Heart Rate Variability during Pulse Photoplethysmography Decreased Amplitude Fluctuations and its correlation with Apneic Episodes

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Abstract

In this study the heart rate variability (HRV) during Decreases in the Amplitude fluctuations of Pulse Photopletysmography signal (PPG) events (DAP) was analyzed for evaluating the possible relations and involvements of the autonomic nervous system, mainly in presence of apneas.

The study uses 45 fragments containing a DAP event and being free of artifacts or other physiologic events which were classified as apneic and non-apneic. A HRV signal processing was carried out in order to obtain several time and frequency indexes. The Smooth Pseudo Wigner-Ville Distribution was used for the analysis of HRV.

One way ANOVA tests for repeated measures and t-tests were carried out in order to analyze the parameter time evolution and differences between groups.

The results show an increase in sympathetic activity during DAP which is deeper for apneic events. Several indexes have shown statistical difference between groups so HRV seems to improve the usefulness of PPG in sleep studies.

1. Introduction

Obstructive sleep apnea syndrome (OSAS), the most common form of sleep disordered breathing (SDB), is characterised by repetitive episodes of upper airway obstruction during sleep, involving periods of breathing cessation [1]. The prevalence of OSAS is estimated as 2% to 3% in children, most of whom are undiagnosed and untreated. The resulting sleep fragmentation and blood gas modifications cause malfunctioning of sleep-related restorative processes, and induce chemical and structural injuries in the cells of the central nervous system. Not only does that cause daytime sleepiness, but it can, in turn, lead to systemic hypertension and an increase in the likelihood of cardiovascular diseases. Childhood is a critical time for acquiring core academic and social skills, and repeated failures related to sleep fragmentation at critical stages of development can fundamentally influence a child's motivation and behavior. Currently, the preferred treatment is the application of continuous nasal-positive airway pressure (CPAP) via a nasal mask in adults, and an adenotonsillectomy is the first line of treatment for most children.

The gold standard diagnostic test for OSAS is overnight polysomnography (PSG). A number of alternatives to PSG have been proposed because of the cost and requirement for technical expertise. One alternative to PSG is pulse photopletismography signal (PPG) which is a simple and useful method for measuring the pulsatile component of the heartbeat and evaluating peripheral circulation.

Several studies suggest that when apnea occurs, sympathetic activity increases. Hypoxia plays a key role in that relationship. The increase in sympathetic activity is associated with vasoconstriction and, possibly, is related to transient arousal. Vasoconstriction is reflected in the PPG signal by a decrease in the fluctuation of the signal amplitude [2]. Therefore, the automatic detection of decreases in the amplitude fluctuations of PPG (DAP) might be useful in indirectly quantifying apneas during sleep [3]. There are studies of the diagnosis of OSAS based on the detection of vasoconstriction using peripheral arterial tonometry [4], which is a similar physiologic signal. The relationship between ANS and PPG has been the subject of some studies [2].

Nevertheless, not all of the DAP events are associated with an apnea event [5]. These events may be related to arousals not associated with apnea. There is a need for alternative criteria for discriminating between DAP events associated with apnea and those without that association. According to [6], heart rate variability (HRV) might be an interesting alternative worth investigating, Schnall et al. [4].

In this study we analyzed HRV during episodes of DAP events with the aim to better relate/unrelate those DAP episodes to autonomic events that are related to apneic events.

2. Data

This study includes the records of 6 children (2 boys, 4 girls) whose mean age was 9.16 ± 7.27 ($mean \pm S.D.$) years. The PSG registers were acquired in Miguel Servet Children's Hospital, Zaragoza, Spain, using a digital polygraph (EGP800, Bitmed) recording six EEG channels, two electro-oculogram channels, a chin electromyogram channel, two ECG channels, air flow (oronasal thermocoupler), and respiratory plethysmography, with transducers placed around the chest and abdomen. PPG and arterial oxygen saturation were recorded continuously by pulse oximetry (COSMO ETCO2/SpO2 Monitor Novametrix, Medical Systems). All of the signals were stored at a sampling rate of 100 Hz, except ECG channels whose sampling rate was 500 Hz. The PSG data were gathered from children suspected of having OSAS, and were scored manually following standard procedures used to discriminate children suffering from OSAS from those who are not.

