KTH Computer Science
and Communication

App For Improving Heart Rate Monitor Based Endurance Training in Running Athletes Through Heart Beat Sonification

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Abstract

Fitness is a large part of todays modern society, especially running. With the advent of the smartphone a large number of apps based on helping runners track and improve their performance has popped up, some of which support some kind of audio feedback. To further build on this this essay explores the possibilities of using sonification of a runners heart rate to aid them in maintaining specific heart rate zones while training. The sonification was implemented on the android platform using a Zephyr HxM BT heart rate monitor. It was tested with three users. I found that while the sonification aided the users in maintaining their heart rate zones, it was achieved through overcompensating, and this resulting in an uneven heart rate. However the concept shows promise, and i suggest some ways it can be improved in the future.

Referat

Friskvård är en stor del av vår moderna värld, speciellt löpning. Efter smarttelefonens ankomst har en stor mängd appar som fokuserar på att hjälpa löpare hålla reda på och förbättra sin löpning kommit. Varvid vissa innehåller någon form av ljudfeedback. För att bygga vidare på detta utforstkar denna uppsats möjligheten att utnyttja sonifiering av en löpares puls för att förbättra hens löpförmåga, genom att ligga inom vissa pulszoner". Sonifiering implementerades i form av en app på Androidplatformen. I uppsatsen upptäcktes det att medans sonifiering hjälpte löparna upptäcka när de kom utanför en pulszon, var det på kostnaden av en jämn puls. Därför föreslås det i slutet sätt att vidareutveckla detta koncept för att bättre hjälpa löpare förbättra sig.

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Chapter 1

Introduction

There exists a myriad of apps designed to help recreational running athletes improve their performance. This is done through various means, such as tracking the distance and route, measuring the heart rate or suggesting programming. Something which has not been explored to any greater extent however, is heart rate sonification; the act of giving an auditory display based on a persons heart beat. Looking at a phone while running to get some information is highly unpractical, therefore i strongly believe the hands free nature of sonification can greatly aid the runner.

The goal of this essay is to survey existing running apps and research in heartbeat sonification to suggest and implement a design for this application in running athletes.

1.1 Problem Statement and scope

This essay attempts find and implement a useful application for sonification of the heart beat for the purpose of aiding recreational running athletes improve the gains of their training. The implementation will be done on an android based mobile phone in the form of an app. To measure the athletes heart rate a Zephyr HxM BT heart rate monitor will be used.

The problem is limited to what is known as endurance training, and only that type of training will be studied and implemented. This also limits the implementation of the sonification to that matter.

1.2 Glossary

1. MHR - Maximum Heart Rate
2. App - Mobile phone application
3. LSD - Long Slow Distance
4. Fartlek - Speed play
5. SDK - Software Development Kit

Chapter 2

Background

This section servers as a primer and motivation for the project. It goes in to some depth attempting to explain why heart monitor based training is meaningful, and also explains the basic points of sonification.

2.1 Existing apps

These are some of the bigger existing apps featuring audio feedback.

2.1.1 Runtastic

The basic version of this app offers no audio feedback or sonification. The pro version does offer audio feedback in the form of regular updates every minute or kilometer. The pro version also offers the option to use a heart rate monitor and customize heart rate zones. It offers no indication of this utilizing sonification. The interface is very simple with its main screen offering to start a workout, and also showing pace, calories burned, speed, duration and distance.

2.1.2 Runkeeper

Runkeeper offers audio cues in the form of a voice which says information such as pace, speed, distance, heart rate and average heart rate zone. Similar to runtastic this can be configured to cue from time passed or distance achieved. The app offers no sonification of heart rate data. The interface is more complex as the app offers a lot of functionality.

2.1.3 Nike+ Running

Nike+ running like Runkeeper offers audio feedback in the form of a voice, however it only offers data from time, distance and pace. It can be configured in a similar manner to Runkeeper. Its interface is the simplest of the three, with the main screen having a "start run" button and not many options.

