SoniHED conference

Sonification of Health and Environmental Data - York 2014

Conference Proceedings

C2D2 Centre for Chronic Diseases & Disorders

Supported by wellcome trust

University of York
Department of Theatre Film and Television

SEI Stockholm Environment Institute

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Sonification of Health and Environmental Data Conference.

York, 2014

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SONIFICATION OF HEALTH AND ENVIRONMENTAL DATA SoniHED

Introduction

Sonification uses sound to portray data and information. It is a relatively new sound design discipline in which standards and grammars have not been fully established yet.

Interest in this discipline has grown distinctly in the last few decades due to the power of sound to engage, its portability and potential to carry a lot of information in a very short amount of time. Whilst improvements in computer processing power and data storage have given researchers extra impetus to develop new tools and techniques for data analysis there is greater emphasis put upon multi-disciplinary research where issues are tackled from the science, arts and humanities perspectives.

The domains of health and environment are strongly related. In particular the environment can have a direct and strong effect on our health. Data in both domains are often intrinsically temporal and they are arguably the type of data we monitor the most in our everyday life (at a very simple level we check weather data - temperature, humidity, wind - and we monitor our health - temperature, blood pressure, etc.).

In our increasingly digital world, we produce data about ourselves and our environment at an incredible speed (e.g. in real-time) and in large volumes (e.g. cloud storage) but the tools we have to look at this information are often too complex to be used by non-experts.

Can sound help us understand, analyse and engage with this large amount of data? And, consequently, can sound help us engage with the way we relate to ourselves, our well-being, and our environment?

The SoniHED Conference is a gathering of experts in health science, environmental science, sound design, sonification and audio perception that aims to propose and discuss latest research in this area.

The Conference is funded by the Centre for Chronic Diseases and Disorders, supported by the Wellcome Trust and by the Department of Theatre, Film and TV and the Stockholm Environment Institute .

We are very pleased to be able to present a large variety of works both scientific and artistic during the Conference that promises to be highly interesting and inspiring.

These Conference proceedings include:

- The abstracts from our seven guest speakers who present work covering a review of sound to data mapping strategies for sonification, auditory perception of sonic interactions, sonification in pervasive medical computing, sonification of ground-level ozone data and sonification of biological cells.

- Nine peer-reviewed articles which were selected for presentation.

These cover acoustic sonification, interactive sonification of movement, interactive sonification of swimming, the use of sonification and music to portray health risk of alcohol to young people, an audiovisual installation of Amyotrophic lateral sclerosis (ALS) Pathophysiology, sonification disply supporting a fuel-efficient driving, sonification of home electricity use and sonification of network environments.

On the day of the Conference five sonification-related creative works will be presented. These are:

> Schmalenberg's *Four-Channel sonification of EEG-data* and Maronidis's *Brain Waves* are sonification works that were submitted in response to our Call for Sonification. These compositions are based on Electroencephalography (EEG) and emotion data measured while a person walked around a city. A short description is presented in these proceedings;
>
> *Jane's story* is an audiovisual immersive installation that aims to stimulate a deeper engagement with the emotional, social and physical issues related to adolescents with chronic diseases;
>
> Space F!ght's *Ozone* is an electroacoustic performance by Radek Rudnicki together with ensemble Space F!ght based on ground-level ozone data; and
>
> *Sonic uncertainties, the multidimensional case* is an installation by artist Mark Fell in collaboration with Prof. Tim Croudace (Health Science) based on personality traits data.

We hope that the work presented in these proceedings will inspire and stimulate new research in the area of sonification of health and environmental data and more widely in the emerging sound design area of sonification.

The Organising Committee:
Sandra Pauletto
Howard Cambridge
Radek Rudnicki

SoniHED Conference
Programme

09:30	Registration and tea/coffee, Department of Theatre, Film and TV (TFTV) Foyer
09:50	Welcome: Sandra Pauletto, Howard Cambridge and Radek Rudnicki Room: Holbeck Cinema
Session 1:	*Chair Howard Cambridge* *Room: Holbeck Cinema*
10:00	Guest Speakers: Kevin Hicks and Patrick Bueker (Stockholm Environment Institute, SEI) *The Sonification of Impacts of Ground-Level Ozone on Human Health and Ecosystems*
10:20	Guest Speaker: Andy Hunt (Electronics Department, University of York) *Sonification in Pervasive Medical Computing*
10:40	Barrass S. *Acoustic Sonification of Blood Pressure in the Form of a Singing Bowl*
11:00	Guest Speaker: Tim Croudace (Health Sciences, University of York) *Strategies for Sonification of Psychometric Data and Sufficient Statistics*
11:20	Tea/coffee break, TFTV Foyer

SoniHED Installations	*Jane's story*, 3Sixty, Ron Cooke Hub *Sonic uncertainties, the multidimensional case*, installation, Large Rehearsal Room

Session 2:	*Chair Radek Rudnicki* *Room: Holbeck Cinema*
11:50	Guest Speaker: Alistair Edwards (Computer Science, University of York) *Sonification of biological cells*
12:10	Cesarini, D., Hermann, T. and Ungerechts, B. E. *An Interactive Sonification System for Swimming Evaluated by Users*
12:30	Yang J. and Hunt, A. *Real-Time Auditory Feedback of Arm Movement and EMG in Biceps Curl Training to Enhance the Quality*
12:50	Jepson, P. and Pelah, A. *Modulating Movement with Sound: Comparing a Target Step Trained by Sound or Vision*
13:10	Lunch, TFTV Foyer

SoniHED Installations	*Jane's story*, 3Sixty, Ron Cooke Hub *Sonic uncertainties, the multidimensional case*, installation, Large Rehearsal Room

Session 3:	*Chair Sandra Pauletto* *Room: Holbeck Cinema*
14:10	Guest Speaker: Roberto Bresin (Royal Institute of Technology, KTH, Stockholm) *Sonification of physical quantities: a review of the most used mapping strategies, with examples in health and environment applications*
14:30	Guest Speaker: Guillaume Lemaitre (Institut de Recherche et Coordination Acoustique/Musique, IRCAM, Paris) *Auditory perception of the actions causing the sounds: a basic for the design of sonic interaction*
14:50	Visi, F., Dothel, G., Williams, D., Miranda, E., *UNFOLDING | CLUSTERS: a Music and Visual Media Model ALS Pathophysiology*
15:10	Walus, B., Pauletto, S., Mason-Jones, A. *Sound and Music in Interactive Sonification: a Novel Way to Communicate Health Risk of Alcohol to Young People*
15:30	Tea/coffee break, TFTV Foyer

SoniHED Installations	*Jane's story*, 3Sixty, Ron Cooke Hub *Sonic uncertainties, the multidimensional case*, installation, Large Rehearsal Room

Session 4:	*Chair Howard Cambridge* *Room: Holbeck Cinema*
16:00	Hammerschmidt, J., Tünnermann, R., Hermann, T. *Ecosonic: Towards an Auditory Display Supporting a Fuel-Efficient Driving Style*
16:20	Lockton, D., Bowden, F., Brass, C., Gheerawo, R. *Bird-Wattching: Exploring Sonification of Home Electricity Use with Birdsong*
16:40	Vickers, P., Laing, C., Debashi, M., Fairfax, T. *Sonification Aesthetics and Listening for Network Situational Awarness*
17:00	*Round Table: Chair Sandra Pauletto* Robert Watt (Head of Communication, SEI), Bresin (KTH), Guillaume Lemaitre (IRCAM), Kevin Hicks (SEI), Patrick Bueker (SEI), Tim Croudace (Health Science)

SoniHED Concert *18:00* *Room: Black Box*	Introduction about EEG and emotion data by Chris Neale *Sonification submissions* Schmalenberg T. - *Four-Channel sonification of EEG-data* Maronidis, D. - *Brain Waves* *Sonification Performance* Space F!ght - *Ozone*

18:40	Wine reception, TFTV Foyer
19:30	End of Conference

SoniHED Guests

ROBERTO BRESIN

TITLE
Sonification of physical quantities: a review of the most used mapping strategies, with examples in health and environment applications

ABSTRACT
In a recent study we have reviewed and analysed 179 scientific publications related to sonification of physical quantities. We identified about 495 mappings that we organised into conceptual dimensions and higher-level categories belonging to both physical and auditory domains. Pitch resulted to be by far the most used auditory dimension in sonification applications, and spatial auditory dimensions are almost exclusively used to sonify kinematic quantities. As a result of our study, we propose a mapping-based approach for characterizing sonification. Examples of sonification of physical quantities in health and environment applications will be presented.

BIOGRAPHY
Roberto Bresin is Professor of Media Technology at the Department of Media Technology and Interaction Design (MID), School of Computer Science and Communication (CSC) since January 2014. Prior to that, Roberto was a researcher at the Department of Speech Music ands Hearing (TMH) since August 1996.
Roberto's main research interests are expressive music performance, sound in interaction, sonification and emotion in sound and music performance. Roberto has been a member of many sonification-related projects including SOM on the sonification of human movements and SONEA on the sonification of elite athletes.

ALISTAIR EDWARDS

TITLE
Sonification of biological cells

ABSTRACT
Cervical screening relies on visual inspection of cells under a microscope. If the visual representation of the cells were accompanied by a sonification of the cells that might support the work of the cytologist. In other words they would be receiving complementary information on the different sensory channels, hopefully leading to better, more reliable results.

A project investigating this approach has been carried out. A variety of auditory representations were tried which will be demonstrated. Different versions as to what should be sonified were also explored.

Results confirm the fact that it is difficult to find appropriate sounds which carry the required information – and are pleasant to listen to. These results suggest that this is indeed a viable approach – but that the problem is rather broader than anticipated.

BIOGRAPHY
Dr Alistair Edwards received a PhD in Educational Technology from The Open University in 1987 and currently is a Senior Lecturer in the Department of Computer Science of the University of York.
His research interests include multi-modal human computer interfaces, adaptation of interfaces for blind users, tactile interaction and use of speech and non-speech sounds in interaction.

TIM CROUDACE

TITLE
Modelling complexity and uncertainty in psychometric data

ABSTRACT
"Most of my research involves models for measurements.
Subjective responses are key to understanding health variations.

Psychometric models are highly suitable for modelling such data and have a long history in other related areas e.g. education and biostatistics. I will explore some of the avenues and issues in modelling of psychometric data that offer alternatives for sonification efforts. This will include considerations of complexity (representation of dimensionality) and uncertainty (representation of error) as well as some specifics related to current work."

BIOGRAPHY
Tim Croudace is Professor of Psychometric Epidemiology at the Department of Health Sciences (University of York).

Tim's research interests span two related disciplines: epidemiology and psychometrics. Tim combines these interests to produce innovative research using state of the art longitudinal data-analysis and 'new' approaches to measurement theory.

KEVIN HICKS AND PATRICK BUKER

TITLE
The Sonification of Impacts of Ground-Level Ozone on Human Health and Ecosystems

ABSTRACT
Ground-level ozone is formed in the atmosphere by the interaction of sunlight with primary air pollutants (such as nitrogen oxides and volatile organic compounds), which are directly emitted by the industry, motor vehicle exhausts, gasoline vapours and chemical solvents. Beside these emission sources related to human activities, vegetation (forests, grasslands) can also emit gases that contribute to the production of ozone. This talk will describe the impacts that ozone can have on human health and plant yields /food security, potentially creating a financial burden for national economies in developed and developing countries. Ground level ozone concentration, and the severity of its impact, varies across the globe from location to location. We will discuss how sonification of ozone data can be used to create awareness of the spatial and temporal dimension of the problem, while at the same time creating music.

BIOGRAPHIES
Kevin Hicks is the Deputy Centre Director and a Senior Research Associate, at the Stockholm Environment Institute at York, Environment Department, University of York. His current research interests cover air pollution impacts on terrestrial ecosystems, linkages between air pollution and climate change, and the transfer of scientific information to the policy process.

Patrick Büker is a plant ecologist and environmental modeller at the Stockholm Environment Institute/Environment Department of the University of York. His main research is on interactions between the atmosphere and biosphere with a focus on assessing interrelated effects of various air pollutants and changes of the Earth's climate on forest and crop growth in developed and developing countries.

ANDY HUNT

TITLE
Sonification in Pervasive Medical Computing

ABSTRACT
In just over 25 years of studying Human Computer Interaction for audio I have seen some great changes, but they have tended to be quite slow and incremental. In the early days it seemed that we spent a few years here and there increasing the usability of a 'mouse', refining how menus operated, or responding to Apple or Microsoft´s latest desktop interface etc. Musical / sonic interfaces were the preserve of a small set of researchers developing our own equipment and being limited to work in our own labs. Suddenly in the last few years something huge seems to have been occurring and it shows no signs of stopping. We are witnessing the arrival and development of mass-market portable (and often wearable) devices capable not only of real-time audio and graphics processing, but with increasingly sophisticated multi-touch or even gesture-based control systems. This talk will summarise the use of sonification and interaction in health monitoring, and present some thoughts about the latest systems and the potential for future pervasive health monitoring.

BIOGRAPHY
Andy Hunt is a Senior Teaching Fellow in the Audio Lab at the University of York UK. His research interests include human-computer interaction for audio and music, interactive sonification, and new musical instruments. He is co-founder, with Thomas Hermann, of the Interactive Sonification Workshop series (Bielefeld 2004, York, 2007, Stockholm 2010 and Fraunhofer, Erlangen 2013). He co-edited The Sonification Handbook with Thomas Hermann and John Neuhoff. He teaches Interfaces for Audio Interaction, Pervasive Computing, Time Management, Musical C Programming and Music for the Media. He enjoys playing in jazz and rock bands, writing music for film and TV, and developing interactive music Apps for iOS.

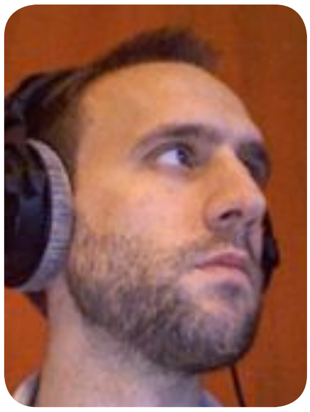
ROBERT WATT

BIOGRAPHY
Robert Watt is SEI's Director of Communications, with responsibility for SEI's global communications, both internal and external.

He and his team of communications experts work closely with SEI researchers to bridge science to policy and raise the profile of SEI. In addition, Rob is in demand as a public speaker on the science and policy of environment and development for large conferences businesses and business leaders and the public sector.

Rob is not only a practitioner; he is also interested in understanding the science of science communication. In particular, the tension of timescales (the urgency of policy-making, the time lag of implementation and the slow variables of environmental and social change), creating the policy/science interface, and the role of storytelling.

GUILLAUME LEMAITRE



TITLE
Auditory perception of the actions causing the sounds: a basic for the design of sonic interaction

ABSTRACT
Research in sound perception generally focuses on a few specific auditory attributes (pitch, loudness, sharpness, roughness, etc.) and their corresponding acoustic properties. Similarly, a common approach in data and interface sonification is to map such attributes to different pieces of information to be decoded by the listener. However, when asked to report what they hear, lay listeners spontaneously describe what has caused the sound (i.e. the sound sources) rather than some attributes of the sound itself. Even highly-trained sound experts encounter difficulties to abstract a sound from its source and focus on acoustics properties, when they recognize the sound sources. This distinction between musical listening (focusing on acoustic properties) and everyday listening (identifying the sources of the sounds) was formalized by seminal sound design researcher William Gaver, who for instance proposed to rely on the semantics of identified everyday sounds (e.g. throwing something to the garbage can) in his design of the sounds of an interface for Apple computers.
But what do we perceive exactly from the sound sources ? I will argue in this presentation that auditory perception may actually be better suited for the perception of the actions and events that cause the sounds rather than the properties of the objects set in vibration. For instance, despite auditory perception of material has been extensively studied, results show that material identification is only moderately accurate and only in certain circumstances. On the contrary identification of different actions causing the sounds (e.g. tapping, scraping) is always accurate, no matter the objects on which the actions are executed.
Recent research shows that the binding of auditory perception and action execution is even more pronounced. Studies in neuroscience has recently shown that listening to action sounds (and in particular the sounds of tool manipulation) activates brain area involved in motor planning and execution. At a behavioral level, we have shown that listening to a sound associated with an action can prime executing that action.
These results are expected to provide a basis for the design sonic interaction and sonification in a number of domains such as sport training and motor rehabilitation. For instance, I will report results that show that adding a complex sonic feedback to a tangible interface allowed users to learn how to adjust the fine parameters a target gesture and better control the interface.

BIOGRAPHY
Dr. Guillaume Lemaitre (Ircam, Sound Perception and Design group, Paris, France)
Guillaume' research interests include auditory perception and cognition, auditory neurosciences, and applications to sound design and product sound quality. He has worked with the department of Psychology at Carnegie Mellon University (Pittsburgh, PA), the Interaction group the University IUAV of Venice (Italy), and Genesis Acoustics, a company that specializes in the sound quality of industrial products in Aix-en-Provence (France). Over the years, Guillaume has been involved in several projects with Ircam. His current European-funded project (SkAT-VG) aims at developing sound sketching tools using vocal and gestural imitations of sounds.

ARTISTS

RADEK RUDNICKI

BIOGRAPHY

Radek is a composer, sound artist and performer who focuses on using improvised material in multidisciplinary projects. He is founder of Space F!ght and co-founder of RPE Duo, Kirki Project and UUCMS, he regularly performs in Europe and USA.

Radek will work together with music ensemble Space F!ght to create a performance based on environmental data provided by NASA (time series of black carbon/particulate matter and tropospheric ozone), which are correlated to air pollution and health related issues.

spacefight.eu

MARK FELL

BIOGRAPHY

Mark is a multidisciplinary artist based in Sheffield (UK). In 1998 he initiated a series of critically acclaimed record releases, featuring both collaborative and solo works, on labels including Mille Plateaux, Line, Editions Mego, Raster Noton and Alku. Fell is widely known for combining popular music styles, such as electronica and techno, with more academic approaches to computer-based composition with a particular emphasis on algorithmic and mathematical systems.

Many International institutions have presented Mark's works: from large super clubs such as Berghain (Berlin), to Hong Kong National Film archive and many others. Fell has received commissions from prestigious institutions including Francesca Von Habsburg's Thyssen-Bornemisza Art Contemporary (Vienna) with a premier at Seville Biennale of Art, and the National Ballet of Madrid have performed to his works. He has been recognised by ARS Electronica (Linz) with an Honorary mention in the digital music category, and was shortlisted for the Quartz award for his contribution to research in digital music.

www.markfell.com

CONFERENCE PAPERS

Barrass S. Acoustic *Sonification of Blood Pressure in the Form of a Singing Bowl*

Cesarini, D., Hermann, T. and Ungerechts, B. E. *An Interactive Sonification System for Swimming Evaluated by Users*

Yang J. and Hunt, *A. Real-Time Auditory Feedback of Arm Movement and EMG in Biceps Curl Training to Enhance the Quality*

Jepson, P. and Pelah, *A. Modulating Movement with Sound: Comparing a Target Step Trained by Sound or Vision*

Visi, F., Dothel, G., Williams, D., Miranda, E., *UNFOLDING | CLUSTERS: a Music and Visual Media Model ALS Pathophysiology*

Walus, B., Pauletto, S., Mason-Jones, *A. Sound and Music in Interactive Sonification: a Novel Way to Communicate Health Risk of Alcohol to Young People*

Hammerschmidt, J., Tünnermann, R., Hermann, T. Ecosonic: *Towards an Auditory Display Supporting a Fuel-Efficient Driving Style*

Lockton, D., Bowden, F., Brass, C., Gheerawo, R. *Bird-Watching: Exploring Sonification of Home Electricity Use with Birdsong*

Vickers, P., Laing, C., Debashi, M., Fairfax, T. *Sonification Aesthetics and Listening for Network Situational Awareness*

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

Stephen Barrass

Digital Design and Media Arts,
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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.

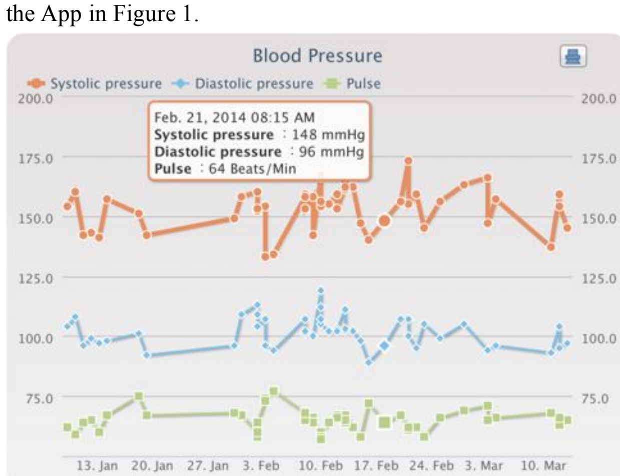

Figure 1. Plot of blood pressure readings

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].

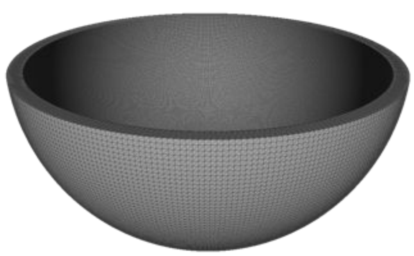

Figure 3. CAD mesh of a Tibetan singing bowl

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.

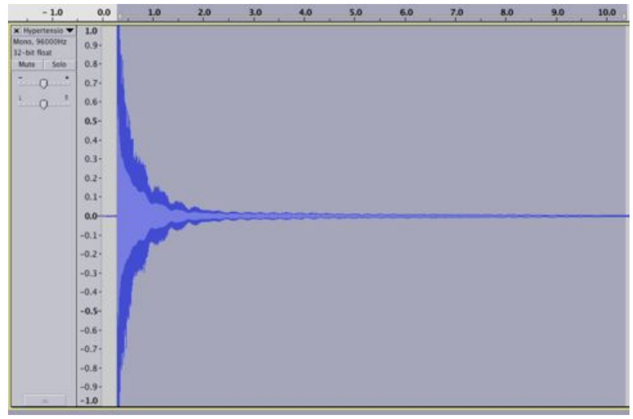

Figure 8. Audio waveform of BP Singing Bowl 1.0 when struck.

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.

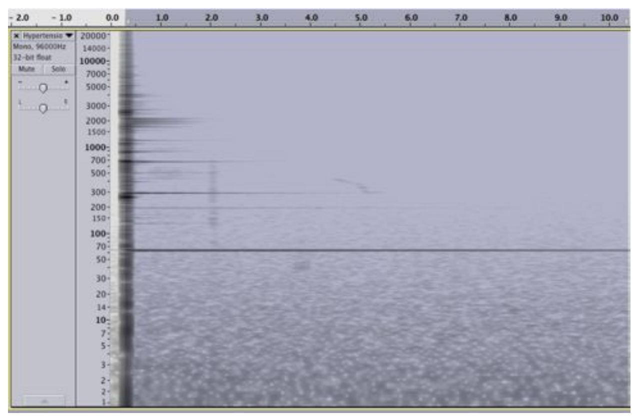

Figure 9. Audio spectrum of BP Singing Bowl 1.0 when struck.

