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iHeartLift: A Closed Loop System With Bio-feedback that Uses Music Tempo Variability to Improve Heart Rate Variability

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***Abstract*—"Musica delenit bestiam feram" translates into "Music soothes the savage beast". There is a hidden truth in this ancient quip passed down from generations. Besides soothing the heart, it also incites the heart to a healthier level of heart rate variability (HRV). In this paper, an approach to use and test music and biofeedback to increase the heart rate variability for people facing daily stress is discussed. By determining the music tempo variability (MTV) of a piece of music and current heart rate variability, iHeartLift is able to compare the 2 trends and locate a musical piece that is suited to increase the user's heart rate variability to a healthier level. With biofeedback, the 2 trends are continuously compared in real-time and the musical piece is changed in accordance with the current comparisons. A study was conducted and it was generally found that HRV can be uplifted by music regardless of language and meaning of musical lyrics but with limitations to musical genre.**

I. Introduction

The HRV of a person has always been a good indicator of a person's cardiac health [1,2,3]. There are numerous publications and inventions citing the use of HRV and its bio-feedback [4, 5, 6] for diagnostic purposes. However, most of them have been in the medical domain; leaving a few out of it. There has been interesting research citing that the richness of the range of the HRV is akin to the richness of the rhythm in music and songs [7, 8, 9]. Hence, this paper proposes a new approach to use HRV, bio-feedback and music to improve on the cardiac fitness of people.

The iHeartLift is developed as a closed loop system that firstly monitors the users' electrocardiography data (ECG) in real time and converts it into real time HRV data. The HRV data is then used for similarity comparison against a music piece or song's MTV. The extent of the similarity comparison is used to select a song that is suitable to improve the HRV of a person. Subsequently, using the improved HRV after listening to the selected song as bio-feedback to select the next song that would even boaster the person's HRV to the healthier level. And it is through this continuous cycle of listening and augmented song selection that iHeartLift seeks to improve one's HRV.

The iHeartLift has been developed. The purpose of this paper is to document the preliminary experiments of the iHeartLift on the above hypothesis. This paper details the methodology, the experiment setups and procedures for the iHeartLife in the section 2 and 3. It analyses the results and implications of the bio-feedback cycle for the iHeartLife in section 4 and concludes with future developments for the iHeartLife in section 5.

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II. Methodology

There are 3 essential components for the iHeartLift to be successful. The first component is the calculation of the real time HRV; the second component is the calculation of the MTV and lastly is the matching of the HRV with a database of MTV to select the song that is best for the next round of listening.

There are numerous ways for the conversion of raw ECG data into HRV data. The most common way is to detect the QRS complexes for the R peak for the R-R intervals. The Root Mean Square of Successive Differences (RMSSD) would then be applied on the sequence of R-R intervals for the calculation of the HRV of the ECG data.

The MTV or the Music Tempo Variability is defined in this paper for the first time as the audible beat-to-beat differences in the intervals as perceived by the human ear over a period of time during the listening of a musical piece. This is so such that the rise and ebb of the flow of the song is allowed to propagate its effects onto the listeners and hence although the music or song having its several fixed tempo and rhythm is perceived as having 1 continuous stream of tempo and rhythm that is an aggregate of the formers. Once the several rhythm channels are combined into 1 singular channel, the beats of the rhythm are detected. As for the beat detection, so long it is intrinsic to the way a person is able to perceive the beats, it will akin to the fact that was stated previously above. Thereafter, the RMSSD is applied to the beat-to-beat intervals of the singular rhythm channel for the calculation of the MTV.

The last process to be done is the controlled matching of the HRV against the MTV. Since the MTV for a piece of music or song is static; their MTV can be pre-processed. During the execution of the program, the similarity comparison between the HRV and MTV can then be done in real time. HRV over time is a trend of the changes of the R-R intervals whereas MTV over time is a trend of the changes in the perceived beat-to-beat interval of the combined musical tempo and rhythm of a piece of music or song. Hence, the comparison of 2 similar trends can be done by using a simple Euclidean distance measure. However, a

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slight adjustment would need to be made to cater to the positive beneficial aspect of what iHeartLift is first set out to do. No doubt, the piece of music or song with the highest similarity would be chosen. However, the Euclidean distance measure is impartial to the positivity or negativity of the MTV trend over the HRV trend; as the Euclidean distance calculates absolute differences. Another measure to ensure the positivity of the MTV over the HRV trend would have to be used in conjunction with the Euclidean distance measure. In this case, the Manhattan distance measure is used after the Euclidean distance measure is used. Therefore, the combination of the 2 measures that would be taken is the minimal absolute Euclidean distance that has a positive Manhattan distance. Depending on precision and how close to real time iHeartLift as to be, a configurable size for the comparison window is implemented. The comparison window follows a sliding window technique for peak-to-peak and beat-to-beat comparison.

