U-shaped patterns in HRV from a polysomnographic point of view: a quantitative analysis

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Abstract

U-shaped patterns are acceleration-deceleration periods in RR interval series, observed mostly during sleep. These relatively short time events (average duration 29.8±4.1 s) are the most laminar structures in the night-time recordings. The aim of this study is a quantitative analysis of sleep events occurring during U-shaped patterns in polysomnography recordings obtained from Sleep Heart Health Study database. 500 polysomnography recordings were analyzed. U-shaped patterns were detected and categorized based on sleep stages, body position, respiratory events and EEG arousals. 4202 U-shaped patterns were found in 463 recordings with a mean value of 8.4(7.7) per patient. The majority of U-shaped patterns coincide with EEG arousals (73.9%). 48% of the patterns occurred at sleep phase changes. Most of the U-shaped patterns were associated with the Wake phase (61%). U-shaped patterns occurred at different body positions: supine – 26.0%, prone – 22.4%, right – 15.2%, left 14.3% and at the position changes – 22.6%. Analysis of respiratory events showed that U-shaped patterns occurred during hypopnea in 32.3% of the cases, central apnea – 1.7%, obstructive apnea – 0.8% and desaturation – 18.6%. The quantitative analysis of polysomnography recordings is a first step to discover the origin of the phenomenon of U-shaped patterns. These first observations show that the U-shaped patterns are strongly associated with EEG arousals and may play role in sleep regulation.

1. Introduction

U-shaped patterns are characteristic changes of the heart rate observed during sleep. They are, in a domain of RR time intervals, the most laminar structures in night-rime recordings. They are defined as acceleration-deceleration periods in RR interval series, with duration between 20-40 s, and amplitude at smaller at least than 85% of the mean RR interval [1, 2].

U-shaped patterns were widely observed in healthy humans. Previous studies showed that these patterns have a considerable impact on the HRV parameters describing the VLF component, persistency, nonlinear correlations and multifractal properties, although their percentage contribution is small compared to the whole night-time series (on the average 3.1±1.7%) [1,3].

It is not completely clear which physiological mechanisms trigger U-shaped patterns in humans. Yazdani et al. using polysomnography recordings reported moderate correlation with movements during sleep [2]. In the literature we found many examples of acceleration-deceleration periods of RR time intervals during sleep associated with the sighs, leg movements, sleep apnea (i.e. cyclical variations of heart rate), arousals [4-7]; however, in most cases these changes of heart rate were too short and with smaller amplitude in comparison to U-shaped patterns. The phenomenon is different from the well-known HRV asymmetry observed by Porta et al [8]. This study is our first attempt to quantitative analysis of sleep events occurring during U-shaped patterns and investigate the origins of this phenomenon using polysomnography data.

2. Data

We use 500 polysomnography recordings (244 males; 59.7(10.7) years and 256 females; 60.6(10.3) years) from Sleep Heart Health Study (SHHS) database [9,10] which is a part of The National Sleep Research Resource collection. The SHHS study was implemented by the National Heart Lung & Blood Institute to determine the cardiovascular and other consequences of sleep-disordered breathing (ClinicalTrials.gov Identifier: NCT00005275). In selected group, 142 of patients had hypertension, 110 reported usually runny and snuffy nose, 101 frequent sinus infection, 21 diabetes, 38 asthma, 20 myocardial infraction and single cases of other cardiovascular and respiratory diseases.

Unattended polysomnography recordings were performed in home using The Compumedics P-Series Sleep Monitoring System. The system recorded the collection of signals: SpO_2, heart rate (HR), EEG (C3-A2 and C4-A1), ECG (one channel), EOG (left and right), EMG, Respitrace Inducatnce Plethysmography (Thorax and Abdomen), Body position, external ambient light and nasal airflow. Sleep stages will be identified for each 30 second epoch using Rechtshaffen and Kales criteria [11]. EEG arousals and breath-related events such as: hypopneas (identified if the amplitude of any respiratory signal is reduced by 30% of the amplitude of "baseline", if this change lasts for ≥ 10 s and for >2 breaths), SpO_2 desaturation, obstructive and central sleep apnea (OSA, CSA) were annotated using standard criteria.

3. Methods

U-shaped patterns were detected from night-time RR intervals series using automatic algorithm based on support vector machines. Next, the number and the percentage of total detected U-shaped patterns coexistence with the sleep events were calculated. The coexistence with the pattern was annotated when the sleep event begun or ended in any moment of occurring of the U-shaped pattern.

