ACOUSTIC SONIFICATION OF BLOOD PRESSURE IN THE FORM OF A SINGING BOWL

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ABSTRACT

The Hypertension Singing Bowl is an Acoustic Sonification shaped by a year of blood pressure data that has been 3D printed in stainless steel so that it rings. The design of the bowl was a response to a medical diagnosis of hypertension that required regular self-tracking of blood pressure. The culture of self-tracking, known as the Quantified Self movement, has the motto "self knowledge through numbers". This paper describes the process of designing and digitally fabricating a singing bowl shaped from this blood pressure data. An iterative design research method is used to identify important stages of the process that include the choice of a sonic metaphor, the prototyping of a CAD baseline, the mapping of data to shape, and the acoustics of the mapping. The resulting Hypertension singing bowl is a meditative contemplation on the dataset that is a reminder to live a healthy lifestyle, and a poetic alternative to generic graphic plots of the Quantified Self.

1. INTRODUCTION

The increasing availability of low cost wearable sensor products has led to a growing interest in self-tracking in sports, health and fitness. The Quantified Self (QS) movement advocates "*self-knowledge through numbers*" [1] through the analysis of this data. Participants in QS meet-ups are invited to "*share what you are doing, and learn from others*" by showing visualizations, and telling stories about datasets, self improvements, technologies and other aspects of self-tracking culture [2].

Mark Carrigan observes that stories about self-tracking often include personal context and a qualitative interpretation of the numbers. He introduced the term "*qualified self*" to refer to "*self-knowledge through words*" that comes from telling stories about the data. He goes on to define the term "*qualitative self-tracking*" as "*using mobile technology to recurrently record qualities of experience or environment, as well as reflections upon them, with the intention of archiving aspects of personal life that would otherwise be lost, in a way susceptible to future review and revision of concerns, commitments and practices in light of such a review"* [3].

Jenny Davis makes the point that telling stories about self-tracking data can also be a mechanism for constructing self-identity.*"Self-quantifiers don't just use data to learn about themselves, but rather, use data to construct the stories that they tell themselves about themselves*" [4]. She also observes that personal reflections on the data can go beyond words to include artistic constructions such as a poem, or a collage. Deborah Lupton expands on the kinds of data that are collected by self-trackers in her analysis of cultures of self-reflexion. "*Many self-trackers record non-quantifiable data as part of their practice, including journaling accounts of their daily activities, emotional states and relationships, collecting audio data or visual images and producing visualisations that centre on their aesthetic or explanatory properties rather than their representation of numbers.* [5]

In a recent post on the Quantified Self site, Enrico Remirez showed images of physical visualizations that included a 3D bar chart made from children's playing blocks, and a sculpture made from graphs cut out of cardboard and bound around a spine [6]. Physical visualizations like these are usually considered to be educational props, or artistic interpretations of the data. However, a recent study by Yvonne Jansen and colleagues found that a 3D print of a 3D dataset can be more effective for 3D information retrieval tasks than a screen-based version [7]. In another study, Rajit Khot and colleagues found that participants were more conscious of their daily physical activity when heart rate data was presented as a 3D printed object than when it was shown on a screen [8].

These studies support the proposal in this paper that stories about self-tracking may not necessarily have to be told in words to enable the personal reflection that may transform numbers into identity. Stories can be told non-verbally through paintings, sculptures, and music. Stories about numbers may be told non-verbally through graphic visualizations, physical visualizations, and data sonifications. Building on these techniques, this paper introduces a new technique, known as acoustic sonification, as a medium for telling stories about numbers. Acoustic sonifications are physical visualizations that also make sounds [9]. Could an acoustic sonification be constructed from self-tracking data? Would this sonic object also facilitate story telling and promote reflection on personal health and fitness? Could the sound increase the curiosity to explore, or enable alternative perceptions and interpretations of the dataset?

