An Experimental Study in Generative Music for Exercising to Ease Perceived Exertion by use of Heart Beat Rate as a Control Parameter

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ABSTRACT
This paper investigates whether generative music, adapted to a user's heart beat rate, can be used to ease the perceived exertion. A generative system was implemented and tested on 13 test participants in a controlled environment on a training bike. The test participants performed a cycling workout of three minutes in two conditions in a self-chosen pace, with and without music. Their pulse were used as the physiological exertion. The perceived exertion was rated by the test participants according to Borg's 6-20 exertion scale. Five out of 13 participants showed indications supporting the notion, while 2 out of 13 indicated the opposite. 6 out of 13 participants neither showed indications supporting nor opposing the theory. The results could be useful for exercises, where the change of heart pulse is gradual, but further work is needed in cadance-based exercises.

ACM Classification Keywords
H.5.5 Sound and Music Computing: Modeling - Signal analysis, synthesis, and processing

Author Keywords
Exercise; Exertion; Pulse

INTRODUCTION
This article reports a design and evulation case, based on a brief presented by a company that produces wireless speakers, headsets, and earphones for business and sport usage. The problem revolves around one of their products (wireless sports earbuds), which has a sensor for in-ear heart rate monitoring. The earbuds are designed for use while exercising. The company is interested in exploring innovative applications to promote the product. The current app supplied with the product logs the sensor reading and provides verbal feedback of the pulse to the user. This is what the company seeks help for and what this article addresses - an attempt to come up with other useful and innovative applications of this technology. The guidelines set by the company were 1) to use non-speech sound and/or music, 2) to use the pulse sensor monitoring, and 3) to focus on exercising.

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Based on these guidelines and background research, the following design objective has been framed: *Design and evaluate a generative music-system that adapts the tempo of music according to the heart beat rate of a user during exercise, and show that it helps decreasing the perceived exertion.*

This paper first provides background research pertaining to related fields, then documents the design and implementation of the interactive system, followed by evaluation and discussion of the results. It contributes to the expanding field of HCI in relation to sports [8], and use of interactive auditory feedback in the form of generative music. The main impact is on exercising contexts, where the change of heart pulse is gradual, e.g., level running and long distance biking. Further work is needed to see how the experience is affected in cadance-based exercise, e.g., strides in running and revolutions in biking.

BACKGROUND
Recently, the effect of music on human physiology has received serious attention. Music has been shown to affect physiological parameters such as heart beat rate (HBR), blood pressure and flow and breathing interval [11, 2]. However, it is important to note that music is profoundly subjective and the findings do not apply to everyone. Confining to the effects of music on exercise, numerous studies have been conducted to investigate correlations in this area [6, 10, 13, 9, 4]. Parameters such as music tempo (BPM) and loudness have been investigated and related to effects such as exercise performance [6, 10, 9] and perceived exertion [6, 13, 9]. It is suggested that music can ease exercising and improve performance [6]. In a study by Waterhouse and Edwards [12] test participants were asked to do a cycling workout in a self-chosen work-rate. Music with different BPM was played while monitoring the power output. A control group, where no music was played, was used to compare the results. The results showed that by increasing the BPM of the music, the power output increased.

Most of these studies make use of already existing music pieces. The music is generally selected based on the BPM at an attempt to match the expected HBR of the exerciser. However, in [6] it is suggested that the optimal tempo of the music listened to while exercising should match the HBR of the exercisers. Little is done to match these numbers. Of the two, HBR and BPM, the BPM is of course the easiest to manipulate and match to the other. This could perhaps be

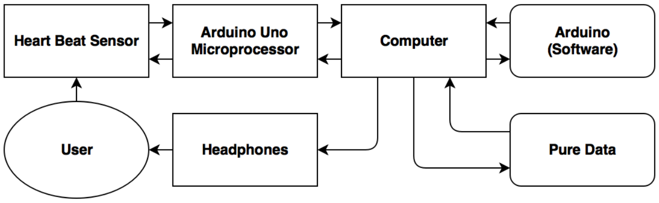

Figure 1. Diagram illustrating the flow of data between the user, hardware and software to generate the user-feedback.

implemented by the use of a generative system, which adapts the tempo to the HBR of the exerciser.