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.

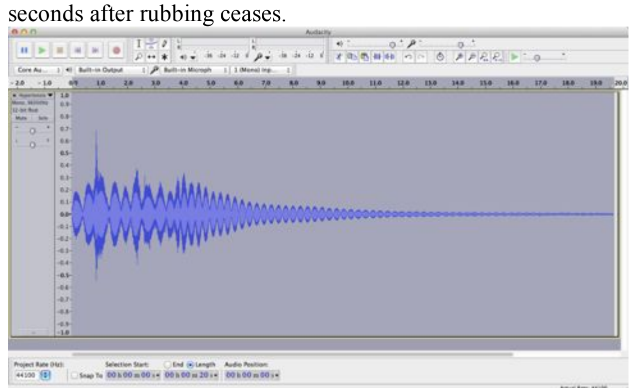

Figure 10. Audio waveform of BP Singing Bowl v1.0 when rubbed and left to ring.

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.

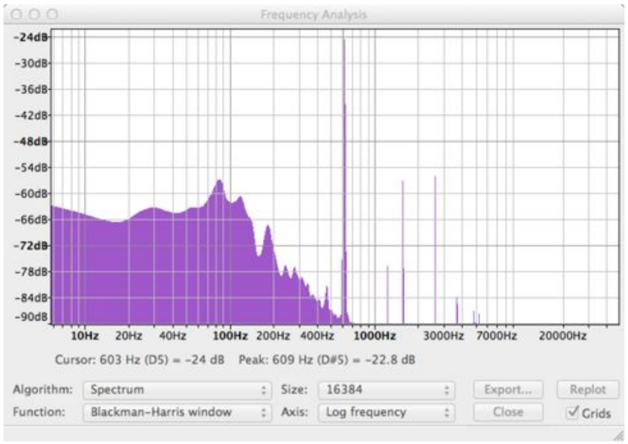

Figure 11. Frequency analysis of BP Singing Bowl v1.0 when rubbed and ringing.

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

[1] G. Wolf. "Quantified Self". http://www.webcitation.org/66TEHdz4d. Archived from the original on 2012-03-26. Retrieved 2014-08-01.

[2] G. Wolf and K.K Kelly. Quantified Self Blog, http://www.quantifiedself.org. Retrieved 2014-08-06.

[3] M. Carrigan. "Qualitative Self-tracking and the Qualified Self", http://markcarrigan.net/2014/07/23/qualitative-self-tracking-and-the-qualified-self/. Retrieved 2014-08-06.

[4] J. Davis. "The Qualified Self", http://thesocietypages.org/cyborgology/2013/03/13/the-qualified-self/. Retrieved 2014-08-06.

[5] D. Lupton. "Beyond the Quantified Self: the Reflexive Monitoring Self", http://simplysociology.wordpress.com/. Retrieved 2014-08-06.

[6] E. Ramirez. "What We're Reading", http://quantifiedself.com/2014/08/reading-22/. Retrieved 2014-08-06.

[7] Y. Jansen, P. Dragicevic, and J.D. Fekete. "Evaluating the efficiency of physical visualizations", In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '13)*. ACM, New York, NY, USA, 2593-2602. DOI=10.1145/2470654.2481359 http://doi.acm.org/10.1145/2470654.2481359

[8] R.A. Khot, L. Hjorth, and F. Mueller. "Understanding physical activity through 3D printed material artifacts", in *Proceedings of the 32nd annual ACM conference on Human factors in computing systems* (CHI '14). ACM, New York, NY, USA, 3835-3844. DOI=10.1145/2556288.2557144 http://doi.acm.org/10.1145/2556288.2557144

[9] S. Barrass, "Digital Fabrication of Acoustic Sonifications", *Journal of the Audio Engineering Society*, vol. 60, no. 9, pp 709-715, September 2012.

[10] A. Jense. "Possibilities for 3D Printing Musical Instruments", *Masters Dissertation in Industrial Design Engineering*, University of Twente.

[11] CCRMA. "3D Printing for Acoustics Workshop", https://ccrma.stanford.edu/workshops/pa3d2012/2013/. Retrieved 2014-08-06.

[12] A. Hassaei, “3D Printed Record”, http://www.amandaghassaei.com/3D_printed_record.html. Retrieved 2014-08-06.
[13] Wolter, J. (2013) “Gramohorn 3D printed Acoustic Speaker”, http://www.gramohorn.com/, accessed 3 February, 2014.
[14] Left Field Labs. “Music Drop”, http://musicdrop.leftfieldlabs.com/. Retrieved 2014-08-06.
[15] J. Miller. “3D Printed Muffler”, http://jmillerid.com/wordpress/2013/03/vacuum-pump-muffler/. Retrieved 2014-08-06.
[16] H. Lipson. “Fully Functional Loudspeaker is 3D Printed”, http://www.cornell.edu/video/fully-functional-loudspeaker-is-3-d-printed. Retrieved 2014-08-06.
[17] C. Reas and B. Fry. Processing. http://processing.org/. Retrieved 2014-08-06.
[18] NM. McLachlan, B. Keramati Nigjeh and A. Hasell. The Design of Bells with Harmonic Overtones, *Journal of the Acoustical Society of America*, 114 (1), p 505-511.
[19] Meshlab, http://meshlab.sourceforge.net/. Retrieved 2014-08-06.
[20] netfabb. http://www.netfabb.com/. Retrieved 2014-08-06.
[21] J. Bertin, *Semiology of graphics*, University of Wisconsin Press, 1983.

AN INTERACTIVE SONIFICATION SYSTEM FOR SWIMMING EVALUATED BY USERS

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ABSTRACT

This paper presents a novel setting for the measurement, real-time processing and interactive acoustic representation (sonification) of hydrodynamic pressure induced by the interaction of hands of swimmers and the water mass, causing propulsive momentum changes. The sound is presented in real-time both to the swimmer, via in-ear waterproof headphones, and to the coach. The setting was used in a first empirical test concerning the symmetry of hand actions during breaststroke swimming. The swimmers were asked to attend to the sonification and in case they perceive asymmetry they should try to enhance their interaction, interactively. The use of the setup was judged positively by the swimmer. In combination with the actual motion and body perception the functional sounds were judged to be a supportive tool to change hand-water-interaction.

1. INTRODUCTION

Elite swimmers are masters in displacing water mass at low energy costs resulting in high swimming speeds. To increase the mastership of self-induced locomotion it is advantageous to dispose a specialized cognitive control transmission tool, the "swimmer's talent of feel for water". A communication about this intimate interplay is hardly possible between coach and swimmer or between swimmers due to lack of a measurable comparison of this particular perception. Yet this is a key prerequisite for the *Cognitive control* of self-induced interaction in aquatic space, demanding coupling of self-perception of limbs' actions and perception of displaced water mass.

An experienced swimming coach of elite swimmers motivated this interdisciplinary approach bringing together researchers from biomechanics, mechatronics and sonification. The coach wanted to know how the communication with elite swimmers concerning the "feel for water" could be improved in order to better bridge the gap between biomechanical analysis and internal information transmission, which governs the necessary fine motor control to adapt to changing conditions, whether they are internal (fitness) or external (open water swimming). He pointed out that in his opinion the pressure difference of the flow around the hands would be the decisive parameter when asked what would be the representative agent of the feel for water. He wondered if the flow sensing understood from studies of fish movement might benefit elite swimmers and enhance other human aquatic space activities.

Indeed, the displacement of water mass can be felt and measured. Self-induced interaction simply means the transfer of metabolic energy via limbs action to the energy field of a unit of water volume. This change is represented by the term *pressure*[1]. The meaning of the term *liquid pressure* is not equivalent to the term pressure used in solid physics since water gives way to solid objects. Hence the measurement of hydrodynamic pressure[2] in currents differs from the pressure term used in solid body physics. Studies on flow sensing in fish swimming revealed that pressure differentials [11] or pressure gradients [10] are the relevant agents that stimulate neuromasts to produce and send signals aiding to detect the aquatic world as well as self-induced stream characteristics – also used to distinguish the foreign fish from self-induced flow.

Considering these measurable parameters and that physics of sound and hydrodynamic pressure wave are similar [6] the idea arose to represent the hydrodynamic pressure changes due to swimming actions by audible sound. By the sound another feedback channel is used by the swimmer. As beneficial side effect, for the first time people outside the water can better learn what happens in detail. [8] presented the acoustic mapping of some kinematic variables representing the wrist and ankle location in relation to the pelvis per breaststroke cycle; they concluded that motor performance and perception of movements may be enhanced.

Sonification transforms information systematically from a data space to the auditory space [3], in this case the data space is the change of hydrodynamic pressure values due to displaced water mass. The method to convert data into sound is independent of the method to measure data. The selection of the optimal mapping and sound domain is not yet decided [1]; it can be ecologically oriented (e.g. sounds like falling water) or a purely free selected functional synthetic sound to accentuate an aspect. Hermann [4] in 2012 introduced the sonification of hydrodynamic pressure starting from data that were recorded and published by Toussaint [16] in 2002; they used – among others – a parameter-mapping sonification by which the change of the pressure to suction (during the outsweep of the hand action in crawl stroke) was perceptually emphasized.

Considering the effects of unsteady flow aspects [9,16,7] the focus on changes in hydrodynamic pressure is justified, as it represents the origin of the physical *work* done on the water [18]. Kinematics of limbs actions is no indicator of flow effects since the effect of interaction with water mass is not

[1] energy change per unit volume and hydrodynamic pressure are measured in Pascal, respectively
[2] also named static pressure.

considered: drag does not explain the interaction effects even if repeatedly stated [7]. Unsteady flow means that time-average methods cannot be applied since static pressure varies locally and with time (body undulation) while so-called engineering turbulence can be treated by time-average equation [12].

Referring to the coach's practical claim, a tool is required to allow for real-time sonification of pressure data as an audible immediate feedback for the swimmer and the coach, simultaneously. For the time being the use of functional sound representing invisible effects due to interaction of limbs and displaced water mass requires the selection of tools like pressure probes, pressure sensors, a sonification program, loudspeakers and equipment to be combined into a new setting that enables the measurements at the deck of a 25 m pool. The general objectives for this first test are to investigate how sonification can affect symmetry while swimming, which requires (a) a symmetry operationalization on the basis of pressures, (b) to measure the local flow-induced pressure changes, (c) real-time sonification and (d) to check different test situations with and without auditory feedback, finally (e) to receive the swimmers' feedback using a questionnaire.

The current paper introduces a novel sonification system and method and focuses on the results from the questionnaire: Section 2 introduces the design of the whole measurement / sonification system; Section 3 explains asymmetry, and why it was chosen for these studies; Section 4 presents the sonification designs (direct and task-oriented mapping); Section 5 shows the design and execution of the experiments, whose results are presented in Section 6 together with a discussion; finally Section 7 concludes the paper.

2. SYSTEM DESIGN

The static[1] pressure component of water is sensed with the "piezo-probe" method, which uses an open hole on a large surface, over which fluid can flow. Electronic measures of such pressures are obtained with a set of 4 differential analog pressure transducers attached to 4 elastic plastic tubes with the open end. The open ends are placed as "piezo-probes" between the fingers of the two hands of the swimmers as depicted in Fig. 1.

The system setup, depicted in Fig. 2, is composed of 4 probes, 4 sensors, a microcontroller, a USB connection, a Notebook running GNU/Linux and SuperCollider sound synthesis environment and stereo speakers / earphones. A new measurement system was developed since an existing measurement system, the Aquanex [6], a device by which palmar-dorsal static pressure data are normalized to a unit area before being presented graphically, represents a closed structure that does not allow to process them in real-time, but only acquire data offline, thus impeding interactive real-time sonification. To transform hydrodynamic pressure into electric signals 4 differential pressure sensors (Freescale MPX5010DP) are used, connected to the Analog-to-Digital ports of an 8 MHz microcontroller (Atmel ATMega32). The chip, running a self-written firmware, samples the sensors at a frequency of 640 Hz and performs a 10:1 averaging filter, providing a filtered stream of data at rate of 64 Hz to the application on the PC. SuperCollider, running on Linux Operating System on the PC, processes the incoming data and implements both data logging and sonification.

(a) Right dorsal (b) Right palmar (c) Left palmar (d) Left dorsal

Figure 1: Positioning of the probes on the two hands

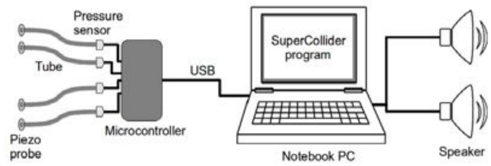

Figure 2: Setting modules and information flow.

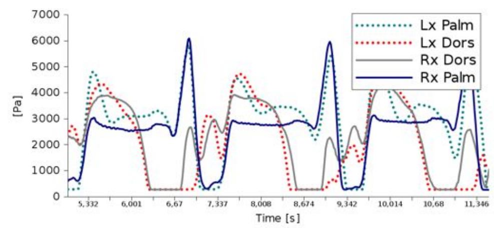

Figure 3: The hydrodynamic pressure over three breaststroke cycles for the four measuring points.

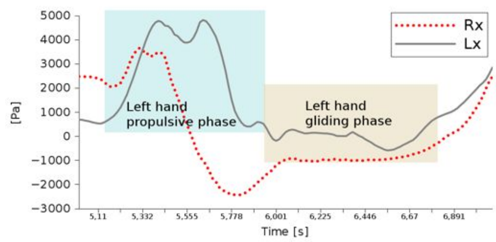

Figure 4: The hydrodynamic pressure-difference over one breaststroke cycle for each hand.

Figs. 3–4 show selected data segments acquired using the sensor system. The raw data quality is good, i.e. the signal-to-noise ratio is 34 dB (also thanks to the averaging filter implemented on the microcontroller). The data are qualitatively and numerically comparable to data reported in existing literature [14]. Fig. 3 shows a plot of the data for all four probes of three breast swimming cycles. Fig. 4 shows a plot of the data for the palmar-dorsal pressure difference for a single breast swimming cycle. From a perceptual point of view all subjects (authors included) that tested the system reported that latency between action and auditory feedback is negligible. The delay can be estimated to 20–30 ms (depending on the actual PC hardware and operating system).

[1] Static pressure is not related to solid physics. Indeed, regarding flow physics, toghether with dynamic pressure (related to the speed of the flow), it is `the other' component of the omnidirectional static pressure.

3. SYMMETRY IN SWIMMING

In order to evaluate the methods and system a specific task was selected to (a) shape the sonification to provide task-relevant information, (b) give study-participants a clear goal optimization task, and (c) more easily evaluate the effect of the sonification. In particular the objective is to attend to and enhance symmetry of hidden effect of hand-water interaction while performing breaststroke swimming.

Breaststroke swimming, according to rules in competition, demands that the hands move simultaneously and on the same horizontal plane. Judges control it via visual inspection. The level of symmetry of hydrodynamic pressure while swimming is unknown. Measuring pressure-changes during simultaneous hand action, respectively, is a means to detect the level of symmetry. Pressure changes in a flow in general are the relevant stimuli to control the action cognitively. As a matter of fact the pressure changes are the cause of momentum change and if the pressure fields are not equal on both sides a resultant yaw will disturb the body locomotion.

3.1. Asymmetry Measures

The first step in the direction of enhancing symmetry is to define what exactly is meant by asymmetry and thus to operationalize the term in form of a mathematical expression. In fact, symmetry can be understood from different perspectives, e.g. that the *geometric shape* the fingers of left and right hand exhibit over time (when observing the swimmer from above) are axial symmetric to the body axis; or that the turning points (i.e. local maxima and minima) of the hands' velocity occur at the same time (independent of the actual value). In fact, symmetry has many facets. As the importance of hydrodynamic pressure was emphasized, here a definition is proposed and adopted for asymmetry from the time-variant net pressures of left and right hand (i.e. palmar minus dorsal pressure). The instantaneous asymmetry is thus defined as

$$\mathrm{asym}(t) = P_l(t) - P_r(t).$$

The overall asymmetry can be computerd over larger time intervals such as a complete breast swimming cycle, or over a 25m lap by integrating the absolute value $|\mathrm{asym}(t)|$ of the instantaneous asymmetry over time. Note that the adopted definition of asymmetry is structurally identical to [5], yet here applied to pressures.

4. SONIFICATION DESIGNS

The sonification design process was started on the background of past experiences with sonifying offline data of the same type as introduced in [4], which were, however, created on the basis of 5 sensors attached to a single arm. In this current setup, two pressures (dorsal/palmar side) of each hand (left/right) are measured, leading to reconsider the mappings, and in particular the use of spatial information in sound.

A principle which remains plausible and which thus did not change is the *excitatory* mapping, which means in this case that the amplitude of the sound scales with the amount of activity. The underlying rationale is that the sound should fade into silence once the action stops. As pointed out in Sec. 3, starting from the pressure difference $P_r(t)$, $P_l(t)$ between the palmar and dorsal piezo probes, resulting in zero values independent of the depth of the hand below water level[1]. In consequence, the pressure values $P_r(t)$, $P_l(t)$ can be taken to represent activity or *energy transfer* on the water. Instead of a direct mapping of these values to amplitude, they are fed into leaky integrators $y[n] = (1-\lambda)\, y[n-1] + \lambda x[n]$, where x is the input and y the output at sample n. Thus the excitatory mapping is a linear mapping from y to the amplitude of the sound streams. The leak rate λ is manually tuned to get a half-time of approximately 0.5 seconds.

For this study the following two sonification designs, that represent different conceptual approaches were created.

4.1. Baseline: Absolute Continuous Sonification

A non-parametric baseline and direct sonification is chosen, with an analogue representation of $P_r(t)$ (resp. $P_l(t)$) as pitched tone, thus mapping the pressure exponentially from [0, 5000] (hPa) to frequencies in the range of [350 Hz, 2637 Hz][2] . Dealind with activity of the left (resp. right) body side, a spatial mapping is highly intuitive. In result two continuous sound streams – with amplitude and frequency mapped as explained before – are played on the corresponding left and right sound channel of a stereophonic sonification.

The mapping was subjectively tuned to be appropriate in sound level and audible using in-ear headphones worn under a bathing cap. The sonification is highly direct, and a well-established baseline/benchmark sonification, familiar from auditory graphs and many other sonification applications in sports. Concerning the symmetry, users can extract information about the instantaneous asymmetry both from a displacement of the stereo position from the center position, as well as from attending to the pitch difference between the left and right channel. The latter is, however, difficult to pick up as the tones change rapidly in time. Tests were carried out also with mappings that are continuous in time but discretized and quantized in pitch (either on a semitone scale or even higher intervals such as minor thirds), yet the baseline continuous mapping was chosen for its simplicity.

A sound example for breaststroke swimming sonification is provided online[3]. Therein you can hear that the breast swimming cycle becomes a distinct auditory gestalt, whose shape varies between instances, but is clearly reproduced. A second swimmer exhibits basically the same structure but is quite different in the details, showing that the sonification is capable to convey structural differences as auditory shape. In the remainder of the text the direct mapping will be called S1.

4.2. Task-oriented Asymmetry Sonification

This sonification is particularly optimized to convey specifically and explicitly guiding information to experience and minimize asymmetry of hydrodynamic pressure between

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[1] and thus the hydrostatic pressure.

[2] Corresponding to the MIDI notes 65 to 100, spanning roughly 3 octaves.

[3] Listen to S1 on www.techfak.uni-bielefeld.de/ags/ami/publications/CHU2014-AIS/

the hands while swimming. As explained in Sec. 3.1. the adopted the definition of asymmetry is

$$asym(t) = P_r(t) – P_l(t).$$

To acknowledge that the asymmetry is a continuous and steady variable, the sonification is continuous, using a pitched, spectrally shaped and spatially panned single sound stream whose timbre is controlled by a brightness parameter. Specifically a continuous formant-filtered periodic signal using the SuperCollider UGen Formant is used:

```
SynthDef(\form, { |freq=540, amp=0.3, pan=0, bright=0|
        var sig;
        sig = Formant.ar(freq, 2*freq,
            freq*(0.1+bright)*10,
            5*amp*((0.1+bright)**0.8));
        Out.ar(0, Pan2.ar(sig, pan));}).add;
```

The fundamental and the formant frequency are coupled to achieve a pitch-dependent spectral shape. The brightness affects the bandwidth, and also the amplitude as the filtering otherwise perceptually affects the audible level. Amplitude is adjusted empirically. Given this synth, the following mapping was chosen to create an asymmetry-dependent sonification:

- the absolute asymmetry value |asym(t)| is mapped to the brightness, so that higher instantaneous symmetry deviations become more salient as a spectrally richer sound;
- the average signed value, starting from the most recent zero crossing of the asym(t) function is mapped to the spatial panning, so that the spatial location guides to the body side where more action is required to 'symmetrize' the activity;
- the average unsigned value is mapped to the frequency of the formant synthesizer in a narrow range, so that pitch does not dominate the perceptual effect compared to the other variables. The higher the pitch gets, the more relevant the asymmetry is.
- Given that it is generally preferable that sound fades without ongoing action, the absolute immediate pressure value $|P_r(t)| + |P_l(t)|$ is mapped to the amplitude of the sound.

A sound example for this breaststroke asymmetry sonification is provided online[1]. In the remainder of the text the task-oriented mapping will be called S2.

5. EXPERIMENT

With the described setting a first time study has been carried out, while its evaluation needs different steps due to the complete novelty. In a first step, a questionnaire was presented in order to evaluate different aspects of acceptability to use sonification as a tool of intervention, and whether trends exist that are to be considered in further operations of the setting.

The aim of the study is to assist the swimmers in the task, to harmonize the effects of hand-water-interaction provided they detect asymmetries between left and right hand due to the functional sounds while swimming breaststroke.

Hypotheses: Swimmers alter the pressure-time curves that result from by the simultaneous interaction of each hand with the water respectively, in the sense of harmonization, if asymmetry-focused sonification is used as a feedback tool.

Study design: The new setup is used in a first field test concerning the symmetry of effects of hand-water interaction during breaststroke swimming. The data are acquired and the functional sounds are processed for each hand separately. Two different sonification mappings (S1 and S2) are provided. The swimmers are asked to attend to the sonification and in case they perceive an asymmetry between the sounds they should try to enhance their interaction, interactively.

Tests execution: The test design was composed of 4 different tasks with minor pause at turning points. (1): swim 2 × 25 m fully equipped without feedback, (2): swim 4 × 25 m fully equipped and feedback by S1 (S2), then (3): 4 × 25 m fully equipped and feedback by S2 (S1) and finally (4): 2 × 25 m fully equipped without feedback. In task 2 and 3 the swimmers were asked (a) to make their own judgment if the sounds per hand signalize asymmetry and (b) to decide whether to execute the cycle differently. No hints were given on how to change the effects of the interaction, because the 14 participants were merely recreational swimmers.

