Comparison of Heart Rate Variability Measurements in Infants

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Abstract

The relationship between heart rate variability (HRV) parameters is unclear and the optimum parameters to use for clinical application are not known. To address this problem, adult data are only available for a few of the numerous HRV parameters, and few data are available for infants. The purpose of this paper is to study the correlation of common HRV measurements for infants. Eight-hour polysomnogram recordings for 110 infants from the CHIME study are used to calculate HRV parameters for non-overlapping, successive 5-minute segments in the same sleep states. For each pair of HRV parameters in each sleep state, Pearson's correlation coefficient is computed for each individual and bootstrap method is applied to calculate correlation for all infants. Results show high correlations between parameters where expected within and across domains. Some differences are noted compared to adult data.

1. Introduction

Since the confirmation by many studies that heart rate variability is a strong and independent predictor of mortality after acute myocardial infarction, the application of heart rate and heart rate variability is rapidly increasing in clinical studies. It has been considered a potential predictor of sudden infant death syndrome or apparent life-threatening event in infants. However, there are many methods used in quantifying heart rate variability (HRV), including time-domain, frequency-domain, time-frequency-domain, and nonlinear methods. The relationship between individual parameters is unclear and the optimum parameters to use for clinical application are not known. To address this problem, adult data are only available for a few of the numerous HRV parameters, and few data are available for infants. The purpose of this study is to perform a systematic investigation of the correlation of common HRV measurements for infants.

From previous studies using adult data, it is widely accepted that pNN50, RMSSD, and HF form one highly correlated group to measure the high frequency variation in heart rate [1, 2, 3, 4]. Previous studies concluded that RMSSD and pNN50, especially RMSSD, can be used as surrogates for HF, since time domain variables are inexpensive to compute compared with frequency domain variables. Unfortunately, controversial results were also reached in the study of the correlation between other HRV parameters [2, 3, 5, 6]. One study found that LF and total power over 24 hours is highly correlated with RMSSD, HF, and pNN50, which implicated them as vagal dependent parameters in their subjects [3]. However, most other researches show that LF is dependent on sympathetic tone rather than vagal tone [2, 5, 6].

In general, although numerous HRV parameters have been used in many clinical or diagnostic studies, the relationship between these HRV measures has never been studied systematically. This study uses all of the common HRV parameters in the time, frequency, and nonlinear domains. There are differences between this study and previous studies. Previous studies of the relationship among HRV measurements were performed on adult data, and few considered sleep state. In addition, other studies used the mean or median of HRV parameters over a long period of time for each subject to calculate the correlation coefficients, and did not include as many HRV parameters. We use a series of 5-min HRV measures per infant per sleep state for the correlation study. This will also take into account the variance in each sleep state per infant.

2. Material and methods

Eight-hour RR intervals (1000Hz) of 110 infants from the Collaborative Home Infant Monitoring Evaluation (CHIME) study are used to evaluate the relationship between HRV parameters [9]. The infants in CHIME study were originally categorized into four groups, healthy (15), preterm (54), SIDS siblings (19) and infant with apparent life-threatening events (ALTE) (22). The heart rate variability (HRV) was calculated for the entire eight-hour period using 5-minute epochs in one continuous sleep state (QS -- quiet sleep, REM – rapid eye movement sleep, AWK – awake). There are 24 HRV parameters included in this correlation study including: time domain -- Mean, Median, standard deviation (SD), interquartile range (IQR), coefficient of variation (CV), and root mean square (RMS) for both RR and the successive differences in RR; frequency domain -- high frequency power (HF,HFW), low frequency (LF,LFW), total power, and LF/HF ratio obtained by Fourier Transform and Wavelet transform; and nonlinear -- approximate entropy (ApEn), Poincare scatter coefficient, and fractal dimension (FD). Scatter plots and Pearson's correlation coefficients are used to view and measure the relationship between each pair of HRV parameters.

Since the calculation of HRV parameters is influenced by sleep state and since the infants are from different patient populations, we are also able to evaluate whether the relationship is affected by sleep state and group differences. Therefore, within each sleep state, correlation coefficients are calculated for each of the infants, for all of the infants, and for each group of preterm, ALTE, SIDS siblings, and healthy infants.

A 5-number summary and standard deviation are used to summarize the results. We define the 5-number summary here as 2.5th, 25th, 50th, 75th, 97.5th percentile of the coefficients in our study. The 50th percentile is the median, and the 25th and 75th percentiles are quartiles. The distance between the quartiles and the median shows how spread out the distribution of the result is.

Different from other correlation studies that used one averaged HRV value over the entire long-term recording for each sleep state per infant, we use the HRV values of all 5-min segments from the entire 8-hour RR interval data for the calculation of correlation coefficients. Therefore, for one HRV parameter, a vector of 5-min measurements for each sleep state and infant are used to calculate the correlation coefficients. A certain number of 5-min segments in each sleep state is required for further analysis. We only include infants who have at least five 5-min segments for each of the three sleep states, which eliminated 41 from an initial set of 151 infants from the study.

