Int. J. Human-Computer Studies 85 (2016) 68–71

Contents lists available at ScienceDirect

Int. J. Human-Computer Studies

journal homepage: www.elsevier.com/locate/ijhcs

Diagnosing blood pressure with Acoustic Sonification singing bowls☆

Stephen Barrass

Digital Design and Media Arts, University of Canberra, Canberra, Australia

ARTICLE INFO

Article history:
Received 21 January 2015
Received in revised form
28 July 2015
Accepted 13 August 2015
Available online 1 September 2015

Keywords:
Acoustic sonification
Singing bowls
Blood pressure
Medical diagnosis

ABSTRACT

Acoustic Sonification maps a dataset onto the shape of 3D acoustic object. This concept has been demonstrated in the form of the Hypertension Singing Bowl shaped by a year of blood pressure readings. The sounds produced by this prototype raise the question of whether useful information about the dataset can be heard by interacting with the bowl? This paper explores the feasibility of Acoustic Sonification through a case study on the diagnosis of blood pressure in five categories of risk. The readings that define each category are used to generate five Diagnostic Singing Bowls based on the CAD model in the prototype. The set of Diagnostic Singing Bowls was 3D printed in stainless steel. The first set of bowls did not increase in pitch with severity of diagnosis as predicted by the acoustic model. Inspection showed that this was due to artefacts introduced by the 3D printing process. A next iteration of the mapping addressed this problem, and a second set of Diagnostic bowls was printed that do increase in pitch with the severity of the risk, as expected. The feasibility of using these bowls for diagnostic purposes was tested by generating two Patient bowls from blood pressure readings recorded from human patients. The resonant frequency of the Patient bowls most closely matches the frequency of the Diagnostic Bowl in the same category of risk. These results suggest that Acoustic Sonification may be a feasible technique that could have practical applications.

1. Introduction

The Hypertension Singing Bowl is a 3D printed Tibetan Singing Bowl that has been shaped by a year of blood pressure data. The bowl was created by modulating the shape of a CAD model with the dataset and 3D printing it in stainless steel (Barrass, 2014). The 3D printed bowl rings when it is struck, and sings when it is rubbed with the puja stick, just like a traditional singing bowl. The association of the singing bowl with meditation and relaxation adds a narrative of contemplation and reflection on personal health data as a means of healing and wellbeing.

The Hypertension Singing Bowl is a demonstration of the Acoustic Sonification technique where data is mapped onto a resonant shape to produce sonic information from the data. Unlike digital sonifications, Acoustic Sonifications are not limited by processor speed, floating point operations, sampling rate or bit depth. Acoustic Sonifications do not require electrical power, and are produced from the entire object, rather than from a speaker. The interaction with an Acoustic Sonification is not affected by the size or complexity of the dataset. The manual manipulation of a physical object allows tapping, scratching, rubbing and other actions that are not limited to the simple operations of a mouse, buttons or keyboard used to interact with computer based sonifications.

The sounds that can be produced from the Hypertension Singing Bowl raise the question of whether information about the dataset can actually be heard? Furthermore, how do you purposefully design an Acoustic Sonification to convey useful information about a dataset? This paper develops a method to address these questions, through a case study on the diagnosis of blood pressure categories from singing bowls that builds on the Hypertension Singing Bowl prototype.

The next section provides background on data sonification in medical applications. The following section introduces the case study on diagnosing categories of health risk from blood pressure readings. The section after that develops a method for Acoustic Sonification based on the case study with Diagnostic Singing Bowls. The feasibility of this method is then tested by creating 2 singing bowls from patient datasets. Section 4 compares the data bowls with the Diagnostic bowls. The results from the study are discussed and conclusions are drawn that include directions for further work.

2. Background

Doctors routinely diagnose illnesses by listening to the body through a stethoscope, and medical students receive extensive training on how to listen for symptoms in the sounds made by the

☆This paper has been recommended for acceptance by Henrik Christensen.
E-mail address: stephen.barrass@canberra.edu.au

http://dx.doi.org/10.1016/j.ijhcs.2015.08.007
1071-5819/

lungs, heart, intestines, and organs. Various sensors are also used to gather information from inside the body, and this data can be transformed into sound using a technique called data sonification (Kramer et al., 1999; Barrass and Kramer, 2001). For example, the "beeping" device in the operating theatre often heard on TV programs is a Pulse Oximeter that makes blood oxygen levels and heart rate audible, and this information is so important that the device is legally required in many countries. The effectiveness of data sonification has been tested with medical students who performed better in a simulated operation when eight dynamically changing variables were presented as sounds, rather than graphs (Fitch and Kramer, 1992). The sonification of texture and periodicity has been shown to be effective for detecting unhealthy regions in MRI brain scans (Martins et al., 2001) and cervical cancer in microscope slides (Edwards et al., 2008). Other experiments with the sonification of medical datasets have included EEG (Barrass et al., 2006; Hinterberger and Baier, 2005), and EMG (Pauletto and Hunt, 2006).