2.2 Training

2.2.1 Endurance Training

Endurance training means training within the 60%-75% zone of the MHR[Benson and Connoly(2011), p. 4-5]. This type of training is aerobic, meaning the vascular system is full of blood, and done at a slower pace for longer periods of time. It promotes endurance, meaning improving of how long the athlete can maintain the pace. There exists two primary ways of training in this zone: LSD, which is a very long and slow run typically up toward 40-60 minutes, and "fartlek", swedish for speed play, which is a type of interval training where the athlete keeps going from 60% heart rate to 75% and then back down again[Benson and Connoly(2011), p. 58]. This paper focuses on the former which more continuous nature makes implementing some type of heart rate sonification more natural.

The problem with anaerobic training, meaning high intensity for shorter periods of time like sprinting, is that sometimes there can be a delay physical response to the activity. This means that the heart rate monitor might not be useful during the activity itself.

2.2.2 Heart Rate Monitor Based Training

To be able to use sonification of the heart beat there of course has to be a method of obtaining it. This is done through a heart rate monitor. However using a heart rate monitor for training purposes presents several effective techniques of improving performance. Heart monitor based training is heavily based on knowing the athletes MHR. This is something that has proven to be relatively difficult to find. The standard way of finding the MHR, known as the Haskell and Fox method(several more methods can be found in [Benson and Connoly(2011), p. 27], is $220 - age(years)$, so a person that is 40 years old would have a MHR of 180. Although this might give a de-

cent indicator of where the athletes MHR might lie, it can still differ a lot between different people[Benson and Connoly(2011), p. 22-23].

There are several biological factors that influence a persons MHR and the only way to find a persons true MHR is through a test aimed to achieve it. A detailed method of obtaining the MHR can be found in appendix A.

For an athlete to progress in their training they need to constantly overload their training capacity so that the body adapts, and their athletic ability improves[Reaburn and Jenkins(1996)]. Without a heart rate monitor it can be difficult, mostly for runners with less experience, to know what their heart rate is. One way of estimating the heart rate is to use what is known as "perceived rate of exhaustion", but it is inexact and varies depending on the athletes experience[Benson and Connoly(2011)]. As an analogy: If a strength athlete wishes to improve their strength, they need to overload their system, this is mainly done through increasing the weight. If the athlete does not know the weight they can only go by how heavy it feels, something that can vary depending on many factors, such as how much sleep they have had or how much they have eaten. Therefore it is much more difficult to overload the system if they do not know if they are actually achieving the numbers that they should be. In a similar way this applies to running as well. A runner might believe they are in the right training zone based on their level of exhaustion, but in reality they are much lower than they should be. Therefore heart monitor based training can be meaningful.

2.3 Sonification

2.3.1 Theory

As defined by [Kramer(1994)] sonification is the non verbal representation through sound. A more accurate description however is as [Grond and Hermann(2011), p 1] states: "we can speak of sonification when sound is used as a medium that represents more than just itself. In other words, sound becomes sonification when it can claim to possess explanatory powers". In the context of this project this means that sound is used to explain to the user when they are within their given heart rate zone.

