 1994, 1996). HRV can be quantified by time and frequency indexes (Akselrod et al., 1981; Task Force, 1996). The standard deviation of normal R–R intervals (SDNN) reflects global variability, whereas the root-mean-square of successive normal R–R interval differences (RMSSD) and high frequency (HF) power are thought to be linked to vagal activity. Despite certain divergences (Eckberg, 1997; Houle and Billman, 1999) low frequency (LF) power is usually considered as an index of sympathetic activity with a parasympathetic component and the LF/HF ratio, or the normalized LF/(LF+HF) ratio, is thought to represent sympathovagal balance at rest (Task Force, 1996; Malliani, 1999).

To quantify HRV, an electrocardiographic (ECG) signal is recorded using chest electrodes to obtain a QRS complex with sufficient amplitude and stable baseline. One of the difficulties facing HRV analysis is the confounding influence of environmental factors and movements that upset the stationarity of ECG recordings and can warp the data interpretation. HRV is also strongly influenced by changes

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in respiration (Brown et al., 1993; Bernardi et al., 2000). This major influence is often ignored in studies concerned with HRV changes in different experimental situations.

HRV indexes have been determined under various conditions of observation. Taking as an example the field of sports science, HRV has been generally examined during short-term supine wake periods under spontaneous or controlled breathing (Uusitalo et al., 1998; Buchheit et al., 2004b,c) but also during standing ECG recordings (Janssen et al., 1993), during exercise (Buchheit et al., 2004a), and during 24-h Holter recordings (Bonaduce et al., 1998; Catai et al., 2002), with sometimes distinct analysis of night- and daytime data (Catai et al., 2002) or during the night only (Pichot et al., 2000; Bosquet et al., 2003). Nighttime recordings are interesting because sleep constitutes a condition free of external disruptive events. However, sleep is not a uniform state, but is characterized by large variations in the sympathovagal balance all along the non-rapid eye movement (NREM)–rapid eye movement (REM) sleep cycles with switches from low SDNN, low LF/(LF+HF) and low interbeat autocorrelation coefficient between successive R–R intervals (R–R_n and R–R_{n+1}, rRR) during slow wave sleep (SWS) and the preceding sleep stage 2 to high levels of these HRV indexes during REM sleep (Zemaityte et al., 1984; Berlad et al., 1993; Vanoli et al., 1995; Trinder et al., 2001; Brandenberger et al., 2001). Sleep is associated with body movements and spontaneous electroencephalographic (EEG) arousals throughout the night and is also interrupted by short- and long-term awakenings, which all evoke prominent HR increases that disrupt the ECG signal. Thus the marked modifications of autonomic activity that appear across the night can exert a masking effect when all-night recordings are considered.

In this report, we will give arguments for the use of ECG recordings during SWS for correctly assessing time and frequency domain HRV indexes.

2. Material and methods

Sixteen subjects (10 males, 6 females) aged 21–31 years participated in the study. They were not taking any medication, did not smoke and had normal eating habits. They had a body mass index between 20 and 25 $kg.m^{-2}$. Before the study, a clinical examination was performed including a screening of medical, surgical and family antecedents, a physical examination including supine and standing blood pressure measurements and an ECG. The subjects gave written informed consent to participate in this study, which was approved by the local Ethics Committee.

2.1. Protocol

The experiments were performed in soundproof, air-conditioned sleep rooms following two days free of strenuous physical activity. Since results from a previous study (Buchheit et al., 2004b) did not reveal any difference in HRV indexes during SWS in the habituation night and the experimental night (SDNN: 50.7±3.4 vs 56.0±4.8 ms; NS; HF/(LF+HF): 0.56±0.03 vs 0.57±0.03; NS), only one experimental night was conducted in the present study. Cardiac and polygraphic sleep recordings were made from 2100 to 0700 h with a sampling frequency of 256 Hz using an Astro-Med EEG system (Grass Instruments, West Warwich, RI, USA). The continuous ECG signal was obtained with a modified C5 lead connecting the electrodes to an analog preamplifier. The R–R sequence was extracted from the ECG signal using an automated R–R extraction algorithm (R–R Interval Software, Astro-Med EEG System). Four electroencephalograms (EEG) (F3, C3, P3 vs A2 and C4 vs A1), one chin electromyogram and one electrooculogram were recorded. Electrodes for sleep and cardiac recordings and the sensor straps for respiratory recording were applied between 2000 and 2100 h. Thoracic and abdominal movements were recorded using a Crystal Trace Piezo Respiration Sensor (Astro-Med System) to determine breathing frequency. Subjects were supine from 2100 to 2300 h. Lights were switched off from 2300 to 0700 h, when the subjects were awakened. They were then asked to empty their bladder. After 20 min of rest lying down, subjects were asked to stay quietly supine for 10 min without speaking or making any movement. Each subject breathed at the frequency recorded during the first SWS episode by synchronizing the breathing pattern with an electronic metronome rhythm, so that the respiratory rate would influence HR oscillations in the same way during SWS and during wake.

2.2. Sleep analysis

Polygraphic sleep recordings were visually scored at 30-s intervals using standardized criteria (Rechtschaffen and Kales, 1968) to get the overnight pattern of sleep stages.

2.3. HRV analysis

The first 5-min ECG stationary segment in the first SWS episode lasting at least 15 min, without any ascending or descending slow HR trend (slope of all R–R <1%) was used to determine HRV indexes during sleep. It was verified that this segment presents a round cluster of points (Poincaré plot) and a low rRR which characterize SWS and indicate the absence of abrupt HR changes (Zemaityte et al., 1984; Otzenberger et al., 1998). During quiet wake in the early morning hours, the last stationary 5-min segment of the controlled breathing period was analyzed. The R–R intervals, i.e. the length of time between the R peaks of consecutive QRS complexes, were calculated and checked for artifacts. Occasional ectopic beats were identified and replaced with interpolative R–R interval data. Each R–R interval was plotted against the previous R–R interval to produce a 5-min Poincaré plot (R–R_{n+1} vs R–R_n). The rRR, (Otzenberger et al., 1998), the mean of R–R intervals