We pursue two different methods for calculating the overall correlation. The first is to calculate correlation coefficients for each infant. The five number summary plus variance across infants summarizes the results. The second is to generate a composite correlation across all infants. Different infants have a different number of 5-min segments in each sleep state. A bootstrap method is used to measure the correlation, while equally weighting the contribution from each infant. The idea of the bootstrap method is to use the same amount of data from each infant in the correlation study, such that the infants have the same contribution to the final result. The procedure for using the bootstrap method is as follows: 1) find the minimum number of 5-min segments among all infants for each sleep state (Nqs, Nrem, Nawk); 2) randomly choose Nqs/Nrem/Nawk segments from all other infants in QS/REM/AWK to form a bootstrap sample set; 3) calculate the sample correlation based on this bootstrap sample; and 4) repeat steps 2 and 3 a large number of times, i.e. 1000 times, to obtain 1000 bootstrap replicas of the correlation coefficients. The mean, median, or other statistical measurements of these replicas can be used as an accurate estimation of the true correlation. Taking the 25th and 97.5th largest of these 1000 replicates can give us the rough 95% confidence interval.

Table 1. Median of the correlation coefficients of the all infants' bootstrap dataset in QS

HRVs	Mean	SDNN	IQRNN	IQRSD	RMSSD	HF	LF	Tpower	LF/HF	HFW	LFW	LFW/HFW	ApEn	Poincare	FD
Mean	1.000	0.6051	0.6273	0.7198	0.7372	0.6458	0.4084	0.5187	-0.2316	0.6631	0.4537	-0.2738	-0.1475	0.6700	0.5691
SDNN		1.0000	0.9318	0.7074	0.7405	0.6536	0.7506	0.8026	-0.0006	0.7029	0.8515	0.0017	-0.4824	0.9281	0.6389
IQRNN			1.0000	0.7499	0.7686	0.6837	0.7162	0.7839	-0.0349	0.7280	0.8116	-0.0634	-0.3373	0.9838	0.6817
IQRSD				1.0000	0.9767	0.8610	0.4753	0.6373	-0.3376	0.8831	0.5462	-0.3868	0.0919	0.8205	0.9269
RMSSD					1.0000	0.8881	0.5013	0.6657	-0.3325	0.9117	0.5721	-0.3806	0.0283	0.8394	0.9347
HF						1.0000	0.5156	0.7095	-0.2437	0.9672	0.5341	-0.2879	-0.0299	0.7496	0.7522
LF							1.0000	0.9701	0.1700	0.5065	0.8390	0.0786	-0.3337	0.6971	0.3948
Tpower								1.0000	0.0702	0.6915	0.8415	-0.0189	-0.2845	0.7856	0.5388
LF/HF									1.0000	-0.2432	0.0836	0.7821	-0.4722	-0.1016	-0.3961
HFW										1.0000	0.5890	-0.2854	-0.0565	0.7945	0.7714
LFW											1.0000	0.1275	-0.3889	0.7891	0.4471
LFW/HFW												1.0000	-0.5466	-0.1367	-0.4519
ApEn													1.0000	-0.2769	0.1782
Poincare														1.0000	0.7511
FD															1.0000

