Simulation of Cardiac RR Interval Time Series

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Abstract

An RR interval simulator was developed as part of the Computers in Cardiology Challenge (entry no. 184). The simulator was based on observed physiological changes in normal subjects.

A template, which represented slow trends in RR interval during 24 hours, was derived from a number of parameters that represent sleep and wake states.

The variations about the template were generated so that the frequency spectrum of the final signal was similar to data from normal subjects. The frequency spectrum of normal RR intervals shows a strong 1/f component, a peak at around 0.1 Hz and a peak corresponding to respiratory rate between 0.15 Hz and 0.4 Hz. These were simulated by adding to the template pink noise, a number of random phased sinusoids at around 0.1 Hz and a signal that represented respiration. Variations due to respiration were dependent on sleep and wake states.

1. Introduction

The development of Holter techniques has meant that ECGs can easily be recorded for 24 hours. Development of computer processing techniques allows the automatic calculation of RR intervals from these recordings, with manual checking when necessary.

Characteristics in the frequency domain of 24 hour RR interval recordings have been observed [1-3]. The main features include a 1/f component from 0 to 0.04 Hz, a peak around 0.1 Hz and a peak that occurs somewhere between 0.15 Hz and 0.4 Hz. The origin of some of these features remains a subject of debate [4-9].

External influences upon RR intervals include breathing, posture, sleep and exercise. Changes to RR intervals can occur suddenly (over one or two beats) or gradually (over many hours).

Figure 1 shows how RR intervals vary over a 24 hour period for a normal subject. Some events can clearly be seen: for example exercise may have occurred 6 hours after the start of the recording when the RR interval reduced to approximately 0.4 s. Sleep is likely to have occurred between 10 and 17 hours after the start of the recording when the mean RR interval rose to approximately 1 s.

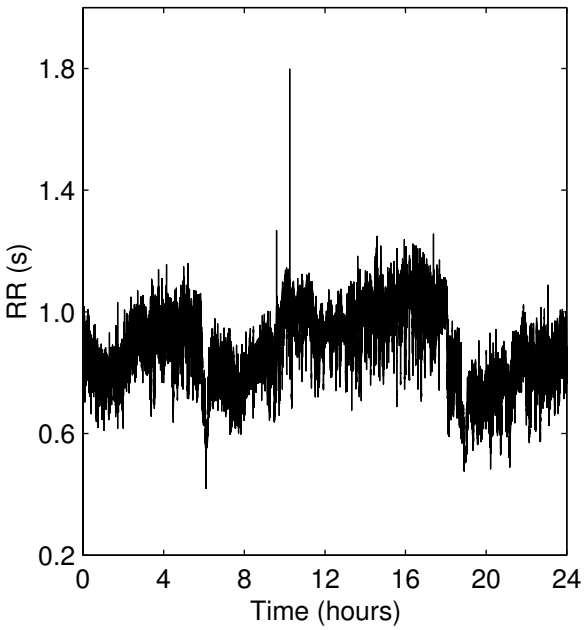

Figure 1. Twenty-four hour RR interval data from a normal person (recording was from noon to noon).

We aimed to simulate RR interval changes across 24 hours, by taking into account the known properties of heart rate variability and the effect of external influences.

2. Methods

To develop the simulator we created a data set with samples every 0.2 s, which represented RR intervals that had been regularly sampled. This enabled us to add different effects to the signal. Once the signal was completed we converted these regular values to consecutive RR interval lengths in accordance with the challenge rules.

First we developed a 'template' for the RR interval data. This represented how the mean RR-interval would vary across the 24 hours. Figure 2 shows how this template was built and table 1 includes the parameters

used to calculate the template. The template took into account a number of life style options such as when to go to bed, how long it takes to get to sleep, sleep duration, when to wake up, how long it takes to get up and the level of activity during the day. The template also included baseline wander and recording artefacts.