Swimmers (S&S): 14 swimmers (7 female, 7 male) aged 25.8 (±7.78) years gave written consent to participate; 4 participants named themselves to be active swimmers since 11.2 (±5.75) years at regional level, and 8 participants claimed to be familiar with the gliding variant in breaststroke. Nobody experienced in interactive sonification test before, S&S just know of a few examples, that sonification exists. The investigators could not present auditive examples of underwater interactive sonification of flow before the tests, since there were not yet any functional sounds worldwide.

Evaluation Method: A questionnaire is fundamental to figure out aspects concerning the setting, the sound acceptance, and whether the setting is a supportive tool to harmonize the effects of hand-water-interaction. The proof if this setting is a relevant feedback tool is not only a technical issue because the individual acceptance is also a matter of fitting, listening and finally cognition.

It was possible to refer to a questionnaire that had been proven successful in another study with Interactive Sonification [13]. The paper-based questionnaire is composed of several parts, statements and questions, whereby the answers to questions used a 7-point Likert ordinal scale ranging from 1 (totally disagree) to 7 (totally agree). The swimmers answered the questions directly after the 4 tests.

The questions asked included the influence of the tubes for the measurement of the pressure on hands or wearing the in-ear headphones, the audibility of the sounds, the emotionality of the sounds, the perceived effectiveness of the sounds as well as questions related to the attitude for further use of interactive sonification with the intention to adapt the planning and further execution of actions by S&S. Since two sounds were offered to the S&S, the question of the more accepted sound was obvious. The question most frequently asked by practitioners was whether the S&S swam faster using this type of intervention could not be checked in the questionnaire.

6. RESULTS

All 14 S&S filled out the questionnaire. They knew that the scale value (4) applies to "not know" or "no decision

[1] Listen to S2 on www.techfak.uni-bielefeld.de/ags/ami/publications/CHU2014-AIS/

possible" and is (1) for "totally disagree" of a statement, and (7) for "totally agree". Trend statements are based on means of the individual scale values per statement. Given the novelty of the test content and the inexperience of the S&S to deal with tasks focusing on water motion perception for the purpose of changing the hand-water interaction no clear trends in the rating of statements were hypothized. The results of the questionnaire are presented in figures 5, 6 and 7, all showing Means. .

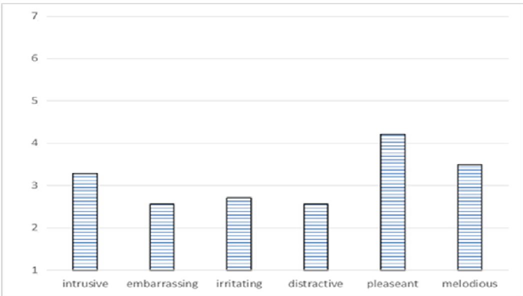

Figure 5: Evaluation of emotions of sound 1: *1 = totally disagreed and 7 = totally agreed.*

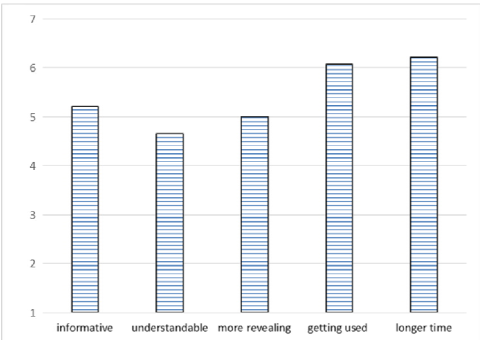

Figure 6: Evaluation of acceptance of sound 1: *1 = totally disagreed and 7 = totally agreed.*

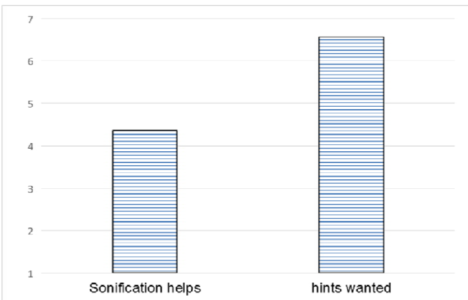

Figure 7: Evaluation of sound 1 as a relevant tool of intervention and rating “Hints wanted”: *1 = totally disagreed and 7 = totally agreed.*

The question on the preference of sound 1, the continuous baseline mapping, with respect to sound 2, the task-oriented mapping, was answered by only 8 S&S, and the mean value of 4.0 can be interpreted as an expression of general uncertainty. Thus, for simplicity, the following trend statements concentrate on sound 1 only. The ratings for Sound 1 are related to emotional evaluations (Fig. 5): the statements "melodious" or "pleasant" were neither rejected nor accepted while negative attributions were rated "weakly rejected". Concerning statements "informative", "understandable", "more revealing", "getting used" and "longer time" the trend is conclusive that this sound should be represented in the future, supported by ratings as "weakly agreed" to “agreed” for the statements “longer time” and “getting used” (Fig. 6). The question "Did sonification help to work on symmetry of hand-water-interaction?" was generally "weakly agreed" and thus the sonification may be regarded as a potentially helpful intervention tool. The statement "I would like to know more about what I could do to prepare the intended symmetry" scored an average 6.5 showing strong support from all inexperienced swimmers. It is not inconceivable that this awareness will affect the other ratings. Therefore, a conservative trend prediction for statements is required, which should be respected by the researchers for any further investigation, also in the light that most of the mean rating values were hardly different from "weakly agreed" (Fig. 7). As a concluding remark, the noises due to pool situation were not considered to create problems to listen to the sounds. While swimming there is a natural perception of flowing water and the swimmers’ judgment if the sounds match with that individual feel for water is just above “don’t know the answer”.

7. CONCLUSION

A new measurement setup for the interactive sonification of effects of hand-water-interaction was presented. The setup combining the measurement of the change of hydrodynamic pressure with functional sound mapping, was used for real-time feedback on the symmetry of effects of hand-water-interaction using two sonifications. Listening to the sounds while swimming breaststroke, swimmers tried to meaningfully merge sound and their own perceptions of the action, striving for a higher symmetry of effects of hand-water-interaction. It can be assumed that the novel sonification design making the asymmetry information perceptually available to swimmers is a welcome tool to enhance the effects of swimming actions. The sonification design is excitatory meaning that without ongoing interaction the sound fades into silence or by following a guidance paradigm, i.e. the spatial location of the sound indicates what body side requires more action to yield a symmetric activity. Different aspects of asymmetry are conveyed via perceptual variables like brightness and pitch.

It is noteworthy that, although the perception of the continuous baseline mapping (sound 1) seemed not to be an easy affair there was a promising agreement that the cyclic sound characteristic were in accord with the feel for water supported by the positive trend “sonification helps”. In future, the swimmer will hear sound examples and will have the possibility to discuss adjustments before the tests. Moreover, the swimmers who were initially less interested in the "secrets" of the determination of the hydrodynamic pressure became very curious about the internal relationship of hand-water-interaction. Presumably the situation when stroking and listening is happening simultaneusly differs from just listening to the sounds. It would be a promising aspect for future applications. Furthermore, the selection of sounds should not overstretch the S&S. The setup can further be used, because no complaints were registered, i.e., the swimming movements were not hindered and the sounds were good to hear. It can be assumed that the sounds act as an intervention tool stimulating the S&S to change the hand-water-interaction. Finally, a familiarization to the sound can be expected after a few cycles, and also an outlasting curiosity using this tool during training.

For completeness it should be mentioned that only one other study has been undertaken elsewhere in the world: Chollet et al (1992) introduced a sonification feedback into crawl stroke, to shorten the swim times over 100 m after several days of training. To register only the palmar pressure, the swimmers had to wear paddles, which hindered the self-perception of change of hydrodynamic pressure in general around the hand; a sound was elicit when a predetermined threshold was exceeded. As a statistical result, the group receiving feedback simultaneously as sound and also about the pace swam the 100 m distance in comparably shorter time (no real values reported). As a reason a "finer correction of the propulsive distance of the hand" was introduced. In the study described here, no feedback on the current speed was given to the students. The researchers are working on the integration of speed into the auditive real-time feedback. Whether the students' judgment regarding assistance through interactive sonification, which they judged with a weak agreement, is true, will be examined yet on the basis of comparison of the pressure time-curves per stroke and per test.

Finally, initial analyses of the results curves for hydrodynamic pressure under different feedback situations reveal two trends: (a) it is likely that some of the swimmers did adapt to the feedback and (b) the asymmetry in the post test was more remarkable compared to pre test. Further research is required to clarify whether this asymmetry increase is due to fatigue or the intermediate use of sonification. As often, a study opens up more questions than it answered. The gained information encourage to continue the quest towards increased communication (and training) means for swimmers / coaches. It is regarded as particularly important to establish this new setup for regular training of few swimmers in a longitudinal evaluation, hoping to better understand the benefits and the potential of interaction sonification in swimming sports.

8. REFERENCES

[1] Dubus, G., Bresin, R. (2013) A Systematic Review of Mapping Strategies for the Sonification of Physical Quantities. *PLoS ONE 8(12)*: e82491. doi:10.1371/journal.pone.0082491

[2] Havriluk, R. (1988). Validation of a criterion measure for swimming technique. *J. of Swimming Research*, (4), 11-16

[3] Hermann, T., Hunt, A., & Neuhoff, J. G. (2011). *The sonification handbook*. Logos Verlag.

[4] Hermann, T., Ungerechts, B., Toussaint, H., Grote, M. „*Sonification of Pressure Changes in Swimming for Analysis and Optimization*. The International Community for Auditory Display (ICAD), Atlanta, GA, 60-67, 2012.

[5] Jaszczak, M. (2008). The dynamical asymmetry of the upper extremities during symmetrical exercises. *Human movement* 9.2: 116-120.

[6] Jensen, F. B,. Kuperman, W. A., Porter, M. B. & Schmidt, H. (2011): Computational Ocean Acoustics. Springer NY.

[7] Klauck J.M. & Ungerechts, B.E. (1997) Swimming power output measurements in a flume vs power transfer in swimming using external weights - a comparison of devices. B. O. Eriksson, L. Gullstrand (eds.) *XII FINA World Congress on Swimming Medicine*, Goeteborg. FINA Lausanne, 291-297

[8] Kliche, D. & Effenberg, A. O (1996) Biomechanische Betrachtung zum intrazyklischen Geschwindigkeitsprofil im Brustschwimmen für Sprinter. *Blaue Reihe der DSTV*, Bd.12: 56

[9] Matsuuchi, K., Miwa, T., Nomura, T., Sakakibara, J., Shintani, H., & Ungerechts, B. E. (2009). Unsteady flow field around a human hand and propulsive force in swimming. *Journal of Biomechanics*, *42*(1), 42-47.

[10] McHenry, M. (2011) The biomechanics of superficial neuromasts and their role in behavior. In: H Bleckmann, S Coombs, J Mogdans (Eds.) *Abstract Int'l Congress of Flow Sensing in Air and Water*. Bonn, Germany: 18.

[11] Montgomery, J. (2011) Role of the lateral line in fish behavior. In: H Bleckmann, S Coombs, J Mogdans (Eds.) *Abstract Int'l Congr. of Flow Sensing in Air and Water*. Bonn, Germany:

[12] Naka, Y., & Obi, S. (2009). Velocity–pressure correlation measurements in complex free shear flows. *Int'l J. of Heat and Fluid Flow*, 30(3), 411-420.

[13] Neumann, A., Hermann, T., Tünnermann, R. (2013). Interactive Sonification to Support Joint Attention in Augmented Reality-based Cooperation. *Proc. of ISon 2013*.

[14] Perrotin, O., D'Alessandro, C. (2013) - Adaptive mapping for improved pitch accuracy on touch user interfaces. *New Interfaces for Musical Expression 2013-05-27* p.15

[15] Schmitz, G., Mohammadi, B, Hammer, A., Heldmann, M., Samii, A., Münte, T.F., Effenberg A.O. (2013). Observation of sonified movements engages a basal ganglia frontocortical network. *BMC Neuroscience* 14:32

[16] Toussaint, H. M., Van Den Berg, C., & Beek, W. J. (2002). Pumped-up propulsion during front crawl swimming. *Medicine and science in sports and exercise*, *34*(2), 314-319.

[17] Ungerechts, B. (1981). *Über die Hydrodynamik schnell schwimmender Wirbeltiere*. Ruhr-Universitat Bochum.

[18] Webber, D. M., Boutilier, R. G., Kerr, S. R., & Smale, M. J. (2001). Caudal differential pressure as a predictor of swimming speed of cod (Gadus morhua). *J. of Experimental Biology*, 204(20), 3561-3570.

REAL-TIME AUDITORY FEEDBACK OF ARM MOVEMENT AND EMG IN BICEPS CURL TRAINING TO ENHANCE THE QUALITY

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ABSTRACT

In this paper, we describe the design of a sonification device using an electromyography (EMG) sensor and Mircosoft Kinect motion tracking camera to extract muscular and kinematic data while undertaking biceps curl exercise. A software platform has been developed using Max/MSP to convert acquired data into sonic feedback.

The system has been tested in a comparative user trial, with 22 participants being split into two groups. One group had the auditory feedback and the other did not. All participants completed a 3-session experiment on different days. We investigated whether the extra sonic feedback provides positive influence on both the exercise quality and training outcome.

Three parameters were analysed: movement speed, range of movement and total repetition effort. The results indicate that the sonification group performed consistently better than the other group except the movement range, which shows no improvement in both groups. They also indicate that sonification contributed the most to keeping a good steady pace of movement. Subjects in the sonification group also gave positive comments on the presence of sound, especially about distracting them from feeling fatigue.

This study underlines the potential of developing sonic interaction programmes for both general exercise and physiotherapy.

1. INTRODUCTION

In recent years, we have been seeing an increase in the variety of ways for presenting and interacting with computer data. This trend is seen in the increasing popularity of mobile computing devices and the newly introduced wearable devices. Companies such as Apple, Samsung, Nike, Microsoft have released fitness products incorporating body sensory devices. Still more products are under development and we assume that a new age of wearable devices is imminent.

Researchers have noticed a strong connection between the use of sound and the quality and extent of human body movement [1]. The most commonly used example is the use of music to assist rhythmically critical actions such as figure skating, dancing, etc. Sonification, serving as a method to objectively convey and interact with data through the use of sound [2, 3], has some advantages when used in assisting sport activities. Firstly, sound allows a screen-free situation, which enables users to focus more on their intended physical task, such as rowing [4] and jogging [5].

Secondly, music or sound can provide useful information for maintaining good rhythmic motor coordination and relaxation, and can lead to a positive mood and a raising of confidence and motivation [6]. In [7], researchers found the volume and tempo of music had effects on running speed, heart rate, and exercising arousal levels under a treadmill running condition.

Thirdly, sound is more attention grabbing than visual alerts when it comes to notification. This makes it superior in alarm situations [8]. In the same way, sound can be useful in improving sports movement that by notifying users if any changes needed to be made.

The structure of this paper is as follows: Section 2 gives an overview of the research hypothesis. Section 3 provides a description of the sonification system we developed. In Section 4, full details of the experiment are presented with the results and analysis. Section 5 covers the analysis of subjects' comments. Sections 6 & 7 draw conclusions and discuss the next stage of the research and its prospective as a commercial product in the future.

2. RESEARCH OVERVIEW

In this study, we hypothesized that by listening to real-time auditory feedback of healthy adult's muscle activity (during biceps curls) along with kinesiological data, subjects will have better exercise performance and progress than those who do the same exercise without real-time audio feedback.

We envisaged that sonification could serve as a virtual training supervisor that provides instant feedback on the movement itself as well as notification sounds to correct any movement deficiencies.

The criteria of the sonification are:

- Reflective: The sonification should directly reflect the movement being performed.
- Suggestive: The sound should be capable of reminding the user about the quality of the exercise. It should also suggest where the user could make changes if necessary.
- Listening experience: the sound also should be interesting to listen to or at least have sufficient variation to prevent boredom.

3. SYSTEM DESCRIPTION

Based on the research hypothesis, a sonification system has been developed featuring both sensory devices (hardware) and a software platform. This section presents the design of the sonification system.

3.1. Hardware

The muscle's activity and the kinematic data of hand movements are chosen as inputs to the sonification mapping. Two types sensors are used accordingly.

For muscular activity, a surface EMG (electromyogram) sensor is used to extract myoelectric signals directly from the active muscle. The EMG signal is a direct reflection of the muscle current level of activation. EMG is widely used in the study of postural tasks, functional movements and training regimes [9].

A wearable EMG belt was designed (see Figure.1a), consisting of an EMG sensor[1], an Arduino Duemilanove microprocessor and a Bluetooth modem. The EMG signal is sent to computer via the Arduino at 9600 baud.

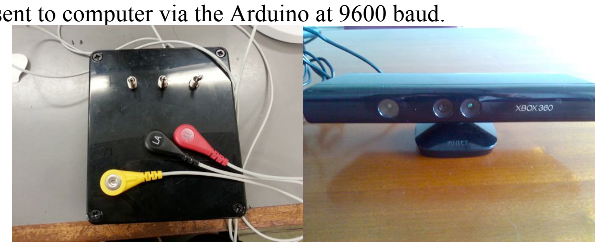


Figure 1 a) EMG Belt (Left), b) Kinect Camera (Right)

For limb position extraction, a Microsoft Kinect (Figure.1b) camera was placed in front of user. A tracking program named Synapse[2] was used to acquire 2D coordinates relative to the center of the subject's torso and to transmit the coordinates via Open Sound Control (OSC). The reason for using relative coordinates is to provide consistency regardless of the position that the user stands within the visual frame.

3.2. Software

The software platform (see Figure 2) was developed using Max/Msp, and has 3 main functionalities.

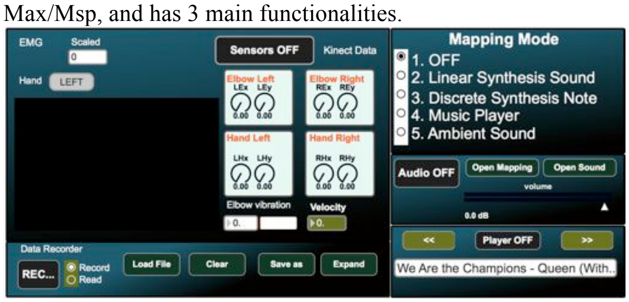


Figure 2: Main interface of the sonification software

(1) **Data management**: This section handles bio-signal acquisition. The sampling rate for the data recorder is set at 50Hz, because biceps curls are relatively slow action exercises (typically less than 1Hz). Therefore, being able to output 50 sets of data (coordinates, EMG, speed, etc.) per second is more than enough for both sonification and analysis purposes. This part of the program also handles basic analysis of the data, such as finding the rate of change (v) of the y-coordinate and the dynamic range of the movement (difference between the lowest and highest y-coordinates of the hand).

(2) **Sound engine** featuring a subtractive/FM synthesizer and an audio sampler. In order for the sound to distinctively represent the movement and muscular activities, the following 5 parameters are controlled by the bio-signal in different combinations. They are: loudness, pitch, filter cut-off frequency (brightness), noise level and sample playback speed.

To avoid boredom in long-term use, four types of sounds are available to choose from:

- **Linear frequency synthesis**

This preset produces a synthesised sound with a linear pitch variation during the biceps curl. The sound itself comprises a sawtooth waveform and a triangular waveform, resulting in a rich spectral content. The pitch is linearly controlled by the current vertical position of the hand with a valid frequency range from 0Hz (lowest hand position) to 620Hz (highest position). The amplitude of the EMG signal shapes the brightness of the sound through a linear mapping to the cut-off frequency of a band-pass filter. The overall sound characteristic was described as 'sci-fi' by some of the users. In additions, a white noise will be triggered if the movement velocity is over a threshold value, thus encouraging the exercise to be taken at a slower pace.

- **Discrete bell-like sound**

In terms of the timbre, this preset is spectrally simple. The vertical hand position triggers a range of notes between C4 and E5. The vertical range is divided into 10 equidistant sections. When the y coordinates moves from one section to another a new note will be triggered. To avoid boredom, the note selection varies each time based on two Markov chain probability matrices. One is used in biceps contraction (moving up) with an ascending note progression and the other is used in biceps extension (moving down) with a descending note progression. The same white noise as above is used as a warning to slow down.

- **Music player**

This mode allows users to upload their *own* music files and have them played back during exercise. The EMG signal is used to control the brightness of the sound via a low-pass filter. Thus the more activity generated from the muscle the greater the clarity in the music. This is to encourage users to work hard to hear good quality music. If the user moves his/her arm too quickly, the pitch of the right channel is altered so that the music does not sound 'correct'. This is used as a warning or a penalty if the user is moving too quickly. The incorrect effect only lasts for one repetition and will then be reset to normal pitch.

- **Ambient sound**

This also uses the sampler as above, but triggers the sound of a soft breeze blowing during the exercise. It aims to create a relaxing sensation for the user rather than giving precise feedback on the movement. The EMG signal is mapped to control the cut-off frequency of a low-pass filter so that wind sounds 'harsher' when more effort is put in. The speed warning

[1] Purchased from http://www.advancertechnologies.com/
[2] http://synapsekinect.tumblr.com/

is replaced by a sine wave beep instead of white noise, which would be hard to hear in the noise-based soundscape.

(3) **Mapping engine**: manages the data connection between the bio-signal and the sonic parameters. The sound presets are stored and changed in this patch. Parameter mapping [2, 3] is used as the main mapping method.

If more hardware details are required, please refer to the previous paper of this research, which focused on the user experience of different types of auditory feedback [10].

4. EXPERIMENTATION & DATA ANALYSIS

The sonification system was applied in the comparative trial. Full details are described in the following sections.

4.1. Experimental Setup

The experiment was carried out in the Audio Lab, University of York, U.K. 22 people participated: 19 males, 3 females. A laptop was used with the sonification software installed. Auditory display is via a pair of speakers.

Subjects were randomly assigned to one for the two groups: *sonification group* and *control group*. Auditory feedback during the exercise was given only to the sonification group.

The experiment involved three sessions on different dates. In each session, participants were asked to select a dumbbell, whose weight was challenging for the subject's own standard. All three sessions involved the same type of exercise. Yet participants had control of the quantity of repetitions and sets as a factor of studying progression and participants' motivation of exercise.

Figure 3. Demonstration of the exercise

Prior to the exercise, subjects were briefed (and shown a demonstration) that there are *three quality criteria*:

(1) Aiming for a large movement range, which means trying to lift the dumbbell as high as possible and when lowering the dumbbell trying to return to the natural straight-arm position.
(2) Aiming for a slower pace. The ideal speed for each direction (up or down) of movement is at least 2 second.
(3) Subjects are free to do whatever amount of exercise they feel comfortable with but the more the better.

Participants in the sonification groups were also demonstrated the four different sound presets and they are allowed to choose any of the presets based on their own preferences. After each session, all subjects were asked to fill in a survey to express their tiredness and comment on their experience.

The following data were recorded

(1) **Normalised EMG**: Due to differences between different subjects' biceps, some might have a larger range while others might have smaller. Therefore, in order for all users to be able to achieve a full control range, calibration is required based on subject's rest-stage EMG and the maximum contraction EMG then scale this range to a control range of 0 to 1023.