Putting the 3 processes together would result in the following steps that the iHeartLift is built upon:

1. Monitor user's ECG in real time
2. Calculate HRV from user's ECG
3. Plot the trend of user's ECG
4. Compare the HRV trend and MTV trend using the sliding window technique
5. Select the best song or music piece based on the above defined criteria
6. Play the musical piece to the user
7. Repeat from step 1

This continuous cycle can then be used for extended periods using the dynamically affected ECG to fuel as inputs for the next selection of song; truly giving meaning to "What the Heart Desires."

III. Experiment

A. Hardware and Software Prototype

The iHeartLift was developed using C and java. The collection of Electrocardiography (ECG) data was done by using the Bluetooth-enabled ECG sensor from Alive Technology Pte Ltd. The control, device interface and user interface is developed using java. Java offers better threading, control and storage capabilities to handle the voluminous data and the large amount of processes; both synchronous and asynchronous. The evaluative algorithms are all developed in C as dynamic linked libraries. The libraries are linked to the prior via Java Native Interface. Hence, fast real-time evaluative performance is not an issue in this context

B. Environment and Test Subject

The experiments were conducted in the bio-signal processing laboratory of the Institute for Infocomm Research (I2R). The hardware used was a Dell m4400 precision workstation laptop, a Bluetooth receiver for the laptop, a Bluetooth-enabled ECG sensor from Alive Technology Pte Ltd, a pair of earphones and a comfortable couch. The participants for the experiment are randomly selected staff from I2R. The experiments are all conducted after 3pm in the afternoon. This is to allow for daily work stress, if any, to build up in the participants. All the participants were healthy and were not suffering from any illnesses like cold, flu, etc. They participated in the experiment willingly and were not under any type of duress or diagnosed to be suffering from any congenital heart disease or depression. Therefore, the only tension their hearts were facing were daily stress built up from their daily activities.

C. The Experiments

There were 2 sets of experiments. The first set is the control experiment. The control experiment will act as a gauge of effectiveness of using iHeartLift versus not using iHeartLift. The second experiment involves using the iHeartLift bring about a change in the heart rate variability.

The control experiment setup involved a randomly selected healthy participant from the group of people. The ECG sensor was placed upon the participant. He/she was asked to relax on the couch to stop environmental fatigue or stress. The participant's ECG was monitored for 1 hour. Thereafter, continuing to the iHeartLift experiment.

In the iHeartLift experiment the participant was still in the prior setup, but was asked to wear a pair of headphones. This was for the input of music and also to complete the cycle between iHeartLift and participant. Real-time monitored ECG was processed by iHeartLift to select the musical pieces with similar MTV improve the participant's HRV. The musical pieces were 1-minutes long from the pop and contemporary genre. The automated constant update and playing, by means of ECG biofeedback, is the main approach used in this paper to improve the HRV. Most of the participants using the iHeartLift were monitored for about an hour. However, there were some participants that were monitored for shorter periods due to sudden arising circumstances.

Numerous research by the Institute of HeartMath had shown that different genre of music affects the human heart in different ways with varying degrees of effects [10]. Therefore, the aspect of if music will affect a person cardiac's well-being is not being experimented upon here.

IV. Results And Analysis

The results obtained from these preliminary experiments are positive. This is in actual fact a very good start for this research. The HRV as stated previously was calculated using RMSSD. In this experiment, due to the fact that changes in the selection of the musical piece must occur in real-time, the number of successive NN intervals for calculation was small; the number of successive NN intervals was 10. This was small compared to the standard practice of applying RMSSD to collected ECG data of 5 minutes in medical practice. However, the method used in iHeartLife was augmented by applying a sliding window across the successive NN intervals monitored. Even though a small window size of 10 successive NN intervals was used, the results obtained were astonishing for these preliminary experiments.

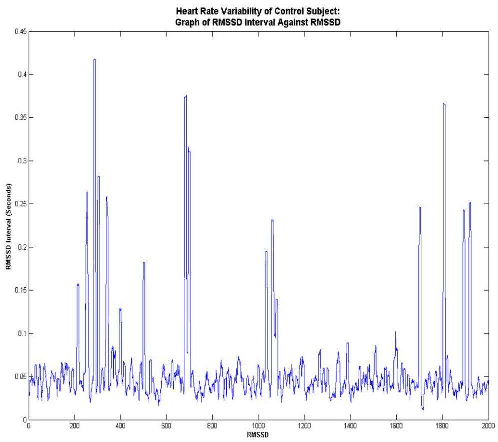


Fig. 1. Heart Rate Variability of Control Experiment

In the control experiment, the plot of RMSSD intervals against Nth RMSSD showed very little large RMSSD intervals. Majority of the RMSSD was restricted to small durations as seen in Fig 1. However, when the same participant in the control experiment was using the iHeartLift and being monitored at the same time, the results obtained were simply astonishing. There was very significant increase in the RMSSD of large intervals. This actually meant that there was an increase in the HRV of the participant upon using iHeartLift as shown in Fig 2.