Chapter 3

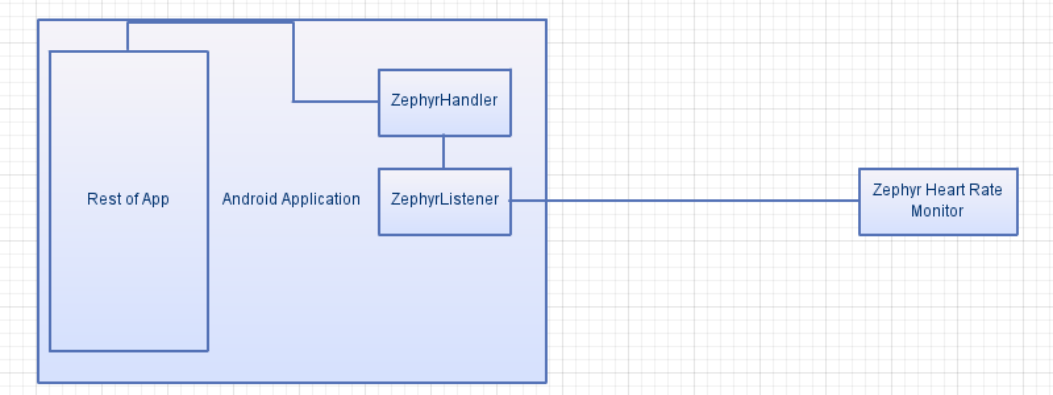
Method

In this section the basic workings of the app are explained, it does not go into much technical details. The interface is showcased to give an overview of what the testers were presented with. The design of the sonification is explained in greater detail, and the method of the tests are explained in greater detail.

3.1 Application Design

The app is built for Android using the Android SDK and Java. To communicate with the Zephyr heart rate monitor the Zephyr HxM BT API is used. Packets are sent every second over bluetooth containing information about the heart rate and the current speed. An overview of the system is as follows.

Figure 3.1: Design of the connection between the phone and heart rate monitor.



In figure 3.1 the app has class called ZephyrListener that is connected to the heart rate monitor and listens for packets. The Zephyr API then handles converting the packets to the users heart rate. The ZephyrHandler handles connecting and disconnecting to the heart rate monitor. The ZephyrHandler is the connected to the rest of the app.

3.1.1 Interface

The interface is very simple only allowing the user to connect and disconnect from the heart rate monitor, and starting a workout.

Figure 3.2: First screen of the app

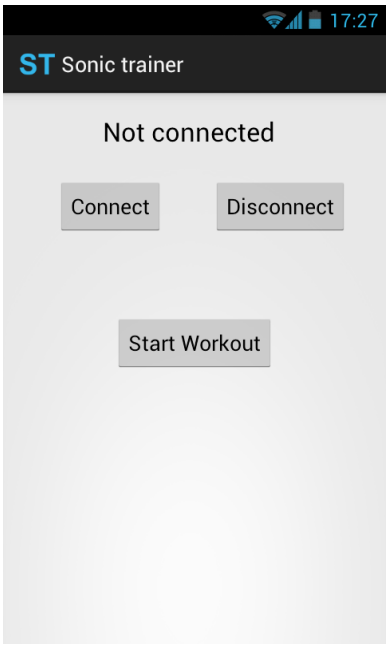


Figure 3.2 shows the first and main screen of the app. The buttons allows the user to connect and disconnect the heart rate monitor, and the "Start workout" button brings up a list of available workouts.

Figure 3.3: Workout screen activity.

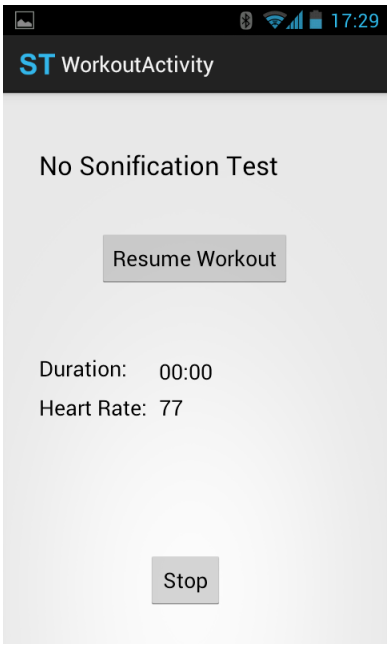


Figure 3.3 shows the screen after a workout has been started. In this case it is the test workout without sonification. It features only duration and heart rate.

Figure 3.4: Preferences screen activity

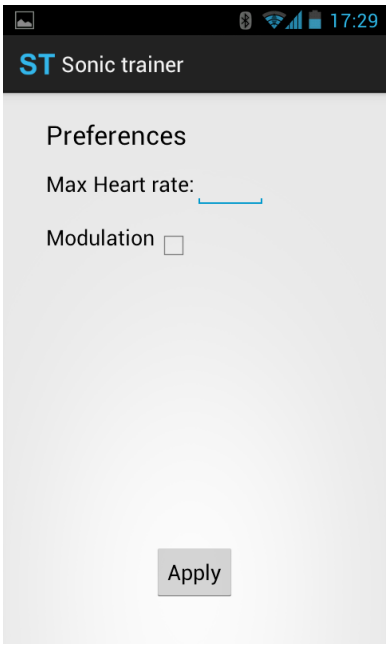


Figure 3.4 shows the preferences available for the user. The user can, and has to, enter their MHR. Modulation changes the way the sonification sounds in that it is multiplied by a signal with the same frequency as the heart rate, but is not used for the testing.