3. Method

Blood pressure readings have two parts: the diastolic pressure when the heart is contracted, and the diastolic pressure when the heart is relaxed. The doctor typically takes these readings by listening through a stethoscope. A cuff is inflated around the brachial artery in the upper arm to cut off the blood flow. The cuff is released and the doctor then listens for a knocking sound, which is the signal to read the systolic blood pressure. At the point when the knocking disappears, the diastolic reading is taken. Doctors use blood pressure readings to diagnose five major categories of risk, as shown in Table 1. A reading of 110/70 is classified as "Normal" and does not require treatment. A lower reading is classified as Hypotension, which may cause dizziness and fainting. Higher readings are classified into 3 levels of Pre-Hypertension, Stage 1 Hypertension and Stage 2 Hypertension, where increasing pressure on the arteries and organs has consequences for long term health.

Table 1
Diagnosis of blood pressure readings.

85/55	110/70	130/70	150/95	160/100
Hypotension	Normal	Pre-Hypertension	Hypertension 1	Hypertension 2

The diagnosis of blood pressure provides a case study for testing the feasibility of Acoustic Sonifications. A useful sonification will allow the perception of the five ordered diagnostic categories from the mapping of the data into sound (Barrass, 1998). One way to do this is to create a Diagnostic Singing Bowl for each category of risk. The Diagnostic bowls are modelled on the process used to produce the Hypertension Singing Bowl prototype (Barrass, 2014). This process maps a blood pressure reading to the radius of a spoke that connects the top and bottom of the bowl. The mapping of data to radius affects the resonant frequency of the bowl, which is a function of the radius (Inácio et al., 2006). The perception of pitch is closely related to resonant frequency, and ordered differences in pitch should allow the perception of ordered categories of risk.

The mappings of systolic and diastolic blood pressure readings onto the geometry of the bowl are described in Eqs. (1) and (2)

$$\text{SysRadius} = \text{Radius} + \text{Wall}*k*(\text{SysMax}-\text{SysData})/(\text{SysMax} - \text{SysMin}) \tag{1}$$

$$\text{DiaRadius} = \text{Radius} + \text{Wall}*k*(\text{DiaMax}-\text{DiaData})/(\text{DiaMax} - \text{DiaMin}) \tag{2}$$

The variation in radius with the data is normalised so that it falls within the wall thickness of the bowl, to ensure that the spokes are attached across the data range. The Hypertension Singing Bowl contains 100 readings which amounts to 100 spokes,

Table 2
Diagnostic Singing Bowls-version 1.0.

				
1598 Hz	1654 Hz	1579 Hz	1560 Hz	1541 Hz
Hypotension	Normal	Pre-Hypertension	Hypertension 1	Hypertension 2

Table 3
Fundamental frequency of Diagnostic bowls, version 2.0.

				
3143 Hz	3214 Hz	3263 Hz	3297 Hz	3322 Hz
Hypotension	Normal	Pre-Hypertension	Hypertension 1	Hypertension 2

1 for each reading. The width of the spokes is limited by the resolution of the 3D printing process and material, and the gap between the spokes is limited by the circumference of the bowl.

$$SpokeGap = (2PI*Radius-NumSpokes*SpokesWidth)/NumSpokes \tag{3}$$

A supported wall is one connected to other walls on two or more sides. For steel, the minimum supported wall of 1 mm is determined by the ability to print the product and infuse it with bronze. Walls that are too thin may collapse during the infusion process.

This model was used to generate a CAD mesh from the systolic and diastolic pressure that define each category of risk. The CAD mesh is computationally generated with the Processing graphics programming software (Reas et al., 2007). The systolic reading adjusts the radius of the upper part of the spoke, and diastolic reading adjusts the radius of the lower part. The range of movement of the spokes was adjusted so that the Normal reading of 110/70 produces a smooth singing bowl, where the spokes match the rim radius, as the reference point in the series. Lower readings in the Hypotension direction move the spokes outward, lowering the resonant frequency of the bowl. Increasing blood pressure in the Hypertension direction moves the spoke inward, raising the resonant frequency of the bowl.

