Using Real-Time Sonification of Heart Rate Data to Provide a Mobile Based Training Aid for Runners

JOHN SANDERSON[1] and ANDY HUNT[2]

[1]The Department of Electronics, University of York, Heslington, York, UNITED KINGDOM
e-mail: john.sanderson@theappbusiness.com
[2]The Department of Electronics, University of York, Heslington, York, UNITED KINGDOM
e-mail: andy.hunt@york.ac.uk

September 23rd 2016.

Abstract

Heart rate is a human biometric that is often monitored by runners as a method of maximising the benefits from training at different intensities. However, it is a variable that is difficult to communicate in real time, often being monitored at irregular intervals via visual feedback on a watch face or studied post-run using analysis software. This project addresses this issue by presenting a system that uses sonification of heart rate data to provide real-time, audible feedback to athletes. The system aims to improve the efficiency of heart rate zone based training amongst runners by combining the motivational benefits of music with parameter mapping sonification techniques. It is implemented in the form of an iOS based application, providing both a unique and accessible training aid for individuals. The testing provided promising results, with the two implemented sonification systems both invoking responses in the participant's heart rate, causing them to successfully follow a predefined, intensity based training plan. However, further testing is required before the system can be shown to improve the *efficiency* of training. Qualitative feedback that was collected also confirms that the application was enjoyable and motivational, suggesting that there is further potential for such a system to be introduced to the public market.

1 Introduction

Running is an integral part of our human development. As children it forms the basis of all physical games and activity, but as we develop into adults, running, and indeed all forms of physical activities, are often seen as unimportant, with participation levels typically falling as we grow older [4]. However, this is a trend that appears to be changing, especially in the UK which saw an increase of 1.4 million people playing sport once a week in the year following the London 2012 Olympic and Paralympic Games [22].

In particular there has been a dramatic increase in the number of people running regularly [20,21]. This is perhaps due to the increased popularity of informal, non-competitive events such as Parkrun[1], a weekly 5 kilometre run, which now has almost 900,000 registered runners and over 380 weekly events in the UK [16].

Additionally, the use of sporting related technology such as GPS watches and smartphone applications, that allow external peripherals such as heart rate monitors and cadence sensors to be connected, is becoming more common amongst both serious and casual runners. These peripherals measure various variables in real-time, providing data that can be used during or after training. However, this real-time data is usually communicated via visual feedback cues, demanding the attention of the user to be distracted from their surroundings, something that is not always possible when exercising in an uncontrolled environment. This information is therefore difficult to

[1] http://www.parkrun.org.uk

interpret, interact with and respond to.

A biometric that is of particular interest to athletes is heart rate. Heart rate, usually measured using a chest or wrist based monitor, is often used as a method of gauging the intensity of exercise. Intensity, along with frequency and duration are cited by Jeukendrup and Van Diemen as being the three key principles to monitor during endurance sport in order to maximise the efficiency of training [11]. However, although controlled by an athlete, intensity is difficult to monitor and is usually based on *'feel'*. Conconi et al investigated how heart rate (and therefore intensity) and running speed are related [3]. The authors concluded that, up to speeds of approximately 20km/h, there was a linear relationship.

This relationship between heart rate, running speed and intensity makes real-time monitoring of heart rate data an ideal candidate for aiding more efficient training. When training with heart rate monitors, it is common for athletes to use four or five predefined heart rate zones, each dictating a different level of intensity [3]. The first zone (Zone 1) is typically described as *"easy running"* and is believed to have no effect on cardiorespiratory fitness. Zone 2 is at a higher intensity, but still below lactate threshold (the point at which the blood lactate concentration rises exponentially [8]), Zone 3 is around the lactate threshold and Zones 4 and 5 are above the lactate threshold, or at *"maximum effort"*. Heart rate zones are typically expressed as a percentage of an athlete's maximum heart rate (HR_{max}).