(2) **Active hand y coordinate**: This parameter reflects the vertical movement (relative height) of the active hand.

(3) **Velocity of y coordinate**: The rate of change of the y-axis coordinate. Positive velocity indicates biceps contraction whilst negative velocity indicates biceps extension.

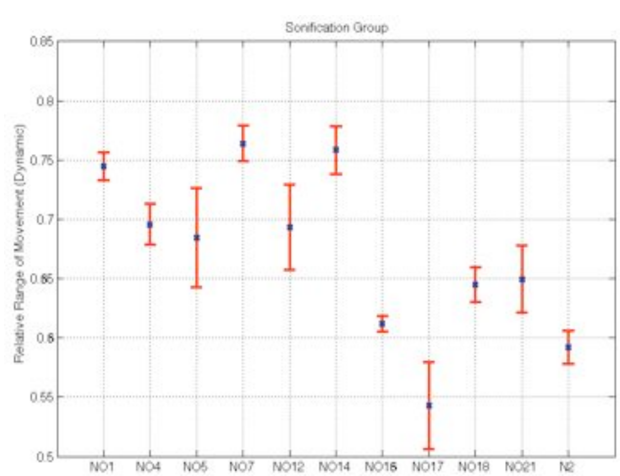
(4) **Dynamic of y coordinate**: The difference between the highest y coordinate and lowest y coordinate in each repetition.

4.2. Experimental Results and Analysis

Three dependent variables were collected in the experiment. They are movement range, movement velocity and effort. This section presents discussion on each variable then follows with an influential statistics section.

4.2.1. Movement Range

The *movement range* is the distance completed in a repetition. The distance is the vertical coordinate difference between straight-arm hand position and peak-hand position when lifting the dumbbell. The coordinate is ranged from 0 (straight-arm position) and 0.8 (shoulder position) and 1.0 (top of the head). Referring to the quality criteria in 4.1, subjects should aim for a large movement range. Figure 4 demonstrates the average dynamic per repetition of each participant from all three sessions (the sonification group being shown at the top and below that the control group).



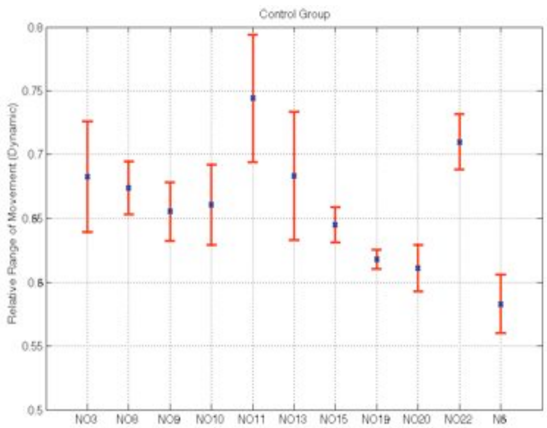


Figure 4. Movement range comparison (blue crosses are the mean movement ranges, error bars are the standard deviations)

For the group performance, the mean movement range for the sonification group and control group are 0.67 and 0.66 respectively. According to the graph, surprisingly, the control group performed more stably than the sonification group. The standard deviations of the mean movement range between groups are 0.07 (sonification) and 0.04 (control).

Although the sonification provided reference to the vertical position of the subject's hand, it did not contribute to any variation in exercise quality. During the experiment, the researcher observed that 3 participants in the sonification group did not achieve a good movement range. They either started another repetition without completely lowering the forearm or did not reach the top possible position. It appears that tired subjects do not use the sound to maximize their movement range. This may be because they are not explicitly warned that their movement is falling short of the maximum.

4.2.2. Movement Velocity

This data represents the average velocity (vertical coordinate change per second) per repetition in a session. Based on the quality criteria in 4.1, a lower velocity value is considered to be better quality.

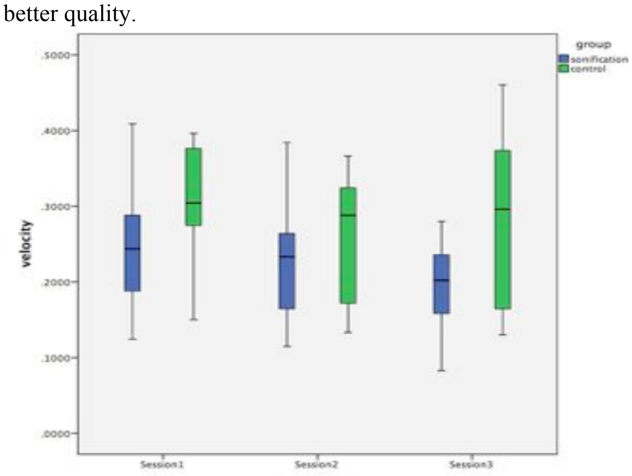


Figure 5. Average velocity comparison

This is the most influential attribute out of the three dependent variables as sonification showed its superiority in maintaining a slow pace of the exercise (see Figure 5). The boxplot suggests that, overall the sonification group had a lower velocity value. The sonification group also improved consistently throughout the three sessions. Yet without audio feedback, subjects in the control group tended to exercise much quicker even though a demonstration was shown at the beginning of the first session about the criteria of exercise. The extra sonic cue seems to have served as an active *reminder* of the speed of movement.

4.2.3. Total effort

Prior to the experiment, we compared the mean weights of the dumbbell selection. They are 5.0kg (sonification group) and 4.7kg (control group). Therefore, we treated the initial mean dumbbell weights as approximately equal (6% in difference). The total effort is a combination of the weight of dumbbell and the amount of repetitions. It is calculated as the equation below,

$$effort = w \cdot r$$

where w is the weight, r is the repetitions. The results in three sessions are shown in Figure 6. There is an increase in the medians of the sonification group. In all sessions, the sonification group is noted with both higher upper quartiles and median values although the lower quartiles are very similar.

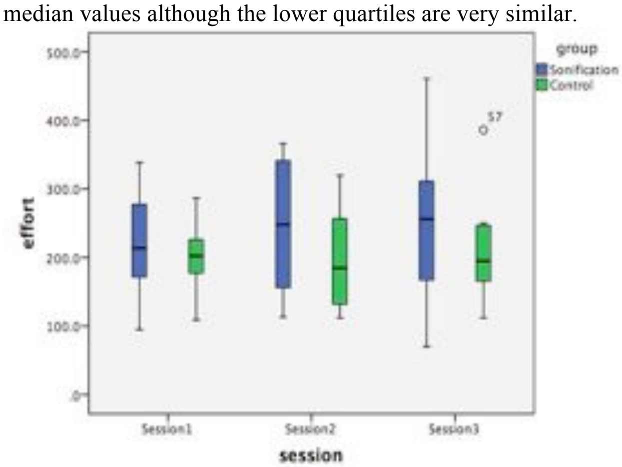


Figure 6. Total effort comparison

However, it should be noted that the experiment only lasted for 3 sessions whereas generally weight training requires a longer time to show clear improvement in muscle strength. The difference between two groups is not significant enough to make a judgment that sonification can definitely lead to a quicker improvement in exercise quality than the control group. Yet, the results underline a possibility that if subjects enjoyed listening to the sonic feedback the motivation improved, which caused a better improvement in the amount of repetitions completed.

4.2.4. Influential Statistics

A one-way multivariate analysis of variance (MANOVA) was conducted using the abovementioned three dependent variables for the final session between two groups. It aims to investigate the difference in the overall exercise quality between two groups. No serious violations were found in the preliminary assumption testings, including normality, linearity, univariate and multivariate outliers, homogencity of variance-covariance matric es. There is no statistically significant difference between sonification group and control group on the combined dependent variables, F(3, 18), p = .161 (Wilk's Lambda), partial eta squared = .244.

When the dependent variables results were considered seprately, we found a significant difference of the velocity, F(1, 20) = 4.934, p = .038 and partial eta squared = .198. This dependent variable has a large effect size (19.8%) . The results show that sonification group has a slower movement velocity (M = .191) than control group (M = .279). The results indicate the sonic feedback serves best at reminding the speed of movement in order to achieve slow and steady exercise movements.

5. QUALITATIVE RESULTS

Comments have been gathered from the sonification group about the use of sonification. 8 out of the 11 subjects expressed that the sounds they received had a positive effect on their exercise. 2 participants in the same group did not make any comments of the sonic feedback and one expressed that he did not enjoy it.

The following is some of the comments made by the participants:

"I enjoyed the sound"

"I tried to avoid the over-speeding sound"

"The sound distracted me from feeling tired" – Three participants expressed that the sound served as a distraction from fatigue. This is also supported by [11].

"It felt annoying at first but later it kept me going."

"I think the sound is getting clearer comparing to the last session."

"Personally I wouldn't listen to this while I was exercising." – Two participants mentioned that they did not enjoy the sound at all and felt it sound very noisy to them (both used the linear synthesis sound preset).

"I just felt very tired"

These comments indicate that the sonification feedback provided a mostly positive effect on both providing training guidance and general experience. It is reasonable that some people may find the sound uncomfortable to listen to. It pinpoints a fact that the current sound design consideration is still biased to being informative and not enough effort was put into accommodating different aesthetic preference. We believe with careful fine-tuning the sound aesthetic can be improved in order to provide a better experience.

6. CONCLUSION

In this research, a sonification system was designed for providing real-time feedback of subject's physical exercise. A latitudinal experiment was conducted to compare the exercising quality between a sonification group and a control group (no sound feedback) over a three-sessions period. The exercise quality was monitored regarding participants' movement speed, range and the total effort.

The study shows that sonification group performed consistently better in terms of movement velocity and effort, but there is no difference in the movement range. Although MANOVA analysis shows there is no significant difference between two groups in session 3 considering the combined dependent variables, significant result was found in movement velocity with a large effect size, indicating that the sonification a strong influence on maintaining a slow biceps curl speed. Although there is no significant result in the total effort, the post-session survey concluded that most participants in the sonification group found the auditory feedback to have positive effect on their actions.

We believe that the sonification device has the potential to be further improved and eventually developed into a sophisticated product to improve the general quality of physical exercise.

7. FUTURE WORK

At the time of submitting this paper, a crossover experiment has been carried out to study the difference between doing biceps curl with and without sonification feedback in different phases.

With the new age of wearable device and the technology focus on fitness and health, an exciting period is waiting ahead. This project has the potential to contribute to the field of fitness assistive devices and thus to encourage more people to do regular physical exercise to a relatively good standard. As for the system, although it is still in its prototype stage, it can be developed into a smartphone add-on, offering convenient accessibility to users.

Another possible extension of the project is to facilitate the sonification system in rehabilitation training. In this context sonified bio-feedback could be used to monitor and correct the patient's prescribed exercise.

8. ACKNOWLEDGEMENT

We would like to express our sincere gratitude to all the participants who took part in the experiment.

9. REFERENCES

[1] A. Effenberg, "Movement Sonification: Effects on Perception and Action" in Multimedia, IEEE, 12.2:53-59,2005.

[2] T. Hermann, "Taxonomy and Definitions for Sonification and Auditory Display" in *Proc. of the 14th International Conference on Auditory Display*, France: IRCAM, 2008.

[3] T. Hermann, A. Hunt and J. G. Neuhoff "The Sonification Handbook", Logos Verlag, 2011.

[4] N. Schaffert and A. Effenberg, "Listen to the Boat Motion: Acoustic Information for Elite Rowers", in *Proc. of Interactive Sonification Workshop (ISON)*, Stockholm, Sweden, 2010.

[5] S. Barrass, N. Schaffert and T. Barrass, "Probing Preferences between Six Designs of Interactive Sonifications for Recreational Sports, Health and Fitness", in *Proc. of the Interactive Sonification Workshop (ISON)*, Stockholm, Sweden, 2010.

[6] N. Harmon and L. Kravitz, "The Effects of Music on Exercise" in *IDEA FITNESS JOURNAL*, 4(8), 72-77, 2007.

[7] J. Edworthy and H. Waring, “The Effects of Music Tempo and Loudness Level on Treadmill Exercise”, in *Ergonomics*, 49:15, 1597-1610, 2006.

[8] D. Woods, “The Alarm Problem and Directed Attention in Dynamic Fault Management”, in *Ergonomics*, 38:11, 2371-2393, 1995

[9] P. Konrad, “The ABC of EMG: A Practical Introduction to Kinesiological Electromyography”, Noraxon, USA 2005.

[10] J. Yang, and A. Hunt, “Sonic Trainer: Real-time Sonification of Muscular Activity and Limb Position in General Physical Exercise” in *Proc. of the Interactive Sonification Workshop (ISON)*, Erlangen, Germany, 2013.

[11] A. Szabo, A. Small and M. Leigh, “The effects of slow- and fast-rhythm classical music on progressive cycling to voluntary physical exhaustion” in *Journal of Sports Medicine and Physical Fitness*, 39(3), 220-225, 1999.

Modulating movement with sound: comparing a target step trained by sound or vision.

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ABSTRACT

We experimented with acoustic feedback designs to explore intuitive mappings used to guide stepping movements of walking in healthy subjects. The accuracy with which subjects reproduced a target movement based on alternative pre-programmed movement to sound mappings was compared. The most effective mapping produced a mean percentage error in either step distance or duration of approximately 12%. In additional experiments, we measured the relative accuracy of such movements based on visual feedback as compared to auditory feedback. Mean percentage errors (±std) in visual and auditory feedback cues were: Vision 11.5 ± 7.0; Audition 12.9 ± 11.8. Results indicate that, when played to their respective sensory strengths, visual and auditory feedback can be comparably effective in entraining for stepping movements.

1. INTRODUCTION

Disruption to normal multisensory and motor processes following a neurological accident, such as a stroke, may lead to sensory and physical impairment including the loss of normal proprioceptive feedback from muscles and joints. Rehabilitation can be aided through augmented visual and/or auditory biofeedback that stimulates neuro-plasticity [1], but the design and effectiveness of feedback, particularly in the auditory domain, are non-trivial issues.

Design of acoustic feedback to help in the rehabilitation of gait and movement in general could take several forms. Rhythmic cuing is effective in improving gait training for stroke patients [2], [3] to help synchronise steps and improve frequency. Another approach is to provide acoustic spatial clues to help navigate 3-D environments [4] or distance to objects in obstacle based tasks [5]. Shea et al [6] showed that acoustic models could be effective in training timed key-pressing tasks, compared with a group that received only visual feedback. Ghez et al. [7] designed auditory feedback based on musical principles to investigate whether sonifying hand position or joint motion could provide a substitute for the loss of natural feedback from joint and muscle receptors. An initial spatial target matching exercise found that trying to use acoustic feedback to provide accurate location information for the hand could be learnt but required training and did not achieve the accuracy of vision. It was noted that visual feedback can only partially compensate for proprioceptive loss and, while the primary source for positional information, it is not as effective at capturing dynamic information such as velocity and acceleration. These, it was suggested, might be expressed more effectively with sound because of differences in neural processing between vision and audition - speed of processing for example - and its role in movement timing and synchronization for activities such as music and dance.

1.1. StroMoHab

StroMoHab (Stroke Mobility Rehabilitation), was developed as an aid for gait rehabilitation following stroke. At its core is an OptiTrack passive optical motion capture system (eight V100 cameras) used to track the position of reflective markers attached to a subject. A treadmill sited in front of the cameras allows a user's movement to be captured while walking on the spot. Feedback of the user's movements is by way of an avatar displayed on a TV monitor. The system as used in these experiments, without treadmill is shown in figure 1.

Besides providing visual feedback of actual movements, it was anticipated that the avatar could present target movements for the patient to follow. This suggested the idea of an acoustic avatar to provide complementary acoustic feedback and/or movement training cues. It was the latter the experiments set out to test.

By converting a particular movement into a structured sound, how well could a listener recreate the (unseen) movement by listening to the generated sound and then attempting to reproduce the sound?

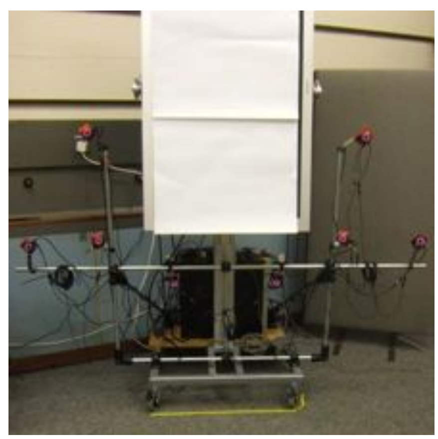

Figure 1: StroMoHab as used in the current experiments, showing motion capture cameras and screen (temporarily covered).

Initial attempts to find appropriate ways that sound might help guide movement were somewhat arbitrary. Discussion in [7] on representing velocity and acceleration in the auditory domain provided ideas for a way forward. Also, comparisons by Hunt and Kirk [8] on the pros and cons of simple one-to-one versus complex, multi-parametric mappings suggested that, for training test subjects in a novel task, a simple approach would probably work best. It was decided to take an elementary approach, examining principles by paring down the various components into simple representations. For example: using a simple gait related movement – just a single step; examining the step motion in one plane only (sagittal), tracked using a single toe mounted marker; and using a small subset of parameters for motion (velocity and acceleration) and sound (gain and pitch).

2. COMPARING THE EFFECTIVENESS OF ALTERNATIVE MAPPINGS OF STEP VELOCITY AND ACCELERATION TO GAIN AND PITCH FOR USE IN A SIMPLE ACOUSTIC MODEL OF A STEP

2.1. Methods

Alternative ways of mapping movement to sound were compared using a training paradigm. Participants (n=7) were asked to listen to a model sound played over headphones and then attempt to recreate, as closely as possible, the sound they had heard by making a simple step movement. The model sounds were generated by mapping the velocity and/or acceleration of an emulated step to the amplitude and/or frequency of a sine wave. The distance and duration of each step attempt was recorded for comparison to the distance and duration of the emulated step. If they succeeded in recreating the sound then the distance and duration of the step taken matches the emulated step.

A target step involved keeping one foot rooted and moving the other forwards (Figure 2). When looking at the motion only in the sagittal plane i.e the forwards motion, the pattern of acceleration is approximately sinusoidal. A sine wave of peak 2.5 m/s^2 and period 0.9 seconds was used as the basis of the emulated step. Position data was calculated from the acceleration so that in generating the model sounds the data would follow the same processing path as motion capture data generated by the participants. The length of the resulting emulated step was 0.322 meters.

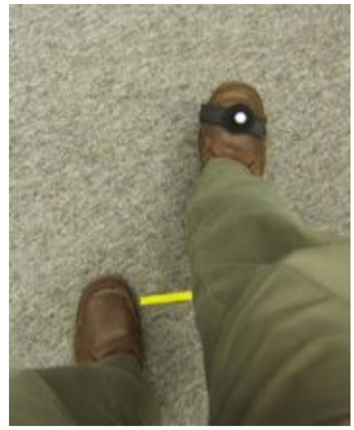

Figure 2: Example of a single step and marker attached to foot

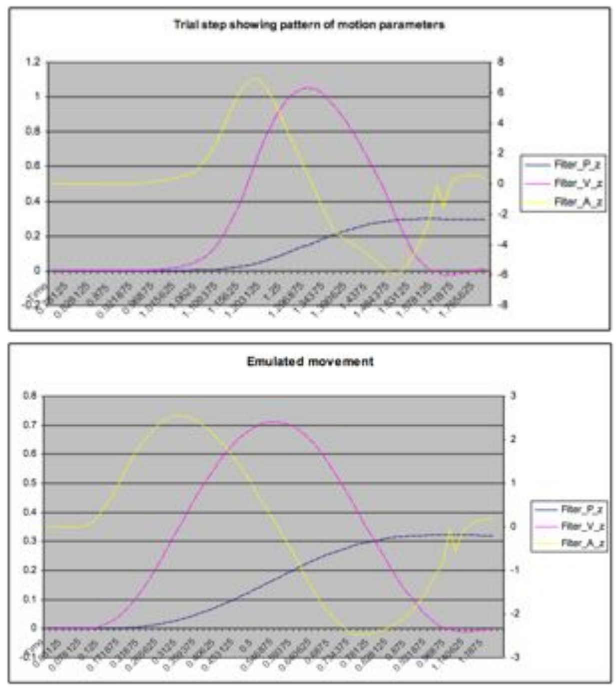

Figure 3: Motion of real step recorded as basis for emulation model (top); and bottom, the corresponding traces for the emulated step.

Velocity and acceleration were calculated by numerical differentiation of position data for both the motion capture and emulated data (Figure 3).

Position data were sampled by motion capture at 64 Hz and fed through a 4th order Butterworth IIR filter prior to numerically deriving velocity and acceleration. Values of velocity and acceleration were used to change gain and pitch parameters in OpenAL (Open Audio Library Application Programming Interface) which was used to render sound through a PC sound card. Gain and pitch are adjusted using a float value:

- gain = 0 (source is muted) to 1.0 (max volume permitted)

- gain = 0.5 (6dB attenuation)
- pitch = 1.0 (base frequency)
- doubling the pitch value raises the frequency by an octave, halving the pitch value lowers the frequency by an octave.
- the source was a sine-wave oscillator, base frequency = 250Hz, with a peak equal to the maximum PCM value (±32767, 16-bit mono samples)

Five different model sounds were created by mapping the velocity and/or acceleration of an emulated step to amplitude and/or frequency of the 250 Hz sine wave:

1. velocity to gain
2. velocity to gain and pitch
3. acceleration to gain
4. acceleration to gain and pitch
5. velocity to gain
6. velocity to gain, acceleration to pitch

These gain and pitch values were calculated for each of the mappings as follows:

1. gain = velocity (i.e. no scaling)
2. gain = velocity; pitch = velocity + 0.5 (i.e. f = 125 Hz as the foot just starts to move)
3. gain = |acceleration|*0.25
4. gain = |acceleration|*0.25; pitch = (acceleration*0.25) + 1.5
5. gain = velocity
6. gain = velocity; pitch = (acceleration * 0.25) + 1.5

Participants were presented with six model sounds (velocity to gain was repeated). Each sound was listened to twice before five ‘on the spot’ steps were made whilst listening to concurrent acoustic feedback through the headphones. This *two-five* pattern was repeated 10-times for each of the model sounds, by each participant. They were not given any information about the basis of the sounds and were simply presented with sounds and asked to recreate them by making a step-like movement.

2.2. Results

Statistical significance was not achieved with the small sample size. None of the motion to sound mappings tried showed any particular advantage in helping to reproduce the distance of the step. However, consistent with the temporal nature of sound, some of the mappings appeared to have the potential to modulate step duration more than others with velocity to gain appearing the best (Figure 4).

One subject appeared to find the tests difficult, which is borne out by looking at normalised scatter plots comparing performances across subjects where subject C appears as an outlier in both temporal and spatial domains (Figure 5). Removing subject C reduces overall errors across all tests by around 30 per cent.

