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Heart rate sonification - using sound to monitor heart beat when running

Author: Hobrik Wärnegård
Adress: Sturegatan 38,
114 36 Stockholm
Telephone: +46 73 598 99 13
Email: hobrik@hobrik.se

Supervisor: Anders Askenfeldt
Supervisor: Roberto Bresin

Abstract

This report ranks the most popular Android apps for runners and examines if sonification of heart rate is a good tool for serious runners to use the information from a heart rate monitor. This has been done by implementing an Android app that uses heart rate sonification to warn the runner when the heart rate goes outside a defined heart rate interval. The app was tested by letting three runners run with the implemented app and the highest ranked of the existing apps.

The results show that the heart rate sonification can be useful for a serious runner. The interval chosen for the tests was 140-150 bpm. The average heart rate of the runners was 153, 147 and 150 bpm. The corresponding results when the highest ranked existing app - which was Record Beater - was 163 and 162 bpm.

Sammanfattning

Denna rapport rankar de populäraste Android-applikationerna för löpare samt undersöker om ljudsättning av puls är ett bra verktyg för en seriös löpare att utnyttja informationen från en pulsmätare. Detta har gjorts genom att implementera en Android-app som genom ljudsättning av puls varnar löparen när pulsen går utanför ett angivet pulsintervall. Appen har testats genom att låta tre löpare få springa med den implementerade appen samt den högst rankade av de existerande apparna.

Resultaten visar på att ljudsättning av puls kan vara användbart för en seriös löpare. Intervallet som valdes för testerna var 140-150 slag/minut, där medelvärdet för pulsen hos löparna var 153, 147 och 150 slag/minut. Motsvarande resultat den högst rankade existerande appen Record Beater var 163 och 162.

Contents

1 Introduction

Wireless heart rate monitors have been available and affordable for the general population for quite some time now, enabling real-time feedback of heart rate to people when they are outside a controlled environment. The recent developments in smartphone techlonogy has made it not only possible but common for people who are out running to bring their phones. They use it to listen to music, keep track of time as well as measure distance covered and altimeter data.

Linking heart beat monitors and mobile telephone's together has been made possible and the most common running apps all provide support for heart rate monitors. But they only display the heart rate on the phone. It is not always convenient to look at the telephones display, making this information harder to use than it has to be.

Sonification is when nonspeech audio is used to deliver information[1]. A simple example is the Geiger counter, which beeps in intervals according to the amount of radiation that is picked up. The idea in this study is to use a sonification of the heart rate to auditory display the heart rate to the runner. The most common apps for running are ranked and an Android app that uses heart rate sonification is implemented. The implemented app is tested and compared to the highest ranked from the existing apps. The purpose of this is to find out if heart rate sonification is a good way for a runner to use information from a heart rate monitor.

2 Background

2.1 Why is heart rate a useful tool for runners?

Heart rate is routinely used when assessing response to exercise. When performing aerobic exercise such as running there is a correlation between heart rate and the body's oxygen consumption, or aerobic capacity (VO_2max). Research has shown that there exists an individual limit on the maximum heart rate (HR_{max}) that cannot be manipulated with increased training. The aerobic capacity can increase with exercise but will always be proportional to the HR_{max}.

There exists alot of different methods for approximating the HR_{max}. The most commonly used is

$$HR_{max} = 220 - age \tag{1}$$

This equation is not the best approximation, but the alternatives all have considerable error. The best known is

$$HR_{max} = 205.8 - 0.685(age) \tag{2}$$

which has a standard error of ± 6.4 bpm[2]. If a more accurate value is needed, an individual performance test must be performed[3]. The error made in approximating the HR_{max} will be multiplied when approximating the VO_2max. The consequences of approximating VO_2max using approximations in HR_{max} is not always appreciated in the fitness industry[2].

More simply put, how close to the maximum physical capacity a runner is can be estimated with the heart rate provided the HR_{max} is known.

2.2 Sonification

Sonification is by the International Community for Auditory Display (ICAD) defined as *"the transformation of data relations into perceived relations in an acoustic signal for the purposes of facilitating communication or interpretation"*[1]. This provides an understanding of not only what sonification is but also it's purpose. It also separates music from sonification, which focuses on the perception of sound as an artistically created work of art rather than to communicate or provide means to an interpretation of the actual relations of the data.