Currently, many generative systems are reported in the literature. A good example is algorithmic composition, which consists of the employment of different types of algorithms (fractals, L-systems, statistical models [7]) combined sometimes with data in order to produce musical sounds and compositions. If the data is acquired and musical system parameters are updated in real-time, to facilitate a cloosed-loop interaction for changing the performance (therefore the data), we then talk about a *reactive music system*. Recently, a reactive music system for jogging has been reported in [1]. Other forms of compositions may include evolutionary music that relies on e.g., genetic algorithms and genetic-programming [7].

DESIGN AND IMPLEMENTATION

The first task in design is to compose music which appeals to a greater audience. The elements of the composed music are:

- Tempo, controlled by a sensor input capturing the heart rate in a 1:1 ratio. An estimate of the range of heart rate during exercise can be given based on Borg's Rating of Perceived Exertion Scale [3], and correspond to 90-170 beats per minute (BPM).
- Beat: Since it is the element the people can make syncronization adjustments, the beat should have enough strokes to choose among to follow yet sound interesting and motivating among the whole range of tempo.
- Genre: Different music genres and sub-genres should be evaluated and assessed to contextualize and structure the tempo and beat of interest.

These elements result in the following design requirements: 1) Appeal to a greater audience, 2) Vary the tempo between 90 - 170 BPM, 3) Follow the heart rate of the user (1:1 ratio), 4) Compose a dominant beat with enough strokes to follow under low and high exertion.

The genre of *drum and bass* was evaluated and decided upon, as it complies with these requirements. The implementation is depicted in Fig. 1. The heart rate is captured by an infrared sensor (seeed ear-clip heart beat sensor), which is attached to the earlobe. The sensor is connected to an Arduino Uno microprocessor, which parses the feedback to a computer via an USB-interface. The data is first received in Arduino's own IDE, using the code example for the sensor, from the developers' webpage[1]. The BPM is calculated here and then parsed

[1] http://www.seeedstudio.com/wiki/Grove_-_Ear-clip_Heart_Rate_Sensor

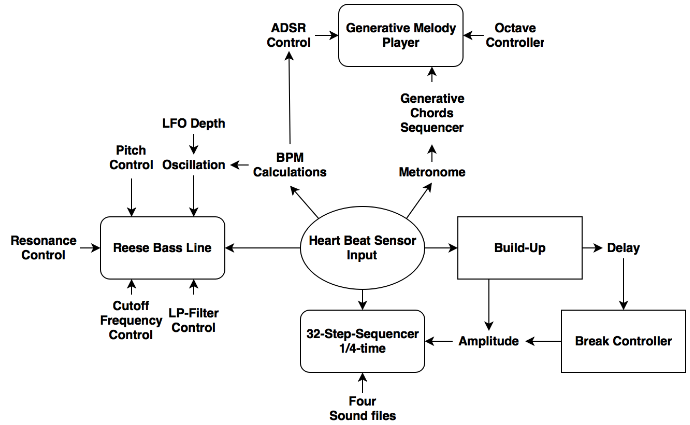

Figure 2. Diagram illustrating the connection between elements within the Pure data patch, centered around the input of the heart beat sensor.

Figure 3. Illustration of the test setup. The blankets were used in an attempt to reduce vibrations and noise.

to *Pure data*, a software program for visual programming of sound. The heart beat rate synchronized music is sent back to the user through a loudspeaker system. Figure 2 depicts how the music is composed in Pure Data. The details of the music generation is reported elsewhere; suffice to say here that a number of parameters in the generative drum & bass synthesizer are calculated based on the heart rate.

EVALUATION

A test was conducted to examine the use of heart rate as a control parameter in music to ease perceived exertion. It is important to note that the experiment was performed in lab conditions and does not reflect natural usage. An elements such as wind resistance e.g, which also acts as cooling, is not captured in a stationary setup. The setup is meant to give a better understanding of the concept. A bike was used in conjunction with an Elite Qubo Digital training stand. The bike had 27 gears, which the participants could use as desired. The saddle height was adjusted if needed. The headphones used were a set of V-Moda Crossfade LP (see Figure 3).