Mobile phones are not only used for their activity tracking capabilites, but are increasingly being used as a means to listen to music whilst exercising. Music is used during exercise both as a form of mental distraction and as a motivator. This mood enhancing quality to music during exercise is discussed by Karageorghis and Terry [12], who conclude that music does not only motivate athletes and contribute towards a more stable frame of mind, but it can also act as a stimulus, helping athletes to maintain a particular effort level for longer. In addition to its motivational benefits, sound is also used as a method of feedback in sport. This is particularly true in a training environment where coaches will often provide auditory feedback of performance-related information that could only otherwise be accessed through visual feedback.

Sonification, that is, the use of non-speech audio to convey information [13], has the potential to be used as a means by which to communicate data to athletes in real-time (previously explored by [1, 2, 5–7, 10, 17–19] amongst others). By capitalising on the recent technology trends amongst runners, and exploiting the motivational benefits of music, this project explores whether sonification can be used to provide real time, auditory feedback of heart rate data whilst running to improve the efficiency of training to heart rate zones.

2 System Design

When designing the system, seven key design specifications were outlined. These specifications were created to ensure that the project's aims and objectives would be delivered within the given time frame. The specifications were:

1. The employed sonification technique(s) should aim to guide the user through their training plan in an unobtrusive and intuitive manner.
2. The user's heart rate must be monitored in real-time in order to provide accurate and instant feedback.
3. The user should be able to select their own personal choice of music.
4. The application should be simple and intuitive to use. It should be designed to complement exercise and should not hinder this in any way.
5. The heart rate monitor should communicate to the application via Bluetooth.
6. The calculated maximum heart rate and heart rate zones must be specific to the user.
7. The user must be able to customise the length of their run and specify their training plan with regards to their heart rate zones.

When considering these specifications, the first task that was undertaken was to identify the software and hardware that would be used to implement the application. Due to some previous experience with developing applications for iOS, an Apple iPhone 5s was chosen as the mobile device. Specifically the application, called 'Sonorun', was developed using the Xcode IDE (Integrated Development Environment) using the Swift programming language. The audio processing capabilities of the application, used to implement the sonification, were provided by the Audio Kit[2] framework, a free library of audio synthesis, processing and analysis tools. Finally, the user's heart rate was monitored and communicated back to the iPhone by the Polar H7 Bluetooth heart rate monitor.

[2] http://audiokit.io

In order to create an application that could be tailored for each individual there were a number of important user interaction elements that had to be design and implemented. Firstly, the heart rate zones had to be specific to each user. Therefore, the application needed to calculate these zones based on an estimation of the user's HR_{max}. Equations 1 and 2, developed by Dr Dan Heil [15] were used to estimate the HR_{max} of male and female users respectively. These equations consider the user's age, weight and gender, all of which are contributing factors to a user's HR_{max}. The application required these variables to be provided by the user before a run could commence.

$$HR_{max} = 211.415 - (0.5 \times age) - (0.05 \times weight\ in\ lbs) + 4.5 \quad (1)$$

$$HR_{max} = 211.415 - (0.5 \times age) - (0.05 \times weight\ in\ lbs) \quad (2)$$

The heart rate zones used by the application were based on percentages of this estimated HR_{max} value. Four zones were used, increasing in 10% intervals from 60% to 90% of the user's HR_{max}. In addition to calculating individually specific heart rate zones the application also allowed the user to create custom training plans based on 5 minute zone intervals. For example, the user may choose to run for 30 minutes, increasing from zone 1 to 4 over 20 minutes before decreasing their intensity back to zone 2 over the final 10 minutes.

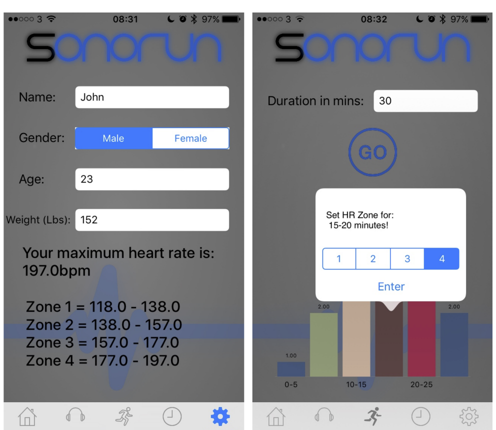

Figure 1: Screenshots showing a user's information, used to calculate their HR_{max} (left) and a custom, heart rate zone based runs (right).

