Comparison of Heart Rate Variability Measures for Mental Stress Detection

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Abstract

Mental stress is one of the well known major risk factors for many diseases such as hypertension, coronary artery disease, heart attack, etc. Conventionally, detecting mental stress in an individual is performed by interviews and/or questionnaires. In this study, we have investigated various heart rate variability (HRV) measures for detecting mental stress by using ultra short term HRV analysis. A number of HRV measures were investigated, e.g, Mean of heart rates (mHR), Mean of RR intervals (mRR), Power spectra in Very Low (VLF), Low (LF), and High (HF) frequency ranges, Symphatovagal balance index (SVI), etc. Experiments involved 60 segments of RR interval time series signals during mental stress state and normal state. Results revealed that the following HRV measures: mRR, mHR, normalized LF, difference between normalized LF and normalized HF, and *SVI were effective measures for mental stress state and normal state classification.*

1. Introduction

Mental stress is a kind of feeling which is created in our minds when we feel threatened and tensed which come from various situations. It can inhibit personal happiness and productivity. Nowadays stress becomes the most common problem. It can make us feel depressed, rejected, disgusted, angry, and finally may bring us some chronic diseases such as hypertension, cardiovascular diseases, etc.

It is important to recognize whether we are under stress or not. If we can detect stress warning signs early, it will be possible to prevent its impacts on our life. There are a number of stress detection methods, for example, interviewing, questionnaire, behaviour observation, and analysis of body signals such as EEG, ECG, etc. In this work, we are interested in the use of body signal derived from the ECG called RR interval signal. The analysis of RR interval signal in terms of Heart Rate Variability (HRV) has been widely used for monitoring Autonomic Nervous System (ANS). Heart rate variability refers to the regulation of the sinoatrial node which is the natural pacemaker of the heart by the sympathetic and parasympathetic branches of the Autonomic Nervous System. HRV is defined as variations between consecutive heartbeats, and it is used to describe the balance in sympathetic and parasympathetic activities. A number of research work supports that mental stress affects on HRV [1], [2], [3], [4], [5]. There are various HRV measures that we can adopt for pathologic state detection including mental stress state. In this paper, we would like to investigate a number of HRV measures to seek for an effective measure for mental stress detection.

The paper is organized as follows. Section 2 describes methodology. Section 3 describes experimental results. Finally, Section 4 is the conclusions of our research work.

2. Methodology

Our method consists of three steps. There are Pre-processing, HRV measure calculation, and HRV measure evaluation. The details of each step are explained below.

2.1. Pre-processing

In this step, the RR interval signal data are prepared for analysis properly in time domain and frequency domain. Based on the work in [2], we have used segments of RR intervals within 50 s to get the reliable HRV measure values by using ultra short term analysis. And the RR interval signal data are resampled at 2 Hz using linear interpolation to get the reliable values of HRV measures based on spectrum in the frequency domain.

2.2. HRV measure calculation

There are two standard methods for HRV analysis [6]. One is the time domain analysis. This method extracts HRV measures from RR interval signals directly. Another method is frequency domain analysis which extracts HRV measures from power spectrum after the RR interval signals are transformed from time domain to frequency domain by Fourier transform. The details of HRV measures are explained below.

2.2.1. Time domain

There are many HRV measures that can be defined on time domain. In this paper, we consider only some promising measures. There are mean RR interval (*mRR*), mean heart rate (*mHR*), standard deviation of RR interval (*SDRR*), standard deviation of heart rate (*SDHR*), coefficient of variance of RR intervals (*CVRR*), root mean square successive difference (*RMSSD*), Number of pairs of adjacent RR intervals differing by more than 20 ms to all RR intervals (*pRR20*), and Number of pairs of adjacent RR intervals differing by more than 50 ms to all RR intervals (*pRR50*). The formulae for calculating the selected HRV measures in time domain are shown in Table 1.

Table 1. HRV measures in time domain.

