Automatic stress-relieving music recommendation system based on photoplethysmography-derived heart rate variability analysis

Il-hyung Shin, Jaepyeong Cha, *Student Member*, Gyeong Woo Cheon, *Student Member*, Choonghee Lee, Seung Yup Lee, Hyung-Jin Yoon and Hee Chan Kim, *IEEE Member*

***Abstract*— This paper presents an automatic stress-relieving music recommendation system (ASMRS) for individual music listeners. The ASMRS uses a portable, wireless photoplethysmography module with a finger-type sensor, and a program that translates heartbeat signals from the sensor to the stress index. The sympathovagal balance index (SVI) was calculated from heart rate variability to assess the user's stress levels while listening to music. Twenty-two healthy volunteers participated in the experiment. The results have shown that the participants' SVI values are highly correlated with their prespecified music preferences. The sensitivity and specificity of the favorable music classification also improved as the number of music repetitions increased to 20 times. Based on the SVI values, the system automatically recommends favorable music lists to relieve stress for individuals.**

I. Introduction

Many studies have shown that music has profound effects on the human body and mind, such as improvements to blood flow, blood pressure, and heart rate [1, 2]. Recently, music therapy has begun to receive scientific consideration; it has been successfully applied to the treatment of patients suffering from diseases such as cancer [3], autism [4], and attention deficit hyperactivity disorder [5, 6]. In general, listening to music is a well-known means of stress relief, but it is also particularly important for patients who are unable to communicate. Previous music recommendation systems have used a context-based method [7]. However, recently, the physiological response to music has been regarded as an objective criterion for music selection [8]. Additionally, many studies have shown that heart rate variability (HRV) is highly correlated with stress indices [9, 10]. Thus, HRV measurement has been adopted as a noninvasive and relatively easy method for assessing the severity of stress [11].

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I.-H. Shin is with the Interdisciplinary Program, Biomedical Engineering Major, Graduate School, Seoul National University, Seoul, Republic of Korea (e-mail: lepagats@melab.snu.ac.kr).

J. Cha and G. W. Cheon are with the Department of Electrical and Computer Engineering, Johns Hopkins University, Baltimore, MD 21218 USA (e-mails: jcha8@jhu.edu and gcheon1@jhu.edu).

C. Lee is with the Interdisciplinary Program, Bioengineering Major, Graduate School, Seoul National University, Seoul, Republic of Korea (e-mail: lch2722@ snu.ac.kr).

S. Y. Lee is with the Department of Biomedical Engineering, University of Michigan, Ann Arbor, MI 48109 USA (e-mail: paulslee@umich.edu).

H.-J. Yoon and H. C. Kim are with the Department of Biomedical Engineering, College of Medicine, Seoul National University, 101 Daehak-ro, Jongno-gu, Seoul 110-799, Republic of Korea (e-mails: hjyoon@snu.ac.kr and hckim@snu.ac.kr; corresponding author to provide phone: +82-2-2072-2931; fax: +82-2-745-7870; e-mail: hckim@snu.ac.kr).

The aim of this study is to develop a personalized music recommendation system (automatic stress-relieving music recommendation system, or ASMRS) to lower individual stress levels by using photoplethysmography (PPG)-derived HRV analysis. One of the technical challenges of this goal is to numerically and reliably evaluate changes in stress level. To properly estimate the stress index using HRV analysis requires continuous heart rate data for a period of more than 5 min [12]. Because most contemporary music has relatively short playback times (~4 min), it has been difficult to examine the correlation between specific music and HRV signals. Additionally, simple repetition of the same music may provoke unknown stress [8].

In this work, we present a wearable, wireless PPG sensor module for signal acquisition and a novel HRV analysis algorithm for the stress assessment of a person listening to music. In section 2, the detailed system setup and algorithm are described. Experimental protocols are described in section 3. The experimental results for 22 healthy volunteers are summarized and discussed in section 4.

II. Materials and Methods

A. System Specifications

The ASMRS comprises three parts: a sound system, a wireless PPG sensor module, and a PC program for HRV analysis and automatic music recommendation. The sound system is composed of general speakers that are connected to a PC and placed in the room. The speaker volume is adjusted to minimize negative effects on the subject. The wireless PPG sensor module consists of a pulse oximetry sensor (PureLight, Nonin, USA); a signal processing module (Webdoc SpO_2, ELBIO, Republic of Korea) for PPG signal amplification, acquisition, and data processing; and a Bluetooth® module (HC-06, HC-IT, China), as shown in Figures 1b–e.