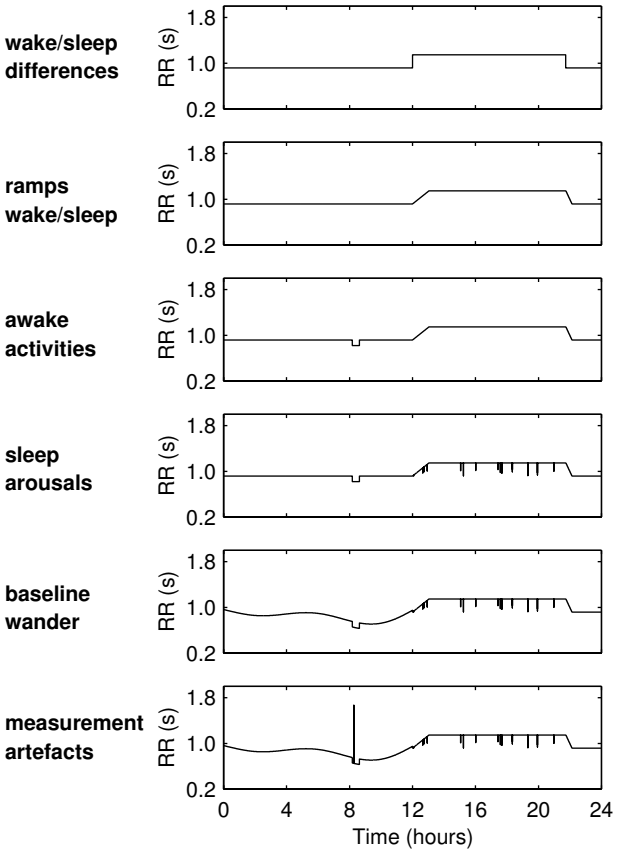

Figure 2. Template of RR interval, developed by superposition of parameters that represent sleep and wake states.

Secondly we developed variations around the mean RR values. This was done by modulating the interval with a random amount of pink noise, a number of random phased sinusoids with a frequency around 0.1 Hz, and a respiration signal. These signals are shown in figure 3.

The respiration signal was formed by concatenating sinusoids of different frequencies and amplitudes. The frequency and amplitude of each sinusoid was chosen randomly within a range. This range was dependent on wake and sleep, activity level and sometimes the previous values. This simulated respiration such when an activity occurred and respiration rate increased and respiration depth was highly variable. In contrast when there was no activity respiration rate slowed down and the variation in

Table 1. Parameters used to build up the template of the RR interval.

Parameter	**Randomly changing parameters**	**Boundaries**	**Notes**
Wake/sleep differences	Time sleep occurs	12 to 14 hours after recording starts	
	Time to get up	7 to 10 hours after falling asleep	
	Mean RR daytime value	0.8 - 1.1 s	
	Mean RR night value	0.8 - 1.2 s	Mean RR night value is at least 0.2 s longer than mean RR day value
Ramps	Length of wake to sleep ramp	40 - 110 min	
	Length of sleep to wake ramp	15 - 30 min	
Day activities	Number of active sessions	1 to 5	
	Duration of active session	3 - 30 min	
	Drop in mean RR interval	10 - 20%	
Night arousals	Number of night arousals	15 - 25	
	Duration of arousals	5 - 15 s	
	Drop in mean RR interval	10 -20 %	
Baseline wander			Sum of three sine waves (periods 13, 7 and 5 hours)
Artifacts	Number of artefacts	0 to 5	
	Increase in mean RR interval	1.5 to 2 s	

depth reduced. For the awake non-active state the sinusoid had different amplitude values for the positive and negative cycles. This was because through observation the level of changes about the mean appeared to be smoother and slightly smaller for positive changes and larger and more abrupt for negative changes. Table 2 contains the parameters for the factors added to the RR interval template.

Figure 3 shows examples in the frequency domain for each of the variations. Each of the variations was randomly scaled and then added to the template.