These questions motivated the experiments described in the rest of this paper. The background section presents a brief history of acoustic sonification, along with some early examples. The body of the paper describes the design and realization of a prototype of an acoustic sonification designed for a dataset consisting of blood pressure readings taken over a one-year period. The discussion reflects on the experiment in the context of the questions raised by theories of the quantified and qualified self. The paper concludes with a summary of the process of designing an acoustic sonification that includes stages for further research and development.

2. BACKGROUND

In 2009 a CAD model of a whistle was uploaded to the Thingiverse.com 3D printing community site. The whistle generated considerable attention, because it did something no other 3D printed object had done before, it produced a sound. But what generated most attention was the difficulty of 3D printing a version that actually whistled. The variability in the results produced by different printers and different settings highlighted the intimacy of the coupling between shape, material and sound.

In 2011 Arvid Jense documented 40 experiments with the 3D printing of CAD designed musical instruments. The experiments included whistles, blown tubes (e.g. pan pipes), Helmholz resonators (e.g. a blown bottle), percussive temple blocks, and "impossible" instruments of a complexity that is made possible with digital fabrication processes [10]. Most of the instruments did not produce any sound at all, and Jense observed that the precision of edges, angles, holes, and surfaces was critical. He also noted that instruments printed in plastic did not generally produce sounds of a musical quality, with the exception of one particular temple block that had an infill pattern that produced a more wood like timbre.

In 2013 the Stanford University Centre for Computer Research into Music and Acoustics (CCRMA) organised a workshop titled 3D printing for Acoustics to introduce product designers to 3D printing with "music making in mind". The participants modelled acoustic objects with Computer Aided Design tools, parametric equations, and 3d scans of pre-existing objects, to produce a slide flute, a pretzel shaped flute, and a percussive washboard [11].

In 2013 the online 3D printing service, Shapeways.com, announced the dawning of a "New Bronze Age" with the introduction of the capability to 3D print CAD models in bronze and brass. Online 3D printing services, like Shapeways, provide access to the latest developments in digital fabrication technologies that can print a growing range of materials. The development of 3D printing in ceramics and glass has been driven by home-wares, and jewellery is driving printing in stainless steel, brass, bronze, silver, and gold. The range of materials continues to expand, and there are almost daily announcements of new printers capable of fabricating rubber, concrete, carbon fibre, bone structures, arteries, organs and even food. The size of the objects is increasing, and there are now even 3D printers at an architectural scale. High resolution printers can produce mechanisms with moving parts, and the capability to print in multiple materials allows electronic circuitry to be embedded. Examples of 3D printed acoustics include gramophone records [12], speakers [13], music boxes [14], and noise mufflers [15]. Researchers in the Creative Machines Lab at Cornell University recently 3D printed a fully functioning loudspeaker with plastic, conductive and magnetic parts [16].

The discovery of the resonant properties of metals in the Bronze Age let to the invention of instruments such as gongs, bells and bowls. The musical properties of brass makes it the material of choice for tubas, horns, trombones, trumpets and other instruments. The capability to 3D print in these metals expands the range of potential 3D printed instruments. In 2011, I 3D printed a bell in stainless steel to test that it would ring, which it did [9]. The modulation of the shape of the bell by a digital dataset caused it to ring with a different pitch and timbre, and the effect of the dataset on the acoustics of the bell was visible in a spectral analysis [9]. This experiment supported the hypothesis that information about a dataset could be heard in an acoustic sonification. However, it also raised many questions. What effects do different mappings of the data onto the shape have on the acoustics? What is the relationship between physical acoustics, and the auditory perception of informative relations in the data? What kinds of information can be understood from different mappings of data into shape and acoustics? What other shapes beside a bell could be used in acoustic sonification? What effects do other instrument shapes have on the interpretation of meaning from the sounds of interacting with the object?

3. HYPERTENSION

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 lethal condition. Experts recommend that everyone should have their blood pressure checked regularly.

A medical diagnosis of hypertension led me to begin self-tracking my blood pressure with a cuff that sends the readings to an App on a mobile phone. The cuff measures systolic pressure, which is the maximum pressure on the arteries when the heart beats, and diastolic pressure, which is the minimum pressure when the heart relaxes. This data is typically plotted in a time series graph, as shown in the screenshot from the App in Figure 1.