As research has progressed, this definition has been found to be too vague. A good example that illustrates this is *Model-Based Sonification* (MBS). Instead of mapping the data to acoustic signals, MBS maps the data to acoustic properties on objects. When a user provides input of some sort these objects then produces the acoustic signals. Using the definition above, is MBS considered sonification? This led Thomas Hermann[4] to propose a more strict definition of sonification:

> A technique that uses data as input, and generates sound signals (eventually in response to optional additional excitation or triggering) may be called sonification, if and only if
>
> 1. The sound reflects objective properties or relations in the input data.
> 2. The transformation is systematic. This means that there is a precise definition provided of how the data (and optional interactions) cause the sound to change.
> 3. The sonification is reproducible: given the same data and identical interactions (or triggers) the resulting sound has to be structurally identical.

4. The system can intentionally be used with different data, and also be used in repetition with the same data.

The most obvious way of using sonification is when visual presentation is either not possible or not practical. One example of this is blind chemists analyzing infrared spectographic data using sonification software[1]. But it can also be successfully used as a better alternative to visual display. Research has shown that human auditory perception is particularly sensitive to changes in sound over time. We are particularly susceptive to periodic and aperiodic events as well as small changes in frequency[1] in continuous signals. This enables detection of small anomalies, patterns and structures in data that are harder to see using visual display.

In everyday life the auditory system processes sounds in several dimensions. Pitch, tempo and patterns are analyzed as well as intensity and location. This is scientifically not fully understood but the diversity enables ways of presenting multiple dimensions of data that could be easier to analyze compared to a visual display.

The recent development in computational technology has made it possible to work with large and complex data sets. There are numerous examples of when sonification has helped scientists discover properties of data that visual display could not reveal[7][8]. But what type of auditory display that is preferrable when analyzing specific properties of data is not known. This makes designing sonification applications difficult and unpredictable, limiting the using of it as a means to interpret data in science today[1].

2.3 Creating sound using Pure Data

Alot of software exists that can be used to create sound, one of them beeing Pure Data (Pd). Pd is an open source branch in the "patcher programming languages" derived from a program written in the 1970's called Max, both developed by Miller Puckette[5]. Pd can run on GNU/Linux, Mac OS X, Windows, Android and iOS.

Pd is a graphical programming language that represents the flow of data. Programs, or *patches*, are created by placing objects on a canvas. The objects are then connected using inlets and outlets found on the objects. The objects can be seen as nodes in a graph and the connections as edges. The resulting graph then represents the flow of data. Events are triggered by data being sent to an object's inlet. The object performs an operation on the data and passes the result on through it's outlet. Sound can be created by sending a data with either a MIDI-note (0-127) or a frequency to a sound generating object.

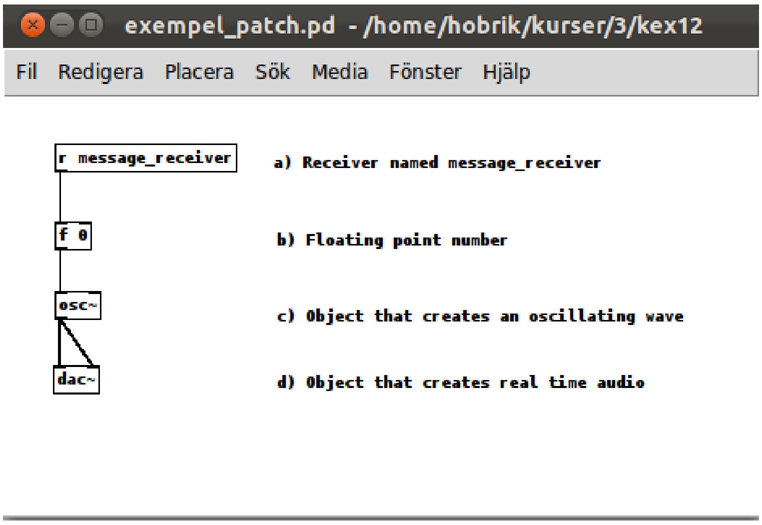

Figure 1: Screenshot of an example Pd patch that plays a given tone

Figure 1 shows a simple Pd patch. Each box represents an object, where inlets are found on the top border and outlets are found on the bottom border. The patch has a receiver object (a), which is the starting point of new events. When a floating point number is sent to the receiver named messge_receiver it passes this number to (b). (b) will not make any changes to the data in the message, and will pass it on to (c). (c) then creates a constant oscillating wave, oscillating in the frequency corresponding to the provided floating point number's value in the message. (c) will then keep feeding this wave to (d), which plays the tone to the audio output. The tone will keep playing until Pd is told to do otherwise by a new message.

