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Heart Rate Variability during Sleep and the Development of PTSD following Traumatic Injury

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Abstract— **In the case of a life-threatening event, posttraumatic stress disorder (PTSD) may develop, causing the patient to experience panic and anxiety as well as social, occupational or other distresses. We look to investigate the role of sleep in the onset of PTSD and how it affects human autonomic functions. Specifically, this paper focuses on analysis of the heart rate variability in order to observe and quantify the activation of the sympathetic and parasympathetic nervous systems in both rapid eye movement (REM) sleep and non-REM (NREM) sleep. We hypothesize that the sympathetic activation is higher in those individuals whose PTSD symptoms continue in follow-up studies.**

Heart rate variability (HRV) signals, extracted from the electrocardiogram (ECG), were analyzed using autoregressive (AR) techniques to calculate the power spectral density (PSD), which in turn yield a low frequency to high frequency (LF/HF) ratio. This technique is established to be an index of autonomic nervous system activation. In addition to this ratio, we also looked at the roots of the AR function in order to obtain a more detailed depiction of the sympathetic activity.

Our results suggest that the LF/HF ratio was higher in subjects with ongoing PTSD symptoms than those subjects without symptoms in both REM and NREM sleep. In the pole analysis, higher sympathetic nervous system activation was observed for PTSD positive subjects in REM sleep, but this sympathetic activity was slightly higher in PTSD negative individuals in NREM sleep.

Keywords—**heart rate variability, posttraumatic stress disorder, sleep, power spectral density, autoregression poles**

INTRODUCTION

Posttraumatic stress disorder (PTSD) develops in a minority of individuals following exposure to severe life threatening events. PTSD has significant morbidity when it becomes chronic [1] so there has been considerable interest in understanding early determinants of the disorder. Sleep appears to play an important role in the genesis and maintenance of PTSD. We have previously reported that subjects developing PTSD have trauma replicating dreams and fragmented patterns of rapid eye movement (REM) sleep [2].

The current diagnostic methods rely on the noninvasive assessment of autonomic nervous system (ANS) activity. Activation of the sympathetic nervous system produces an elevated heart rate, among other consequences, a symptom systematically observed in PTSD patients [3]; whereas, the parasympathetic nervous system creates an opposite effect [4]. Heart rate variability (HRV) analysis has been established as a successful method for indexing these autonomic functions over periods of time [5]. This analysis of the RR intervals (time between peaks in the QRS complex) has proved to be an effective, noninvasive technique to detect such physical afflictions as myocardial infarction and other cardiovascular diseases [6]. In addition, HRV analysis has been recently proposed as an index of psychiatric disorders, including depression, panic, schizophrenia [7], and most recently, PTSD [8].

The fast Fourier transform (FFT) method has been widely used to estimate the power spectral density (PSD) function of HRV signals in order to quantify the contribution of sympathetic activity represented by the low frequency (0.04 to 0.15 Hz) and the parasympathetic activity represented by high frequency (0.15 to 0.40 Hz) [9,10]. However, the FFT method may not be appropriate for the analysis of biological signals including HRV with short data segments. These difficulties can be overcome using the autoregressive (AR) spectrum or poles since the AR may produce an accurate way of estimating the short biological signals [11-13].

In this paper, we use the AR method to analyze the HRV signal obtained from individuals suffering from PTSD, some of whom retain symptoms over a long period of time and others who are clear of symptoms after a short period of time, and we want to gain insights into the underlying mechanism of PTSD. We hypothesize that the PTSD positive subjects have more sympathetic activity during REM sleep compared to those subjects without prolonged PTSD symptoms, with less of a distinction in NREM sleep. This feature can be reflected on the AR model by the dominant low frequency activity in the AR spectrum for the PTSD positive individuals and by computed poles of the AR being closer the unit circle compared to those of PTSD negative status.

METHOD

Subjects are recruited from the Dartmouth Hitchcock Medical Center Trauma Service and the University of Miami, Ryder Trauma Center. Participation exclusion criteria included the following: clinical signs suggesting traumatic brain injury, pain exceeding a moderate level or interfering with sleep, intoxication at the time of injury, previous psychiatric disorder, and the use of any drug affecting the central nervous system. Subjects without these conditions were assessed longitudinally for

PTSD. Those individuals meeting the criteria for the disorder specified in the *Diagnostic and Statistical Manual of Mental Disorders - Fourth Edition* (DSM-IV) [14] and were willing to undergo sleep recordings, received polysomnography within a month of the traumatic incident. In total, 16 subjects (10 male, 6 female) with an average age of 38.5 (± 10.7) years participated in this study. Of these 16 participants, 8 continued to experience PTSD symptoms at a two month follow-up interview (denoted PTSD positive) and 8 did not continue to experience these symptoms at the follow-up (denoted PTSD negative).