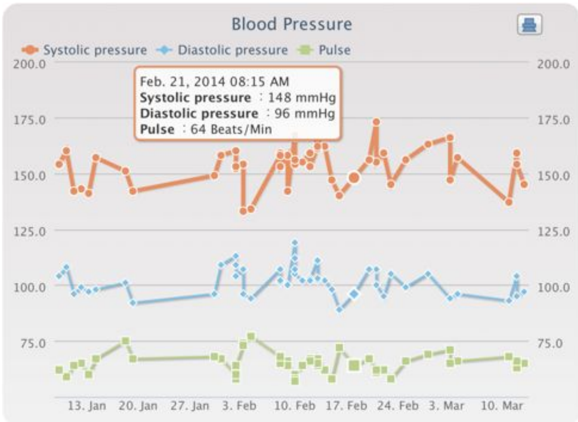

Figure 1. Plot of blood pressure readings

4. DESIGN PROCESS

The plots of my blood pressure are generic and could have been share prices or CO2 emissions. Surely there was a way to make this personal dataset more personal, and more engaging. Could an acoustic sonification provide an antidote to the silent killer?

In previous experiments the choice of a bell provided a metaphor for interaction, and set up the expectations of how the sonification should sound. Other 3D printed instruments could also be sonic metaphors e.g. the pan-pipe, whistle, flute percussion block, washboard, rattle and gramophone record. However, after some consideration, I selected the Tibetan Singing Bowl, because it is associated with meditation and other relaxation therapies that can lower blood pressure. Antique singing bowls are sought out for their unique sounds which are the result of hand crafting from alloys that include gold, silver, mercury, copper, iron, tin, lead, zinc, nickel and other trace elements. Today singing bowls manufactured by casting in bronze are more uniform in shape, material and the sounds they produce. The modulation of the shape of a 3D printed singing bowl by a personal health dataset might also reintroduce a unique sonic character to each bowl.

The simple shape of a singing bowl, shown in Figure 2, makes it straight forward to model as a CAD mesh as shown in Figure 3.

Figure 2. Tibetan singing bowl.

The mesh was constructed from 3D graphic primitives in the Processing 3D graphics programming environment [17].

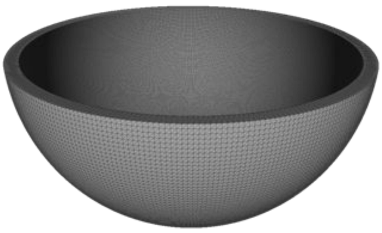

Figure 3. CAD mesh of a Tibetan singing bowl

The next stage was to map blood pressure data onto the CAD mesh. In the previous experiment polar HRTF data was mapped in a circle around the bell shape. The profile of the bell wall was then modulated by the HRTF parameters at that angle. The mapping from data to shape was informed by a study of the relationship between the acoustics and shape of bells by Neale McLachlan, who found that wall thickness and profile affect pitch and timbre [18].

The blood pressure dataset consists of pairs of systolic/diastolic measurements recorded over the period of a year. This dataset does not have a polar spatial dimension that maps directly to the circular shape of the bowl. As a first experiment, the time axis was mapped radially outward from the top centre of the bowl to the outer edge. The circumference of the outer wall was modulated with the systolic data, and the circumference of the inner wall with the diastolic data. The minimum thickness for 3D printing in stainless steel is 1.5mm. The modulations of thickness were added to this core, resulting in walls up to 5mm in thickness, as shown in the CAD model in Figure 4.

Figure 4. Blood Pressure Singing Bowl 0.0 – CAD mesh.

The size of the CAD mesh was reduced by removing overlapping vertices with Meshlab [19]. The mesh was then checked for holes and repaired with netfabb [20]. The cleaned mesh was then uploaded to Shapeways and 3D printed in stainless steel. The resulting bowl, shown in Figure 5, is 64mm in diameter, with volume 37.3 cm^3, and weighs 275g.

Figure 5. BP Singing Bowl 0.0, 3D printed in stainless steel.