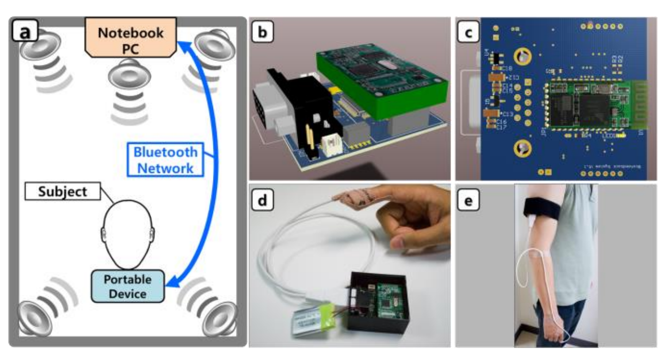

Figure 1. Automatic stress-relieving music recommendation system. *a*. Experimental setup. *b–e*. Portable, wireless PPG device.

The graphical user interface and all the software, depicted in Figure 2, were created by using a customized Visual C# (Microsoft, USA) script with a digital signal processing library (Measurement Studio, National Instruments, USA). The PC program includes PPG waveforms, peak detection results, HRV waveform, power spectral density and statistics. A pipeline of the data flow from the sensor module to the PC program is presented in Figure 3.

Figure 2. Graphical user interface and PC program. *a.* PPG waveform. *b.* Peak detection of PPG. *c.* HRV waveform. *d.* HRV sync waveform. *e.* Previous HRV power spectral density. *f.* Statistics. *g.* Playlist.

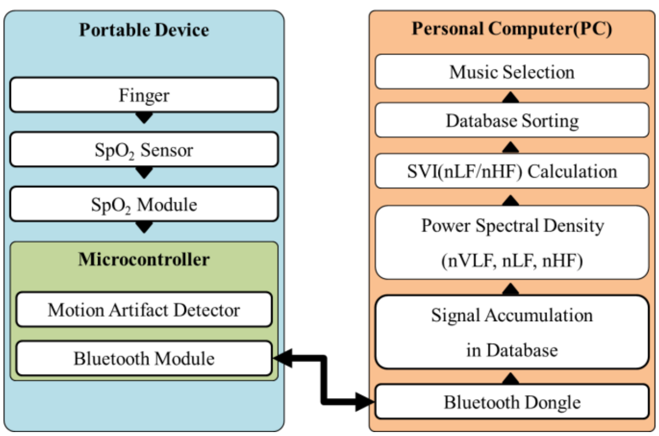

Figure 3. Pipeline of data flow from the sensor module to the PC program.

B. Assessment of Music-induced Stress Relief

The changes in stress level induced by music were estimated by using a HRV parameter known as the sympathovagal balance index (SVI = LF/HF, LF: power spectrum of HRV signal from 0.04 to 0.15 Hz, HF: power spectrum of HRV signal from 0.15 to 0.4 Hz) [9, 11]. As described earlier, at least 5 min worth of data are required for reliable stress analysis. To solve this issue, we used a quasi-continuous HRV signal (QCHS) acquisition method, which accumulates discrete HRV signals from individual music pieces while an entire playlist is repeatedly played in a randomly selected sequence. This strategy, as depicted in Figure 4, can avoid unrelated stress factors caused, for example, by the simple repetition of the same music. The HRV signals corresponding to certain music pieces were saved in the database for post-signal processing. The database was programmed to sort the HRV signals by the title of the music piece. The SVI values were then calculated from the accumulated HRV signals and used as stress indices for the corresponding music pieces. Motion artifacts, defined as beat-to-beat variations of more than 20% over an average duration of 10 s, were excluded from the data analysis. As a result, we were able to compile a reliable data set of the stress indices for specific music pieces on the playlist.

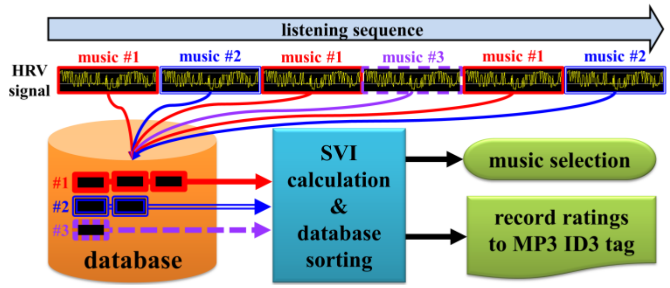

Figure 4. Schematic diagram of quasi-continuous HRV signal acquisition.