Signal processing methods

Electrocardiogram (ECG) signals were sampled at a rate of 100 Hz (Miami) and 128 Hz (Dartmouth Hitchcock). Epochs for the particular sleep stages were visually scored from the sleep recordings by an expert using the standard criteria. Five minute intervals were extracted from periods of REM and NREM sleep, specifically, the first NREM period, the first REM period, the last REM period, and the NREM period preceding the last REM period.

In order to extract the HRV time sequence, the ECG data were resampled at a rate of one half of the original sampling frequency and digitally filtered with order 5 and a cutoff frequency of 20 Hz. Then the RR time intervals were manually estimated and resampled at a rate of 2 Hz using the spline function in order to ensure equally spaced intervals in the HRV time series. Fig. 1 shows the RR interval time series before and after resampling.

As stated in the introduction, we chose the AR model since we have a limited number of HRV samples (5 min. segments). The AR method based on the Burg algorithm was implemented with a model order of 15 to calculate the power spectral density (PSD) on a *MATLAB* platform. After estimating the AR power spectral density, the low frequency and the high frequency values were calculated allowing the LF/HF ratio to be estimated. This ratio is established to be an index of ANS activity. The mean values of these estimations were calculated.

In addition to the AR spectrum, the poles of the AR model were calculated. We mainly focused on the amplitude and the phase of poles representing sympathetic activation (0.04 to 0.15 Hz) and parasympathetic activation (0.15 to 0.40 Hz). Model order 20 was used for the AR pole estimation, in order to differentiate the closely located poles, detail that was not necessary to analyze the power spectrum. We focused on the first pole, that which occurred between 0.040 and 0.095 Hz (0.126 to 0.300 radians) for each subject, in order to analyze the intensity of SNS activity. The magnitudes of these roots were used as an indication of low frequency power. The mean values of the magnitudes were calculated.

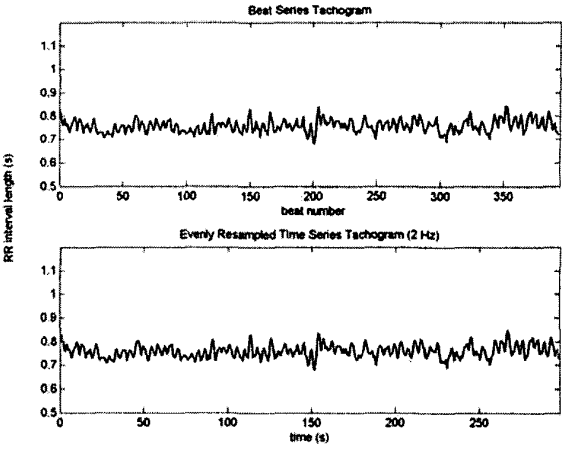

Figure 1. Beat series and evenly resampled time series tachograms from one subject.

RESULT

Fig. 2 shows the AR power spectrum of the HRV signal obtained from one PTSD positive and one PTSD negative subject. Our data show that the LF/HF ratios for HRV during the REM and NREM periods were consistently greater in the subjects who met criteria for PTSD than in the injured subjects without PTSD, as summarized in Table 1.

Of those subjects bearing roots within the previously specified low frequency range, the magnitudes of the roots during REM periods were greater in subjects experiencing PTSD that those individuals without symptoms. Figure 3 shows the roots of two such subjects. On the other hand, during NREM periods, those subjects without persistent PTSD show roots with slightly higher magnitudes than the PTSD positive group. These results are summarized in Table 2.

DISCUSSION

Previous studies have shown that the power spectral density of the FFT and of the AR model can be successfully used to analyze the HRV signal in PTSD positive individuals in comparison to control subjects [8]. In this paper, we used the AR model to show that PTSD subjects who continue to exhibit symptoms months after the traumatic event also have a significantly higher LF/HF ratio in both REM and NREM sleep than those subjects whose symptoms fade more quickly. In addition, this study illustrates higher power in the low frequency range for subjects exhibiting prolonged PTSD symptoms in REM sleep, indicating higher sympathetic activation in these individuals. On the other hand, the poles of the AR model show less of a distinction in the low frequency power for NREM periods.