Striking the side of the bowl with the Puja stick produces a ringing tone at 3628 Hz that lasts for 3 seconds. Rubbing the stick around the rim produces a metallic sound but the bowl does not resonate and sing like a traditional bowl. The failure of this first experiment to produce a bowl that could sing led to the re-examination of a traditional bowl which had walls that were only 2mm thick, and the observation that the walls were twice as thick. Upon reflection on this process, it would have been more efficient to begin by 3D printing baseline bowl as a test before moving on to the mapping stage.

This observation led to an iteration in the design of the form with the specification that the thickness should be 2mm. This constraint required a redesign of the mapping of the data onto the shape. Rather than mapping the timeline along a radius, it was mapped around the circumference. The pairs of systolic/diastolic data were assigned to radial spokes that connect the rim to the base, as shown in Figure 6. The systolic pressure moderates the radius of the upper half of the spoke, and the diastolic data moderates the radius of the lower half. Variations in the data move the upper and lower parts of each spoke inward and outward to produce an individual acoustic effect at each spoke. In theory, rubbing the rim with the stick should activate the spokes to additively synthesise an acoustic sonification of the entire dataset.

Figure 6. BP Singing Bowl 1.0 – CAD mesh.

As before, the CAD mesh was reduced, repaired and uploaded to be 3D printed in stainless steel. The resulting bowl, shown in Figure 7, is 100mm in diameter, with volume 18.7 cm^3, and weighs 162g.

Figure 7. BP Singing Bowl 1.0, 3D printed in stainless steel

Striking the side of the bowl with the stick produces a dominant partial at 609 Hz that rings for 10 seconds. The ringing tail has a tremolo effect at 2Hz visible in the waveform in Figure 8.

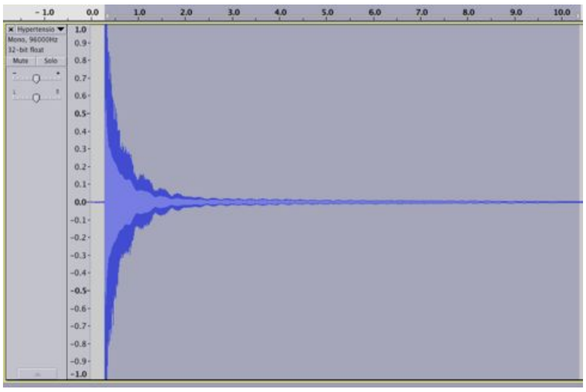

Figure 8. Audio waveform of BP Singing Bowl 1.0 when struck.

As well as the bell tone, the strike also produces an unusual hissing sound that lasts 2-3 seconds, as can be seen as a grey band between 1500 and 2000 Hz in the spectrogram in Figure 9. The tremolo and hissing effects, which are not heard in a traditional bowl, may be caused by the data spokes.

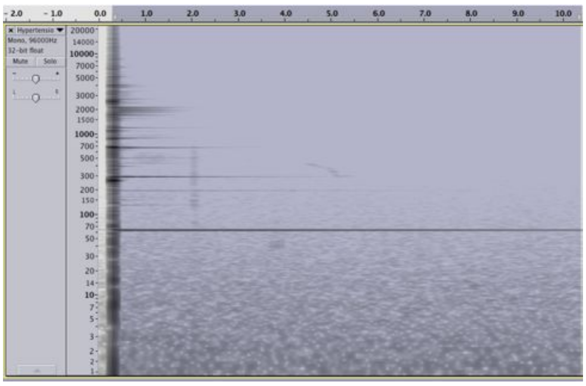

Figure 9. Audio spectrum of BP Singing Bowl 1.0 when struck.

When the rim was rubbed with the stick the bowl began to hum, and then sing like a traditional bowl. The audio waveform in Figure 10. shows the bowl continues ringing for 16 seconds after rubbing ceases.