No	Measure	Unit	Formula
1	*mRR*	ms	$\frac{\sum_{i=1}^{N}(RR_i)}{N}$
2	*mHR*	bpm	$\frac{\sum_{i=1}^{N}(60000 / RR_i)}{N}$
3	*SDRR*	ms	$sqrt\left(\frac{\sum_{i=1}^{N}(RR_i - mRR)^2}{N-1}\right)$
4	*SDHR*	bpm	$sqrt\left(\frac{\sum_{i=1}^{N}((60000 / RR_i) - mHR)^2}{N-1}\right)$
5	*CVRR*		$\frac{SDRR \times 100}{mRR}$
6	*RMSSD*	ms	$sqrt\left(mean\left(\left(RR_{i+1} - RR_i\right)^2\right)\right)$
7	*pRR20*	%	$\frac{Count\left(\left\|RR_{i+1} - RR_i\right\|\right)_{> 20ms} \times 100}{N-1}$
8	*pRR50*	%	$\frac{Count\left(\left\|RR_{i+1} - RR_i\right\|\right)_{> 50ms} \times 100}{N-1}$

2.2.2. Frequency domain

Frequency domain method usually involves estimation of the power spectral density (PSD) of the RR interval signals. The basic measures are Power spectrum of very low frequency (*VLF*), Power spectrum of low frequency (*LF*), and Power spectrum of high frequency (*HF*). In addition, we have considered the measures derived from the basic measures such as normalized very low frequency spectrum (*nVLF*), normalized low frequency spectrum (*nLF*), normalized high frequency spectrum (*nHF*), difference of normalized low frequency spectrum and normalized high frequency spectrum (*dLFHF*), Symphathetic modulation index (*SMI*), Vagal modulation index (*VMI*), Symphatovagal balance index (*SVI*) [1]. All frequency domain measures considered in this work are shown in Table 2.

Table 2. HRV measures in frequency domain.

No	Measure	Unit	Description
1	*VLF*	ms^2	Power spectrum from 0.003 to 0.04 Hz
2	*LF*	ms^2	Power spectrum from 0.04 to 0.15 Hz
3	*HF*	ms^2	Power spectrum from 0.15 to 0.4 Hz
4	*nVLF*	%	$VLF \times 100 /(VLF+LF+HF)$
5	*nLF*	%	$LF \times 100 /(VLF+LF+HF)$
6	*nHF*	%	$HF \times 100 /(VLF+LF+HF)$
7	*dLFHF*	%	$\| nLF - nHF \|$
8	*SMI*		$LF/(LF+HF)$
9	*VMI*		$HF/(LF+HF)$
10	*SVI*		LF/HF

2.3. Evaluation

Classification experiments are performed to distinguish mental stress state and normal state for individual subjects. Classification results in terms of accuracy are calculated and compared to evaluate performance of HRV measures. The classification experiments were performed by using each of HRV measures in time domain (see Table 1) and frequency domain (see Table 2) as a single feature with a minimum distance classifier. Finally, the separability index (*Q*) [7] as defined in Eq. (1) is calculated and used for HRV measure performance evaluation.

$$Q = V^2 /(V^2 + D^2) \qquad (1)$$

where V^2 is the mean-squared within class distance,
D^2 is the mean-squared between class distance.

The separability index *(Q)* values are in the range of zero to one. *Q* approaching to zero indicates optimum separability, and approaching to one indicates inseparability.

3. Experimental results

We performed experiments by using the method explained above. Section 3.1 explains the characteristics of data. Section 3.2 shows values of HRV measures in time domain and frequency domain. Section 3.3 discusses the evaluation results.

3.1. RR interval time series data

RR interval time series signals during normal state and mental stress state from 6 subjects consisting of 60 segments were used. The length of each segment is 50 s. Details are shown in Table 3.

Table 3. RR interval data during normal state and mental stress state.

No.	Subject	Age (year)	Record Duration (s)	
			Normal	Stress
1	S1	26	420	423
2	S2	35	223	224
3	S3	27	194	154
4	S4	27	100	761
5	S5	32	102	157
6	S6	23	119	211

3.2. HRV measures values

The average of values of HRV measures in time domain and frequency domain are shown in Table 4 and Table 5 respectively.