3. Methods

3.1. DAP events detection

The first step in this study was the detection of DAP events. The PPG signal was analyzed using the method described in [3].

This detector is based on a preprocessor stage which suppress the mean, an envelope detection using root mean square technique and a decision rule based on an adaptive threshold. The detector also includes an artifact detector stage based on Hjorth parameters.

The DAP events without artifacts or another DAP event within 40 s previous and 50 s after were manually classified as apneic or non-apneic from inspection of the PSG respiratory signals by a medical expert. A total of 45 DAP events (10 apneic, 35 non-apneic) corresponding to children without sleep disordered breathing where used for the analysis. All DAP apneic events correspond to central apnea.

3.2. ECG signal processing. HRV analysis

A HRV signal processing analysis was carried out in order to obtain several time and frequency indexes to study their value for discriminate between apneic and non-apneic DAP events.

Previous to QRS detection, we implemented a preprocessing in order to improve the accuracy of QRS detection by removing the effect of noise. Nonlinear filtering technique was used for removal of the powerline interference [7]. A wavelet-based ECG delineator [8] was used for QRS detection. After that, a spline interpolation round each detection was carried out to increase resolution in time up to an equivalent sampling rate of 2000 Hz.

An anomalous beat exclusion rule [9] was applied in order to determine normal beats which were used for the interval tachogram generation.

To analyze the spectral parameters of the HRV in a time-frequency plane we used the Smooth Pseudo Wigner-Ville Distribution (SPWVD), since this heart rhythm signal is clearly non stationary.

This distribution is characterized by an independent smoothing, in time and frequency, originated by $\gamma(t)$ and $\eta(\frac{\tau}{2})\ \eta^*(-\frac{\tau}{2})$ windows respectively and is defined as:

$$\text{SPWVD}_x(t,f) = \int\int \varphi(t-t',\tau)x(t'+\frac{\tau}{2})x^*(t'-\frac{\tau}{2})e^{-j2\pi f\tau}dt'd\tau \quad (1)$$

$$\varphi(t,\tau) = \gamma(t)\eta(\frac{\tau}{2})\eta^*(-\frac{\tau}{2}) \quad (2)$$

3.3. Statistical analysis

Three windows, five seconds duration each, from each DAP event were selected for the analysis: 1) control (starting at second 10 previous to DAP), 2) during DAP event (starting at 2 seconds after the DAP detection onset), 3) post event (starting at 15 seconds after the DAP detection onset).

Time domain parameters as mean ($\overline{RR}$), standard deviation of interval tachogram were calculated for each analysis window. Also the increase on RR signal around DAP onset was estimated, see figure 1.

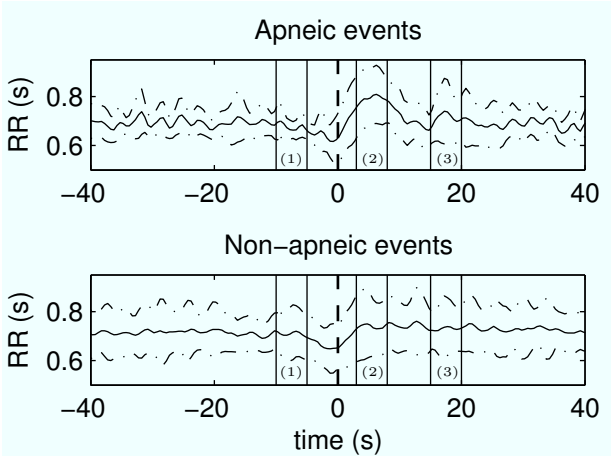

Figure 1. RR mean $\pm$ S.D. for apneic and non-apneic events. Analysis windows (1 control, 2 during, 3 post). Dashed line at reference time indicate DAP onset.