The final element of user interaction was to allow the user to select their personal choice of music to listen to during their run. This would ensure that the motivational benefits of music, explored by Karageorghis and Terry [12], would be maximised. In order to do this Apple's *MPMediaPicker* framework was used. This provided the application with access to the iPhone's internal music library, allowing the user to choose music that may have been chosen anyway whilst running. Implementing this feature also meant that the application did not interfere with what users may consider as being normal training habits.

2.1 Sonification Design

Two sonification systems, implemented using Audio Kit, were designed to be used in the application. Upon receiving the heart rate value (every second) the systems would react based on one of three primary states, whether the user was above, below or in the correct heart rate zone (based on the pre-defined training plan).

The first sonification system, sonification system one, utilises the temporal characteristics of music, or changes to the sound over time. Kramer et al describe the human auditory system as being "particularly sensitive to" these aspects of sound [13]. Despite utilising these temporal features, the system was designed around asynchronous training, i.e. the tempo of the music would have no direct correlation to the athlete's heart rate. This was to cater for all musical preferences. For example, a synchronous system would not necessarily suit users who may draw motivation from slower, less rhythmically driven music. Therefore, the temporal changes in this sonification system acted as a guide to inform the user of the need to either increase or decrease their intensity. Whenever the user was in the correct heart rate zone, regardless of the equivalent intensity, the music would sound as intended.

To create this sonification system, the technique of parameter mapping sonification (PMSon) (see [9]) was primarily used. The speed of the music changed depending on the amount by which the user's heart rate was above or below the zone. For example, when it was below the zone the music increased in speed. This was an attempt to prompt the user to increase their intensity. Similarly, when the user's heart rate exceeded the target heart rate zone the music would begin to slow down, prompting them to decrease their intensity.

These temporal changes formed the basis of this sonification system. However, changes to the pitch of the music were also used to support these changes in speed. These pitch changes would occur if the user had remained outside of the correct zone for more than 30 seconds, slowly increasing in pitch if the user was above the target zone and decreasing when below.

In addition to these two PMSon techniques, a short 'Success' Earcon (see [14]) was also used to inform the user that they have just entered the correct zone.

The second sonification system again utilised the motivational benefits of listening to music. However, rather than using the pitch and speed of the music, this system aimed to exploit the importance of personal music preference by varying the volume of the music. When a user is outside the target heart rate zone the music volume is decreased, thus enticing the user to correct their intensity in order to hear the music that they want to hear.

Again, PMSon techniques are used in this system. This time the parameter that is changed by the user's heart rate was the frequency of two sinusoidal oscillators. As the athlete's heart rate fell below or rose above the target heart rate zone these two oscillators become audible and increased in volume (whilst the volume of the music decreased). One oscillator was panned hard left and the other oscillator panned hard right. The oscillator in the user's left earphone was known as the 'current' oscillator, and its frequency increased or decreased depending on whether the heart rate was approaching or moving further away from the target zone. If below the target zone the tone increased in frequency as they approached the zone and vice versa. The amplitude of this sinusoidal tone also oscillated depending on the whether the user's heart rate. This oscillation was fast if below the target zone (indicating the need to increase intensity), and slow if above the target zone.

The sinusoidal tone heard in the user's right ear was know as the 'target' oscillator. If the user was below the target zone the frequency of this tone was higher than that of the 'current' oscillator. Likewise, if above the target zone the frequency would be lower. As with the 'current' oscillator, the frequency of the 'target' oscillator increased or decreased as the user approached the target heart rate zone. The change in frequency was *opposite* to the change in frequency of the 'current' oscillator. This meant that as the user approached the correct zone, the frequency of the two tones converged. The user's aim was to match the two tones. At this point their heart rate was at the correct level and the music that they were wanting to hear returned to the correct level (and the two oscillators faded out). This change in frequency is indicated by the graph in Figure 2.