We can notice that there are some differences of HRV measures values in normal state and mental stress state in individual subjects. For example, in time domain, mean heart rate (*mHR*) and mean RR (*mRR*) are apparently different between normal state and stress state almost for all subjects (except subject S3). In frequency domain, the normalized low frequency spectrum (*nLF*), Vagal modulation index (*VMI*), Symphatovagal balance index (*SVI*), difference of normalized low frequency spectrum and normalized high frequency spectrum (*dLFHF*) are promising measures since they can give remarkably different values between stress state and normal state almost for all subjects.

Table 4. HRV measures in time domain during Normal state (N) and Stress state (S).

Subj	State	HRV measure							
		mRR	mHR	SDRR	SDHR	CVRR	RMSSD	pRR20	pRR50
S1	N	588	102.0	28	4.9	4.83	12.86	4.17	0.60
	S	634	94.7	23	3.4	3.70	13.40	8.10	0.60
S2	N	617	97.3	39	5.8	6.29	23.66	20.06	3.73
	S	625	96.1	38	5.4	6.04	22.66	20.14	3.14
S3	N	606	99.0	22	3.7	3.65	16.12	7.89	2.40
	S	605	99.2	22	3.6	3.63	12.22	4.94	0.40
S4	N	862	69.7	81	6.6	9.35	54.20	70.83	7.78
	S	752	79.8	44	4.7	5.86	39.12	57.02	18.72
S5	N	661	90.9	51	6.8	7.75	26.34	28.87	5.23
	S	629	95.4	54	8.1	8.65	30.97	39.24	11.10
S6	N	701	85.6	58	6.9	8.25	26.69	30.60	7.43
	S	639	94.3	54	7.9	8.47	23.74	26.75	5.33

Table 5. HRV measures in frequency domain during Normal state (N) and Stress state (S).

Subj	State	HRV measure						
		nVLF	nLF	nHF	SMI	VMI	SVI	dLFHF
S1	N	56.58	40.88	2.54	0.940	0.060	15.854	38.34
	S	69.84	25.71	4.46	0.850	0.150	10.614	21.25
S2	N	54.66	40.20	5.14	0.900	0.100	10.162	35.06
	S	51.38	45.22	3.40	0.924	0.076	17.822	41.81
S3	N	65.72	23.39	10.89	0.689	0.311	2.403	12.50
	S	61.01	33.08	5.91	0.839	0.161	5.927	27.17
S4	N	68.34	28.53	3.13	0.902	0.098	9.223	25.41
	S	41.66	48.19	10.15	0.815	0.185	6.369	38.03
S5	N	75.54	19.83	4.63	0.808	0.192	4.314	15.20
	S	72.32	22.90	4.78	0.833	0.167	6.802	18.13
S6	N	88.65	10.22	1.13	0.913	0.087	14.090	9.09
	S	75.25	22.19	2.56	0.896	0.104	9.393	19.63

3.3. Evaluation of HRV measures

The normal state and stress state classification results for individual subjects by using single HRV measures in time domain and frequency domain are shown in Table 6 and Table 7 respectively.

Based on the average accuracy from all subjects, the following HRV measures in the time domain are the effective ones: *mRR*, *mHR*, *pRR20*, *pRR50*, and *SDHR* with the average accuracy rates of 79.9%, 79.9%, 72.3%, 69.6%, and 68.7% respectively. For the frequency domain, the effective HRV measures are *SVI*, *nLF*, *nHF*, and *dLFHF* with the average accuracy rates of 74.3%, 73.4%, 69.4%, and 68.5% respectively.

Table 6. Normal state and stress state classification results by using HRV measures in time domain.