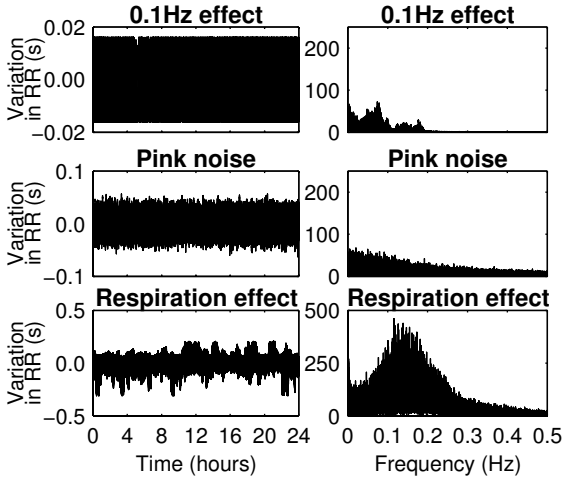

Figure 3. Variations in RR interval, which were added to the template.

3. Results

Three examples of simulated 24 hour RR interval data generated from our algorithm, are shown in figure 4 together with their frequency spectra.

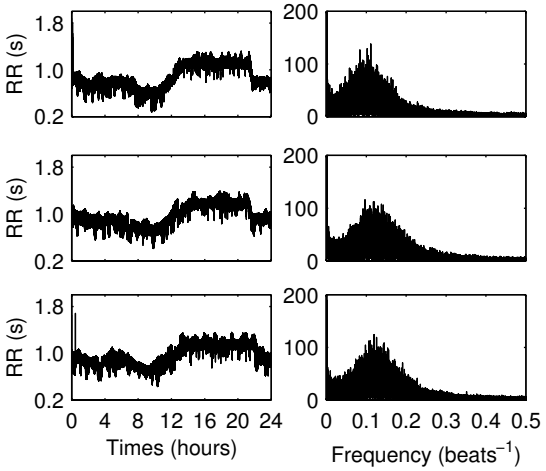

Figure 4. Three examples of simulated 24 hour RR interval changes and their frequency spectra.

Table 2. Parameters used for the factors added to the RR interval template.

Parameter	Randomly changing parameters	Boundaries
Pink gaussian noise	Amplitude	0.025 to 0.05 s
0.1Hz effect	Frequency	0.05 to 0.2 Hz
	Phase	No limits
	Amplitude	0.008 to 0.016 s
Respiration effect (awake active)	Amplitude range	0.05 to 0.15 s
	Amplitude variation	25%
	Frequency range	0.166 to 0.3 Hz
	Frequency variation	15%
Respiration effect (awake non-active)	Positive amplitude range	0.05 to 0.2 s
	Negative amplitude range	-0.05 to -0.3 s
	Positive amplitude variation	5%
	Negative amplitude variation	15%
	Frequency range	0.067 to 0.267 Hz
Respiration effect (sleep aroused)	Amplitude range	0.05 to 0.3 s
	Amplitude variation	5%
	Frequency range	0.067 to 0.267 Hz
Respiration effect (sleep non-aroused)	Amplitude value range	0.05 to 0.2 s
	Amplitude variation	10%
	Frequency range	0.067 to 0.2 Hz
	Frequency variation	15%

4. Discussion and conclusions

The data produced by our simulator differed from real data in the following ways; there was not enough variability in the baseline; there was not a large enough 1/f component; there was no distinct 0.1 Hz peak and the respiration peak needed more power in the high frequency range (0.15 - 0.4 Hz).

To develop our simulator further we need to produce a more variable RR interval template. This could be done by adding more randomness to the baseline and adding extra life style activities. The signals that we used to produce variation in RR interval need to be improved so that the frequency domain characteristics are more comparable to real life. The filter used to produce pink noise needs to be improved so that the 1/f property is more apparent. The scaling of the 0.1 Hz effect needs to be reassessed so the peak is more apparent. The variation due to respiration needs to be improved so that there is more power in the high frequency range (0.15 - 0.4 Hz).

The algorithm for this simulator is straightforward and based on physiological effects. The resulting data sets give semi-realistic values.

Acknowledgements

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