The test was conducted on 13 participants, two female and 11 male, at a dorm. The age ranged from 20 to 27 with an average age of 23.85 and a standard deviation of 2.41. All but two participants were students at bachelor or master level. The remaining two had recently finished a master's and Ph.D. degree. To get a sense of the perceived exertion Borg's 6-20 scale was used [3]. Ratings were multiplied by 10 to give an estimate of the corresponding heart beat rate. The Borg rating was used to compare the subjective perceived exertion with the measured heart beat rate.

Procedure

The test participants were informed of the different steps of the test, which were as follows: A) Warm-up, B) Session 1 (3 minutes, condition X), C) Rating exertion according to the Borg 6-20 scale, D) Session 2 (3 minutes, condition Y), E) Finalization: Off the bike, second rating of exertion according to the Borg 6-20 scale and filling questionnaire, indicating their age, sex, how often they exercise, whether or not they found the music annoying, enjoyed the music, and felt the tempo suited the exercise. The order of the two test conditions, with or without music, were altered between each participant, to avoid systematic bias, like fatigue. During the test, the following data was collected: Heart rate every five seconds, Average speed, and Traveled distance.

Results

Three hypotheses were created before the experiment, to make sense of data. Each hypothesis describes a condition:

1. The use of music when exercising is believed to reduce the perceived exertion, resulting in a lower Borg rating.
2. In cases of similar Borg rating, the average pulse is expected to be greater for the condition with music.
3. In case of a higher Borg rating for the condition with music, the average pulse is expected to surpass that without music.

A graphical overview of the results is provided on Figure 4; the sequel explains specific parts of the results.

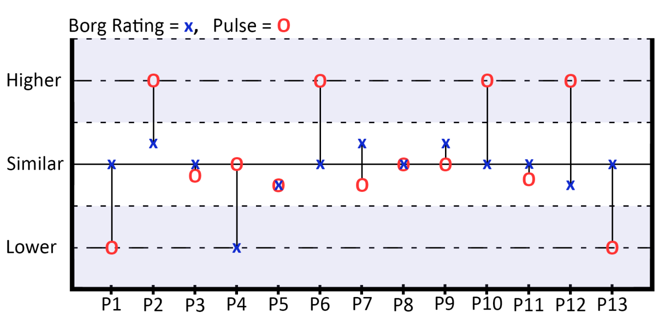

Figure 4. Differences for pulse and Borg ratings in the two test conditions for each participant. All results are with respect to the condition *with* music. The blue areas illustrate a significant differences (lower or higher). The white area illustrates insignificant differences, e.g. participant 1 rated the exertion similar, but had a lower pulse with music.

Speed

In general, the test participants could match their chosen speed from the first session in the next session. In session one the participant's speed was 20.91 km/h while the speed was 21.27 km/h in session two on average (an increase of 1.72%). The average speed with music was 21.26 km/h and 20.92 km/h without music (an increase of speed of 1.63% with music). A statistical test was performed to support this. First the data was tested for normal distribution: neither of the two conditions were parametric. A proper test for non-parametric interval data for repeated measures in two conditions is the Wilcoxon test [5]. The test failed to reject the null hypothesis ($p = 0.78$), meaning that there were no significant difference between the speed in the two conditions. Violating the notion that the data is non-parametric, a t-test returned that in two cases a significant difference was present (participants 2 and 6).

Pulse

The average pulse with music was 123.69 with a standard deviation of 8.89, ranging from an average min. of 110.84 to an average max of 136.62 BPM. The average pulse without music was 123.75 with a standard deviation of 11.72, ranging from an average min. of 104.08 to an average max of 145.43 BPM. A statistical test was used to test for significant difference in pulse in the two conditions. The pulse readings were treated as frequencies and tested with the a two-sample Kolmogorov-Smirnov test to check for difference in the two conditions for each of the participants. The test rejected the null hypothesis in 6 out of 13 cases (participants 1, 2, 6, 10, 12 and 13).

