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Diagnosing blood pressure with Acoustic Sonification singing bowls ☆

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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

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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