3.2 Sonification Design

The sonification consists of two parts; one as a couple of beeps and another a noise created in puredata, for the interested a brief explanation of puredata can be found in appendix D.

There are four different beeps, two for above the zone and two for below the zone. The two below the zone consist of two beeps, the first one when the user goes below the heart rate zone is a high tone beep followed by a lower tone. The other beep is the reverse. For when the user goes above the zone there are four lower tone beeps followed by a higher tone beep, the other one is the reverse of that.

The puredata patch, like the beeps, consists of one part for when the user is too high, and one when the user is too low. A low pitched random noise for when too low, and a high pitch random noise for when too high. The lower pitch noise is created by three separate band pass filters with a random frequency between 500 and 1000 hz with a resonance of 50. The higher pitched version works in the same way buy with frequencies between 6000 and 7000 hz.

The reason for the three separate and random band pass filters is simply that the sounds created were richer and more interesting compared to when only one constant or random one was used. The two sounds are distinct from eachother with no chance of being misinterpreted.

The beeps are not very loud or invasive and serve as a warning for when the user is outside their heart rate zone. The noise however is continuous and persists until the user again reaches the target zone. This allows the user to both be reminded if they miss the beeps, and also serves as a way to anchor the feeling of the heart rate to the noise, allowing the user to get a better feel for their heart rate in relation to training zones.

Figure 3.5: Flow of the sonification

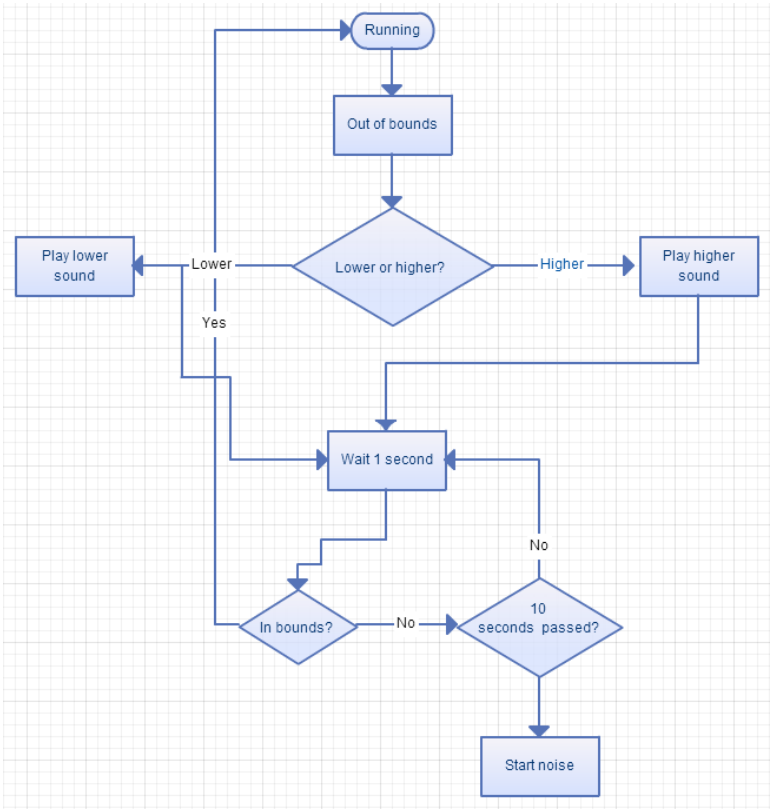


Figure 3.5 is a flowchart of how the sonification works. Whenever the heart rate is outside the zone it is checked whether it is higher or lower. Depending on that a sound is played, and after 10 seconds of being outside the zone a continues noise is played. If the user returns to the zone after the noise has started everything retuns to as it was in the beginning.