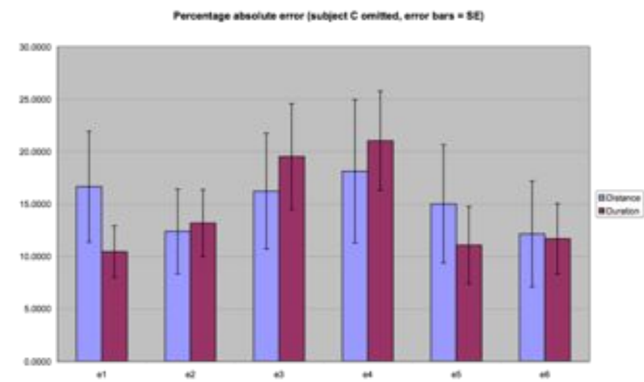

Figure 4: Bar chart showing percentage absolute errors for step distance and duration achieved using alternative mappings

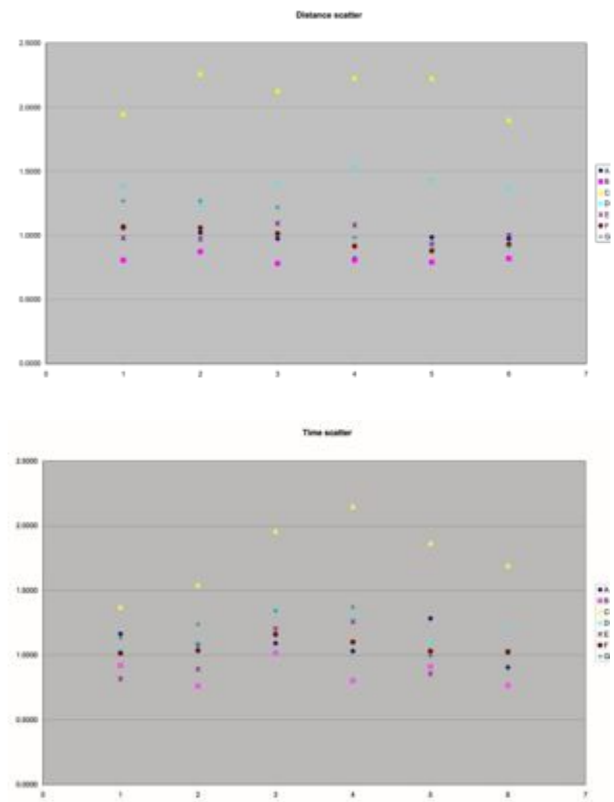

Figure 5: Normalised scatter plots for distance and duration illustrating outlier subject C.

The pilot experiment was run to compare alternative mappings to provide a guide to which might be useful to work on. As such a control was not included, so it is not possible to judge how good performance at the task was and how much benefit acoustic feedback provided.

A second experiment was therefore designed in order to provide some measure of the effectiveness of acoustic feedback as a training tool.

3. COMPARING AUDITORY/TEMPORAL WITH VISUAL/SPATIAL FEEDBACK BASED TRAINING

3.1. Method

Again, a single step was used as the target movement: keeping one foot rooted; moving the other forward; ending the step with the foot flat before returning to the start position. Each test subject (n = 20) was asked to make 20 such movements, one after the other, and to try to keep the steps consistent. The duration and distance of the forward part of the step were recorded using motion capture and formed a baseline measurement of the subject's preferred step distance and duration.

The volunteers then trained either a target step length or a step duration, which consisted of taking 20 steps based on their baseline measurement plus or minus 25 per cent. Whether subjects trained to a lengthened or shortened step measurement was done at random.

Figure 6: Visual/spatial step training using a target marked on the floor

Step length training used measured visual marks on the floor (Figure 6).

The auditory feedback for duration training was designed to provide roughly equivalent cues available implicitly in the visual condition (Figure 7). It used a tone (950 Hz sine wave) based on the velocity-to-gain mapping used in the first set of tests (but of fixed length equal to the target duration). It started playing when the subject started to move, with the bell-shaped envelop providing an indication of the progression of the target step. This approximated to being able to see the whole task in the visual condition. The visual training also provided implicit feedback of results - participants could judge how close to the target they were for every step. This was mirrored in the auditory domain by inserting 'clicks' - one when the target duration had elapsed and another when the participant had finished the step. Coincident clicks indicated a step of the correct duration.

The training phase was immediately followed by the attempt to replicate the target step (with no visual or auditory cues) again, with 20 step attempts.

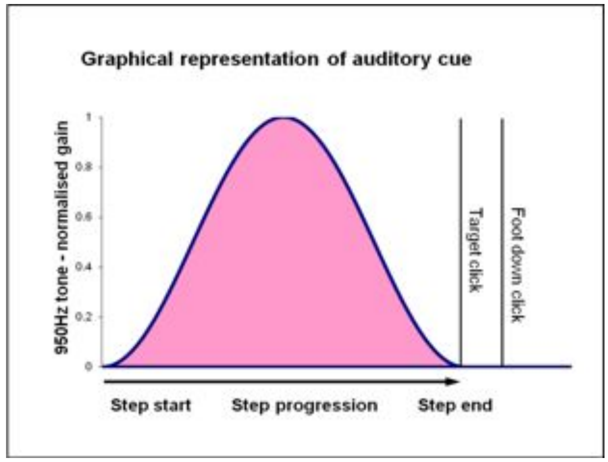

Figure 7: Graphical representation of the auditory training cue

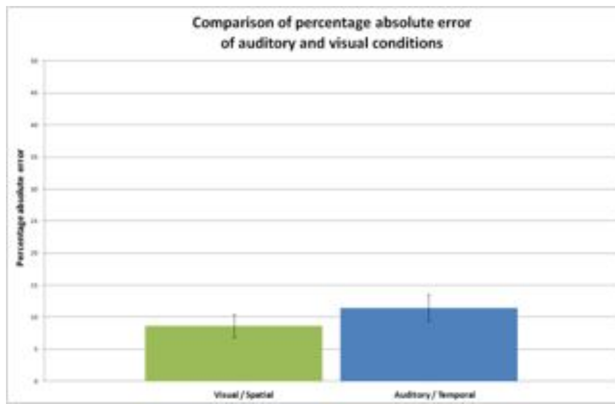

Figure 8: Comparison of mean absolute errors

3.2. Results

A graphic summarizing the results is shown in Figure 8

Auditory temporal cues and feedback are at least half as good as visual spatial cues for a simple step-like task. The ratio of mean error rate, spatial/temporal, = 0.75. 95% confidence interval = 0.51 to 1.11, P = 0.15.

Hence there is no evidence that the spatial and temporal differ, and the important thing is that the ratio of the means is between 0.5 and 1.1.

3.3. Implications

Motor learning is often considered to be dominated by visual feedback [9] during self-guided movements in combination with proprioception. Contrary to expectations, the result of the experiment suggests that under comparable conditions auditory feedback can be at least half as effective, in terms of percentage error, in the temporal domain as visual feedback is in the spatial domain. This offers the possibility that auditory cues to motor learning can be effective to enhance rehabilitation in mobility in addition to visual feedback, or in situations where visual inputs may be limited (such as stepping under foot), restricted or entirely absent (such as for the visually impaired). The comparable levels of error between the visual (spatial) and auditory (temporal) modalities may indicate a shared or similar neural mechanism, or alternatively that motor learning in the two conditions may be bounded by similar sets of constraints.

4. REFERENCES

[1] Holden MK, "Virtual environments for motor rehabilitation: review", Cyberpsychol Behav. 2005 Jun;8(3):187-211; discussion 212-9

[2] Prassas S., Thaut M., McIntosh G., Rice, R. (1997). Effect of auditory rhythmic cueing on gait kinematic parameters of stroke patients. Gait and Posture, 6, 218-223

[3] Thaut MH1, Leins AK, Rice RR, Argstatter H, Kenyon GP, McIntosh GC, Bolay HV, Fetter M., "Rhythmic auditory stimulation improves gait more than NDT/Bobath training in near-ambulatory patients early poststroke: a single-blind, randomized trial", Neurorehabil Neural Repair. 2007 Sep-Oct;21(5):455-9. Epub 2007 Apr 10.

[4] Tapio Lokki, Matti Gr ohn, "Navigation with Auditory Cues in a Virtual Environment", IEEE MultiMedia, vol. 12, no. 2, pp. 80-86, Apr. 2005, doi:10.1109/MMUL.2005.33

[5] Mathias Wellner, Audrey Schaufelberger, Joachim v. Zitzewitz, Robert Reiner. "Evaluation of visual and auditory feedback in virtual obstacle walking". Presence, Vol. 17, No. 5, October 2008, 512-524

[6] Shea CH, Wulf G, Park JH, Gaunt B. "Effects of an auditory model on the learning of relative and absolute timing". J Mot Behav. 2001 Jun;33(2):127-38.

[7] Claude Ghez, Thanassis Rikakis, R. Luke DuBois, Perry R. Cook, "An auditory display for aiding interjoint coordination", Proc. Int. Conf. On Auditory Displays (ICAD) Atlanta, Georgia, April 2000.

[8] Andy Hunt and Ross Kirk.(2000), "Mapping Strategies for Musical Performance". In: M.M. Wanderley and M. Battier, (eds.) Trends in Gestural Control of Music, IRCAM - Centre Pompidou

[9] Michael I. Posner, Mary Jo Nissen and Raymond M. Klein, "Visual Dominance: An information-Processing Account of Its Origins and Significance", Psychological Review, Volume 83, No2, Pages 157-171

UNFOLDING | CLUSTERS: A MUSIC AND VISUAL MEDIA MODEL OF ALS PATHOPHYSIOLOGY

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ABSTRACT

Unfolding | Clusters is a music and visual media installation modeled from published scientific data related to the pathophysiology of amyotrophic lateral sclerosis (ALS). The work aims to create an engaging multimodal experience useful for raising awareness in the greater public about the disease and its scientific process. This paper describes the motivation behind the adoption of a *musification* approach and the musical criteria applied to the data mapping process. Details regarding the mapping structure are illustrated in relation to the different phases of the progress of the disease. The results are then discussed, noting that adopting a musification approach not only helped in obtaining a more engaging audience experience but also in providing expressive solutions that would be useful for modeling other complex biomedical data and processes.

1. INTRODUCTION AND BACKGROUND

This project explores the use of combined sonification and visualization in a multi-modal installation for the purpose of illustrating the condition and progress of degenerative amyotrophic lateral sclerosis (ALS). The use of sonification in biomedical applications is a growing and progressive field, with many such applications in existence.

"Sonification conveys information by using non-speech sounds. To listen to data as sound and noise can be a surprising new experience with diverse applications ranging from novel interfaces for visually impaired people to data analysis problems in many scientific fields." [1].

We consider the sonification in this project a *musification* – in a musification the data is not just auralized but various constraints are created and applied in order to create a musical performance of the data (see section 4 for full details of this process). For this project, the advantage of using a musification to display this data is threefold. Firstly, the data involved in the unfolding process is extremely complex, and some of the mutation processes involve minute changes that would be difficult to illustrate meaningfully using either a visual modality or a direct sonification (see section 4. Method).

Secondly, one of the aims of this project was to generate and raise further awareness of the condition, in line with existing MND/ALS charity core aims. Thus, a musical installation which could engage the audience both visually and in an aurally engaging manner was a useful prospect. Thirdly, the kind of numerical data which represents the amino acid structures and the process of cluster formation as ALS progresses is not easily represented in a manner which can be readily analyzed by the casual viewer – musifying this data by first sonifying it, and then applying a set of musical constraints to the sonified data offers the possibility of engaging the listener with this complex data by allowing them to engage and analyze the music, a process which listeners do automatically and intuitively as part of their everyday listening process in the real world. These reasons are common to many auditory display projects making use of multimodal techniques in the biomedical arena. "*The idea behind sonification is that synthetic non-verbal sounds can represent numerical data and provide support for information processing activities of many different kinds."* [2].

Combining the musification with a visual representation of the datastream further targets one of these functions; that of increased audience engagement through a multimodal experience. Multimodality is a complimentary human perceptual process which has also been exploited by the bio-medical world, e.g., [3]–[5]. *"The human auditory system is very good at detecting minute changes in audio signals and can also monitor several parallel audio streams at one time. This means hearing offers an exciting opportunity for parallel information interpretation tasks to complement existing visual representational techniques."* [6].

Thus, the criteria for this project include creating the maximum engagement for audience members whilst accurately representing, to a high level of detail, the changes involved in the data in a combined musification and visualization.

2. ABOUT ALS

ALS is generally fatal within 5 years of onset and "has a prevalence of 2–3 per 100.000 people" [7]. It is classified as familiar (FALS), if associated to inherited mutations, or sporadic (SALS) if not. SALS represents the majority (about 80%) of cases [8]. The disease is characterized by progressive degeneration of the upper and lower motor neurons of the spinal cord. This causes muscle weakness and atrophy throughout the body, leading gradually to paralysis and death by respiratory failure. Several factors contribute to neuronal death including Ribonucleic Acid (RNA) and protein dysfunctions and immunity [9]. Due to its high complexity, the

pathophysiology of the disease is yet to be completely clarified, however a shared theory is that the involvement of protein aggregation and deposit in neurons is a factor linked to the neuronal toxicity of the disease. Superoxide Dismutase-1 (SOD1) is a ubiquitous enzyme involved in the anti-oxidant processes of the cell. Numerous studies indicate that loss of function of SOD1 is not linked to ALS onset and progression, but rather to the toxic property acquired with its structural changings. SOD1 as a normal form (wild-type) is a homodimer of two identical aminoacidic sequences linked by a disulfide bond formed by cysteine 57 and 146 of the sequence. Zn^{++} ions allow for stability of the proteic structure, together with the Cu^{++} ions of the catalytic site – these portions are referred to as *metal binding sites* (MBS). About 140 different genetic mutations of SOD1 sequence were detected during the last twenty years of study, some of which were associated with a more aggressive form of the pathology. In this study we considered the most common pathology, that is, the substitution of Alanine with Valine in position 4 of the aminoacidic sequence (A4V). Both genetic mutations and biochemical reactions (oxidation) are associated with loss of ions and the consequent dimer loosening (i.e. apoprotein). This structure is more reactive than the wild-type to the association process of different dimers (oligomerisation) in chain-like structures. Note that a more aggressive ALS form is associated to wild-type and apoprotein aggregates [10]. A recent study by Banci and colleagues showed the specific sites indicated as single amino acids of the new-formed bonds in mutated forms SOD1 and the geometrical characteristics of the oligomerisation [11]. Finally, the chain-like structures form clusters associated with neurotoxicity, although a proof of concept of this mechanicistic event has yet to be verified [7].
Today, gene therapy seems to be the most promising strategy for intervention of FALS, and recent findings, depicting a deep heterogeneity of the disease, are paving the way for a multi-targeted therapeutic strategy [12].

3. *UNFOLDING | CLUSTERS*: THE MODEL

Unfolding | Clusters is an installation that maps scientific data from ALS pathophysiology to sonic timbres and melodic patterns in a video-synchronous spatial speaker array that represents the nervous system. The accompanying video presents cues showing neural pathways as they are activated, whilst the associated neuromuscular junction is sounded on corresponding speakers in the array. Over time, the timbre, rhythm, and spatialization of these sonic patterns gradually changes to reflect the progress of the protein unfolding and aggregation. Melodic sequences change according to the mutation of the amino-acidic sequence. As the amino acids aggregate into clusters, timbres become noisier to create additional spectral harmonics and, ultimately, introduce inharmonic distortion and dissonance. Video synchronicity gradually degrades as the nervous system loses control over the muscles and sclerosis hardens the affected nerves of the spinal cord. The spatialization in the 3D speaker array, initially a fully immersive sound world, eventually shrinks completely, reflecting the patients' loss of movement and motor function.
The work aims to create an engaging experience that can appeal to the greater public and raise awareness about the complex scientific findings regarding ALS. Therefore, the criteria adopted for the musification of the data are designed to go beyond direct sonification and include elements of tonality and the use of modal scales to create musical auralizations. The resulting musical structures take advantage of higher-level musical features such as polyphony and tonal modulation in order to engage the audience and at the same time find alternative ways to model the complex processes which occur during the progress of the disease.

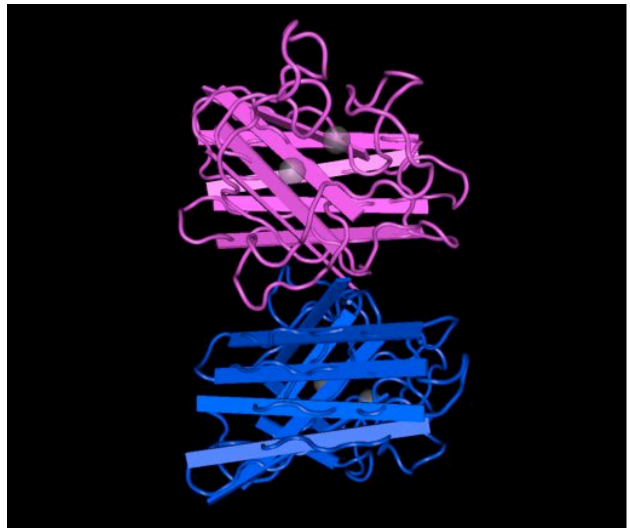

Figure 1: 3D structure of SOD1 protein.

4. METHOD

The installation presented in this research utilizes published data obtained from Nuclear Magnetic Resonance (NMR) studies of SOD1 protein [13]. In NMR spectroscopy the chemical shift is the resonant frequency of a nucleus compared to a standard [14]. This analysis was chosen from the qualitative protein assays as it exhibited a range of frequency values which were not unlike an audio signal when evaluated with NMR analysis. Chemical shifts of amino acid structures change slightly depending on the whole protein molecular structure in which they are arranged. Since the chemical shifts of each single amino acid (AA) composing SOD1 protein sequence are not published, these were obtained from the Biological Magnetic Resonance Data Bank (BMRBD) [13]. These data represent averages of 6486124 chemical shifts of the same AAs in different molecular contexts published to date and are expressed in parts per million (ppm)[1] and approximated to the second decimal figure.

4.1. Mapping layer 1: basic melodic features

Data mapping to musical features is organized in a layered framework (see Table 4). In the first layer, data resulting from NMR analysis [13] is used to assign basic musical features – such as pitch, duration and velocity – to each of the 20 classic amino acids. The main melodic material is defined by the

[1] ppm = (sample value in Hz - standard in Hz) / spectrometer frequency in MHz.

amino acidic sequence of the wild-type SOD1 protein, which comprises 154 instances of the classic amino acids. The molecular structure of an amino acid consists of amine (-NH_2), carboxylic acid (-COOH) and a side-chain (R) specific to each amino acid (Fig. 2).

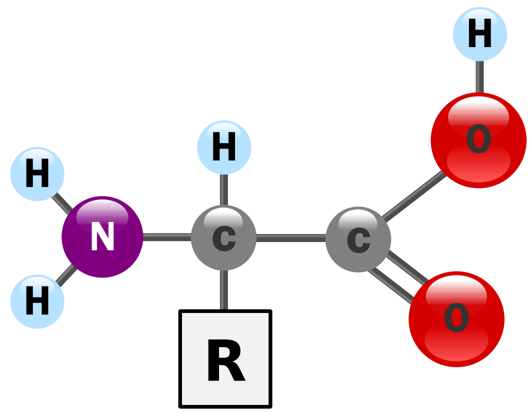

Figure 2: generic structure of an amino acid consisting of amine (-NH2), carboxylic acid (-COOH) and the R group, which is a side-chain that varies for each type of amino acid [15].

The pitch value of each amino acid was defined by mapping the average chemical shift of the respective R group to a note of the chromatic scale. By doing so, the 20 classic amino acids are indexed by increasing R group chemical shift and each one is associated to a note of an ascending chromatic scale, therefore covering a total note range of an octave and a fifth.

AA (short)	R group av. shift	Pitch index	Note
G	0,19	1	C1
P	3,99	2	C#1
M	4,44	3	D1
V	5,80	4	D#1
L	6,07	5	E1
I	7,55	6	F1
A	10,21	7	F#1
C	10,33	8	G1
R	12,03	9	G#1
K	12,72	10	A1
T	14,20	11	A#1
F	14,72	12	B1
W	15,20	13	C2
Q	15,53	14	C#2
S	16,08	15	D2
E	31,08	16	D#2
Y	38,40	17	E2
H	42,36	18	F2
D	43,89	19	F#2
N	48,94	20	G2

Table 1: pitch mapping for each amino acid.

To determine the duration of each note, the average chemical shift of the hydrogen atoms in the molecular structure of the amino acid is used. A set of five discreet durations was defined in order to obtain more consistent rhythmic patterns. The values for each amino acid are calculated and then mapped to the five durations in milliseconds, which correspond to the following note values at 120 beats per minute: sixteenth note, eighth note, quarter note, half note and whole note, as shown in Table 2.

AA (short)	H group Av. shift	Duration (msec)	Note value @ 120 bpm
L	2,66	125	1/16
P	2,78	125	1/16
K	3,18	125	1/16
V	3,21	125	1/16
M	3,30	125	1/16
I	3,33	125	1/16
E	4,04	250	1/8
C	4,29	250	1/8
Q	4,43	250	1/8
A	4,60	500	1/4
R	4,63	500	1/4
T	4,66	500	1/4
D	4,72	500	1/4
S	5,20	500	1/4
G	5,40	500	1/4
N	5,51	1000	1/2
F	6,00	1000	1/2
Y	6,11	1000	1/2
W	6,48	1000	1/2
H	7,02	2000	1

Table 2: duration mapping for each amino acid.

The note MIDI velocity (i.e. the intensity and resultant volume of each note) is determined from NMR data of the nucleotide nitrogen atoms. The four main nucleobases are ordered according to the increasing value of the respective nitrogen group chemical shift and are then associated with four MIDI velocity values (1, 43, 85, 127). The velocity corresponding to each amino acid is determined by taking the value of the first nucleotide of the respective nucleotide triplet.

Nucleotide	N group av. shift	MIDI velocity
Guanine (G)	138,08	1
Cytosine (C)	139,70	43
Uracil (U)	152,54	85
Adenine (A)	178,18	127

Table 3: velocity mapping for each nucleotide.

A custom Max[1] patch was designed to translate the numeric data taken from spreadsheets into MIDI values, which then can be used to control electronic musical instruments and music production software. Each one of the 154 amino acids in the

[1] http://cycling74.com/products/max/

	1. Initial State: Wild-type	2. Binding sites	3. Mutation	4. Bindings breaking
Layer 1: basic melodic features	Wild-type SOD1 melodic sequence.	Notes extracted from the binding sites in the sequence.	Mutation/Change of key A–>V = F#–>D#	The melody continues in the new key.
Layer 2: polyphony and arrangement	Dimer: two symmetrical melodic lines.	New parts extracted from the metal binding sites and disulfide bonds are played by new voices.	MBS lose ions, change in timbre.	The monomers separate = the melody and its inverse are respectively transposed down and up the scale.
Layer 3: spatialization and visuals	Correspondance between speakers and visuals.	New voices correspond to new instances of the visuals.	Correspondance between speakers and visuals.	Correspondance between speakers and visuals.