4. Experiment

The first set of Diagnostic Singing Bowls was generated with Radius = 35 mm, Wall = 3 mm, NumSpokes = 100, SpokeWidth = 1 mm (minimum for stainless steel), and SpokeGap = 1.1 mm.

The CAD model files were uploaded to the *shapeways.com* site and were tested for mesh integrity, bounding box, wall thickness, loose shells, and machine space. The models were then 3D printed in stainless steel, as shown in Table 2. This first set of Diagnostic Singing Bowls each produced a ringing sound when they were struck. However, the frequency of the bowls does not increase in an ordered sequence, as was expected from acoustic theory.

A visual inspection of the bowls showed that the radius of each bowl decreases in a regular manner as specified by the computational mapping of the diagnostic pressure levels. However, there are areas where the gap between the spokes is bridged, creating a connected sub-region. This observation led to an iteration of the mapping scheme to widen the gaps to prevent bridging artefacts. The increase in the gap entailed a tradeoff with the number of spokes, which was reduced to 45. The singing bowl was further simplified by removing the base which does not contribute to the radial vibration modes.

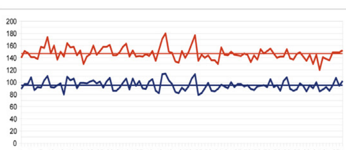
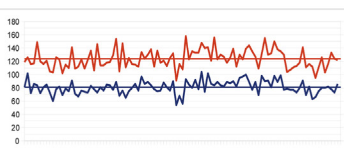
The next set of Diagnostic bowls was generated with Radius = 35 mm, Wall = 2 mm, NumSpokes = 45, SpokeWidth = 2 mm, and Gap = 2.88 mm. As before, the CAD files were uploaded to the *shapeways.com* site, tested for integrity, and 3D printed in stainless steel. This time the resonant frequency of the Diagnostic Singing Bowls does increase in an ordered sequence, as shown in Table 3.

The Diagnostic Singing Bowls ring for 3–5 s when struck. The Hypotension bowl is lower in pitch than the Normal bowl, and the 3 Hypertension bowls are higher, increasing in pitch with severity of diagnosis category.

5. Case study

Two blood pressure datasets were obtained with permission from human subjects. Each dataset contains 100 measurements taken over a 1 yr period. The first dataset, labelled SB, has an average reading of 147/95 which is in the Stage 1 Hypertension category. A singing bowl was generated from the first 45 readings in the dataset, based on the template for the Diagnostic Singing Bowls, as shown in Table 4. The second dataset, labelled MK, has an average value of 124/81, which is in the Normal category. These

Table 4
Patient singing bowls.

SB Bowl	MK Bowl
	
Mean = 147/95, Stdev = 10/8	Mean = 124/81, Stdev=14/10
Category = Hypertension 1	Category = Normal
	
3314 Hz	3245 Hz

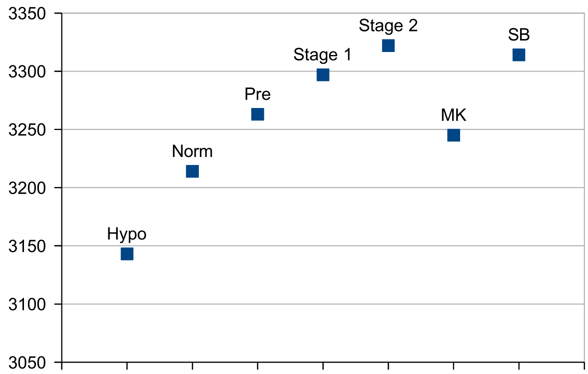


Fig. 1. Frequency (Hz) of Diagnostic bowls and Patient bowls.

readings are more erratic, with a standard deviation of 14/10. The first 45 readings were used to generate the MK Singing Bowl, shown in Table 4.

The Patient bowls both ring for 3–5 s when struck, just like the Diagnostic bowls. The SB Bowl has a higher pitch than the MK Bowl. The pitch of the SB Bowl sounds close to the pitch of the Stage 1 and Stage 2 Diagnostic bowls. The pitch of the MK Bowl sounds most similar to the Normal Diagnostic Bowl, as shown in Fig. 1. The Patient bowls have a more complex timbre than the Diagnostic bowls, due to the more complex spectrum generated by the 45 spokes with different radii.

