Multi-Domain Short Term Heart Rate Variability Analysis to Detecte Single Night Sleep Deprivation on Drivers

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Abstract

Sleep deprivation is associated with road accidents. Autonomic nervous system (ANS) activity can be estimated non invasively from the heart rate variability (HRV) signal calculated from the ECG.

The aim of this work is to find useful parameters to detect sleep deprivation on drivers.

We utilized two groups of non professional healthy drivers aging from 21 to 25 years old. Non-Deprived (ND, sleep >= 4 hours) (N=10) and Deprived (D, sleep < 4 hours) (N=13). The ECG signal on rest for 5 minutes was preprocessed and the RR series calculated.

The RR series was analyzed time-domain, frequency-domain and nonlinear domain. To analyze possible differences of the HRV parameters between the groups of drivers Mann-Whitney was used and a p<0.05 was considered as significant.

This work show that only the nonlinear analysis of short-term HRV, allowed find differences of a single night deprivation through ***SD12*** *ratio of SD1/SD2, a parameter of the Poincaré graph.*

In the future works it will be analyzed HRV of ultra short term in both groups, through multi-domain analysis to find new parameters capable of establish the sleep deprivation on drivers.

1. Introduction

In the last years the traffic accident statistics reported by many countrys show that of driving accidents were caused by drowsy driving [1], [2].

Recent researcher relate the continuous nocturnal driving, drowsy, fatigue, stress and sleep deprivation as the cause of up to 30% of traffic accidents [1], [2].

The sleep deprivation is associated with road accidents. Therefore, identifying states of sleep deprivation could reduce traffic accidents, [2], [3], [4].

Is well know that the Autonomic Nervous System (ANS) activity presents alterations during stress, extreme fatigue and drowsiness episodes. The ANS activity can be estimated non invasively from the heart rate variability (HRV) signal calculated from the ECG, [1], [5].

The analyzing HRV include time-domain analysis, frequency-domain analysis and nonlinear methods [5].

Time-domain analysis is the evaluation method of HRV, which can be done via statistic calculation, measures include mean RR intervals; standard deviation of RR intervals (SDNN); root mean square of the differences between consecutive RR intervals (RMSSD); percentage value of frequency of successive differences of RR intervals that spanned more than 50 ms (pNN50) [4].

Frequency-domain analysis can use Power Spectral Density (PSD) of the RR interval series, in three frequency bands, Very Low Frequency (VLF) (0-0.04 Hz), Low Frequency (LF) (0.04-0.15 Hz), High Frequency (HF) (0.15-0.4 Hz) and Total Power (TP) (TP=VLF+LF+HF). The parameters resulting include peak values of each frequency band power of each frequency band and LF to HF ratio [4].

Nonlinear evaluation methods, such as fractal analysis. Parameters are derived from a Poincaré plot, which presents the correlation between consecutive RR intervals. The standard parameters include short-term variability of heartbeats, SD1 and long-term variability of heartbeat, SD2 [4].

Many drowsiness identification techniques have been proposed based on the analysis of HRV in the frequency domain through the LF/HF ratio, considered an indicator of the balance between the sympathetic and parasympathetic systems in the ANS [5], [6], [7]. Although other researchers propose nonlinear HRV is a useful index of the autonomic activity [8].

The aim of this work is to find useful parameters that allow establishing the sleep deprivation on drivers. These parameters can be obtained from several multi-domain, time, frequency and nonlinear representation of the short-term HRV, such as the Poincaré graph.

2. Materials and Methods

Twenty three subjects non professional drivers aging from 21 to 25 years old, voluntarily participated in the experiment. The subjects healthy and free from any medication.

This study went through ethics approval from the Research Committee of Chatolic University of Argentina.

Every subjects has provided written consentement, relative to data privacy and research with human before starting the experiment and all subjects were free to terminate the experiment at any time.

The subjects were experimentally divided in two groups: Non-Deprived (ND, sleep >= 4 hours) (N=10) and with a single night Deprived (D, sleep < 4 hours) (N=13).

The ECG signal of each subject was obtained on rest position for five minutes by a D1-lead holter with frequency sampler of 250 Hz.

The ECG signal was preprocessed using a Savitsky-Golay 50Hz filter to remove line noise.

The first processed step of filtered ECG signal is to detect a R peaks and after detection a R-R beats interval are computed and the non-equispaced RR interval series calculated. This step is performed manually by using free ECG-KIT tool for ECG processing [9]. Second step removed DC signal and lineal detrending of the non-equispaced RR interval series, with Matlab algoritms.

For multi-domain feature analysis algorithms were developed in Matlab.

The non-equispaced RR interval series was analyzed in time-domain, through statistic calculation. Features are calculated: mean RR, SDNN, RMSSD, pNN50.

The non-equispaced RR interval series was analyzed in frequency-domain, the power spectral density (PSD) was obtained through Lomb periodogram. Features are calculated: TP , VLF, LF, HF and LF/HF.

The nonlinear standard parameters calculated through Poincaré plot are SD1 and SD2, defined as the standard deviation of the projection of the Poincaré plot on the line of identity $y=x$, Figure 1.