	5. Oligomerization	6. Fibrillization	7. Clusters	8. End
Layer 1: basic melodic features	Both the original and the "mutated" melodies are present.	The melodies are trasposed to different registers.	The melodies are trasposed to many registers of the whole audio spectrum.	The melodies are trasposed to many registers of the whole audio spectrum.
Layer 2: polyphony and arrangement	The original melody is stacked with the mutated inverse and vice-versa.	Voices playing the melody in different registers are layered.	Phasing, increasing dissonance and saturation of the audio spectrum, more and more layered voices.	Gradually less saturation.
Layer 3: spatialization and visuals	Increased speed, multiple voices moving.	Increased noise in the visuals and asynchronicity between visuals and sound.	Gaps and sudden movements in the sound spatialization, saturation towards white in the visuals.	Some speakers/neurons stop working. The soundscape converges to one speaker and one instance of the visuals.

Table 4: table displaying the phases of the development of the piece across the three mapping layers.

sequence is played as a note and the resulting melody represents a musical translation of the wild-type superoxide dismutase amino acidic sequence. The melody is then fed through a 'tonalizer' algorithm, which maps the incoming notes to various modal scales. During the mutation, the fourth amino acid of the sequence changes from A to V [10]. To render this event musically, the note corresponding to the mutating amino acid is considered the root of the scale in which the whole melody is played. The mutation therefore causes the melody to change key, modulating from F# to D#, which correspond to the amino acids A and V respectively. As the mutation affects the protein as a whole, a tonal modulation has an impact on the entire melody and is thus clearly delineated to the audience.

To model the process of fibrillization, the SOD1 melodies are transposed to different registers in order to express the formation of different layers of fibrils which occur after the protein unfolding. This eventually leads to the formation of clusters, conveyed through an increasing saturation of the soundscape due to the high number of dissonant voices playing at the same time.

4.2. Mapping layer 2: polyphony and arrangement

The second layer of the mapping framework contains higher concept level mappings related to the development of the musical piece, such as polyphony and arrangement. All the different steps that lead to SOD1 structural changes involve specific amino acids of the sequence. Other voices and parts of the piece are in fact determined by structural features of the SOD1 protein and processes occurring along the development of ALS. To represent the structure of the SOD1 protein – a dimer consisting of two identical amino acidic sequences displaced in symmetrical fashion (see Fig. 1) – the original melody extracted from the amino acidic sequence was inverted and added as a second voice. The symmetrical structure of the resulting 2-voice counterpoint deliberately reflects the shape of the SOD1 dimer. Other timbres and parts are introduced along the piece to denote various further processes. The first step leading to protein unfolding involves the breakage of the disulfide bonds and the loss of metal ions [16]. To represent this musically, the disulfide bonds are located in the protein sequence and the corresponding notes are then used to define a new melodic line played by a synthesized bass. In addition to the disulfide bonds, another important step that leads to the unfolding of the protein structure is the detachment of the Zn^{++} ions associated to specific portions of the protein sequence, also known as metal binding sites [17]. Once again, the corresponding notes in the sequence are employed to determine the part played by a new voice in the composition. The same approach is used to model the new bonds between protein monomers which form during the oligomerization process [11].

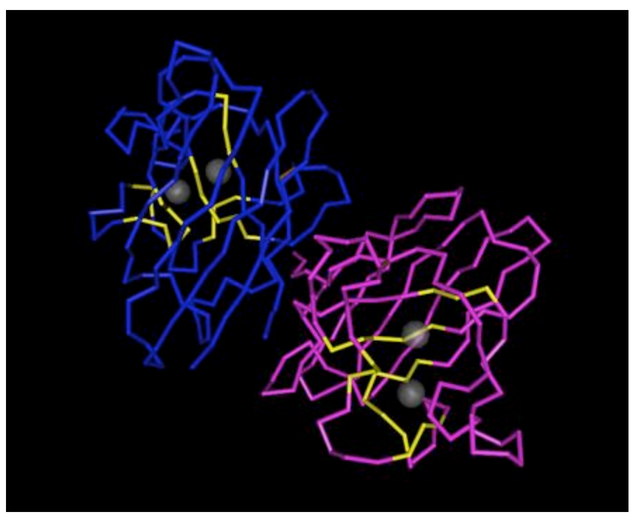

Figure 3: 3D structure of the SOD1 protein. The grey spheres represent the metal ions while the segments in yellow the metal binding sites.

4.3. Mapping layer 3: spatialization and visuals

The third mapping layer consists of high-level features in the installation, such as sound spatialization and visualization. The speaker array is arranged around a cylindrical projection screen on which the visuals are projected (see Fig. 4). This is a representation of a neural structure, where the central cylinder, acting as the central neural system, sends impulses (the visual cues) to cells of the peripheral nervous system, represented by the speakers (Fig. 5). There is an instance of the visuals projected in front of each speaker in the array. As long as the system is "healthy", the speakers respond with sound to the impulses sent by the central system. As the disease advances, communication between central and peripheral systems becomes increasingly asynchronous to reflect the death of motor neurons. The visuals are designed to avoid gratuitous decorative effects, which would violate the criteria laid out for the design of the model. There is a projected vector line that corresponds to each speaker which vibrates according to the frequency emitted by the latter. Increasing noise and distortion are reflected in the visuals – the vibrating line becomes more jagged and as the soundscape becomes more saturated the luminosity of the visuals increases towards white. As some speakers (and the neurons they represent) stop working, the corresponding line ceases to vibrate and the multimedia environment converges to one speaker and one instance of the visual.

4.4. Apparatus

The installation is designed to adapt to different room sizes, from approximately 25 m^2 to 50 m^2 and over. The speaker array consists of 6 or 8 speakers (depending on room size) connected to a multi-channel audio interface. The cylindrical projection screen is made of highly reflective, opaque fabric mounted on a fiberglass ring. To cover the whole projection surface, two or three (depending on room size) projectors are arranged around the cylinder and operated simultaneously via a video expansion module. The audio interface and the video module are both stored inside the cylinder and controlled by a laptop, which streams the multi-channel audio and video data (Fig. 5).

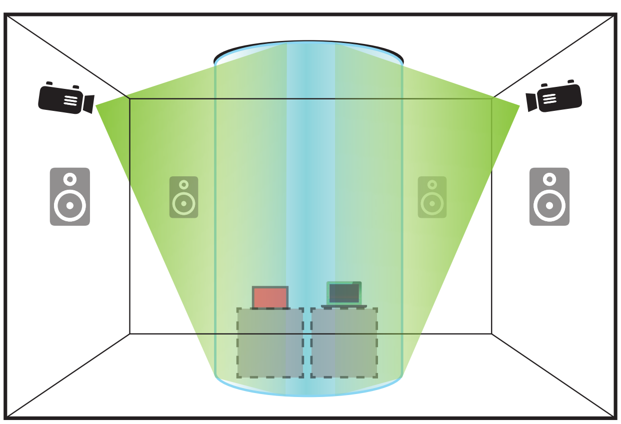

Figure 4: installation layout, front view.

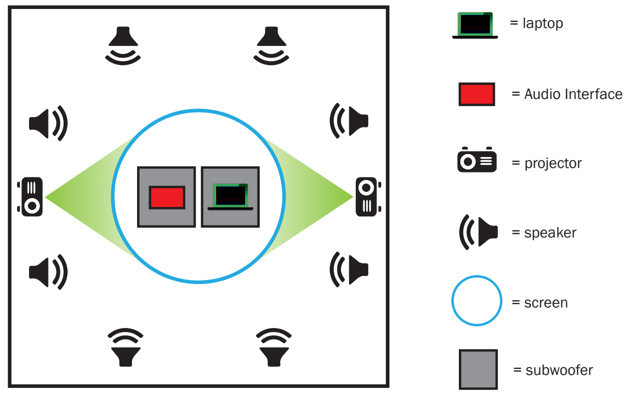

Figure 5: installation layout, floor plan.

Figure 6: *Unfolding | Clusters* installed in the UCLA Art|Sci Gallery, Los Angeles, California, United States.

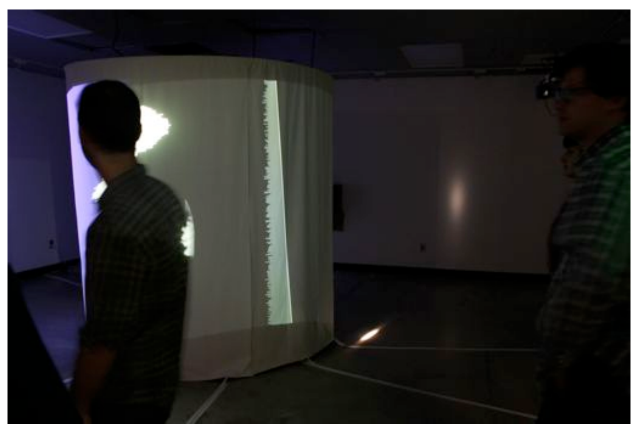

Figure 7: *Unfolding | Clusters* in progress, installed in the UCLA Art|Sci Gallery, Los Angeles, California, United States, June 2014.

5. CONCLUSION AND FUTURE WORK

This paper described the design and development of a multimedia installation which models ALS pathophysiology using music and visuals. The work was aimed at the greater public in order to rise awareness about the disease and its workings, therefore the criteria and constraints for the mapping of the NMR data were adopted in order to control the 'musicality' of the final result and make the piece accessible to a wider audience while, at the same time, remain faithful to the source data without trivializing the seriousness of the condition. The resulting musification employed modal scales, discreet durations and a rhythmic grid to create a surprisingly musical mapping that still retained the complexity of the source data. The sequences of the piece would be relatively difficult to perform for a human musician, even though they sound 'easy' and listenable to a non-musical audience.

Adopting a musification approach not only allowed for a more accessible musical result but also provided expressive solutions for modeling complex events critical for the development of the disease, such as the protein mutation which was represented by a tonal modulation.

Overall, the approach proved to satisfy the initial aim of designing an immersive installation to raise awareness about scientific facts related to ALS and engaging a casual audience. At the premiere no attempt was made to gather formal feedback from the audience. However there are three planned performances in the UK at the time of writing. These performances will be filmed and audience members will be interviewed in collaboration with UK-based MND charities to collect feedback about the work. Future work could usefully be directed towards enriching the timbral variety of the installation, possibly by gathering new data for mapping sound synthesis parameters or timbre morphing.

Additional data mapping could also be useful to further develop the visualisation, which was purposely kept minimalistic in order to avoid unjustifiable decorative effects. A sensible use of colours, for example, might be helpful to further aid the communication of the underlying complex events in a multimodal fashion.

Also, it has been observed that ALS may have many different causes and SOD1 may not be the only protein involved in the progress of the disease [12]. Therefore, it would be interesting to model other possible forms of ALS and develop a stochastic system that determines different progressions of the piece based on the probability of different forms of ALS to occur.

6. ACKNOWLEDGMENTS

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7. REFERENCES

[1] T. Hermann, A. Hunt, and J. G. Neuhoff, *The sonification handbook*. Logos Verlag, 2011.

[2] S. Barrass and G. Kramer, "Using sonification," *Multimed. Syst.*, vol. 7, no. 1, pp. 23–31, 1999.

[3] P. Toharia, J. Morales, O. Juan, I. Fernaud, A. Rodríguez, and J. DeFelipe, "Musical Representation of Dendritic Spine Distribution: A New Exploratory Tool," *Neuroinformatics*, pp. 1–13, Jan. 2014.

[4] G. I. Mihalas, S. Paralescu, N. Mirica, D. Muntean, M. Hancu, A. TUDOR, and M. ANDOR, "Sonic Representation of Information: Application for Heart Rate Analysis," in *Proceedings MIE*, 2012.

[5] E. Jovanov, D. Starcevic, A. Marsh, Z. Obrenovic, V. Radivojevic, and A. Samardzic, "Multi modal viewer for telemedical applications," in *Engineering in Medicine and Biology Society, 1998. Proceedings of the 20th Annual International Conference of the IEEE*, 1998, vol. 3, pp. 1254–1257.

[6] P. Vickers, "Sonification for process monitoring," in T. Hermann, A. Hunt, and J. G. Neuhoff (Eds.), *The Sonification Handbook.* Logos Verlag, 2011.

[7] D. W. Cleveland and J. D. Rothstein, "From Charcot to Lou Gehrig: deciphering selective motor neuron death in ALS," *Nat. Rev. Neurosci.*, vol. 2, no. 11, pp. 806–819, Nov. 2001.

[8] J. M. Ravits and A. R. La Spada, "ALS motor phenotype heterogeneity, focality, and spread: deconstructing motor neuron degeneration," *Neurology*, vol. 73, no. 10, pp. 805–811, Sep. 2009.

[9] G. Liu, M. Fiala, M. T. Mizwicki, J. Sayre, L. Magpantay, A. Siani, M. Mahanian, M. Chattopadhyay, A. L. Cava, and M. Wiedau-Pazos, "Neuronal phagocytosis by inflammatory macrophages in ALS spinal cord: inhibition of inflammation by resolvin D1," *Am. J. Neurodegener. Dis.*, vol. 1, no. 1, pp. 60–74, Mar. 2012.

[10] R. L. Redler and N. V. Dokholyan, "The Complex Molecular Biology of Amyotrophic Lateral Sclerosis (ALS)," *Prog. Mol. Biol. Transl. Sci.*, vol. 107, pp. 215–262, 2012.

[11] L. Banci, I. Bertini, M. Boca, V. Calderone, F. Cantini, S. Girotto, and M. Vieru, "Structural and dynamic aspects related to oligomerization of apo SOD1 and its mutants," *Proc. Natl. Acad. Sci.*, vol. 106, no. 17, pp. 6980–6985, Apr. 2009.

[12] W. Robberecht and T. Philips, "The changing scene of amyotrophic lateral sclerosis," *Nat. Rev. Neurosci.*, vol. 14, no. 4, pp. 248–264, Apr. 2013.

[13] E. L. Ulrich, H. Akutsu, J. F. Doreleijers, Y. Harano, Y. E. Ioannidis, J. Lin, M. Livny, S. Mading, D. Maziuk, Z. Miller, E. Nakatani, C. F. Schulte, D. E. Tolmie, R. K. Wenger, H. Yao, and J. L. Markley, "BioMagResBank," *Nucleic Acids Res.*, vol. 36, no. suppl 1, pp. D402–D408, Jan. 2008.

[14] A. Kowalsky and M. Cohn, "Application of Nuclear Magnetic Resonance in Biochemistry," *Annu. Rev. Biochem.*, vol. 33, no. 1, pp. 481–518, 1964.

[15] Y. Mrabet, *Structure générale d'un acide aminé.* 2007.

[16] K. Teilum, M. H. Smith, E. Schulz, L. C. Christensen, G. Solomentsev, M. Oliveberg, and M. Akke, "Transient structural distortion of metal-free Cu/Zn superoxide dismutase triggers aberrant oligomerization," *Proc. Natl. Acad. Sci. U. S. A.*, vol. 106, no. 43, pp. 18273–18278, Oct. 2009.

[17] F. Ding and N. V. Dokholyan, "Dynamical roles of metal ions and the disulfide bond in Cu, Zn superoxide dismutase folding and aggregation," *Proc. Natl. Acad. Sci. U. S. A.*, vol. 105, no. 50, pp. 19696–19701, Dec. 2008.

SOUND AND MUSIC IN INTERACTIVE SONIFICATION: A NOVEL WAY TO COMMUNICATE THE HEALTH RISKS OF ALCOHOL TO YOUNG PEOPLE

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ABSTRACT

Sonification designs have been increasingly used to complement data presentation and exploration in various disciplines. In medical research they have been applied as an aid for analysis and diagnosis, disease treatment, to assist visually impaired patients, and in physiotherapy. Interactive sonification as a communication channel has the potential to be used to describe health risk data to a range of audiences. The novelty of this approach, its interactive nature and ability to be combined with music may provide an effective alternative to the more dominant visual strategies (i.e. graphs, pie charts etc.), particularly when communicating with young people. In this project *Using Sonification to COmmunicate public health Risk data* (SCORe) we plan to test the role of sound, music and interactive sonification to communicate vital health risk information associated with alcohol consumption to young people.

1. INTRODUCTION

1.1. Alcohol misuse prevention

Health education programmes to fight alcohol misuse have proliferated in the last decades [1, 2]. This, however, has not significantly reduced alcohol consumption behaviors in young people [3, 4]. In fact, studies have indicated that those young people who drink alcohol, consume more than in previous years [5], which is likely to increase the incidence of serious consequences for individuals and society as a whole [6-8]. One of the major public health concerns regarding the misuse of alcohol in young people is binge drinking [9]. Binge drinking, which refers to consumption of eight or more units of alcohol in a single session for men and six or more for women [10], may lead to alcohol dependence [9], other substance abuse [11], crime, violence [12, 13], school problems [14], risky sexual behaviors [15, 16], as well as serious long-term health consequences, e.g. cancer [17], cardiovascular [18] or mental disorders [13]. Given the inadequacy of the presently available prevention measures, new ways of alcohol misuse prevention in young people need to be proposed urgently to remedy the problem. Communication through sound may be one such strategy.

1.2. Challenges of risk communication

The primary goal of any communication strategy for health risk situations (situations which are likely to be unusual and to have a considerable potential for both short and long-term damage) is to provide people with meaningful, accurate and timely information in order to influence decision-making and to promote behavioral changes. Effective communication of risk relies on clearly stated objectives (which are continuously monitored and reviewed); accessible general assessment of the risk; a message that is clear and understandable by the public; as well as an explanation of the complexities and uncertainties of a particular risk [19]. Research has indicated that even in ideal conditions a significant proportion of the communicated information is not remembered, can be misremembered, or even misinterpreted [20].

There are a number of factors that affect risk communication. One of them is risk perception [21]. People's risk perception is usually conditioned by their beliefs about antecedents of an issue, whether it is voluntary or involuntary, and its consequences [20]. Considering their options, people usually employ heuristics and biases [22], such as *optimistic bias* (or *unrealistic optimism*) which causes the person to believe that they are not at risk, or that the probability of a particular threat is low [21, 23]. Understanding the risk depends also on people's ability to foresee or imagine the situation in which they experience the problem [20].

Another challenge in communication of risk is the way people react to it. Quite often people's reaction towards risk messages is defensive. Gerrard, Gibbons, Reis-Bergen [24] indicated that this scenario of reaction to the risk communication is particularly true if the message implies people's past or present unhealthy or unwise behavior. Moreover, decisions influenced by the risk communication are not only calculated rationally as there are also emotional and social components that influence them [25].

Effective communication of health risk information also depends on a degree of people's numeracy necessary to understand risk messages. It has been indicated that individuals with a low level of numeracy have difficulties with comprehension of risk comparison information [26]. For instance, the experiment conducted by Yamagishi [27] showed that death rates of 1,289 out of 10,000 were perceived as higher than rates of 24.14 out of 100. However, even though the use of qualitative expressions for the quantitative values in communication (i.e. frequencies and rates of occurrence) may carry the risk of underestimation and potential misinterpretation [28], the use of qualitative expressions can improve understanding of quantitative statements in health communication, particularly by people with low numeracy skills [22] and thus, opting for qualitative messages or a combination of quantitative and qualitative messages may make communication more effective. One of the integral approaches to effective health risk communication is based on the assumption that an audience is not a homogenous group (i.e. people have different interests, values, levels of education, intelligence, understanding and culture) [29]. Consequently, information as well as communication channels should be adjusted to the particular audience's characteristics and when a specific subgroup of the audience has been identified (i.e. *audience segmentation*), a comprehensive communication strategy can be developed [29, 30].

1.3. Channels of communication

A body of research on communication strategies has indicated that mass media interventions (such as television, radio, newspapers, outdoor media) alone or in combination with other preventive programs can significantly influence the health behavior of mass populations [31]. Entertainment education, through different forms of entertainment such as pre-developed programs (e.g. soap operas, popular music, theatre performances and books) or inclusion of health messages into existing programs, can influence people's awareness and behavior [31]. Visual aids (i.e. billboards, posters, leaflets) are another channel of health risk communication. The literature review of the effects of visual and graphical displays conducted by Lipkus and Hollands [32] indicated that this method of communication has a potential to affect perception of a risk and to eventually influence audience's behavior. Garcia-Retamero and Cokely [33], however, indicated that not all visual solutions are equally effective in conveying the risk information. In fact, the effectiveness of the visual displays depends on the accuracy and clarity of the portrayed information. Given that visual communication relies heavily on numeracy (as indicated earlier), it is not accessible to all members of the society and, thus, other channels of communication need to be explored.

1.4. Communication through sound

1.4.1. Sonification

Visual methods (i.e. graphs, pie charts etc.) have largely dominated presentation of numerical data. However, one of the novel approaches used in communication of data has been through the use of sonification design. Sonification is a subtype of the auditory display that uses non-speech audio to convey information [34].

Sonification designs have been increasingly used to complement data presentation and exploration in various disciplines. In medical research, they have been applied as an aid for analysis and diagnosis [35], potential disease treatment [36], help for visually impairment patients [37], and in physiotherapy [38]. A systematic search has identified no studies on the use of sonification design to communicate health risks data.

As a communication medium, in portraying health risks particularly to young people, interactive sonification features several potential advantages over the dominating visual strategies (i.e. graphs, pie charts etc.). These include its novelty, which can attract attention of young people; interactivity, which allows for exploration of the messages related to alcohol consumption; reliability on technology, which is heavily used and favored by young people [39]; ability to combine it with music (supporting sound design of sonification), which many young people are interested in [40, 41]; and finally, lack of reliance on numeracy, which often is necessary to comprehend at least some risk messages. Therefore, studies exploring sound communication interventions may be an important step forward in designing future prevention campaigns to manage risk in young people.

1.4.2. Film music

Despite its inherent ambiguity, music as well as sonification can serve as a powerful communication channel, allowing people to share emotions, intentions and meanings [42, 43]. Film music can work particularly well in this respect, because it is designed not only to support film narration, providing an emotional amplification, but also to communicate messages vital for the narration [44, 45]. For instance, music informs the audience about the genre of the film (i.e. whether it is an action adventure or a psychological drama), and the general mood of the production (i.e. whether the on-screen events are supposed to be perceived as disturbing or comforting) [45]. Music can also provide insights of the characters' internal feelings, direct the audiences' attention to the specific event on the screen while acting as an agent of continuity for the whole story [46-49].

Even though the overall sound design of a film soundtrack may add an additional layer of narrative articulation to a story, of all the film soundtrack components, music has perhaps the greatest power of influencing perception of a film. This influence is often assumed and taken for granted [50], however, in the recent decades, experimental research in film music has shown music's significant role in supporting the narration as a communication channel and emotional signifier. For instance, experiments have confirmed that music has a stronger influence on the overall mood of the film than behavior of the film characters [51]; that music helps to interpret film character's emotions and whether the audience like or dislike them [52]; that music can alter the meaning of the film directly [53]; that the musical soundtrack influences whether we recall the events portrayed in the film [54].The examples of the experimental research done on the influence of music on the understanding and interpretation of film content point to the conclusion that film music does indeed have the ability to impact and modify visual information and may act as a communication channel.