Subj	Accuracy (%)							
	mRR	mHR	SDRR	SDHR	CVRR	RMSSD	pRR20	pRR50
S1	94.1	94.1	64.7	70.6	64.7	47.1	70.6	35.3
S2	62.5	62.5	50.0	56.3	50.0	56.3	50.0	56.3
S3	60.0	60.0	60.0	60.0	60.0	80.0	80.0	80.0
S4	100.0	100.0	100.0	100.0	100.0	83.3	83.3	83.3
S5	75.0	75.0	50.0	62.5	50.0	75.0	87.5	100.0
S6	87.5	87.5	62.5	62.5	50.0	62.5	62.5	62.5
Avg	**79.9**	**79.9**	**64.5**	**68.7**	**62.5**	**67.4**	**72.3**	**69.6**

Table 7. Normal state and stress state classification results by using HRV measures in frequency domain.

Subj	Accuracy (%)						
	nVLF	nLF	nHF	SMI	VMI	SVI	dLFHF
S1	64.7	70.6	52.9	58.8	58.8	82.4	70.6
S2	50.0	56.3	62.5	68.8	68.8	75.0	56.3
S3	40.0	80.0	80.0	80.0	80.0	80.0	80.0
S4	83.3	83.3	83.3	66.7	66.7	83.3	66.7
S5	50.0	62.5	62.5	62.5	62.5	62.5	50.0
S6	87.5	87.5	75.0	62.5	62.5	62.5	87.5
Avg	**62.6**	**73.4**	**69.4**	**66.5**	**66.5**	**74.3**	**68.5**

The values of class separability index of HRV measures in time domain and frequency domain are shown in Table 8 and Table 9 respectively.

Table 8. Class separability of HRV measures in time domain.

Subj	Separability							
	mRR	mHR	SDRR	SDHR	CVRR	RMSSD	pRR20	pRR50
S1	0.044	0.040	0.588	0.235	0.384	0.942	0.546	0.999
S2	0.630	0.632	0.990	0.914	0.978	0.969	0.999	0.965
S3	0.979	0.980	0.968	0.949	0.980	0.238	0.353	0.432
S4	0.047	0.039	0.012	0.014	0.005	0.211	0.428	0.323
S5	0.272	0.281	0.921	0.482	0.742	0.447	0.205	0.067
S6	0.208	0.221	0.744	0.647	0.968	0.721	0.893	0.687
Avg	**0.363**	**0.366**	**0.704**	**0.540**	**0.676**	**0.588**	**0.570**	**0.579**

Table 9. Class separability of HRV measures in frequency domain.

Subj.	Separability						
	nVLF	nLF	nHF	SMI	VMI	SVI	dLFHF
S1	0.436	0.343	0.606	0.347	0.347	0.726	0.284
S2	0.862	0.815	0.780	0.805	0.805	0.430	0.776
S3	0.607	0.275	0.209	0.159	0.159	0.169	0.189
S4	0.122	0.216	0.169	0.355	0.355	0.525	0.457
S5	0.835	0.786	0.996	0.859	0.859	0.540	0.767
S6	0.098	0.104	0.223	0.836	0.836	0.553	0.119
Avg	**0.493**	**0.423**	**0.497**	**0.560**	**0.560**	**0.491**	**0.432**

Table 10. Top five best HRV measures for normal state and stress state classification based on separability index.

Rank	HRV measure	Separability index
1	*mRR*	0.363
2	*mHR*	0.366
3	*nLF*	0.423
4	*dLFHF*	0.432
5	*SVI*	0.491

Based on the average value of separability index, the prominent HRV measures for normal state and stress state classification are *mRR*, and *mHR* for the measures in time domain, and *nLF*, *dLFHF*, *SVI*, *nVLF*, and *nHF* for the measures in frequency domain. Table 10 shows the top five measures that have high power for stress state and normal state classification from RR interval signals.

4. Conclusions

This work has investigated HRV measures both in time domain and frequency domain for mental stress state and normal state classification in individuals from RR interval time series signals. Experiments are performed on 60 segments of RR intervals obtained from 6 subjects during normal state and mental stress state. Experimental results based on the separability index analysis reveal that the following measures: *mRR*, *mHR*, *nLF*, *dLFHF*, and *SVI* have the high potential to be used as an index for mental stress detection from RR interval signals. However, we still need further investigations with a large amount of data to confirm the reliability of results.

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