6. Discussion

The Patient singing bowls sonify the dataset as a whole, rather than individual points. The Patient bowls sound most similar to the Diagnostic Bowl that corresponds with the average of the patient dataset. This observation suggests that it is possible to hear global information about the average value of the entire dataset by listening to the singing bowls.

Although the bowls ring when struck, they do not “sing” when rubbed, even though they are modelled on a prototype which did sing. The difference is a reduction in the radius from 50 mm to 35 mm. The smaller bowl is difficult to hold and rub, and the rim is narrower. The removal of the base and the wider gaps between spokes may also have affected the vibration of the stick-slip induced vibration modes.

7. Conclusion

This paper explored the feasibility of Acoustic Sonification through a case study with blood pressure diagnosis. This is the first time this has been done, and the experimental method also involved the development of a method for designing Acoustic Sonifications to convey useful information. The results from the experiment are encouraging and suggest that Acoustic Sonifications can allow the perception of global information about a dataset. The sounds of the Patient bowls are influenced by the dataset, and are repeatable. The sounds of the Diagnostic Singing Bowls are systematic and designed using acoustic theory. The results suggest that accurate diagnoses could be made by comparing the sound of Patient bowls with Diagnostic bowls. This experiment provides a first example of how Acoustic Sonifications can be designed and applied in practise.

In further work Acoustic Sonification will be evaluated in trials where subjects will classify a range of blood pressure datasets. These trials will include doctors who routinely use blood pressure readings for diagnostic purposes. These experiments will contribute to the development of a theory of Acoustic Sonification which can provide useful information about a general range of datasets.

Hypertension, or high blood pressure, is a common disorder of the circulatory system, affecting around one in seven adult Australians. It is also known as “the silent killer” because there are no symptoms, and many people are unaware that they have this potentially fatal condition. The association of singing bowls with meditation and relaxation adds a narrative of contemplation and reflection on the dataset that could motivate behaviour change and self-healing. Perhaps one day the sound of a Blood Pressure Singing Bowl could provide an antidote to the “silent killer”.

References

Barrass, S., Kramer, 2001. Using sonification. J. Multimed. Syst.-Spec. Issue Audio Multimed. 7 (1), 23–31, Springer-Verlag New York, Inc. Secaucus, NJ, USA.

Barrass, S., Whitelaw, M., Bailes, F., 2006. Listening to the mind listening. Leonardo Music J. 16, 13–19, MIT Press.

Barrass, S., 1998 Auditory Information Design, (unpublished Ph.D. thesis). Australian National University, http://hdl.handle.net/1885/46072.

Barrass, S., 2014. Acoustic sonification of blood pressure in the form of a singing bowl. In: Proceedings of the Conference on Sonification in Health and Environmental Data, York University, UK.

Edwards, A.D.N., Hines, G., Hunt, A., 2008. Segmentation of biological cell images for sonification. In: Proceedings of the International Congress on Image and Signal Processing (CISP 2008), IEEE Computer Society Sanya, China.

Fitch, T., Kramer, G., 1992. Sonifying the body electric: superiority of an auditory over a visual display in a complex, multivariate system. In: Kramer, G., (Ed.), Proceedings of the First International Conference on Auditory Display (ICAD), Santa Fe Institute, Addison-Wesley Reading, Massachusetts pp. 307–325.

Hinterberger, T., Baier, G., 2005. Parametric orchestral sonification of EEG in real time. J. IEEE Multimed. 12 (2), 70–79, IEEE Computer Society Press Los Alamitos, CA, USA.

Inácio, O., Henrique, L.L., Antunes, J., 2006. The dynamics of tibetan singing bowls. Acta Acust. United Acust. 92 (4), 637–653.

Kramer, G., et al., 1999. Sonification Report: Status of the Field and Research Agenda. National Science Foundation of America, New Mexico.

Martins, A.C.G, Rangayyan, R.M., Ruschioni, R.A., 2001. Audification and sonification of texture in images. J. Electron. Imaging 10 (3), 690–705. http://dx.doi.org/10.1117/1.1382811.

Pauletto, S., Hunt, A., 2006. The sonification of EMG data. In: Proceedings of the 12th International Conference on Auditory Display ICAD06, London, UK.

Reas C., Fry B., Maeda, J., 2007. Processing: A Programming Handbook for Visual Designers and Artists. The MIT Press, Cambridge.