2. THE PROPOSED EXPERIMENT

In our project, we plan to compare the effectiveness of a traditional visual display of health risk communication (a slide presentation with text, images and various graphs) to a presentation augmented by sound (music and sonification) and interaction.

As it is unlikely that the sound will substitute visual representation of data as a universal mode of data representation, we decided to first explore the augmentation of a visual display rather than compare a visual-only to a sound-only display. It is hypothesized that a combination of sound design (sonification) and film music methods within an interactive sonification design will increase the effectiveness, accuracy and attractiveness of the overall presentation.

The experiment will take place at the Theatre, Film and Television Department at the University of York, in October-November 2014. The experiment will be built around a visual presentation, which contains selected data related to alcohol consumption by young people in the European Union and in the UK, and alcohol-related risks.

Participants will be randomly allocated to three groups: 1) Group 1 will receive visual presentation of the selected data; 2) Group 2 will receive the same visual presentation supported by sonification (i.e. sonification of selected data variables) and music composed to support communication of selected variables; 3) Group 3 will receive the same visual presentation as the pervious groups, augmented by sonification, music and interaction.

2.1. Sonification component

The sound design of the sonification will be created to best complement the content of the slides on alcohol health risks. A variety of sonification techniques will be utilized such as parameter mapping, in which data points directly drive selected sound synthesis parameters [55], model-based sonification, in which a data set is seen as a 'material' or 'object' that can produce digital sound when the user interacts with it [56], auditory icons and earcons, in which sound samples are associated to particular data points through a metaphorical or abstract association [57, 58]. For example, the slide dedicated to short-term consequences of alcohol use may be illustrated by sounds emphasizing the impact of alcohol on different organs and senses, while a traditional two-dimensional graph could be illustrated using a parameter-mapping approach.

Special attention will be paid to integrate the sonification sound design with the music so that, like in a film, music and sound design can communicate simultaneously complementary messages (i.e. the emotional and metaphorical content as well as the more literal information).

2.2. Music component

Due to the exposure of young people to media music (i.e. theatre, film, TV, video games), the language of film music used in this experiment is widely accepted and understood and lends itself well for application in communication strategies. The music component of the display (or intervention) will thus be based on functions of film/media music, which were experimentally tested and confirmed by cognitive psychology and musicology researchers as effective in communicating information and improving the interpretation of the message [50, 51, 53, 54].

It is assumed that the music will be used in two distinctive ways: 1) as an overall support for the sonification, creating an emotional context; and 2) an interactive accompaniment linked to sonification responding to participants' actions.

In order to support the interactive design of the sonification, the flexibility of the musical structure will be an essential component. In film, in which non-linear editing practices often collide with the linearity of the music, application of modular structures has provided the flexibility needed during composition (fitting music to the film structure) and music editing [59]. For this reason, in our experiment, the music, supported by computer technology, will feature non-linear structures built from interchangeable modular components. Modular components will be created and edited in Logic Pro and Pro Tools musical applications whereas the final form of the musical accompaniment and the sonifications will be executed through areal-time processing software such as Max/MSP and Ableton Live 9.

In terms of the music style, it has been agreed, that the music will explore subtler sound-design approaches to music rather than the mainstream Hollywood approach. There are several reasons to pursue this particular creative direction. Firstly, it will allow for a comprehensive blend of the musical accompaniment with the sound design of the sonification (i.e. minimizing the danger that sonic elements will compete for the participants' attention). Secondly, Hollywood musical idiom, in particular the pompous action/adventure style, which is ubiquitous in countless films, TV programs, and video games, has significantly lost its impact, becoming sometimes too clichéd for the contemporary audiences. Additionally, complex orchestration, and emphasis on certain instruments, e.g. brass instruments or percussion instruments, frequent key changes, and complex rhythms may negatively impact attention of the user and, consequently, their comprehension of the portrayed messages. However, we intend to vary the musical stylistic approaches during the presentation in order to investigate which one is the most effective in supporting communication of the intended messages. Thirdly, this presentation, although it has storytelling elements, is radically different from a film-like narration, and therefore the narrative coding, which is characteristic of the mainstream approach, cannot be applied in the same way here as in film. Nevertheless, the overall approach will be "cinematic", i.e. the visual presentation will provide the main layer of information, and the sonified data will be almost treated as dialogue in a film, i.e. directly communicating specific messages, whereas the musical component will provide emotional commentary and support for the "image" (visuals) and "dialogue" (sonification). Finally, similarly to the film scenario, music in this experiment should remain in the background and be absorbed by the participants of the experiment on the subconscious level.

2.3 Interaction component

Interaction plays an important role in facilitating users' engagement with presentations of data [60]. Sound and music have their own intrinsic relationship with time therefore, in order to put the user in control of this relationship, we need to allow them the possibility of interacting with the way in which sound and music are played back. In this project we will provide different ways of interacting with music and sonifications which will include: 1) repeated listening, 2) single and simultaneous listening of data streams, 3) single data point listening, 4) choice of listening order, and 5) variation of speed (e.g. the user will be able to slow a sonification down).

During the SoniHED conference we will present an example of the visual presentation augmented by the sonification of the data and musical underscore.

3. CONCLUSION

To conclude, taking into account the potential advantages of interactive sonification in facilitating communication, our group has proposed to experimentally test the role of sound and music within interactive sonification to portray vital health risk data associated with alcohol consumption in young people. Film music was selected as an addition to interactive sonification as it may support communication but also because it is widely accepted and understood by young people. In addition, as sonification and music are both elements of the presentation 'soundtrack', they can complement each other influencing the overall aesthetics of the design, which in turn may increase enjoybility and reduce fatigue of the potential user.

4. ACKNOLEDGEMNTS

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5. REFERENCES

[1] P. Finn and J. Brown, "Risks Entailed in Teenage Intoxication as Perceived by Junior and Senior High School Students," *Journal of Youth and Adolescence,* vol. 10, 1981.

[2] E. R. Weitzman, T. F. Nelson, H. Lee, and H. Wechsler, "Reducing Drinking and Related Harms in College Evaluation of the "A Matter of Degree" Program," *American Journal of Preventive Medicine,* vol. 27, 2004.

[3] D. R. Foxcroft, D. Lister-Sharp, and G. Lowe, "Alcohol misuse prevention for young people: a systematic review reveals methodological concerns and lack of reliable evidence of effectiveness," *Addiction,* vol. 92, pp. 531-537, 1997.

[4] C. S. Stockley, "The effectiveness of strategies such as health warning labels to reduce alcohol-related harms — an Australian perspective," *International Journal of Drug Policy,* vol. 12, pp. 153–166, 2001.

[5] E. Fuller, Ed., *Smoking, Drinking and Drug Use Among Young People in England in 2012*. London: NHS Information Centre for Health and Social Care, 2012, p.^pp. Pages.

[6] F. M. Gore, P. J. N. Bloem, G. C. Patton, J. Ferguson, V. Joseph, C. Co ey, *et al.*, "Global burden of disease in young people aged 10–24 years: a systematic analysis " *Lancet,* vol. 377, pp. 2093-2102, 2011.

[7] J. McCambridge, J. McAlaney, and R. Rowe, "Adult Consequences of Late Adolescent Alcohol Consumption: A Systematic Review of Cohort Studies," *PLoS Medicine,* vol. 8, 2011.

[8] J. Rehm, C. Mathers, S. Popova, M. Thavorncharoensap, Y. Teerawattananon, and J. Patra, "Global burden of disease and injury and economic cost attributable to alcohol use and alcohol-use disorders," *Lancet,* vol. 373, pp. 2223–33, 2009.

[9] R. M. Viner and B. J. Taylor, "Adult outcomes of binge drinking in adolescence: findings from a UK national birth cohort," *Epidemiol Community Health,* vol. 61, pp. 902–907, 2007.

[10] NHS. (2012, 12.04.2014). *Binge Drinking*. Available: http://www.nhs.uk/Livewell/alcohol/Pages/Bingedrinking.aspx

[11] G. Hagger-Johnson, S. Bell, A. Britton, N. Cable, M. Conner, D. B. O'Connor, *et al.*, "Cigarette smoking and alcohol drinking in a representative sample of English school pupils: Cross-sectional and longitudinal associations," *Preventive Medicine 56 (2013) 304–308,* vol. Preventive Medicine, pp. 304–308, 2013.

[12] J. Lindsay, "The gendered trouble with alcohol: Young people managing alcohol related violence," *International Journal of Drug Policy,* vol. 23, pp. 236– 241, 2011.

[13] D. Newbury-Birch, E. Gilvarry, P. McArdle, V. Ramesh, S. Stewart, J. Walker, *et al.*, "Impact of Alcohol Consumption on Young People: A Review of Reviews," *Institute of Health and Society at Newcastle University,* 2008.

[14] M. R. Hayatbakhsh, J. M. Najman, W. Bor, A. Clavarino, and R. Alati, "School performance and alcohol use problems in early adulthood: a longitudinal study," *Alcohol,* vol. 45, pp. 701-709, 2011.

[15] A. Parkes, D. Wight, M. Henderson, and G. Hart, "Explaining Associations between Adolescent Substance Use and Condom Use," *Journal of Adolescent Health,* vol. 40, pp. 180.e1–180.e18, 2007.

[16] A. Stueve and L. N. O'Donnell, "Early Alcohol Initiation and Subsequent Sexual and Alcohol Risk Behaviors Among Urban Youths," *American Journal of Public Health,* vol. 95, pp. 887-893, 2005.

[17] P. Boffetta, "Alcohol and Cancer," *Lancet Oncol,* vol. 7, pp. 149–56, 2006.

[18] D. Davitson, "Cardiovascular Effects of Alcohol," *West J Med 1989,* vol. 151, pp. 430-439, 1998.

[19] HealthProtectionNetwork, "Communicating with the Public About Health Risks," Health Protection Network, Glasgow2008.

[20] A. J. Rothman and M. T. Kiviniemi, "Journal of the National Cancer Institute Monographs," *Journal of the National Cancer Institute Monographs No. 25, 1999,* 1999.
[21] E. Aakko, "Risk Communication, Risk Perception, and Public Health," *Wisconsin Medical Journal,* vol. 103, pp. 25-27, 2004.
[22] E. Maibach and D. R. Holtgrave, "Advences in Public Health Communication," *Annual Review of Public Health,* vol. 16, pp. 219-38, 1995.
[23] N. D. Weinstein, "Unrealistic optimism about future life events," *Journal of Personality and Social Psychology,* vol. 39, pp. 806–820, 1980.
[24] M. Gerrard, F. X. Gibbons, and M. Reis-Bergan, "The Effect of Risk Communication on Risk Perceptions: the Significance of Individual Differences," *Journal of the National Cancer Institute Monographs,* vol. 25, pp. 94-100, 1999.
[25] B. Fischhoff, A. Bostrom, and M. J. Quadrel, "Risk Perception And Communication," *Annu. Rev. Publ. Health,* vol. 14, pp. 183-203, 1993.
[26] C. Keller and M. Siegrist, "Effect of Risk Communication Formats on Risk Perception Depending on Numeracy," *Medical Decision Making,* vol. 29, pp. 483-490, 2009.
[27] K. Yamagishi, "When a 12.86% Mortality is More Dangerous than 24.14% Implications for Risk Communication," *Applied Cognitive Psychology,* vol. 11, p. 495±506, 1997.
[28] F. Mosteller and C. Youtz, "Quantifying Probabilistic Expressions," *Statistical Science,* vol. 5, pp. 1-158, 1990.
[29] M. W. Kreuter and S. McClure, M., "The Role of Culture in Health Communication," *Annual Review of Public Health,* vol. 25, pp. 439-455, 2004.
[30] M. D. Slater, "Theory and Method in Health Audience Segmentation," *Journal of Health Communication: International Perspectives,* vol. 1, pp. 267-284, 1996.
[31] L. C. Abroms and E. W. Maibach, "The effectiveness of mass communication to change public behavior," *Annu Rev Public Health.,* vol. 29, pp. 219-234, 2008.
[32] I. M. Lipkus and J. G. Hollands, "The Visual Communication of Risk," *Journal of the National Cancer Institute Monographs,* pp. 149-163, 1999.
[33] R. Garcia-Retamero and E. T. Cokely, "Communicating health risks with visual aids," *Current Directions in Psychological Science* vol. 22, p. 392−399, 2013.
[34] G. Kramer, B. N. Walker, T. Bonebright, P. Cook, J. Flowers, and N. Miner, "The Sonification Report: Status of the Field and Research Agenda. Report prepared for the National Science Foundation by members of the International Community for Auditory Display.," NM: International Community for Auditory Display (ICAD), Santa Fe1999.
[35] A. D. N. Edwards, A. Hunt, G. Hines, V. Jackson, A. Podvoiskis, R. Roseblade*, et al.*, "Sonification Strategies For Examination Of Biological Cells," presented at the The 16th International Conference on Auditory Display, Washington, 2010.
[36] T. Hinterberger and G. Baier, "Parametric Orchestral Sonification of EEG in Real Time," *IEEE,* vol. 12, pp. 70 - 79, 2005.
[37] M. Berndt-Schreiber, W. Lesiński, and Ł. Trzciałkowski, "Image Data Sonification In Medicine," *Journal of Medical Informatics & Technologies,* vol. 12, pp. 177-182, 2008.
[38] K. Vogt, D. Pirrò, I. Kobenz, R. Höldrich, and G. Eckel, "PhysioSonic - Evaluated Movement Sonification as Auditory Feedback in Physiotherapy," presented at the ICAD, Washington, USA, 2010.
[39] C. Clark and G. Dugdale, "Young People's Writing: Attitudes, behaviour and the role of technology," National Literacy Trust, London2009.
[40] A. C. North, D. J. Hargreaves, and S. A. O'Neill, "The importance of music to adolescents," *British Journal of Educational Psychology,* vol. 70, pp. 255-272, 2000.
[41] P. Nuttall, "Thank you for the music? The role and significance of music for adolescents," *Young Consumers,* vol. 9, pp. 104-111, 2007.
[42] I. Cross, "Music and meaning, ambiguity and evolution," in *Musical Communication*, D. Miell, R. MacDonald, and D. J. Hargreaves, Eds., ed New York: Oxford University Press, 2005, pp. 27-61.
[43] D. J. Hargreaves, R. MacDonald, and D. Miell, "How do people communicate using music?," in *Musical Communication*, D. Miell, R. MacDonald, and D. J. Hargreaves, Eds., ed New York: Oxford University Press, 2005, pp. 2-25.
[44] M. Chion, *Audio-Vision: Sound on Screen*. New York: Columbia University Press, 1994.
[45] S. D. Lipscomb and D. E. Tolchinsky, "The Role of Music communication in Cinema," in *Music Communication*, D. Miell, R. MacDonald, and D. J. Hargreaves, Eds., ed Oxford: Oxford University Press, 2005, pp. 382-.
[46] R. Davis, *Complete Guide to Film Scoring*. Boston: Berklee Press, 1999.
[47] C. Gorbman, *Unheard Melodies: Narrative Film Music* Bloomington: Indiana University Press, 1987.
[48] Z. Lissa, *Estetyka muzyki filmowej*. Kraków: PWM, 1964.
[49] R. M. Prendergast, *Film Music: A Neglected Art: A Critical Study of Film Music in Films*. New York: W.W. Norton & Company, 1992.
[50] A. J. Cohen, "Associationism and Musical Soundtrack Phenomena," *Contemporary Music Review,* vol. 9, pp. 163-178, 1993.
[51] S. Holicki and H. B. Brosius, "Der EinfluB von Filmmusik und nonverbalem Verhalten der Akteure auf die Wahrnehmung und Interpretion einer Filmhandlung.," *Rundfunk und Fernsehen,* vol. 36, pp. 189-206, 1988.
[52] S. L. Tan, M. P. Spackman, and M. A. Bezdek, "Viewers' Interpretations of Film Characters'

Emotions: Effects of Presenting Film Music Before or After a Character is Shown," *Music Perception: An Interdisciplinary Journal,* vol. 25, pp. 135-152, 2007.

[53] S. Marshall and A. J. Cohen, "Effects of Musical Soundtracks on Attitudes toward Animated Geometric Figures," *Music Perception,* vol. 6, pp. 95-112, 1988.

[54] M. G. Boltz, M. Schulkind, and S. Kantra, "Effects of Background Music on the Remembering of Film Events," *Memory & Cognition,* vol. 19, pp. 593-606, 1991.

[55] F. Grond and J. Berger, "Parameter Mapping Sonification," in *The Sonification Handbook*, T. Hermann, A. Hunt, and J. G. Neuhoff, Eds., ed Berlin: Logos Verlag Berlin GmbH, 2011, pp. 363-398.

[56] T. Hermann, "Model-Based Sonification," in *The Sonification Handbook*, T. Hermann, A. Hunt, and J. G. Neuhoff, Eds., ed Berlin: Logos Verlag Berlin GmbH, 2011, pp. 499-430.

[57] E. Brazil and M. Fernström, "Auditory Icons," in *The Sonification Handbook*, T. Hermann, A. Hunt, and J. G. Neuhoff, Eds., ed Berlin: Logos Verlag Berlin GmbH, 2011, pp. 325-338.

[58] D. McGookin and S. Brewster, "Earcons," in *The Sonification Handbook*, T. Hermann, A. Hunt, and J. G. Neuhoff, Eds., ed Berlin: Logos Verlag Berlin GmbH, 2011, pp. 339-362.

[59] B. P. Walus, "Modular Structures in Film Music: The Answer To Synchronization Problems?," *Journal of Film Music,* vol. 6, pp. 125-154, 2011.

[60] A. Hunt and T. Hermann, "Interactive sonification," in *The Sonification Handbook*, T. Hermann, A. Hunt, and J. Neuhoff, G., Eds., ed Berlin: Logos Verlag Berlin GmbH, 2011, pp. 325-338.

ECOSONIC: TOWARDS AN AUDITORY DISPLAY SUPPORTING A FUEL-EFFICIENT DRIVING STYLE

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ABSTRACT

In order to support drivers in adopting a more fuel efficient driving style, there currently exists a range of fuel economy displays, providing drivers feedback on instantaneous and long-term fuel consumption. While these displays rely almost completely on visual components for conveying relevant information, we argue that there are significant benefits in using auditory interfaces for providing feedback while driving,.
We review existing literature and discuss various design strategies for auditory displays that are applicable for supporting a fuel-efficient driving style. Exploring one of these design strategies, we furthermore introduce several prototypical sonification designs.

1. INTRODUCTION

Greenhouse house gas emissions resulting from the energy consumption and pollution from conventional and electric cars is still a major global issue in spite of attempts to curb such emissions through technological improvements and regulation.

Based on the observation that an aggressive driving style can effectively cancel out the positive effects of an efficient engine, manufacturers install vehicles with visual fuel efficiency displays designed to give feedback on instantaneous and long-term fuel economy in order to influence or support drivers to adopt a more fuel efficient driving style.
A visual display, however, is prone to distracting a driver from their main task, i.e. safely operating and steering the car. This is particularly true for a fuel efficiency display: It is precisely in those situations, when drivers should keep their eyes on the road (e.g. when quickly accelerating) that the information from such a display becomes most relevant.
Nevertheless, eco-driving is a highly promising way for car drivers to reduce both fuel consumption and carbon dioxide (CO_2) emission: Vandenbergh et al. have estimated that 32% to 41% of the total CO_2emissions of the United States are directly caused by individual behavior, including household energy use and, most prominently, personal transportation [1]. Based on these findings, Barkenbus recently surveyed a range of possible measures to reduce greenhouse gas emissions for individual transportation, including the use of public transportation, carpooling, and the purchase of more fuel efficient vehicles [2].

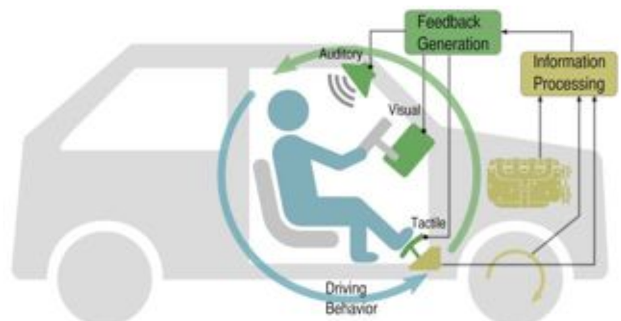

Figure 1: Feedback loop. The driver controls the (acceleration of the) car, which in turn controls the feedback display. The feedback is perceived by the driver and gives supports in improving driving behavior.

Apart from these measures he argues that a more efficient operation of vehicles is an often overlooked opportunity with a potentially large impact on CO_2 emissions. Among a range of interventions to support eco-driving – including public education policies, economic incentives, and regulatory initiatives – Barkenbus specifically recommends the use of feedback systems to help drivers gain an awareness of their fuel consumption and eco-driving performance in dependence of their respective driving behavior [2].
With the uptake of hybrid and electric cars, this aspect is becoming increasingly important, as these cars are far more sensitive to driving behavior than those with a combustion engine. While there are several studies showing that eco-driving has the potential to reduce CO_2 emissions by approximately 10% already for conventional cars [3,4], aggressive driving can cause the fuel efficiency of hybrid vehicles to decrease by more than 30% [5].
Furthermore, it has been shown that eco-driving contributes to a safer driving style as it encourages a steady and moderate speed as well as gentle acceleration. On the other hand, first research results indicate that (visual) fuel economy driver interfaces may lead to a distraction that has a negative impact not only in terms of driving performance [6], but also relating to safety issues [7].

In this paper, we first review existing eco-driving systems, which leads us to propose sonification-based systems as solving

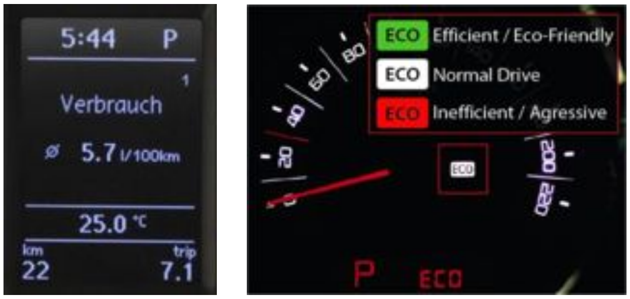

Figure 2: (a) Basic display of instantaneous fuel consumption, measured in L/100km [8]. (b) Eco-driving indicator, which is integrated into the speedometer and can differentiate between three levels of fuel economy [6].

major problems in Section 2.4. We propose various design strategies for auditory-based eco-driving-systems in Section 3 and present several prototypical sonification designs in Section 4.

2. OVERVIEW OF EXISTING ECO-DRIVING SYSTEMS

Driven partly by developments in the hybrid-sector, there currently exists a number of commercially available eco-driving systems, which help the driver in achieving a fuel-economic driving style.

2.1. Visual Online Feedback of fuel consumption

The majority of the available eco-driving systems provide feedback to the driver on the vehicle's fuel economy and thus allow the driver to gain an awareness of how this variable is affected by a specific driving behavior. The devices are usually mounted in the dashboard, allowing the driver to get immediate feedback *while* driving.