3 Methods

3.1 Common running apps comparison

By doing a search sorted after popularity with the keywords ”running heart rate” and ”running zephyr” on Google Play[6] (previously Google Market), the most common running apps could be found. The 4 most popular was picked for further study, as well as one that uses heart rate monitors for real time auditory feedback using sonification.

The selected apps were analyzed from a serious runner's perspective using the features advertised on Google Play and the app developers websites. The ones that can be used to maximize running performance were used in a comparison between the apps.

3.2 Implementation of heart rate sonification app

3.2.1 Basic idea

The app was implemented for Android [1]. The basic idea was to let the user provide a numeric interval in which the heart rate is intended to be in. When the heart rate is in the interval, the user has the option to have music playing. If the heart rate surpasses the interval limit the music is faded out and a warning signal is faded in.

When a new heart beat reading is received the heart rate is shown on the screen as well as written to a log-file together with a timestamp. The app can also be used in logging mode, where it just writes the received heart rate readings to the log-file.

3.2.2 Hardware

The heart rate monitor used was a Zephyr HxM. The heart rate monitor was connected to a Samsung S5690 Galaxy Xcover running Android 2.3.3. The app itself requires a device running Android version 2.1 or greater with support for Bluetooth and an external storage (SDCARD).

3.2.3 External libraries

- Zephyr HxM Android API was used to recieve data from the heart rate monitor.
- pdlib for Android is a library for playing Pure Data patches in Android, which was used to generate the warning sounds.

3.2.4 Algorithms

When the heart rate is slower than the lower limit set by the user, a 200 Hz tone beeping in 0.75 Hz intervals is generated using Pure Data. When the upper limit is passed the tone produced is 900 Hz, also beeping in 0.75 Hz intervals. These were called upper and lower disturbance. Only one of them is played at a given moment. The disturbance volume is increased when the distance from the heart rate interval is increased. If music is playing when either one of the limits is passed it's volume will start to decrease when the disturbance volume is increased. This means that when the heart rate starts to get outside the interval the disturbance is faded in and if music is playing it will fade out.

The volume V_L for the lower disturbance was determined by

[1] The heart rate sonification app was named hobrik_hrs. The source code and a compiled android app can be found at http://www.hobrik.se/hrs.

$$V_U = \begin{cases} min(1.0, 0.2 + 0.8 \cdot x_L) & \text{if } x_L \geq 0 \\ 0 & \text{if } x_L < 0 \end{cases} \tag{3}$$

$$x_L = \frac{L_L + 2 - HR}{2 + 10} \tag{4}$$

where HR is the current heart rate and L_L is the lower limit. This means that when the heart rate is 2 bpm within the lower limit, the disturbance is applied with a low volume. When the heart rate reaches 10 bpm's outside the limit the disturbance volume is set to max.

The same resoning applied to the upper disturbance gives us the upper disturbance volume V_U as

$$V_U = \begin{cases} min(1.0, 0.2 + 0.8 \cdot x_U) & \text{if } x_U \geq 0 \\ 0 & \text{if } x_U < 0 \end{cases} \tag{5}$$

$$x_U = \frac{HR + 2 - L_U}{2 + 10} \tag{6}$$

where HR is the current heart rate and L_U is the upper limit.

The music volume V_M was given by

$$V_M = \begin{cases} max(1 - x_L, 0) & \text{if } x_L > 0 \\ max(1 - x_U, 0) & \text{if } x_U > 0 \\ 1 & \text{otherwise} \end{cases} \tag{7}$$

3.2.5 Disturbance and music

The PD patch that was used to create the disturbance tones is shown in Figure 2. Sending a float value to the receiver "lower" will start the lower disturbance tone with the volume of the float that was sent. Sending a float to the receiver "upper" has the same effect. When a bang is sent to the receiver "tyst", the tone that is playing will stop. Only one tone can be played at a given moment.