3.3 User tests

First the test subject puts on the zephyr heart rate monitor. It is initially placed beneath the pectorals. The test subjects are then instructed to warm up and achieve a pulse within the 60% to 75% zone. If the warm up reveals

that the heart rate monitor is receiving noise, the strap is is repositioned until it gives a good reading. This depends heavily on the individual, but a set of guidelines can be found on Zephyr technologies website.

Then they run for 10 minutes without sonification, followed by 10 more minutes with sonification. Every time the heart rate monitor sends a packet, the heart rate is logged in a database along with its timestamp. From this data the amount of time spent outside of the given zones is extracted and the different tests are compared to each other. More precisely the app does a check whether the current heart rate is inside the heart rate zone, if it is not it will either log that datapost as above or below the heart rate zone. Since the heart rate monitor sends packet every second, every post that was logged as outside the heart rate zone can be considered as a second outside the zone.

The time limit was chosen since 10 minutes of running after a sufficient warm up is enough to determine a pattern in the athletes heart rate. The total time of 20 minutes is not enough to fatigue the average runner so the second half of the 20 minutes will not be exhausting enough to impede the results. The training zone is chosen for its simplicity both for the runner and the measuring.

To infer whether sonification is a meaningful tool for heart monitor based endurance training, the runners ability to stay within a given heart rate zone has to be determined. Therefore the results of how well the test subject can stay in the zone with and without sonification are compared.

Chapter 4

Results

4.1 User Tests

The tests were done wit the following people.

1. Tester 1, 21 year old male, no HRM experience, recreational runner
2. Tester 2, 21 year old male, no HRM experience, untrained recreational runner
3. Tester 3, 21 year old male, no HRM experience, recreational runner with competitive experience

Some main points regarding the data.
Graphs for each user can be found in appendix C.

Figure 4.1: Tester 1.

Figure 4.2: No sonification

- Average BPM: 160
- Time over: 559 seconds
- Time under: 0 seconds
- In zone: 43 seconds

Figure 4.3: With sonification

- Average BPM: 138
- Time over: 63 seconds
- Time under: 0 seconds
- In zone: 537 seconds

Figure 4.4: Tester 2.

Figure 4.5: No sonification

- Average BPM: 150
- Time over: 39 seconds
- Time under: 0 seconds
- In zone: 561 seconds

Figure 4.6: With sonification

- Average BPM: 148
- Time over: 52 seconds
- Time under: 0 seconds
- In zone: 548 seconds

Figure 4.7: Tester 3.

Figure 4.8: No sonification

- Average BPM: 147
- Time over: 0 seconds
- Time under: 0 seconds
- In zone: 600 seconds

Figure 4.9: With sonification

- Average BPM: 152
- Time over: 141 seconds
- Time under: 0 seconds
- In zone: 459 seconds

Chapter 5

Discussion and Conclusion

5.1 User tests

The relatively uneven graphs show that longer tests might have yielded more convincing results. As of now there is a pattern, but there is not enough data to be thoroughly convinced of its validity. However i will base my conclusions on it in conjunction with the testers comments, which are not recorded in this essay.

The user tests went smoothly and the testers had no issues using the app. A comment however was that the zone they were to keep their heart rate within, was too low. As reflected in the results the upper limit was breached relatively often, while the lower was never breached. Furthermore whenever the upper limit was breacher during the sonification test it dropped shortly after. This suggests that the sonification helped the tester keep their heart rate inside the zone. Although while the sonification aided the testers in keeping their heart rate within the given zone, the stability of the heart rate suffered. When the tester achieved a pulse too high and a sound was played, they were inclined to slow down and lower their pulse, which resulted in a larger drop in the heart rate, until after a while the pulse once again went up and above the limit. A large contributor to this behavior is probably the second sound that starts playing after 10 seconds. It is quite louid and annoying, and makes the runner slow down significantly to make it go away. This is not optimal, as lying a few heart beats above the heart rate zone will not be detrimental to the training.