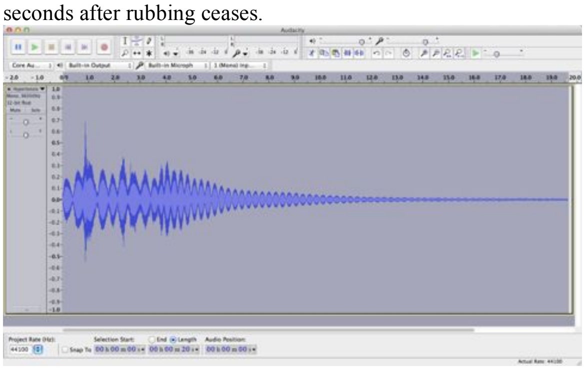

Figure 10. Audio waveform of BP Singing Bowl v1.0 when rubbed and left to ring.

The frequency analysis in Figure 11. shows broadband low frequencies from the rubbing motion, a dominant partial at 609 Hz, and higher partials due to other resonances that may include the data spokes.

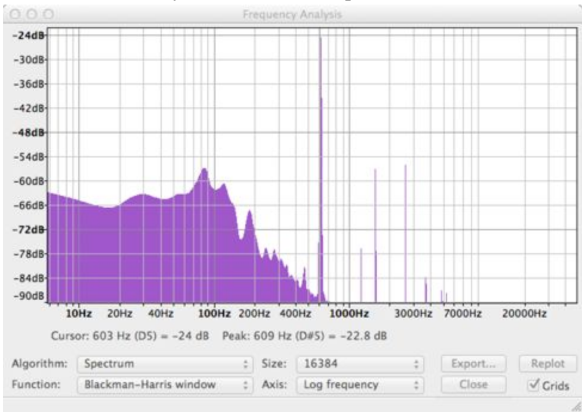

Figure 11. Frequency analysis of BP Singing Bowl v1.0 when rubbed and ringing.

5. DISCUSSION

The singing bowl provides a metaphor for interaction and engagement with the data embedded in its shape. The tangibility of the object invites handling, and the sounds that it produces spark curiosity to explore it further. The bowl can be tapped, or rubbed with different rates and forces to produce different sounds, and could even be used in a musical performance. The association with meditation and relaxation therapies contributes to a narrative of contemplation and reflection on the dataset as a means of self-discovery and self-improvement.

The non numeric and non verbal nature of the singing bowl raises the question of whether someone could really understand information about a dataset from this object. Data visualisation theorist Jaques Bertin defined structural interrelationships that emerge from a dataset as a whole as a higher level of information than the data values in isolation [21]. From this perspective, the capability to listen to the way the entire dataset affects the sound, rather than listening to individual points, could provide an understanding of higher-level structure. However, there is much more work required to understand the perceptions of a dataset that can be obtained by interacting with an acoustic sonification. An initial step would be to 3D print a "baseline" bowl that does not have a dataset embedded in it. The acoustics of this baseline could be compared with bowls constructed from datasets that vary in systematic ways. It should be noted that sonification depends critically on a human listener. Perceptually based evaluation will involve listening for specific features in a constructed dataset. User-centred evaluations will involve testing the usefulness of the acoustic sonification in specific tasks.

6. CONCLUSION

These experiments with the acoustic sonification of blood pressure data have identified important stages of the design process that can guide future designs and further research :

1. Sonic Metaphor: guide interaction, establish sonic expectations, provide a context for interpretation.
2. Baseline Prototype: a CAD model of the Sonic Metaphor, which is 3D printed to test that it works and makes a sound.
3. Data to Shape Mapping: the mapping of data axes onto geometric axes of the Sonic Metaphor, and data values onto geometric variations of the shape.
4. Acoustic Sound Design: an analysis of the acoustics and auditory effects of the Data to Shape mapping
5. Digital Fabrication : the implementation of the Data to Shape mapping in a CAD mesh which is 3D printed.
6. Acoustic Evaluation: comparison of the Acoustic Sonification with the Baseline Prototype.
7. Perceptual Evaluation: a listening test to evaluate the perception of known features in the dataset from the Acoustic Sonification.
8. User-centred Evaluation: testing the usefulness of the acoustic sonification in specific tasks.

7. REFERENCES

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