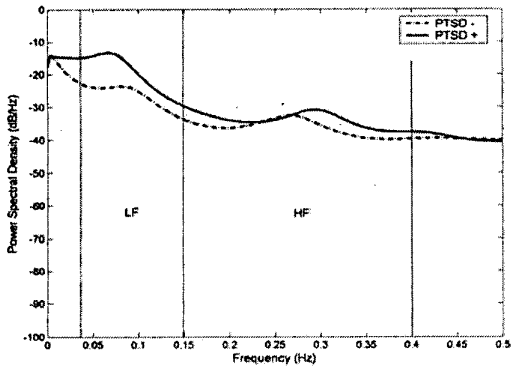

Figure 2. Power spectral density of the data from two subjects during REM sleep. The highlighted low frequency and high frequency ranges were integrated to find the LF/HF ratio.

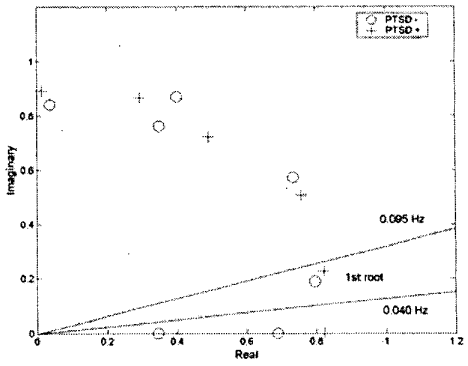

Figure 3. Poles of the autoregressive transfer function of the data from two subjects during REM sleep. Only the first pole in the highlighted area of the low frequency range was used.

TABLE 1
SUMMARY OF LF/HF RATIO RESULTS

sleep stage	PTSD status	mean	std dev
REM 1	-	2.7125	2.0350
	+	6.0875	6.1359
REM 2	-	3.1033	2.0621
	+	4.6333	2.3855
ave REM	**-**	**3.3138**	**2.2032**
	+	**6.1875**	**4.3930**
NREM 1	-	2.1250	2.5212
	+	4.3143	3.4503
NREM 2	-	1.6000	1.1367
	+	2.7833	1.7520
ave NREM	**-**	**2.1563**	**2.4931**
	+	**3.6063**	**2.1452**

TABLE 2
SUMMARY OF POLE MAGNITUDES

sleep stage	PTSD status	mean	std dev
REM 1	-	.7970	.0209
	+	.8193	.0418
REM 2	-	.7598	.0914
	+	.7707	.0638
ave REM	**-**	**.7839**	**.0430**
	+	**.8055**	**.0505**
NREM 1	-	.8119	.0326
	+	.8191	.0573
NREM 2	-	.8018	.0298
	+	.7795	.0150
ave NREM	**-**	**.8094**	**.0163**
	+	**.7972**	**.0296**

Due to the increased activity of the sympathetic nervous system in PTSD positive individuals, the results show that this sympathetic activation observed during the REM sleep stage interferes with adaptive memory processing functions of this sleep stage. Most dreaming occurs in REM sleep, and individuals diagnosed with PTSD are reported to have vivid, lifelike, fearsome dreams [2]. Therefore, our results of heightened sympathetic activation during REM sleep support these dream reports.

The failure to show a significant result for the AR pole analysis in NREM sleep may be due to the absence of a pole in the range 0.040 to 0.095 Hz for several PTSD positive subjects. For those individuals without the specified roots, the model did produce three positive, real roots, indicating possible activity at a very low frequency. In order to isolate the precise contribution from a very low frequency (VLF) range, a higher model order must be used so that the exact peaks can be distinguished. In conclusion, although this particular model failed to show any strong correlation of sympathetic activation to PTSD status, activity in the VLF range indicates there may be strong sympathetic activation that this model does not recognize.

CONCLUSION

The finding indicates a presence of greater activation of the sympathetic nervous system and by extension fear systems, during REM and NREM sleep stages, and the development of PTSD. Although past studies have established an association similar to this relationship among PTSD groups compared with control groups [8], the current study proves a correlation among a group of individuals experiencing PTSD—those of whom continue to experience effects compared with those whose symptoms are alleviated within the first two months.

Our data suggest that the mean value of LF/HF ratio and the amplitude of poles of the AR model for PTSD positive individuals in REM sleep are much larger than those values of PTSD negative individuals. However, we noted a large variance due to a low number of subjects. Currently, we are expanding out database to reduce the variance in our index.

In the future, we want to look more in depth at the behavior of these signals. We are currently investigating the

use of advanced signal processing techniques including the bispectrum and the eigenvector methods.

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