Therefore i suggest an approach that is not absolute with the limits of a

heart rate zone, but rather relies on the users knowledge of her own training needs, and instead uses sonification to inform the user of her heart rate and allow the user to correct it in their own manner in relation to what heart rate they wish to keep.

5.2 Is Sonification Viable

The results show a increased ability for the user to keep their heart rate below a given limit. Although this is at the cost of a more even heart rate, it suggests that sonification is a viable tool for aiding users in keeping track of their heart rate. In conjunction with the fact that most major existing running applications feature some form of audio feedback this strongly implies that sonification of the heart rate is worth exploring further.

5.3 Future work

As proposed in the user test discussion i believe exploring way of continuous, non alarming sonification to aid the user in keeping track of their heart rate. One way of doing this could be through regular sounds, such as a series of beeps or a short tone, pitched based on the heart rate in relation to the zone. So if the user is above the sound is pitched higher and vice versa. This would allow the user to correct their heart rate in a more fluent manner, as the app would not regard any heart rate as faulty.

To further improve upon the concept used in this essay, i suggest including more parameters to base the sonification on. Due to the naturally slow biological response of a change in heart rate, a more direct parameter that is directly related to the heart rate could be of use. By utilizing the speed the runner, which is directly related to the heart rate, it could be possible to implement a more accurate way to help the runner. The app would then instantly notice that the user has lowered their speed and can then await a change in heart rate, and base the sonification on that. Control engineering theory could be of great use when attempting this.

As this study does not explore the extended use of the app there is no way of telling whether regular use of this type of sonification might train the user to keep their heart rate within a certain heart rate zone. That suggests that exploring extended use of this type of sonification might render interesting results.

5.4 Conclusion

In conclusion sonification seems to be a viable method of aiding runners. The ease with which it is interpreted is corroborated by the results of this essay. However the way it was implemented in this essay was unsatisfactory and needs to be improved greatly to be able to aid runners improve their performance. Android as a platform using a heart rate monitor connected through bluetooth was both efficient and easy to develop for. For any further projects it should be more than suitable. Puredata, while not utilized to any greater extent in this essay, is a very powerful tool for generating sounds based on variable parameters, and could be used to great effect when aiming to create a more continuous form of sonification.

Bibliography

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Appendix A

Max heart rate test

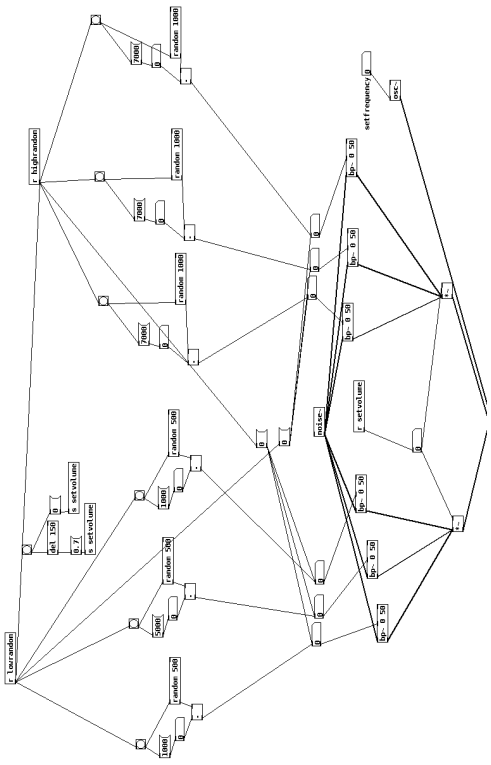
1. Find a running track or a small and gradual incline that goes for about 400 to 600 meters. Put on your heart rate monitor
2. Do a good 0.5- to 1-mile warm-up (0.6 to 1.6 km).
3. Perform one lap or one incline lap as fast as you can. Check your heart rate at the end of the lap.
4. Take a 2-minute recovery walk or run, and then repeat the run. Again, chech your heart rate when you finish.
5. Take a 2-minute recovery, and repeat the run again. Again, check your heart rate when you finish. Your heart rate at the end of this third trial will be a pretty good indicator of your maximum heart rate.