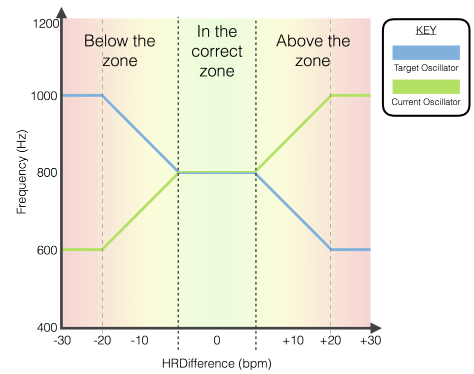

Figure 2: Graph indicating how the frequency of the current and target oscillators varied with heart rate.

As with the first sonification system, a 'Success' earcon was also played at this point to inform the user when they have entered the target zone.

2.2 Control Test Design

In addition to these two sonification systems a control test was designed without sonification, but still using auditory instructions. Sonification is defined by Kramer et al as *"the use of non-speech audio to convey information"* [13]. Therefore, in order to create a system that would provide results by which the sonification systems could be compared, the control test was comprised of spoken prompts, by definition, not a form of sonification. The spoken prompts were designed to guide the athlete through a training plan, meaning that whilst using the system the athlete would hear no music. The prompts indicated to the user when they needed to change zones, when they were above or below the target zone and when they had entered the target zone.

3 User Testing and Results

This section provides an overview of the user testing that was completed as part of this project. A description of the procedure and participants is given before the quantitative and qualitative are presented.

3.1 Participants and Procedure

Once the system had been implemented, a series of quantitive and qualitative user tests were completed. Due to there being three systems incorporated into the application (one speech and two sonification systems), each test consisted of three separate runs, each of 20 minutes in length performed around the same 1.7 mile loop. Each of these runs therefore consisted of four separate heart rate zone intervals (of 5 minutes) including three zone transitions. The zone progression used was zone 1, zone 2, zone 3 and zone 2. This ensured that the participants warmed up sufficiently and also experienced a transition up and down from a zone.

During the tests the iPhone was placed in an arm pouch and strapped securely around the participant's upper arm with the headphones attached. A participant wearing this setup can be seen in Figure 3.

Figure 3: A participant wearing the headphones and the arm strap containing the iPhone. The heart rate monitor, worn around their chest, is not visible.

Due to limited time available during the testing phase of the project only two participants were involved with the user tests. Both participants were 20 years of age, of similar weight and exercised regularly.

3.2 Quantitative Results

Before completing each test, the operation of the system was described to the athlete and they were given an opportunity to ask any questions about what they might expect to hear. This was to ensure that they would be aware of how to react to particular changes in sound.

The heart rate data collected during each test was analysed and the percentage of time spent inside the correct heart rate zone was calculated and compared across each system. Additionally this percentage was also calculated whilst ignoring the first 30 seconds of each five minute interval (e.g. 0:00-0:30, 5:00-5:30, 10:00-10:30 etc). This was to take into account the transitional phase when moving between two zones or beginning a run from rest. Table 1 displays these results for both participants across all three systems.

Table 1: A comparison of the percentage of time spent in the correct heart rate zone across all three tests for both participants.

	Speech System	**Sonification System One**	**Sonification System Two**
Overall Score (User 1)	90.92%	77.44%	77.94%
Excluding first 30secs (User 1)	98.80%	80.18%	86.27%
Overall Score (User 2)	35.65%	43.65%	64.29%
Excluding first 30secs (User 2)	35.30%	42.30%	67.93%

Figures 4 and 5 present each participant's measured heart rate data along a time dependent plot. These graphs provide a visual representation of how their heart rate varied over time with regards to the upper and lower heart rate zone boundaries. They also allow for particular differences or patterns to be tracked across each of the three systems.

Figure 4: A comparison of the heart rate data of participant one across all three tests.