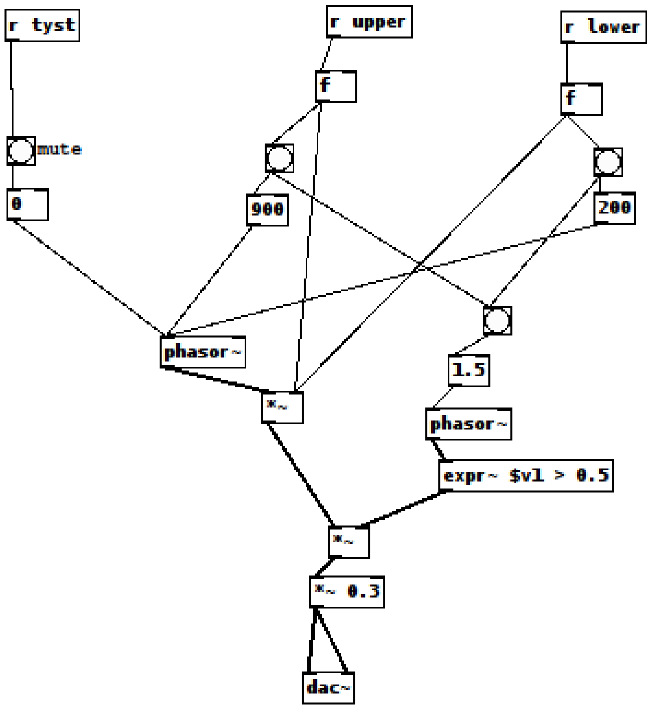

Figure 2: The PD patch "varningar.pd" that was used in the app.

Music was played using the built in MediaPlayer service in Android. The application scans the directory /sdcard/media/hobrik_run for mp3-files. The list of mp3-files is used as a playlist.

3.3 Heart rate sonification app evaluation

The sonification app was tested by letting subjects run a 2.8 km track with both the sonification app and the best ranked commonly used running app. The subjects had a break of approximately 10 minutes between the runs and the first app used in each test was varied. The heart rate interval in the tests was set to 140-150 bpm.

After the test the subjects were asked the following questions:

1. Would you prefer a different kind of sonification of the heart rate?
2. Did the sonification help you stay in the interval?
3. Do you think sonification is a good way of presenting information from a heart rate monitor when running?

4. Would you like to keep running using heart rate sonification?

4 Results

4.1 Common running apps comparison

The results from the comparison can be seen in Table 1. The ranking was done by counting the number of important properties of the app. Matching music to steps was considered a more important property than a history of laptimes.

Property	RecordBeater	CardioTrainer	Endomondo	My Tracks	Runkeeper
Tracking of:					
- Time	x	x	x	x	x
- Distance	x	x	x	x	x
- Pace	x	x	x	x	x
History of laptimes		x	x	x	
Heart rate monitor support	x	x	x	x	x
Voice feedback	x	x	x	x	
Compete with previous runs	x	x			
Match music to steps	x				
Rank	**1**	**2**	**3**	**3**	**5**

Table 1: Existance of properties analyzed in the selected apps and resulting rank.

4.2 Heart rate sonification app evaluation

4.2.1 Data

A total number of three subjects performed the test described in section 3.3, all males with ages 21,21 and 23. The average heart rate and time spent in the interval (140 - 150 bpm) from the tests is shown in Table 2. Data from the beginning of each run until the heart rate reached the lower limit of the interval was excluded. Due to loss of contact with the heart rate monitor, data from one of the runs could not be obtained.

	Average heart rate (bpm)		Time spent in interval (%)	
Subject	HRS app	Record Beater	HRS app	Record Beater
1	153	163	35	10
2	147	-	73	-
3	150	162	50	3

Table 2: Average heart rate and time spent in pre-selected interval during run with the heart rate sonification app versus Record Beater for each test.