From [Benson and Connoly(2011)]

Appendix B

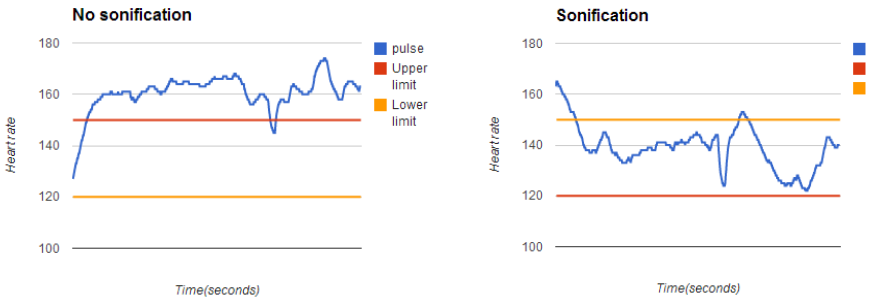
Puredata Patch

Figure B.1: The puredata patch used by the app



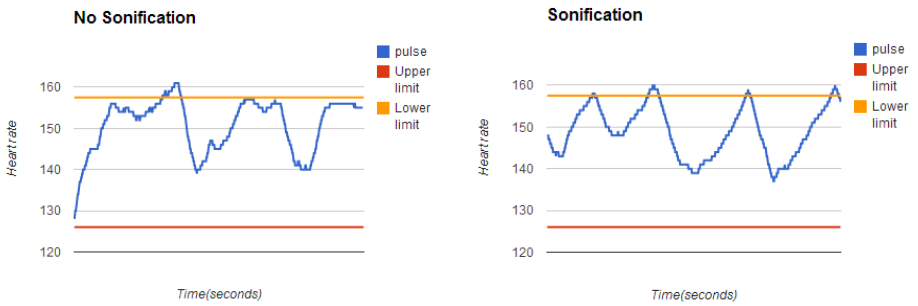
Appendix C

Test data



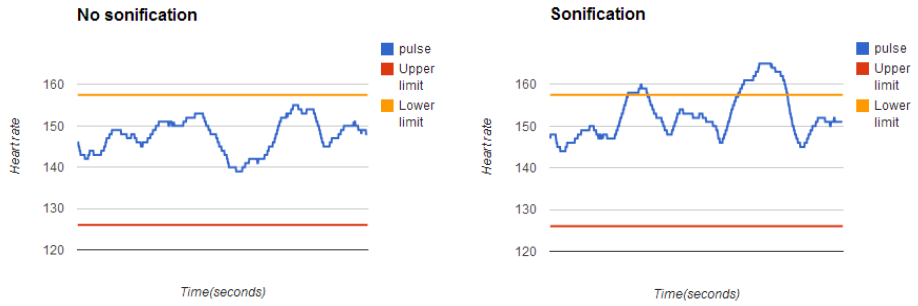
(a) No sonification (b) Sonification

Figure C.1: Test data for user 1



(a) No sonification (b) Sonification

Figure C.2: Test data for user 2



(a) No sonification (b) Sonification

Figure C.3: Test data for user 3

Appendix D

Puredata explanation

Puredata is a real time graphical programming language for audio processing. It allows for real time generation and manipulation of sounds. This is done through creating what is known as patches, circuits that generate sound. It is commonly used for live music performances, but it can be used for anything else that requires real time sound generation. An example is in the following figure.

Figure D.1: Very simple puredata patch.

In figure D.1 we can see a very simple patch generating a 440 hz tone and sending it to the sound output. In patches it is possible to define objects designed to receive input and send it to the objects connected to

it. So for example in figure D.1 it would be possible to have an object receiving the a number and setting the frequency for the tone. There exists an implementation of puredata called libpd for Android. Through this it is possible to communicate with a patch through Java by sending messages to the puredata engine.