Total power, high (HF), low (LF) and very low (VLF) frequency components, low to high frequency ratio (LF/HF) were computed from power spectra in a standard way for each instant t. The normalized with regard to total power high (HFn) and low (LFn) frequency components

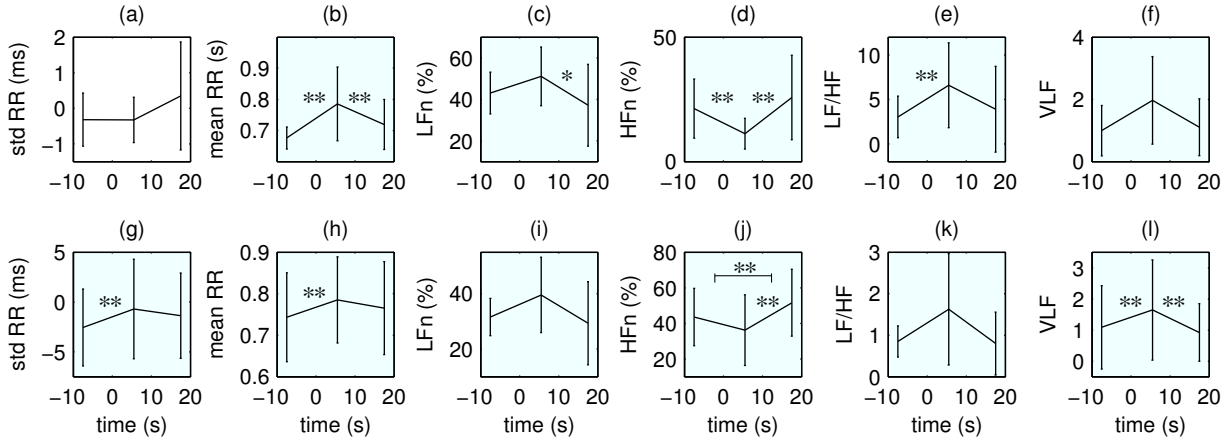

Figure 2. One way ANOVA tests for repeated measures Apneic (a-f), Non-apneic (g-l). $*p < 0.05$ $**p < 0.01$.

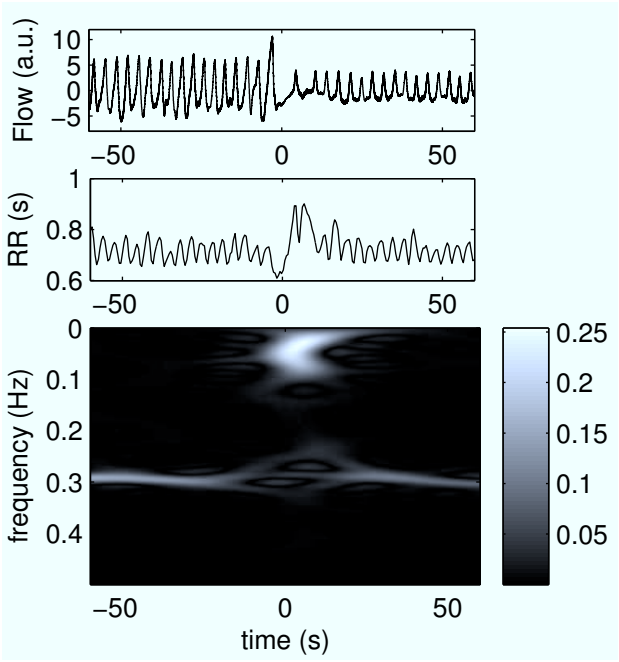

Figure 3. SPWVD of the RR for a DAP apneic event.

were calculated. Difference between the value of each parameter in the windows during and post event with respect to the control window was also considered.

In order to compare the evolution across time of HRV indexes in the different windows of each group, one way ANOVA tests for repeated measures were performed. Bonferroni's all pairs post-hoc analyses were used to evaluate significant statistic differences ($p < 0.05$). In addition, two sample t-tests were carried out in order to compare the parameter variations across DAP windows between the apneic and control groups.

4. Results

Figure 1 shows the RR mean $\pm$ S.D. for apneic and non-apneic events. In both cases a decrease on the RR intervals just before the DAP event occurs followed by an increase. As can be noticed in the figure, this apneic events increase (0.27 ± 0.09) seconds is bigger than non-apneic events increase (0.24 ± 0.11) seconds, but not statistically significative.