4. Results

The results descriptive analysis of total number of U-shaped patterns detected in the study group were presented in Table 1. U-shaped patterns were found in 92.6% of patients and mean number of U-shaped patterns was 8.4(7.7) per patient. We observed that the number of U-shaped patterns increasing with the sleep time. The histogram of probability density of occurring U-shaped patterns in the following hours before wake up was showed in Figure 1.

The most common case of the coexistence of U-shaped patterns and the other sleep events was presented in Figure 2. In this example U-shaped patterns occurred at the EEG arousal, wake sleep stage, and excitations in EMG, EEG, Thorax and Abdomen signals, but with no change in SpO_2 level.

Table 1. Descriptive analysis of the number of U-shaped patterns and their properties in the study group.

Total number of U-shaped patterns	**4202**
Mean per patient	8.4(7.7)
Min-max	0-47
Number of patients with at least one U-shaped pattern	463/500 (92.6%)
Mean length	44(12) RR intervals
Mean relative amplitude (related to mean RR interval)	66.9(15.3)%

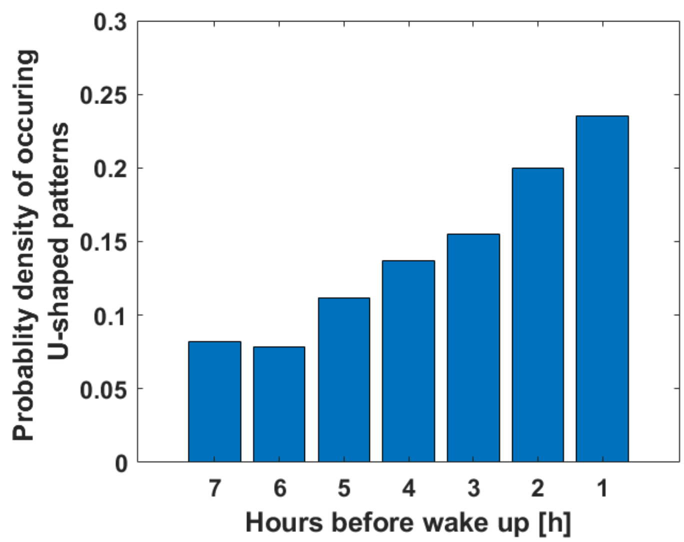

Figure 1. Probability density of the occurrence of the U-shaped patterns in the last 7 h of sleep.

U-shaped patterns occurred with the wake stage in 27.5% cases, 12.1% during N2, 11.0% during REM, 0.7% during N3 and 0.7% during N1. The rest 48% of U-shaped patterns occurred at sleep stage changes (33.4% of the patterns occurred at sleep stage changes from or to wake stage). The percentage distribution of the sleep stages in a study group with at least one detected U-shaped pattern was: N2 – 43%, W – 24%, REM – 16%, N3 – 12%, N1 – 4% and N4 – 1%.

Significantly more U-shaped patterns were detected at supine and prone body position, 25.6% and 22.4% of total number of the patterns, respectively, in comparison to back positions – 15.2% at right and 14.3% at left. 22.5% of all detected U-shaped patterns occurred during body position changes. The percentage distribution of the body position in a study group with at least one detected U-shaped pattern was: supine – 32%, prone – 22%, right – 23% and left – 23%.