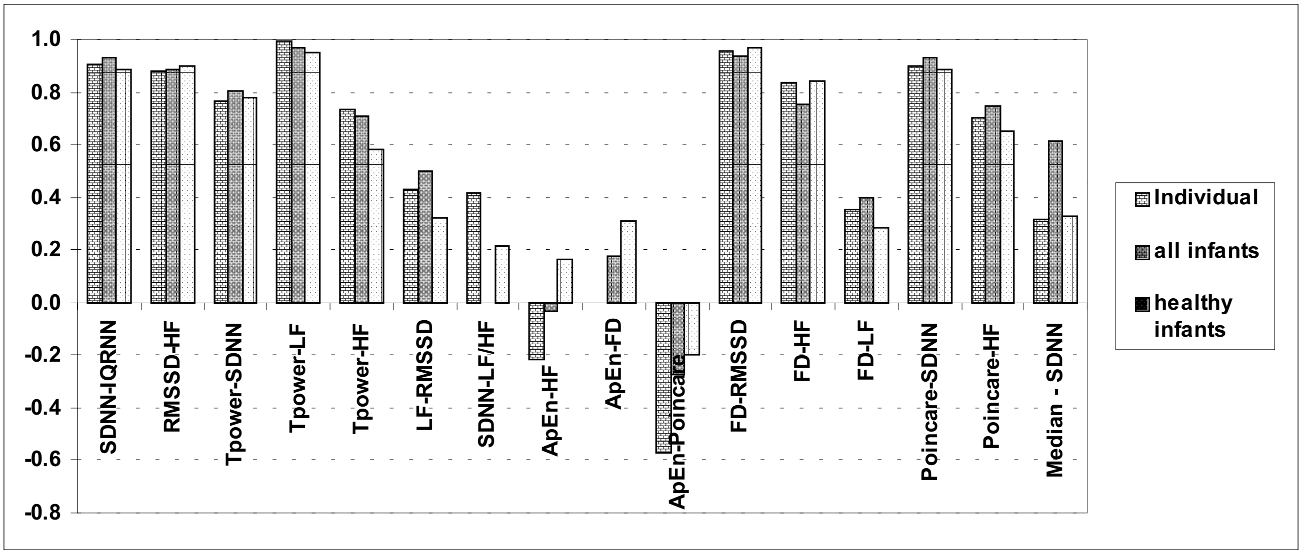

Figure 1. Median correlation coefficient for quiet sleep

3. Results and discussion

For each pair of HRV parameters, there are five 5-point summaries for each sleep state, which are gained from the following groups: individual coefficients, bootstrap coefficients of healthy, preterm, SIDS siblings, ALTE, and all of the infants, respectively. These results and corresponding scatter plots are used to evaluate the correlation. Table 1 and Figure 1 show the correlation coefficients of selected HRV pairs.

After obtaining the correlation coefficients and getting a general idea of the correlation, rules for both the level of correlation and consistency across infants are needed to determine some conclusions regarding correlation of HRV. There are four levels of correlations defined here for this study, very strongly correlated, highly correlated, somewhat correlated, and not correlated. (1) For very strong correlated pairs, the threshold is set as: the median of the correlation coefficients is not less than 0.95, and the standard deviation is not larger than 0.06. (2) For the highly correlated pair: the median of the correlation coefficients is not less than 0.80, and the standard deviation is not larger than 0.2. (3) For the somewhat correlated group: the median of the correlation coefficients is not less than 0.5, and the standard deviation is not larger than 0.3. (4) The remaining are defined as the not correlated group.

Among these 24 HRV parameters, pairs which are expected to be strongly correlated according to the definition, include Mean & Median, SDNN & CV, and RMSSD & CVS. The results from our infant data confirmed this. However, SDNN and IQRNN should also be strongly correlated according to their definition. Our results showed that the level of correlation is high, but the consistency across individual infants is not satisfied. By our rules, they belong to the highly correlated group.

A widely accepted highly correlated group of HRVs that measures the vagal input include: SDSD, IQRSD, NIQRSD, RMSSD, CVS, pNN50, HF, NHF, and HFW. Many previous studies support this result. Our results also confirmed the highly correlated relationship among these parameters with the following exceptions. First, even though it does not meet the highly correlated criteria, the correlation coefficients between HF and RMSSD for REM/AWK are still high, ranging from 0.7238 to 0.9184. Another exception is between SDSD and IQRSD for the AWK (r = 0.6468~0.8625). However, they are highly correlated for both QS and REM. Third, the correlation study shows that pNN50 correlation with other related parameters varies extensively from infant to infant, although the bootstrap correlation coefficients are large. Fourth, while the normalized high frequency power (NHF) is expected to be highly correlated with other HRV parameters that measure the high frequency component or beat-to-beat variation of RR interval, this is not the case in our study.

Some of our results conflict with those reached in previous studies using adult data. Total power was shown to be highly correlated with SDNN [2, 5, 6]. Our results indicate that the total power is very strongly correlated with LF, but somewhat correlated with SDNN for REM and AWK. In terms of whether LF is correlated with RMSSD and HF, we found a negative answer as most studies did, although high correlation between them is surprisingly found in one study [3]. Furthermore, no high correlation was found in our results between HF and FD, HF and ApEn, and ApEn and FD, as found in [8]. LF/HF ratio was not found to be correlated with any other parameters.

In addition, some rarely studied pairs of HRV measurements were evaluated in this paper, such as correlation between nonlinear measurements of HRV (ApEn, Poincare, and fractal dimension). There is little correlation among any of the three nonlinear parameters. Important results are summarized in table 2.

Table 2 Summary of rarely studied relationships

High correlation	Somewhat correlated	No correlation
Poincare vs. SDNN/IQRNN	FD vs. HF	LF/HF vs. all other HRV
FD vs. RMSSD	Poincare vs. FD in QS	ApEn vs. all other HRV

While, there are some differences in correlation coefficients between HRV parameters for different sleep states, the resultant correlation coefficient values show that the correlation in AWK is generally weaker than corresponding correlations in other two sleep states. However, the differences across sleep state are not significant, at least to the highly correlated pairs, consistent results are reached for most of the correlations. In addition, the group difference does not change the relationship significantly.

4. Conclusion

When selecting measures for individual applications, an understanding of the relationship between HRV parameters is necessary in order to select the simplest methods and fewest number of necessary parameters. This study evaluates the relationship between common HRV parameters in infants. Some results confirmed previous studies, such as the highly correlated group that measures vagal activity. However, differences are noted compared to adults, for instance, the correlation between HF/ApEn and ApEn/FD are not highly correlated as indicated in adult data. Furthermore, important parameters, LF/HF and ApEn, are found to have no correlation with any other HRV parameters. In addition, neither sleep states, nor group difference affects the relationship significantly.

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