The results of the ANOVA test for each parameter is shown in figure 2. The patterns are very similar for apneic and non-apneic events, but the changes are deeper for apneic. An increase on LFn associated with a reduction in HFn during DAP window, followed by an augment on HFn and a decrease on LFn within the post event window reflects an activation of the sympatetic system followed by a recovery period with a vagal increase, see figure 3. Some parameters as mean RR, LFn, HFn and LF/HF for apneic and RR standard deviation, mean RR, HFn and VLF for non-apneic show statistical significance during the test. The results of the T-test for each analysis window are shown in Table 1. These results reflect statistical differences between apneic and non-apneic mainly in the window during DAP for LFn, HFn and LF/HF. This mean that there are no relevant differences between the two groups previous and after the DAP event, and that differences during the DAP event are due to the deeper changes that appear for apneic. Differences during the DAP event with respect to control show an increase in sympatho-vagal balance of about 118% for apneic events, whereas this increase is just about 56% for non-apneic. This behavior is also noticed in the parameters increase showed in Table 2, where the statistical differences appear for the increase between the control values respect to the values during DAP. The increase in sympatho-vagal balance shows differences statistically significant ($p = 0.002$).

Table 1. T-test for each analysis window ($mean \pm S.D.$)

T test	control window			during DAP window			post event window		
	apneic	non-apneic	p	apneic	non-apneic	p	apneic	non-apneic	p
$\overline{RR}$	0.67 ± 0.035	0.71 ± 0.086	0.257	0.78 ± 0.12	0.74 ± 0.11	0.241	0.72 ± 0.08	0.73 ± 0.09	0.716
LF	43.05 ± 10.06	30.91 ± 13.40	0.011	51.10 ± 14.13	35.06 ± 15.84	0.006	37.19 ± 19.73	30.46 ± 14.81	0.246
HF	21.29 ± 11.85	32.89 ± 22.96	0.133	11.21 ± 6.15	28.99 ± 22.86	0.019	25.75 ± 16.97	39.44 ± 23.42	0.093
LF/HF	3.02 ± 2.33	1.90 ± 1.96	0.137	6.60 ± 4.78	2.75 ± 2.97	0.003	3.88 ± 4.83	1.96 ± 3.94	0.202
VLF	0.99 ± 0.81	0.81 ± 0.85	0.550	1.97 ± 1.41	1.30 ± 1.20	0.143	1.10 ± 0.91	0.74 ± 0.66	0.171

Table 2. T-test for increase parameters ($mean \pm S.D.$)

T-test	apneic	non-apneic	p
Δ $\overline{RR}$	-0.11 ± 0.09	-0.03 ± 0.07	0.005^*
Δ LFn	-8.04 ± 10.56	-4.14 ± 12.28	0.368
Δ HFn	10.08 ± 6.70	3.89 ± 8.94	0.048^*
Δ LF/HF	-3.57 ± 2.97	-0.84 ± 2.19	0.002^*
Δ VLF	-0.97 ± 1.58	-0.49 ± 0.75	0.177

(a) control - during DAP window

T-test	apneic	non-apneic	p
Δ $\overline{RR}$	-0.04 ± 0.06	-0.02 ± 0.04	0.22
Δ LFn	5.86 ± 16.61	0.45 ± 17	0.35
Δ HFn	-4.45 ± 9.53	-6.54 ± 12.45	0.62
Δ LF/HF	-0.87 ± 3.15	-0.06 ± 4.05	0.56
Δ VLF	-0.11 ± 1.13	0.06 ± 0.50	0.47

(b) control - post event window

5. Discussion and conclusions

In our research, we have investigated the HRV during DAP events, analyzing the differences between the DAP events associated with apnea and those without that association. Several time and frequency domain parameters have been defined for this study.

Our results show an increase on sympatetic activity during DAP events, in concordance with [2]. This sympatetic activation is deeper in case of association with apnea.

The statistical differences between DAP events associated with apnea and those without indicate that HRV analysis is useful for discriminate between this two groups. Consequently HRV analysis improve the utility of PPG signal in sleep disorder diagnosis.

Although a broader study using more events and including obstructive apneas is needed, our results indicate that a combination of ECG and PPG signals offer interesting information to sleep disorders diagnosis, with the great advantage of being less complicated and better suited for ambulatory monitoring than PSG.

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