The data vectors for the Poincaré plot are:

$RR_n = (RR_1, RR_2, RR_3, \ldots, RR_n)$
$RR_{n+1} = (RR_2, RR_3, RR_4, \ldots, RR_{n+1})$

$$\begin{bmatrix} x_1 \\ x_2 \end{bmatrix} = \begin{bmatrix} \cos\left(\frac{\pi}{4}\right) & -\sin\left(\frac{\pi}{4}\right) \\ \sin\left(\frac{\pi}{4}\right) & \cos\left(\frac{\pi}{4}\right) \end{bmatrix} \begin{bmatrix} RR_n \\ RR_{n+1} \end{bmatrix}$$

x_1 and x_2 correspond to the rotation of RR_n and RR_{n+1} by $\frac{\pi}{4}$

$$x_1 = \frac{RR_n - R_{n+1}}{\sqrt{(2)}} \quad ; \quad x_2 = \frac{RR_n + R_{n+1}}{\sqrt{(2)}}$$

$$SD1 = \sqrt{Var(x_1)} \quad ; \; SD2 = \sqrt{Var(x_2)}$$

Other parameter calculated is the ratio $SD12 = \frac{SD1}{SD2}$ associated SD12 ratio with the randomness of the HRV [10] and as a measure of the balance between HRV in the short and long term by its analogy and properties similar to LF/HF, [11]. It was also calculated the area of ellipse, parameter which reflects the the total variability as measured by the Poincaré plot.

$$S = \pi \cdot SD_1 \cdot SD_2$$

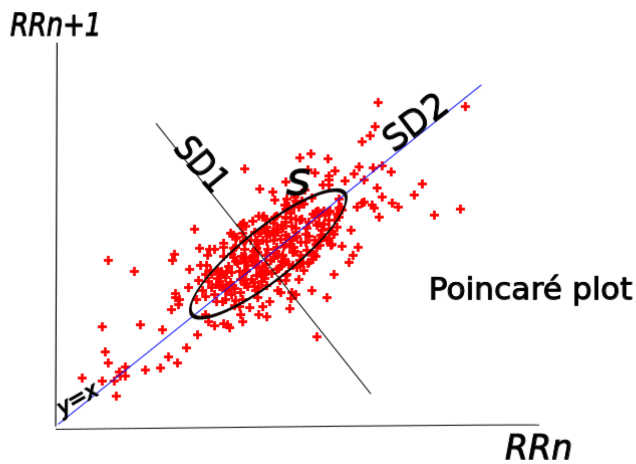

Figure 1. Poincaré plot of the non-equispaced short-term RR interval series.

To analyze possible differences of the HRV parameters between the two groups of drivers the Mann-Whitney test was used and a ***p*** value of **< 0.05** was considered as significant.

3. Results

3.1. Tables

Table 1. ND and D groups, multi-domain calculated parameters, means and Standar Deviation (SD).

	ND (SD)	D (SD)	*p*
RR [ms]	846.59 (107.28)	794.32 (112.19)	0.25
SDRR [ms]	62.35 (18.40)	61.01 (23.31)	0.83
pNN50 [%]	21.79 (16.74)	15.98 (16.63)	0.31
RMSSD [ms]	44.08 (20.61)	36.67 (18.20)	0.37
TP [ms^2]	4.90e+03 (2.54e+03)	5.11e+03 (3.32e+03)	0.97
VLF [ms^2]	1.72e+03 (914.37)	1.88e+03 (1.51e+03)	0.78
LF [ms^2]	1.95e+03 (930.90)	2.19e+03 (1.57e+03)	0.92
LFnu	64.43 (10.95)	70.38 (10.80)	0.20
HF [ms^2]	1.12e+03 (922.76)	957.68 (882.38)	0.47
HFnu	31.8002 (10.70)	26.47 (11.89)	0.28
LF/HF	2.36 (1.14)	3.34 (1.81)	0.23
S [ms^2]	8.85e+03 (6.27e+03)	7.79e+03 (6.49e+03)	0.51
SD1 [ms]	31.21 (14.60)	25.97 (12.90)	0.37
SD2 [ms]	82.09 (22.87)	82.22 (30.61)	0.97
SD12	**0.37 (0.10)**	**0.30 (0.05)**	**0.04**

4. Discussion and conclusion

In Table 1, both the parameters of the time-domain and those of the frequency-domain resulted with non-significant ***p*** values. In the nonlinear analysis, the parameter **SD12**, ratio of SD1/SD2, of Poincaré plot, resulted with a ***p*** value of **0.04**.

This work show that only the nonlinear analysis of short-term HRV, allows to establish differences in a single night deprivation between ND and D groups through **SD12** a parameter calculated from the Poincaré graph.

Previous investigations, found higher correlations, although of moderate intensity, were observed between SD12 and LF/HF. These analyzes considered the SD1/SD2 relationship as a measure of the balance between HRV in the short and long term by its analogy and properties similar to LF/HF, [10], [11].

Also associated SD12 ratio with the randomness of the HRV [12].

Recent research show that unlike frequency-domain measurements, Poincaré plot analysis is insensitive to changes in trends in the RR intervals [10], [11], [13].

This work shows the importance of the analysis in multiple domains to find some parameter that shows differences between the ND and D drivers groups.

With the results found it could be considered that SD12 nonlinear parameter has a better behavior than LF/HF to show the differences between the two groups, but this requires further studies.

In future work, the number of drivers in each group will be increased, the HRV parameters will be analyzed, in particular SD12 and LF/HF of the RR series in the short term and ultra short term, equal to or less than one minute in both groups, through of a multidomain analysis to find parameters capable of establishing differences in the in the sleep deprivation on drivers.

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