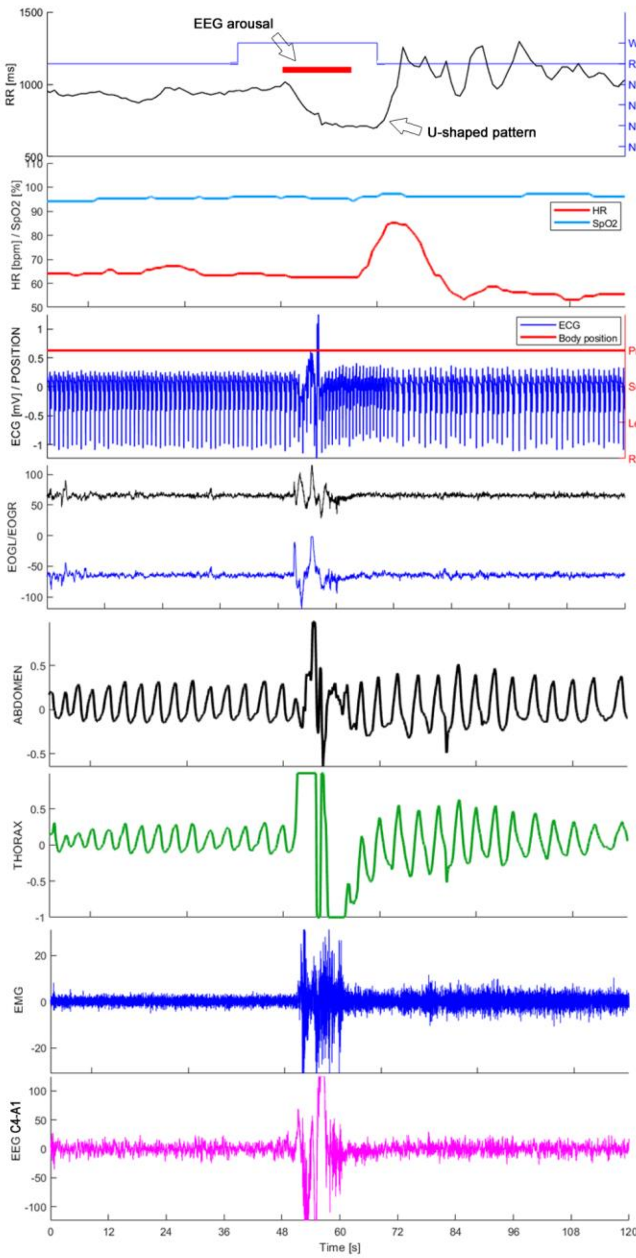

Figure 2. Example of U-shaped pattern, sleep events and the signals obtained from unattended polysomnography recording.

We observed high coexistence level between U-shaped patterns and EEG arousals. 73.9% of all detected patterns occurred at these events. Considering breath-related events, 32.3% of all U-shaped patterns occurred during hypopnea, 18.6% during SpO_2 desaturation and only 0.8% and 1.7% with OSA and CSA, respectively.

Table 1. Percentage of U-shaped patterns occurred at sleep events.

Sleep event	Total number of events in database	% of U-shaped patterns occurred at the sleep event
EEG arousal	51 077	73.9% (3105/4202)
Hypopnea	92 823	32.3% (1357/4202)
SpO_2 desaturation	61 880	18.6% (780/4202)
OSA	5 081	0.8% (34/4202)
CSA	1 646	1.7% (71/4202)

5. Discussion

Low level of coexistence between the U-shaped patterns and body position changes, OSA, CSA enhances prior assumptions, based on literature findings, that the main origin of U-shaped patterns are not movements and apneas (unfortunately, in SHHS database there are not signals from leg movements). At once, the quantitative analysis showed that the largest number of U-shaped patterns occurred at Wake sleep stages (27.5% of all U-shaped patterns), sleep stage changes from or to Wake stage (33.4%) and EEG arousals (73.9%). 1738/4202 (41.4%) of U-shaped patterns occurred during either Wake stage (or sleep stage changes from or to Wake stage) and EEG arousal (according to arousals classification criteria, brief arousals (e.g. arousals < 15s. long) do not automatically require a change in sleep stage).

Arousals are divided in 4 levels, including D-bursts and K-bursts (*subcortical* arousals), the standard definition of a microarousal (MA) and phases of transitory activation (PAT; MA and PAT are considered as *cortical* arousals) [12]. We found similarities between U-shaped patterns and heart rate responses to PAT arousals including duration, mean number at night (per patient) and distribution during sleep [12, 13]. The examples of cardiac responses to PAT arousals, similar to the U-shaped patterns, was found in the study by Basner et al. [14] as well.

EEG arousals play a regulatory role in the sleep. It was shown that cardiac responses due to these sleep events are initialized by sympathetic activation [12]. The number of arousals rely on sleep propensity and sleep pressure. At the beginning of the night, when the sleep pressure is high, the arousal threshold is relatively high and peaking of subcortical D-bursts and K-bursts, characterized by lower cardiac responses, is present. Alternatively, at the end of the sleep, the arousal threshold is lower and the number of cortical (PAT) arousals (with much stronger cardiac responses) increases. It is complementary with the probability density of U-shaped patterns observed in this and our previous studies. Following this hypothesis, U-shaped patterns, as the cardiac response of cortical arousals (PAT), may be considered as a marker of sleep regulation. It is also supported by Yazdani et al. study which showed that the features of U-shaped patterns change due to sleep deprivation [15].

6. Conclusions

U-shaped patterns are associated with EEG arousals, much stronger in comparison to the other sleep events analyzed in this study. We found many similarities between cardiac responses (initialized by sympathetic activation) due to PAT arousals and U-shaped patterns. Further verification, primarily made by annotation of PAT arousals in analyzed database should be performed.

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