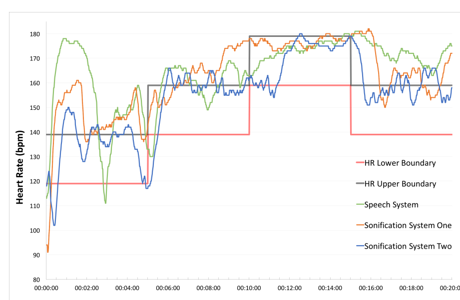

Figure 5: A comparison of the heart rate data of participant two across all three tests.

3.3 Qualitative Results

Immediately after using each sonification system the participants were asked a series of questions in order to gauge their thoughts on the implementation of the sonification and how it influenced their training. After all three tests had been completed the participants were also asked a few more general questions about their thoughts on the application as a whole. A selection of interesting responses is presented in Table 2.

Table 2: A selection of responses given by the two participants immediately after using each sonification system.

Question	**Answer**
Was the sonification easy to follow? Was it obvious when you were above, below or in the target zone? (Sonification System One)	I found it easier to follow than the speech system! I did normally need the pitch change to inform me that I was outside of a zone, but this might have been due to my choice of music. The 'Success' tone really helped. (Participant 2)
Do you *think* that the system helped you stay in the correct zones more than the speech system? (Sonification System One)	No, not really as the transitions between zones were less defined. It was a lot more entertaining though! (Participant 1)
Do you have any comments on the changes in pitch and tempo? Where they sufficient or too subtle? (Sonification System One)	I didn't think the changes in tempo were particularly obvious, more drastic changes would have helped. The pitch changes were really clear, especially when the music went higher. (Participant 2)
Was the sonification easy to follow? Was it obvious when you were above, below or in the target zone? (Sonification System Two)	It was much easier to follow. It was really easy obvious when I was above or below the zone. Probably the best of the three systems. (Participant 2)
Do you *think* that the system helped you stay in the correct zones more than the speech system? (Sonification System Two)	Definitely, more so than the previous two tests. (Participant 2)
Did you find the sonification annoying or did it help to motivate you to change your intensity? (Sonification System Two)	It was a bit annoying, but I think that made it motivating. It was much more motivating than the first system. (Participant 1)

4 Discussion

Upon completing the user testing the results that were collected were analysed. This section discusses the findings observed in the results from both the quantitative and qualitative tests.

4.1 Discussion of Quantitative Results

When comparing the quantitative results of the two participants, the percentage accuracies across all three tests can be seen to vary significantly. This is perhaps most obvious with the difference in results from the baseline speech test with participant one being over 2.5 times more accurate than participant two. The consistently lower accuracy of participant two reinforces the importance of designing individually specific forms of auditory feedback, as previously noted by Schaffert et al [17].

Although lower than the speech system, the accuracy from both sonification systems for participant one are largely similar, scoring close to 78% in both cases. When ignoring the 30 seconds immediately after a zone transition the accuracy for the sonification systems increased, with a more significant increase being observed for the second sonification system.

Interestingly, for participant two, the percentage accuracies of using both sonification systems were higher than the speech system, thus contrasting with the results of the first participant. This may be due to the non-continuous prompts given by the speech system (i.e. only given every 30 seconds when outside of a zone) making it harder for the participant to follow the zone progression. In particular, the results of the second participant show that when using the second sonification system the percentage accuracy was almost twice as much as for the speech system and 50% more than for the first sonification system. This result suggests that the more immediate *awareness* form of feedback employed for this sonification system resulted in a stronger response in the participant's intensity.

When viewing the results along a continuous trace (Figures 4 and 5) it was observed that the sonification systems did cause the athlete to successfully progress through the heart rate zone training plan. Importantly it should also be noted that both systems did invoke a response in the heart rate of both participants. When their heart rate rose above a target zone, an almost instant response can be seen in reaction to the audible feedback provided by the sonification systems, the response perhaps being more immediate when using the second sonification system.