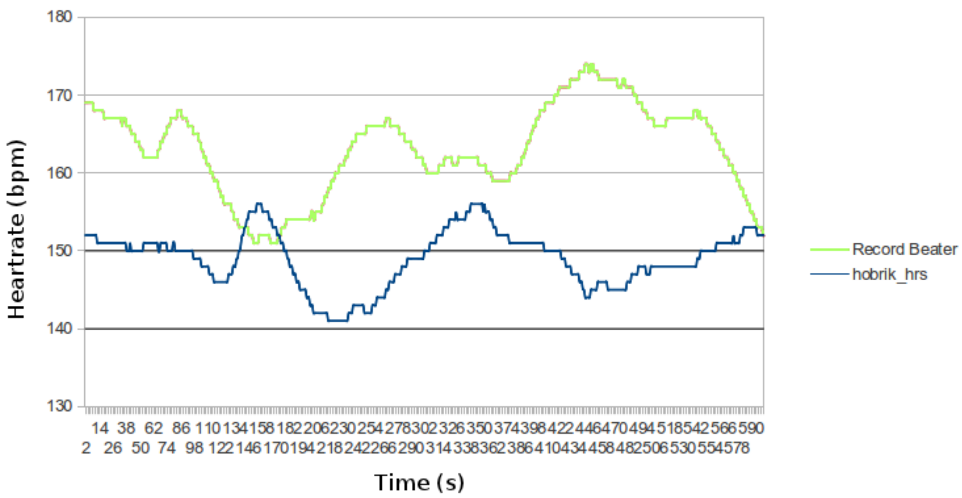

Figure 3: A sample of 10 minutes showing heart rate of subject number 3 when running with the developed heart rate sonification app and Record Beater.

4.2.2 Questions

(1) Would you prefer a different kind of sonification of the heart rate?

"No, the fading of music and disturbance was really good."

"No, but the disturbance should be louder when it starts."

"A little bit. I think the sound should stop as soon as the heart rate is below the lower limit."

(2) Did the sonification help you stay in the interval?

"Yes, but I think I need to run more with the app to get used to how my heart rate behaves when i change the pace."

"Yes, definitely."

"Yes, my body wanted to run faster but the app told me to take it easy."

(3) Do you think sonification is a good way of presenting information from a heart rate monitor when running?

"Yes, it was nice not to have to look on a watch to see if I was in the interval."

"Yes."

"Yes."

(4) Would you like to keep running using heart rate sonification?

"If I was training for a race i would. If not, I'm not so sure."

"Yes, if you could make it work with an iPhone."

"Yes, if I had the money to buy a heart rate monitor I would."

5 Discussion

5.1 Common running apps

As seen in Table 1, all of the selected apps in the comparison measure time, distance and pace. These are probably the most interesting to any runner. What distinguishes the bottom three from each other is mainly social features, such as communities to upload data and receive feedback and support. These features have little or no influence on the running results, which is why they are excluded from the comparison.

The design of the apps - the "look and feel" - has probably a big inpact on whether the runner likes the app or not. This is highly individual and has not been taken into consideration.

5.2 Heart rate sonification

From Table 2 we can see that there is a big difference in both the average heart rate and time spent in the interval between the apps. The average heart rate is within the interval for all three test runs with the heart rate sonification app, which suggests that the subjects managed to interpret the sonification and use it to stay in the interval. The answers to Question 2 in section 4.3.2 provides a theory to why the difference between the runs are so big: the selected interval forced the subjects to run slower than what was comfortable.

All of the subjects wanted to use heart rate sonification when running to some degree, which suggests that heart rate sonification is useful to a serious runner. The basic idea of the sonification used was well received, but there is room for improvement. Answers to Question 1 suggest that the interval in which the fading of disturbance and music volume takes place should be configurable by the user, as well as the volume that is applied. From Figure

4.2.1 we can see that the rate at which the heart rate changes during a run is quite slow. This is something that needs to be taken into consideration when designing heart rate sonifications.

How heart rate sonification will affect the performance of the runners can not be determined from the tests. The test subjects only tested the applications once. As the subjects would get used to using the sonification the percentage of time spent in the interval during the run is likely to increase. To fully evaluate the use of heart rate sonification for runners it should be compared to visual display of heart rate and if different kinds of sonifications can be useful in certain heart beat intervals.

6 Conclusions

The best Android app available today for a serious runner is Record Beater.

Test results suggests that sonification is a good way to present information from a heart rate monitor. To which extent has not been determined.

Further studies in heart rate sonification for runners should focus on different kinds of sonifications, their long term durability and how they compare to visual display of heart rate.

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