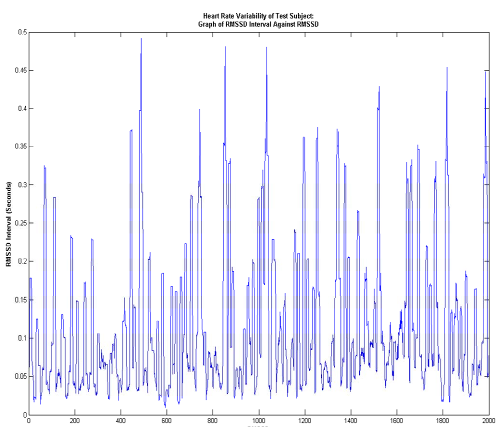
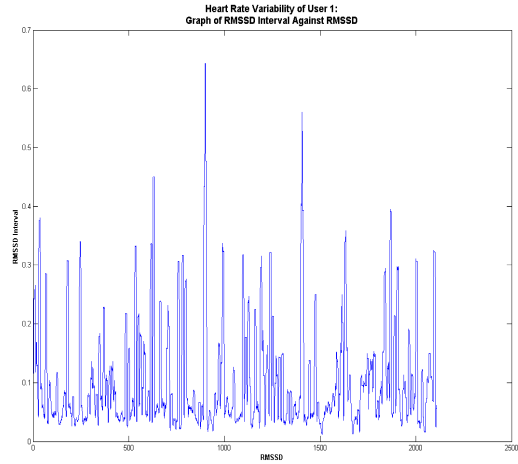
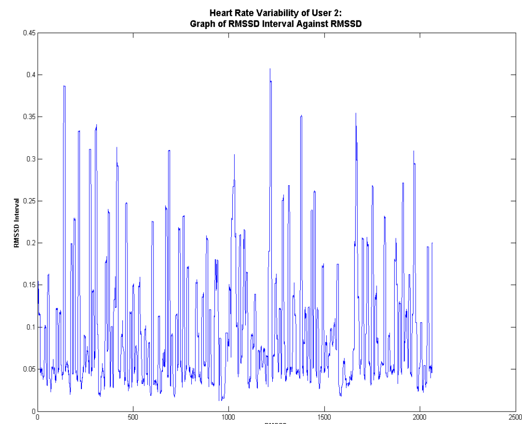


Fig. 2. Heart Rate Variability of Control Experiment but under iHeartLift program

This could be due to the fact that only music pieces or songs that have positive trends over the HRV are used. Due to the fact that our bodies have the ability to harmonize with a source, the rhythmic functions of our body's organs are synchronized with the music's rhythm. Since the music's tempos and rhythms are immutable and our body's organs' natural rhythms are not, it will not be altered by our bodies' rhythm. Therefore, the harmonization could only occur in the way that our body was the one harmonizing with the music and not a mutual harmonizing of both sources.





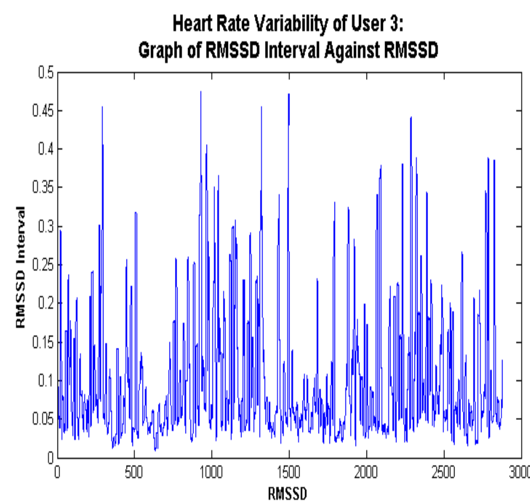


Fig. 3. Heart Rate Variability of Actual Experiment but under iHeartLift program

In the actual experiments, the trend of improvement among all the participants could actually be seen in similar graphs of RMSSD intervals against Nth RMSSD. More

