On the binaural brain entrainment indicating lower heart rate variability

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I. Introduction

Products based on binaural beat technology are popular as these claim to relax the user by altering (i.e. entraining) the brain's neuronal rhythm and a Google search will result in more than a million hits [1]. Whilst this is possible in certain approaches, for example in photic frequency following effects such as in brain-computer interfaces [2]; binaural brain entrainments uses two beats (usually sinusoidal tones) that are different in frequency by a small amount that generates a third pseudo-rhythm at the difference of the two frequencies [3]. Furthermore, binaural brain entrainment is also claimed to allow altered states of consciousness and hemispheric synchronisation [4]. However, the effects of this entrainment on the cardiac rhythm appear to be understudied, though equally important as the effects on the brain. Hence, the investigation here is set out with this aim.

II. METHODOLOGY

Electrocardiogram (ECG) data were recorded from five subjects (one female, four males, age range 24-39) from six weekly sessions. Three electrodes were used - one reference and two active in bipolar montage: one on left wrist and one on right wrist to give one lead ECG configuration. The sampling frequency was set as 256 Hz. Electroencephalogram was not used here as the aim of the work was not on studying entrainment effects in the brain. Ethical approval was obtained and the study protocol conforms to the ethical guidelines of the Declaration of Helsinki. The subjects signed consent form after being briefed on the objective of the study and were paid a small honorarium for their time.

Subjects were instructed to close their eyes and relax while listening to the audio using flat frequency response Etymotic insert earphones. Two different conditions (each lasting two minutes) were designed:

- Relaxed - where the subjects listened to waves hitting the beach (i.e. soothing music). The relaxed mode is the usual conventional method used in most studies related to ECG biometric [5];
- Entrained condition – where the subjects were listening to binaural tones. The binaural tones were generated using two sinusoidal (tone) waves, one with frequency of 400 Hz to the left ear and another with frequency of 408 Hz to the right ear and both tones were masked by the same soothing music as in the other condition.

The order of the two conditions was alternated in the different sessions even though the subjects were not aware of the conditions as they listened to the same music (as the binaural tones were masked by the music). The entrained condition evokes an effect where the brain rhythms oscillate around the spectral difference of the two tones of 8 Hz. The frequency difference of 8 Hz between the two tones was selected as this frequency falls in alpha rhythm, which appears during relaxed and eyes closed conditions [6].

To reduce baseline wander and high frequency noise, ECG signal was digitally filtered from 15 to 40 Hz. The cut-off at 15 Hz ensures reliability of R peak detection in the ECG signal, where the R peaks were detected using a threshold, *Th* >0.2**max_amplitude_ECG* (for all the subjects) and time intervals between the peaks (known as normal to normal (NN) interval) were computed.

Heart rate variability (HRV) gives a useful indication of the health of the cardiac rhythm and can be computed using NN intervals. Other than ECG, ballistocardiogram and pulse wave from plethysmograph could also be used but ECG provides cleaner waveform and easier detection. One hundred NN intervals were obtained from each subject per session giving a total of 1200 values for each subject (600 per condition). Figure 1 shows an example of the R peaks and NN intervals.

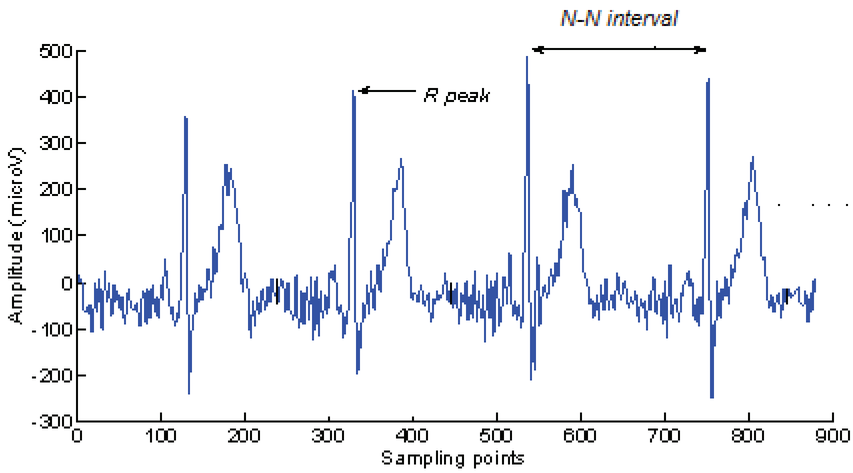

Figure 1: Example of a segment extracted from ECG signal.

Standard deviation of the NN interval (SDNN) is a commonly used HRV measure and reflects the cyclic components leading to variability and Parseval's theorem allows computation of this spectral component in time using the NN intervals. To avoid inaccuracies from short ECG records and to avoid non-uniform sampling issue, SDNN was computed as HRV measure instead of direct spectral analysis.

The 600 NN intervals from the relaxed condition were divided into 30 sets each and SDNN values were computed from each set. Similarly, 30 values of SDNN were obtained for the entrained condition for each subject.

III. Results and Discussion

Table 1 shows the mean and standard deviation values of the NN intervals for each subject. Wilcoxon-ranksum test was used to compare the 30 sets of SDNN values for the two conditions for each subject and it was found that the SDNN decreased for subjects 1, 2 and 4 ($p<0.05$). It is known that lowering of HRV denotes poorer health status of the heart as reported in cardiological [7] and non-cardiological issues such as worrying [8]. Factors such as induced stress from laboratory environment is irrelevant here as it would be present for both the conditions.

In the literature, Conte et al. [9] has shown HRV improvements using binaural beats. Our results differ from those by Conte et al. and we presume this could be due to the different approaches used. First, our study uses time domain HRV features to circumvent non-uniform sampling that is an issue for Fast Fourier Transform used in their study. Secondly, HRV data was computed using ECG signal in our case (which we believe is more accurate) as opposed to using plethysmograph. Thirdly, original principles from Oster's method [10] was used to generate the binaural beats while their study utilised a commercial brain entrainment software. Fourthly, their study used data from a single session of 20 minutes with binaural experiment following the control which could allow additional 'relaxation' for the binaural case while our data was based on two minutes recordings obtained over six sessions which allowed alternation of the presentation order thereby removing residual effects from either condition.

While the results are not conclusive as only a small pool of subjects was used and it is possible that longer entrainment period could alter the results, nevertheless the less variability in the heart beat intervals indicates that the entrainment method warrants further independent research to establish its effect healthwise, both beneficial and detrimental.

TABLE I. NN TIME INTERVAL VALUES (IN SECONDS) FROM EACH SUBJECT

Subject		**Condition**	
		Control	**Binaural**
S1	Mean	0.85	0.86
	Std	0.082	0.084
S2	Mean	0.87	0.81
	Std	0.076	0.061
S3	Mean	0.87	0.85
	Std	0.086	0.10
S4	Mean	0.87	0.86
	Std	0.091	0.083
S5	Mean	0.88	0.92
	Std	0.16	0.14

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