III. Experimental Design and Protocol

A performance evaluation of the developed system was conducted with 22 healthy volunteers with no history of stress-related disorders. The volunteers were 10 males and 12 females, with a mean age of 17.6 years (standard deviation: 2.7 years). The experimental protocol is summarized in Table 1. All participants were allowed to move freely in the room during the examination. At the beginning, they were asked to select six songs (three favorite and three annoying) from a predefined music list and rank them in order for the comparison study. Each set of six songs was played 30 times per test, and the sequence of the songs was shuffled every time. While the music was playing, HRV signals from each participant were acquired and transmitted to the PC program. The data were saved and accumulated in the stack according to the SVI value. The stress indices were ID3 metadata tagged in the music file (MP3 format). The resultant rankings for the songs obtained from the experiment were compared to prespecified rankings from individual participants.

TABLE I. Experimental Procedure

Seq.	Instruction
1	Subject selects three favorite and three annoying songs by assigning a rank according to preference.
2	The set of six songs is played 30 times per test. The sequence of the songs is selected randomly each time.
3	The HRV signal corresponding to a specific song is saved to the database and accumulated for the 30 repetitions.
4	The songs are ranked in order of the SVI value as a stress index (0: most stressful; 5: most comfortable).
5	The stress index is recorded to the ID3 Tag region of each MP3 file to use in other types of MP3 player software.
6	The ASMRS results are compared to the subject's prespecified rank.

IV. Results and Discussions

To evaluate the performance of the system, we first plotted SVI values according to the number of repetitions in the QCHS.

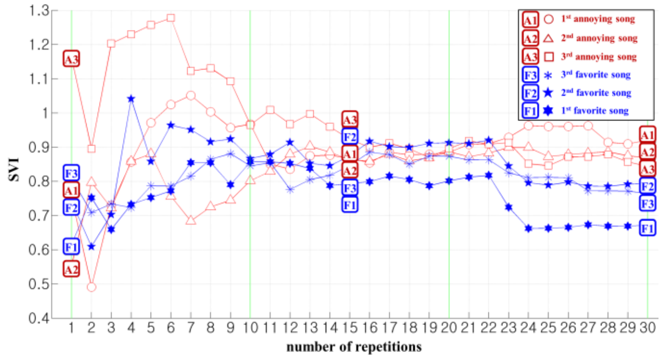

Figure 5. Graph of changes in the SVI value according to the number of repetitions of a specific song.

Figure 5 shows the experimental results, in which the SVI values are accurately matched with the subjects' prespecified preferences for the music pieces after approximately 20 repetitions of the music. A sufficient number of short HRV signals were accumulated, which provided enough data for the analysis. These results are in accordance with a previous report that a higher SVI value corresponds to a higher stress level [6]. Consequently, these observations suggest that our QCHS algorithm may be suitable as a reliable stress index for SVI approximation.

Next, we compared the estimated preference ranks from the SVI values with the subject's prespecified preference ranks. As shown in Figure 6, both the sensitivity and specificity of the ASMRS classification function improved as the number of repetitions increased: 1, 15, and 30 repetitions produced 56.1%, 74.2%, and 78.8% of total classifications located in the true positive (TP) and true negative (TN) regions, respectively.