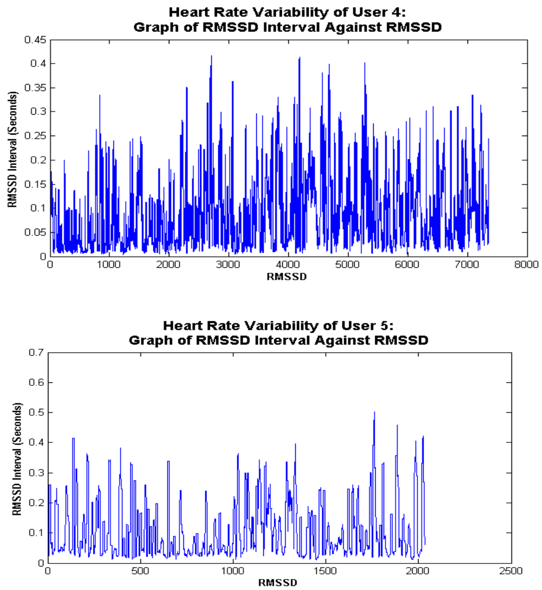


Fig. 4. Beneficial Improvement to HRV Regardless of the duration of usage of iHeartLift program

interestingly was the effects of iHeartLift that were felt by all participants almost immediately. The language and the type of musical piece already in the music database do not impede the effects that iHeartLife had on the participants. The musical database was populated by musical pieces of from a variety of melodies and languages. Therefore, the originality of the musical piece or song has minimal impact on the user. In figure 4, it is noted that regardless of the duration the participants used iHeartLift, be it as long as 1 hour or as short as 15 minutes, the same beneficial effects are being felt.

V. CONCLUSION

iHeartLift with its unique way to elevate the HRV of a person using music is proposed in this paper. Results from the experiments have shown that through the use of HRV biofeedback and MTV of music, the HRV of the users of iHeartLift can be elevated to a level with higher richness in the variety of HRV as shown in Fig 5.

In future works, the research will be focused on finding the optimal designer musical pieces that will improve one's HRV and is unique to each individual. Continuing experiments has shown trends for individual's hearts to reach their most optimal HRV as shown in Fig 6

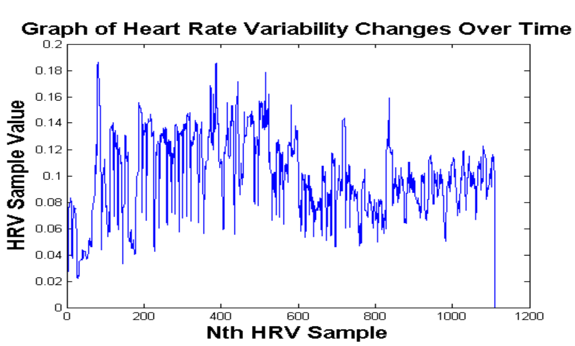


Fig. 6. HRV tapering to an optimal value after using iHeartLift

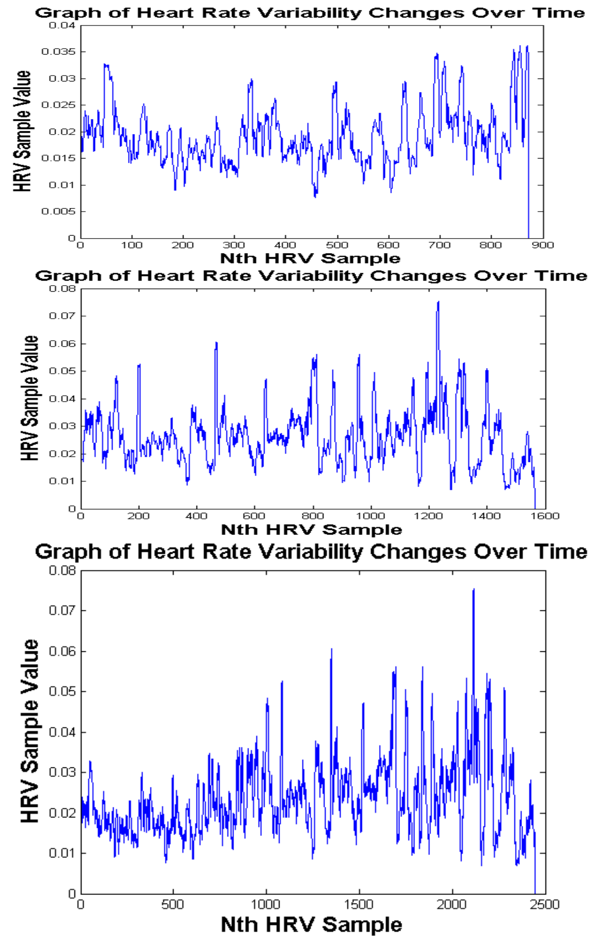


Fig. 5. Results of using iHeartLift. Top figure is the before HRV.

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