4.2 Discussion of Qualitative Results

As with the quantitative results, the qualitative results also produced some varying responses. The two participants produced contrasting responses when using the first sonification system wth participant one stating that they did not think it helped them improve their accuracy and participant two stating the opposite. Interestingly, in both cases the participants thoughts did correspond with the quantitative results. For the second system both participants thought that the sonification improved their accuracy, however only with participant two did the quantitative results reflect this.

A common response for the first sonification system was that the changes in tempo were perhaps too subtle, with the athletes often requiring the pitch to change before responding. This is perhaps an explanation for the slower responses in heart rate (when compared to the second sonification system) observed in the quantitive results. Despite these subtle changes the participants still said that they found the system to be a motivator with one participant stating that they found it *"more immediate than the speech system"*. Both participants also agreed that the sonification was much more entertaining than the speech system due to the inclusion of the music.

Both participants said that they found the second sonification system the easiest to follow and found that it was more motivating than the previous two systems. However, this increased motivation, resulting in a quicker response in heart rate, was due to the sonification sounding *"annoying"*, a fact communicated by both participants. This perhaps balances the argument of the better results produced using this system with the more entertaining sonification provided by the first system.

The overall impression of the application was positive from both participants. They agreed that it did not hinder their running in any way, was simple to use and they benefited from personal music choices. Additionally, they both stated that the sonification gave them a better understanding of their heart rate zones whilst running.

5 Conclusion

This project explored whether real-time sonification of heart rate data, together with the motivational benefits of music, could be used to improve the efficiency of runners' training. Implementing the system as an iOS based mobile application provided a method of training that complements the current trend of using technology, either for tracking purposes or for listening to music, whilst running. The application provided the ability to be customised to any individual's ability and allowed training plans based on heart rate zones to be created. The system included two sonification designs, that both used parameter mapping sonification combined with event based earcons.

In terms of the application's concept, the participants involved with the user testing both agreed that it provided a unique combination, functioning as both a music player and a training aid. The ability to select music based on their own personal preference proved popular. However, whilst using the first sonification system (which used parameter mapping sonification to change temporal and pitch attributes of the music) the rhythmical nature of the songs selected (i.e. whether they contained a strong, beat driven rhythm) did have an impact on hoe easily the temporal changes were interpreted. This is potentially a reason for why the more obvious, motivational based implementation of the second sonification system (which *rewarded* the user with their music choice when in a correct zone) produced more desirable results, particularly with the second participant.

Due to the limited number of participants that were involved with the user testing, the results were inconclusive in proving whether sonification can improve the *efficiency* of training with heart rate zones. However, the results did show that the two sonification systems that were used did invoke changes in heart rate. Although the overall level of accuracy amongst the two participants varied significantly, both experienced changes in heart rate that were in line with the zone based training plan that the sonification systems were attempting to guide them through. This suggests that sonification does have the potential to be used as a form of auditory feedback whilst training with heart rate.

The system presented in this study provides a modern, unique, attractive and, more importantly, practical method of approaching heart rate zone based training in a form that can be adopted by casual and serious runners alike. Before the true success of heart rate based sonification can be judged, further testing must take place. However, this study has successfully laid the foundations for further work to be undertaken to explore how sonification can be used as a training aid for both runners and other sportsmen and women.

References

[1] *Improving Running Mechanics by Use of Interactive Sonification*, KTH, Stockholm, Sweden, April 2010.

[2] Jordi Bolíbar and Roberto Bresin. Sound feedback for the optimization of performance in running. *SMC Sweden 2012 Sound and Music Computing, Understanding and Pracicing in Sweden!*, page 39, 2012.

[3] Ferrari Conconi, Michele Ferrari, Pier Giorgio Ziglio, Paola Droghetti, and Luciano Codeca. Determination of the anaerobic threshold by a noninvasive field test in runners. *Journal of Applied Physiology*, 52(4):869–873, 1982.

[4] Department for Culture, Media and Sport. Adult participation in sport, August 2011.