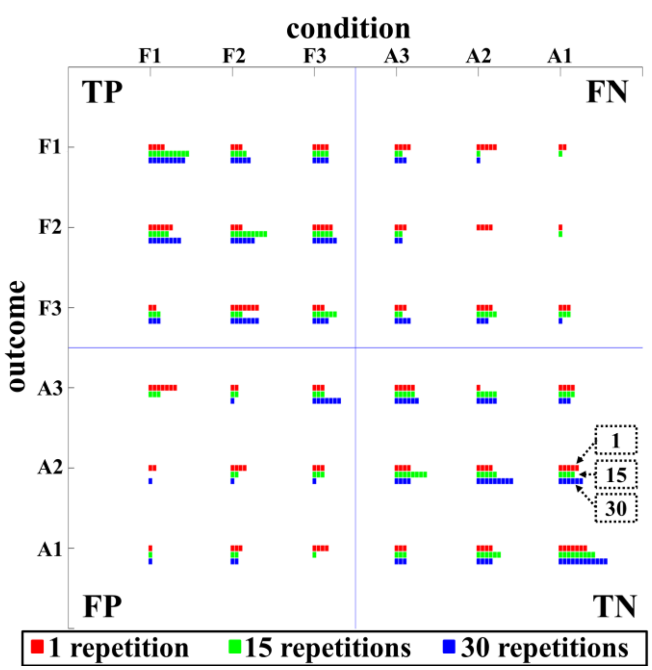

Figure 6. Graph of test results for the classification of favorite/annoying songs by participants (six songs in a contingency table with a total of 22 subjects after 1, 15, and 30 repetitions).

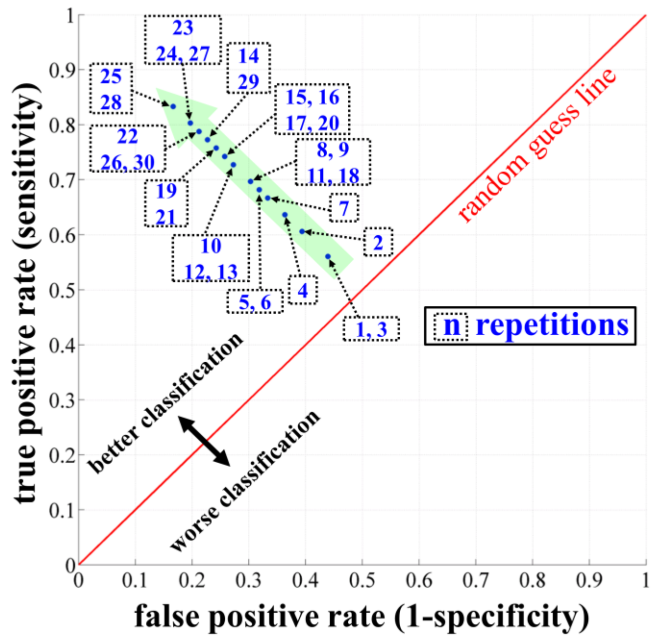

Figure 7. Improvement of classification performance in ROC space according to increases in the number of repetitions.

By converting these results into a receiver operating characteristic (ROC) space, as plotted in Figure 7, we also observed an improvement in the performance of the ASMRS as the number of repetitions increased. However, beyond 25 repetitions, the performance appeared to be saturated and did not improve further. Additional studies will be necessary to identify the optimal conditions to determine the most reliable stress indices.

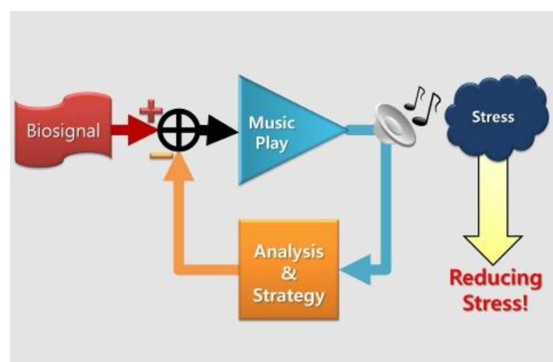

Figure 8. Schematic of the proposed stress-relieving music recommendation system.

Based on the SVI values, the ASMRS can recommend a favorable music list that lowers stress levels. A schematic of the feedback control is depicted in Figure 8. Either the individual can indicate threshold levels or a predefined SVI value can be used to prepare a favorable/annoying music list. Because the SVI values can also vary depending on the conditions of the body or environment, we can apply an option for an active recommendation mode. In general, the proposed system may be well-suited for individual listeners to choose favorable music according to their moods or body conditions based on biosignals. Additionally, the ASMRS can contribute to the field of music therapy, which is often required for patients who are unable to communicate. Because the system can automatically recommend songs to relieve mental stress, it may be used for the treatment of patients.

V. Conclusion

A portable and wireless music recommendation platform is developed for individual users to relieve stress levels while listening to music. A performance evaluation was conducted with 22 healthy volunteers. The experimental results demonstrated that our ASMRS can successfully detect HRV signals and estimate SVI values for stress level indicators. The analysis results suggest that the ASMRS can be used to automatically adjust suitable music files for individuals to effectively relieve stress levels.

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