Borg rating and questionnaire

The Borg scale performed well in comparison with the actual pulse recordings. The average Borg rating of exertion in the condition with music was 12.69 (average pulse 123.69) and 12.85 without music (average pulse 123.75). This corresponds to an increased rating of 1.26% greater exertion. The data was tested for normal distribution, but was found not to be. Dealing with ordinal data, the Wilcoxon test was used once more to test if a significant difference was present between the two conditions. The test failed to reject the null hypothesis, showing that no significant difference was present between the two data set. The t-test was then used to compare the ratings pairwise for each of the participants in an attempt to identify differences on an individual level. One instance of a significant difference between the ratings of the two conditions was found. Participant four with a rating of 11 with music and 14 without music.

In the supplementary part of the questionnaire, 4 out of 13 participants found the music annoying. Looking at their Borg ratings this have not resulted in higher perceived exertion in the condition with music. All but one of the participants who answered that they found the music annoying have the same Borg rating in each of the conditions. The last participant rated the condition with music 11 versus 14 in the condition without. 8 out of 13 answered 'yes' to that they enjoyed the music. 8 out of 13 felt that the tempo of the music suited the exercise.

DISCUSSION

In relation to the hypotheses outlined in the previous section, the results show some ambiguity. 12 out of 13 results of Borg ratings followed the second hypothesis but the pulse readings were less conclusive with four results satisfying the same hypothesis. This ambiguity is captured on an individual level, but is lost when comparing the full data sets. The Wilcoxon

Test indicated that no significant difference was present between the two dataset, which is why the t-test was used to identify differences on an individual level for the Borg ratings. A significant difference was present with a single individual, participant no. 4, rated the perceived exertion as 11 with music while 14 without. According to the established hypotheses, participant 4 needs to show no sign of significant lower speed or pulse, which is the case. The rest of the individuals had matching Borg ratings for each of the conditions or one lower or higher in one of the conditions, which was deemed insignificant by the t-test. For these individuals the second hypothesis should be met to support the theory. Participants 1, 2, 6, 10, 12 and 13 showed significant differences in pulse according to the Kolmogorov-Smirnov test. Participant 1 and 13 had a significant lower pulse with music, which fails the second hypothesis. Participant 2, 6, 10 and 12 had a significant higher pulse with music, which supports the theory. Participant 2 and 6 were the only participants showing a significant difference in speed, which is also reflected in their pulse. Both went significantly faster in the condition with music. The slight change of average speed in the two test conditions suggests that the music did not possess a self-reinforcing effect of the speed. This leads to the next issue.

Two of the participants expressed that the change of tempo was confusing. This was expressed even though the test was performed in a controlled and level environment. This suggest that the change of tempo every five second might be too often, and should be performed less frequent. Taking this complain a bit further on a hypothetical level, it suggests that the setup is not suited for interval training such as mountain biking and short distance running. The system is thought best suited for exercising types where change of pulse is gradual, like level running and long distance biking. Further work is needed to see how aspects such as cadence (strides in running, revolutions in biking) affects the experience.

CONCLUSION

No general indication directly supports the notion that generative music adapted to heart beat rate can be used to ease perceived exertion for the setup used in this paper. The average pulse in the two conditions were almost identical - 123.69 BPM with music against 123.75. The Borg ratings were also very close - 12.69 with music against 12.85, 1.26% greater perceived exertion in the condition with no music. The speed on average showed the same very slight advantage with music at 21.26 km/h against 20.92 km/h in the condition with no music - an increase of 1.63% with music. The numbers for the perceived exertion and speed both showed slight improvement with music. In the end the average differences in Borg ratings, pulse and speed were thought as similar. The results on an individual level seem more nuanced.

In summary, the hypothesis that generative music adapted to heart beat rate eases perceived exertion, showed indications supporting this theory in 5 out of 13 participants, while 2 out of 13 indicated the opposite. 6 out of 13 participants neither showed indications supporting nor opposing the theory. At this point further work is required to be able to establish a more adequate conclusion. Testing with a larger and more specific sample group, e.g. based on preference in music genres, would be required. However, the individual results did show indications that generative music adapted to heart beat rate might work for some individuals. The results might be very different with other generative systems and different sport types, indicating further work in the field.

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