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Non-Linear analysis to characterize dysautonomia through artificial electrocardiogram models

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Background, Motivation and Objective. Dysautonomia (or autonomic disfunction) is the failure in modulation of the autonomic nervous system (ANS) that may cause several visceral changes like orthostatic hypotension, anhidrosis and gastrointestinal dysfunction (McLeod et al, 1992). It is common to manifest in some diseases, like Guillain-Barré syndrome, diabetes mellitus, and other neurodegenerative diseases (Low et al, 2002). Since dysautonomia affects some vital organs that could bring many complications over time, it is crucial to characterize how this modulation works to provide a better understanding of this condition and better diagnostics. The ANS modulation can be assessed by the heart rate variability (HRV), making possible to study variations in heart rate along the time (tachogram) influenced by sympathovagal activity (Task Force, 1996). The standard parameters of HRV can be made by time-based or frequency-based estimations, but both had some limitations and pre-requirements, like stationarity and long signals. Since HRV has non-linear characteristics, different researches are trying to analyse it by means of non-linear techniques, such as Poincaré Map (Brennan et al, 2001) and Recurrence Quantification Analysis (RQA) (Zbilut et al, 2002), as alternatives methods to the standard ones, highlighting other signal factors linked to the abnormal condition and avoiding pre-requirements. However, these new techniques still need a systematic study considering the meaning of their non-linear factors associated with the physiological phenomena. By using the same non-linear techniques, we evaluate artificial electrocardiogram (ECG) signals, emulating different physio-pathological conditions coming from different structures from the heart, allowing the control of each ECG parameter associated with dysautonomia in each condition. By controlling these ECG parameters, we were able to interpret how non-linear factors are associated with the physio-pathological condition and propose a new method with specific set of parameters, to proper quantify different heart-neurological diseases by using only ECG recordings.

Methods. We built 4 different ECG models (Deterministic-ECG, Atrial Fibrillation, Long QT Syndrome and ECG-Noisy) based on the McSharry model (McSharry et al, 2003), which constructs the ECG signal from the Power Spectral Density (PSD), thus disregarding any change caused by sinus rhythm pathologies. Afterwards, the it was conjugate the effect over the signals and its factors by adding noise on the LF/HF balance. Particularly, it was studied the different autonomic interactions, including loss of sympathetic, attenuation of vagal and normal condition. Then it was calculated the tachogram of each ECG model to evaluate their heart rate variability (HRV) and added noise, being able to see different interactions of HRV characteristics to noise. It was calculated their Standard deviation of Normal to Normal (SDNN) and Root mean square of successive differences (RMSSD) in short and long periods of time. Posteriorly, it was calculated the non-linear metrics through Poincaré, where by estimating the relationship between successive beats over time getting long and short-term information, homogeneity and trend. Finally, it was

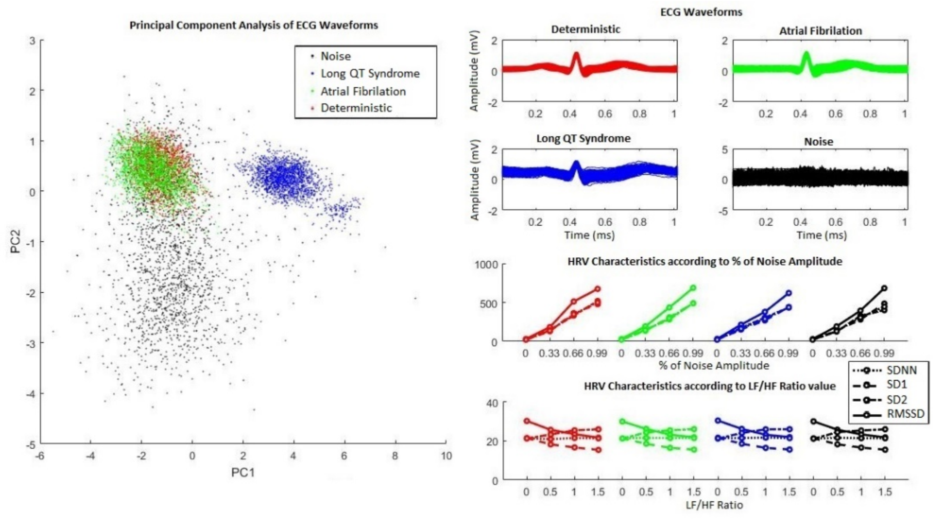
applied a spike sorting-like procedure (Quiroga, 2012), where it is applied a Principal Component Analysis (PCA) in the waveform, which is a technique to distinguish the main differences associated with the ECG-complexes waveforms.

Results. It was calculated every HRV standard characteristics (SMNN and RMSS) for each one of the four conditions, according to a percent combination of LF/HF ratio and noise. Figure 1 show that, the standard HRV characteristics and Poincaré factors exhibit a linear correlation with the increase of noise. However, they show a significative sensibility according to the LF/HF modulation. The PCA on the ECG-complexes shows that each cluster characterize according to each condition, highlighting their specificity and a proper signature.

Discussion and Conclusions. It was possible to show that waveform analysis was not enough to distinguish each group by its PCA. Considering HRV analysis, it was possible to show that nonlinear techniques are much more sensitive to LF/HF modulation, especially on HF changes. The technique shows to be sensitive to noise added in tachogram, it raises linearly to noise, which increase total power of PSD. In resume, our technique shows promising results to detect cardiac changes, by analysing ECG waveforms and non-linear techniques. These techniques, such as Poincaré are sensitive to LF/HF modulation in all proposed situations, while classical measurement does not have the same sensibility. The non-linear parameter SD1 seem to be correlated to vagal activity once it decreases when lowering vagal modulation (HF magnitude) and SD2 seem to be correlated to total power once it increases when rising LF magnitude, results like those stipulated in other studies (Task Force, 1996; Brennan, 2001). Other nonlinear techniques should be tested, like RQA, could bring a new approach with the studies of trajectory that could correlate to HRV, once it was already used in HRV on some works (Marwan, 2002) and show promising results.

Figures.

Figure 1: Results obtained from our work. **A.** Principal component analysis from each waveform separating clusters by condition. **B.** Waveform for each condition, showing the morphology of each condition. In **C.** and **D.** In **C.** we analyse the metrics sensitivity to noise, showing that it raises linearly to the noise. In **D.** we analyse the metrics sensitivity to LF/HF modulation.



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