[5] Alfred O Effenberg. Sonification - ein akustisches informationskonzept zur menschlichen bewegung. *Beitrage zur Lehre und Forschung im Sport*, 111, 1996.

[6] Joel Forsberg. A mobile application for improving running performance using interactive sonification. Master's thesis, KTH Computer Science and Communication, 2014.

[7] Andrew Godbout and Jeffrey E Boyd. Corrective sonic feedback for speed skating: a case study. In *Proceedings of the 16th international conference on auditory display*, pages 23–30, 2010.

[8] Matthew L Goodwin, James E Harris, Andrés Hernández, and L Bruce Gladden. Blood lactate measurements and analysis during exercise: a guide for clinicians. *Journal of diabetes science and technology*, 1(4):558–569, 2007.

[9] Florian Grond and Jonathan Berger. Parameter mapping sonification. In Thomas Hermann, Andy Hunt, and John G. Neuhoff, editors, *The Sonification Handbook*, chapter 15, pages 363–397. Logos Publishing House, Berlin, Germany, 2011.

[10] Jason A Hockman, Marcelo M Wanderley, and Ichiro Fujinaga. Real-time phase vocoder manipulation by runner's pace. In *Proceedings of the International Conference on New Interfaces for Musical Expression*, pages 90–93. Citeseer, 2009.

[11] Asker Jeukendrup and Adrie Van Diemen. Heart rate monitoring during training and competition in cyclists. *Journal of Sports Sciences*, 16(sup1):91–99, 1998.

[12] C I Karageorghis and P C Terry. The psychophysical effects of music in sport and exercise: A review. *Journal of Sport Behavior*, 20:54–68, 1997.

[13] Gregory Kramer, Terri Bonebright, Perry Cook, John Flowers, Nadine Miner, John Neuhoff, Robin Bargar, Stephen Barrass, Jonathan Berger, Grigori Evreinov, W Tecumseh Fitch, et al. Sonification report: Status of the field and research agenda. *prepared for the National Science Foundation by members of the International Community for Auditory Display*, 1999.

[14] David McGookin and Stephen Brewster. Earcons. In Thomas Hermann, Andy Hunt, and John G. Neuhoff, editors, *The Sonification Handbook*, chapter 14, pages 339–361. Logos Publishing House, Berlin, Germany, 2011.

[15] nowlin. Maximum heart rate calculator, 2016. [Online]. Available: http://nowlin.com/heartrate.htm [Accessed: 23/03/2016].

[16] Parkrun. Parkrun, 2016. [Online]. Available: http://www.parkrun.org.uk [Accessed: 09/11/2015].

[17] Nina Schaffert, Klaus Mattes, and Alfred O Effenberg. A sound design for the purposes of movement optimisation in elite sport (using the example of rowing). 2009.

[18] Nina Schaffert, Klaus Mattes, and Alfred O Effenberg. Listen to the boat motion: acoustic information for elite rowers. In *Human Interaction with Auditory Displays–Proceedings of the Interactive Sonification Workshop*, pages 31–38, 2010.

[19] Nina Schaffert, Klaus Mattes, and Alfred O Effenberg. The sound of rowing stroke cycles as acoustic feedback. *International Community for Auditory Display*, 2011.

[20] Sport England. Further swimming decline dominates latest sports figures, June 2015. [Online]. Available: https://www.sportengland.org/media-centre/news/2015/june/11/further-decline-in-swimming-numbers-dominate-latest-sports-figures/ [Accessed: 05/11/2015].

[21] Sports Marketing Surveys Inc. Uk's running population reaches remarkable 10.5m says sports marketing surveys inc., August 2015. [Online]. Available: http://www.sportsmarketingsurveysinc.com/uks-running-population-reaches-remarkable-10-5m-says-sports-marketing-surveys-inc/ [Accessed: 03/11/2015].

[22] UK Government. Inspired by 2012: The legacy from the london 2012 olympic and paralympic games, July 2013. [Online]. Available: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/224148/2901179_OlympicLegacy_acc.pdf [Accessed: 06/02/2016].