A very basic example for a fuel economy display can be seen in Figure 2(a), which shows the current consumption as a plain number, typically in terms of MPG for the United States, and either L/100km or km/L for other parts of the world, depending on cultural preference. A slightly more advanced display is shown in Figure 2(b), which differentiates between three levels of fuel economy: Normal, Inefficient, and Eco-Friendly. This simplified way of displaying levels of consumption allows the driver to more easily perceive this information, but obviously lacks in precision, which is also something that was criticized by study participants who were asked about such a display in a recent study of Lee et al. [6].

In addition to the instantaneous consumption, there are displays showing accumulated consumption, where information is aggregated over a longer period of time. This can either be a couple of minutes, one whole trip, or the time between fuel stops. Typically, consumption is averaged over the time period and displayed in a similar way to instantaneous consumption. A more complex form can be seen in Figure 3(a), which displays a quite detailed (but at the same time also more difficult to perceive) history of the consumption.

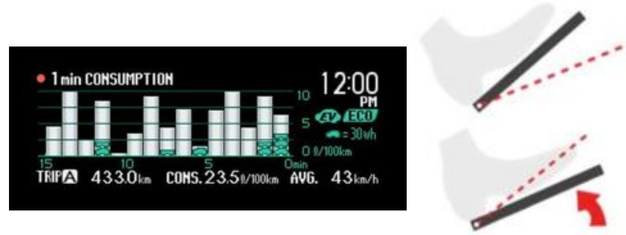

Figure 3 (a) Consumption monitor of the Toyota Prius [9]. This display offers a detailed view on the fuel consumption over the last 15 minutes. (b) Active acceleration pedal (Eco Pedal). When pressing the pedal beyond the dotted red line, the pedal actively exerts counter-pressure [10].

2.2. Offline Feedback

A second type of feedback can be seen in Figure 4. Here, driving behavior and consumption data is first being monitored and logged during operation of the car and recorded onto a flash drive. Later, the driver can download the data to a PC, where it is analyzed and presented to the user with an additional piece of software. An example of such a system is Fiat's eco:drive [11].

The analysis of the gathered data is somewhat more sophisticated than for online feedback systems, as the software takes into account not only fuel consumption and emissions, but also acceleration, breaking and gear shifting patterns and is able to suggest specific changes to the driving behavior [12].

The obvious disadvantages, however, are that the user is required (a) to dedicate extra time, and (b) to do it *outside* the vehicle for this feedback system to have any effect, i.e. the feedback is decontextualized, in time and place, from the act of driving the car.

Thus, while it may not be ideal for private use, it can be a great review tool for professional transport companies.

2.3. Haptic Feedback (Eco Pedal)

A third type of feedback exists in form of an active acceleration pedal (cp. Figure 3(b)). When being pressed down, the pedal can actively increase its resistance, which might either be related to the current speed limit [14] or the fuel consumption in order to avoid excessive and wasteful acceleration [15].

This form of feedback is certainly a promising direction of research and it seems to be effective in increasing the compliance with speed limits [16]. However, in a recent study that compared different types of feedback systems designed to support a fuel-efficient driving style, the concept of an eco pedal was rated significantly lower than other systems – both in terms of user acceptance and perceived usefulness [10].

Figure 4: Screenshot of the Fiat eco:drive software [13]. The software uses data that was captured while in the car and assesses various aspects of driving behavior.

2.4. The use of auditory feedback

To our best knowledge, there currently exists no system that uses auditory feedback as means to support the user in achieving an improved fuel economy.
We argue, however, that especially for the scenario of providing feedback *while driving*, there are significant and considerable benefits in using this modality:

- Research has suggested that in order to be most effective, feedback should be given as "close" to the respective action as possible [17]. The auditory channel is perfectly suited to make this possible, as the driver can actually perform the act of driving (with the hands on the steering wheel and the eyes on the road), and at the same time attend to the given feedback.
- Looking at specific driving behavior, it has been shown that braking and acceleration processes are crucial for determining fuel economy, which is also why feedback on fuel consumption would become of increased relevance in these situations. On the other hand, drivers would be ill-advised to shift their focus from what is happening on the street to a visual indicator of fuel consumption in the dashboard, as those situations are also highly critical in terms of safe driving. With auditory feedback, a driver can be "in the loop" concerning fuel consumption (cp. Figure 1), while at the same time keeping the eyes on the road.
- Finally, an auditory feedback system would be comparatively easy to install and implement, as it would basically require no additional hardware and can utilize the loudspeakers that are already installed in the vast majority of cars anyway.

3. Related work

By now, a multitude of studies clearly show a positive effect of eco-driving on fuel economy: Johansson et al., for example, evaluated, how the recommendations of eco-driving instructors influenced the driving behavior of 16 driving school teachers and found that both fuel consumption and the emission of carbon dioxide were reduced by an average of 10.9% as a result of the instructions [4]. Vangi et al. developed a method for automatically assessing driving behavior of bus drivers and found that economical driving can provide direct savings in fuel consumption of up to 25% [18].
Although the variance of found fuel efficiency improvements are rather large, they are in the majority of cases highly significant and warrant the effort to support eco-driving behavior for a broad range of people.

Manser et al. compared a broad selection of "fuel economy driver interface concepts" (FEDICs) in three different stages, including a usability study and a driving simulation evaluation [19]. Among other results, the authors found out that *simple* representations of fuel economy information were generally the most usable and that study participants also had a preference for those types of feedback, as compared to textual representations.
Also, they observed that, when using a (visual) FEDIC display, drivers made more glances away from the road, indicating that there are "potential safety implications due to FEDIC use".

While the majority of feedback displays use rather conventional methods of displaying fuel consumption, there are also more creative propositions, like for example in [29] (cp. Figure 5) where the curve of the speedometer needle displays the deviation from the most fuel efficient driving speed.

3.1. The importance of unobtrusiveness

Tulusan et al. analyzed, which aspects of eco-feedback systems are beneficial for drivers to accept them as meaningful support for achieving an efficient driving behavior [20].

They found that unobtrusive feedback systems were most preferable for the users and state that the car industry should "enhance and promote the notion of interaction cultivated between feedback technologies and drivers, firstly by developing unobtrusive systems, not posing additional workload and frustration to drivers and being seamlessly interweaved into driving".

In another study, Lee et al. evaluated a commercial eco-driving system [21] and found that the increased cognitive load might even lead to an *increased* fuel consumption in some circumstances [6].

3.2. Auditory displays

While auditory fuel economy displays are virtually non-existent in the commercial sector, there already has been (albeit very little) work within the sonification community:

Nees and Walker included the topic of energy conservation systems in a survey paper on auditory displays for in-vehicle technologies [22], and very recently Nees et al. reported on planned research on how to best use auditory displays in a fuel efficiency driver interface [23].

Figure 5. Curvy Speedometer [29]. The tip of the needle indicates the current speed of the car while its curvature indicates, how far the current speed is from the most fuel-efficient speed

4. DESIGN STRATEGIES FOR AN AUDITORY DISPLAY TO SUPPORT ECO-DRIVING

4.1. Direct sonification of current fuel consumption

This first conceptual approach to creating auditory displays to influence driver behavior is similar to the one for visual displays, i.e. to directly sonify the data on current fuel consumption. The design is based on a number of decisions, which are important for the system to be accepted. First, the sonification can be either continuous or event-based: For an event-based sonification, one then would have to decide, how and when a sound is triggered. This might simply be on each kilometer driven or on the expenditure of a specific amount of fuel. Another possibility could be the occurrence of a peak in fuel consumption or when the driver manages to achieve a comparatively good fuel economy. Ultimately, it must be decided, which sound is produced; if one should use, for example, auditory icons [30] or earcons [31] – and which ones would be appropriate.

For a continuous sonification, it must be decided, how the input data is mapped onto a specific characteristic, e.g. pitch, loudness, or brightness of a sound. This also introduces the question of polarity [25], i.e. if a rising fuel consumption should, for example, go along with a rising or falling pitch of a sound.

Finally, as it has been shown in user studies, it is crucial for the acceptance of a fuel economy display that it is rather unobtrusive. We propose to make use of the concept of *blended sonification* [26] in order to achieve this, i.e. to create a sonification that blends into the user's environment by working with pre-existing sounds – e.g. the sound of the engine – and manipulate (e.g. augment) this sound in a way that it conveys additional (fuel consumption) information.

4.2. Sonification of secondary parameters

Another design approach for an auditory fuel economy display is the sonification of specific aspects of driving that are known to significantly affect the fuel consumption.
One of these aspects is certainly the driver's braking behavior, which obviously has a direct impact on how much energy is wasted while driving. An auditory display could help in creating an awareness for the negative effects of too frequent or unnecessarily hard breaking, which can occur due to an aggressive or insufficiently anticipatory driving style.

4.3. Gamification

Creating an awareness for the car's fuel consumption and providing feedback on how it is affected by driving behavior is a necessary (or at least very important) part in achieving wide-spread adoption of eco-driving habits.
However, we also have to think about how to *motivate* drivers in achieving this goal over a longer period of time.

In the context of eco-driving, we propose to make use of an gamification-like approach in order to do so: Gamification is an emerging area of research, which deals with improving user experience and user engagement by using game elements in non-gaming contexts [27].

In contrast to a fuel economy display that neutrally conveys consumption data or even tries to point out situations where the driver is wasting energy,

a gamification approach emphasizes and reinforces the progress the driver makes towards a fuel-efficient driving style, e.g. by using virtual rewards like badges or achievement points.

To the best knowledge of the authors, the concepts of gamification have yet to be applied to an (exclusively) auditory display, which is most likely due to the fact that they have originated from a *video* game context and as such are naturally difficult to translate to an auditory display.

We argue, however, that this is a promising research direction, which would contribute both to increasing the driver's motivation and to improving the user acceptance for a fuel economy display, and we are currently working on a first concept of such an *auditory gamification display*.

4.4. Sonifying advanced support information

Another approach for supporting a fuel economic driving style with the help of an auditory display is to sonify more advanced support information, such as hints for speed reductions or stop signs.

Bär et al., for example, have proposed a system that can calculate – based on detailed information on the position of stop signs, speed limits and a height profile of the road – when to freewheel, i.e. when the driver can completely stop accelerating [28]. Similarly, Raubitschek et al. examined, how a driver can make use of predictive traffic light information [29].

We argue that in those safety-critical situations – i.e. when approaching a crossing or traffic lights – an auditory display is the best option to convey such support information.

4.5. Supporting specific qualities of driving

A final possibility for an auditory display to help to establish a fuel economic driving style for a broad range of people is by subliminally supporting a feeling of *safety* or *calm*, which in turn might have a positive effect on the driving style.
The hypothesis here is that such feelings will also lead to a calmer way of driving – just as for example a more sportive feeling would lead to a slightly more aggressive driving style.
Although this approach comprises a wider range of aspects of car-design, sound could play a major role in achieving such a feeling.

5. SONIFICATION DESIGN

The focus of this paper is to approach eco-feedback systems from a conceptual side and to propose and elaborate on design directions for connecting different data types with auditory feedback. All our aforementioned approaches are subject of our ongoing sonification developments. Our first prototype illustrates the direct sonification of fuel consumption (cp. Section 3.1).
For this approach, the first possibility is to make the absolute consumption audible. The information reflects the instantaneous use, which correlates (to some degree) with the RPM of the engine and the perceived speed of the vehicle. However, the sound complements the other cues as it makes the fuel use explicit. We present a sonification example where fuel consumption is represented by a sequence of grains, each grain signaling the expenditure of a small amount of fuel. Comparable with a Geiger counter, which ticks faster at higher radioactivity, the rate of grains here signals the instantaneous consumption (listen to sound example S1 on our website[1]).
A second possibility, which reduces the correlation with the RPM and perceived speed and is also more in line with the majority of visual fuel economy systems is to base the direct sonification on the relative consumption, i.e. the instantaneous fuel consumption per metre. As this is a variable that does not integrate in the same way as fuel drops do, we propose as sonic representation a sharp bandpass-filtered noise signal, where the cutoff frequency is controlled by the input data, so that a wind-like sound emerges. In consequence, strong accelerations, or for instance driving fast on low gear becomes highly salient as high-pitched noise (cp. sound example S2).
As a combination of these two approaches, our third sound example signals the expenditure of a small amount of fuel with a grain, whose pitch is controlled by the relative consumption, providing a continuous awareness for both variables (cp. sound example S3).
Obviously, these few sonification examples scratch only the surface of what is possible to represent the fuel economy while driving. More comprehensive sound designs and evaluations for how these sonifications affect drivers in their driving style will be reported in our future papers.

[1] http://www.techfak.uni-bielefeld.de/ags/ami/publications/HTH2014-ETA/

6. SUMMARY

In this paper we presented our work in progress on auditory interfaces to support fuel efficient driving. We highlighted important design aspects such as unobtrusiveness, directness and gamification. Furthermore, we presented a first prototype, which is illustrated by examples of the sonifications.
With the presentation of various design strategies, we hope to motivate diverse future work that might lead to better fuel economy displays and want to encourage discussions on the use of auditory displays for in-vehicle usage.
As next steps, we plan to evaluate the proposed sonification designs and compare them to visual fuel economy displays: We have developed a driving simulator that reduces the complexity of a driving task to the aspects that are relevant in the context of a fuel-efficient driving style, thus allowing for a meaningful and reproducible evaluation of different approaches and sonifications.

7. ACKNOWLEDGMENT

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8. REFERENCES

[1] M. P. Vandenbergh, J. Barkenbus, and J. M. Gilligan, "Individual carbon emissions: The low-hanging fruit," *UCLA Law Review*, vol. 55, pp. 08–36, 2008.
[2] J. N. Barkenbus, "Eco-driving: An overlooked climate change initiative," *Energy Policy*, vol. 38, no. 2, pp. 762–769, Feb. 2010.
[3] *Workshop on Eco-Driving: Findings and Messages for Policy Makers*, 11 2007.
[4] H. Johansson, P. Gustafsson, M. Henke, and M. Rosengren, "Impact of EcoDriving on emissions and fuel consumption," in *International Scientific Symposium on Transport and Air Pollution*, Avignon, France, no. m, 2003.
[5] J. J. Romm and A. A. Frank, "Hybrid vehicles gain traction," *Scientific American*, vol. 294, no. 4, pp. 72–79, 2006.
[6] H. Lee, W. Lee, and Y.-K. Lim, "The effect of eco-driving system towards sustainable driving behavior," in *Proceedings of the 28th of the international conference extended abstracts on Human factors in computing systems - CHI EA '10*. New York, New York, USA: ACM Press, Apr. 2010, p. 4255.
[7] V. L. Neale, T. A. Dingus, S. G. Klauer, J. Sudweeks, and M. Goodman, "An overview of the 100-car naturalistic study and findings," *National Highway Traffic Safety Administration, Paper*, no. 05-0400, 2005.
[8] "*Basic fuel consumption monitor*," http://partner.volkswagen.de/content/medialib/vwd4/global/mom/new_sharan/content/sharan_mfa_verbrauch/_jcr_content/renditions/rendition.570.270.file/sharan_mfa_verbrauch.jpg, [last accessed: 30.07.2014].

[9] "*Toyota Prius Consumption Monitor*, "http://www.toyota.com.au/static/images/16lin-toyota-prius-gallery-prius-multi-information-display-940x529.jpg, [last accessed: 30.07.2014].

[10] A. Meschtscherjakov, D. Wilfinger, T. Scherndl, and M. Tscheligi, "Acceptance of future persuasive in-car interfaces towards a more economic driving behaviour," *Proceedings of the 1st International Conference on Automotive User Interfaces and Interactive Vehicular Applications - AutomotiveUI '09*, no. AutomotiveUI, p. 81, 2009.

[11] "*Fiat eco:drive*," http://www.fiat.com/ecodrive/, [last accessed: 17.07.2014].

[12] L. Orofino, L. Cilimingras, and E. Morello, "Eco-drive: Driver behaviour evaluation system to reduce co 2 emissions," in *World Automotive Congress*, 2010.

[13] "*Screenshot of Fiat's eco:Drive*," http://www.fiatusa.com/deprecated/en/mobile_apps/images/apps/fiat-ecodrive/FiatEcoChallenge.jpg, [last accessed: 30.07.2014].

[14] A. Varhelyi, M. Hjälmdahl, R. Risser, M. Draskóczy, C. Hydén, and S. Almqvist, "The effects of large scale use of active accelerator pedal in urban areas," in *Paper presented at the ICTCT workshop on ISA–Intelligent Speed Adaptation*. ICTCT, 2002.

[15] "*Nissan Eco Pedal*," http://www.nissan-global.com/EN/TECHNOLOGY/OVERVIEW/eco pedal.html, [last accessed: 17.07.2014].

[16] A. Várhelyi, M. Hjälmdahl, C. Hydén, and M. Draskóczy, "Effects of an active accelerator pedal on driver behaviour and traffic safety after long-term use in urban areas," *Accident Analysis & Prevention*, vol. 36, no. 5, pp. 729–737, 2004.

[17] J. Froehlich, L. Findlater, and J. Landay, "The design of eco-feedback technology," in *Proceedings of the 28th international conference on Human factors in computing systems - CHI '10*. New York, New York, USA: ACM Press, Apr. 2010, p. 1999.

[18] D. Vangi and A. Virga, "Evaluation of energy-saving driving styles for bus drivers," *Proceedings of the Institution of Mechanical Engineers, Part D: Journal of Automobile Engineering*, vol. 217, no. 4, pp. 299–305, Jan. 2003.

[19] M. Manser, M. Rakauskas, J. Graving, and J. Jenness, "Fuel economy driver interfaces: Develop interface recommendation. report on task 3," *Fuel economy driver interfaces*, May 2010.

[20] J. Tulusan, L. Soi, J. Paefgen, M. Brogle, and T. Staake, "Which eco-feedback types prefer drivers most ?" pp. 1–8, 2011.

[21] "*KIA Eco-Driving System*," http://kia-buzz.com/eco-driving-system/, 2008, [last accessed: 22.07.2014].

[22] M. A. Nees and B. N. Walker, "Auditory Displays for In-Vehicle Technologies," *Reviews of Human Factors and Ergonomics*, vol. 7, no. 1, pp. 58–99, Aug. 2011.

[23] M. A. Nees, T. Gable, M. Jeon, and B. N. Walker, "Prototype auditory displays for a fuel efficiency driver interface," in *The 20th International Conference on Auditory Display (ICAD-2014)*, 2014.

[24] B. N. Walker and G. Kramer, "Mappings and metaphors in auditory displays: An experimental assessment," *ACM Transactions on Applied Perception (TAP)*, vol. 2, no. 4, pp. 407–412, 2005.

[25] R. Tünnermann, J. Hammerschmidt, and T. Hermann, "Blended Sonification: Sonification for Casual Interaction," in *The 19th International Conference on Auditory Display (ICAD-2013)*, 2013.

[26] S. Deterding, M. Sicart, L. Nacke, K. O'Hara, and D. Dixon, "Gamification. using game-design elements in non-gaming contexts," in *Proceedings of the 2011 annual conference extended abstracts on Human factors in computing systems - CHI EA '11*. New York, New York, USA: ACM Press, May 2011, p. 2425.

[27] D. Vangi, A. Virga, T. Bar, R. Kohlhaas, J. M. Zollner, and K.-U. Scholl, "Anticipatory driving assistance for energy efficient driving," in *Proceedings of the Institution of Mechanical Engineers, Part D: Journal of Automobile Engineering*, vol. 217, no. 4. IEEE, June 2003, pp. 1–6.

[28] C. Raubitschek, N. Sch, E. Kozlov, B. Bernard, N. Schutze, and B. Baker, "Predictive driving strategies under urban conditions for reducing fuel consumption based on vehicle environment information," *Integrated and Sustainable Transportation System (FISTS), 2011 IEEE Forum on*, pp. 13–19, June 2011.

[29] M. Sohn, T. Nam, and W. Lee, "Designing with unconscious human behaviors for eco-friendly interaction," *Proceedings of the 27th international conference extended abstracts on Human factors in computing systems - CHI EA '09*, p. 2651, 2009.

[30] E. Brazil and M. Fernström, "Auditory icons," in The sonification handbook, T. Hermann, A. Hunt, and J. G. Neuhoff, Eds. Logos Publishing House, Berlin, Germany, 2011, pp. 325–338.

[31] D. McGookin and S. Brewster, "Earcons," in The sonification handbook, T. Hermann, A. Hunt, and J. G. Neuhoff, Eds. Logos Verlag Berlin, 2011.

BIRD-WATTCHING: EXPLORING SONIFICATION OF HOME ELECTRICITY USE WITH BIRDSONG

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ABSTRACT

This paper reports on work in progress to develop *Powerchord*, a near-real-time sonification system for electricity use data. Built around a common model of UK electricity monitor, Powerchord plays a variety of birdsong of different intensities in response to the instantaneous power readings from multiple household appliances, providing a form of ambient feedback intended to fit with the soundscapes of everyday domestic life while still enabling a deeper understanding of the energy use of appliances in the home.

We start by setting the context of the broader ‘design for sustainable behaviour’ and energy use feedback fields, noting the predominance of visual feedback displays. We then describe findings from a programme of design research with householders, which highlighted that energy’s ‘invisibility’ is a barrier to behaviour change. Co-creation work with householders led to exploring the development of sonification of energy data, first in summary form, and then in near real-time. The affordances of birdsong are discussed, and future research possibilities outlined.

1. INTRODUCTION: THE CHALLENGES OF ENERGY BEHAVIOUR CHANGE

Design for behaviour change has grown significantly as a field of research in recent years [1]. It aims to reduce the undesirable social and environmental impacts of products and services, or increase the desired impacts, through design (in a broad sense) concentrating on *understanding* and *influencing* people’s interactions with technology. It is inherently multidisciplinary, drawing on knowledge, perspectives and models from a number of fields relating to human behaviour.

‘Interventions’ largely take the form of redesign of products and services themselves, or the design of interfaces, usually digital—and usually visual—which give users information and feedback (and sometimes *feedforward* [2]) on use or the impacts of their actions. The digital approach builds on significant work in human-computer interaction (HCI) on *persuasive technology* [3] and on the effectiveness of behavioural feedback from other disciplinary perspectives. The field’s growth parallels an increased policy focus on ‘behaviour change’ for social and environmental benefit, drawing on behavioural economics and ‘choice architecture’ [4] and addressing everything from encouraging exercise and healthy eating, to compliance with tax return procedures, as well as sustainability issues such as water and energy use, recycling, and transport choices.

A proliferation of taxonomies and models of behaviour change techniques, and practical guides for designers working on behaviour change [5,6,7], reflects this popularity: it is a fashionable field commercially as well as academically and politically.

However, while some techniques use multisensory approaches, the majority of feedback-based systems are primarily visual [8], and often assume a particular level of numeracy, or data literacy, on the part of the user. There is currently little work exploring the potential of non-visual interfaces in this context; sonification could enable ambient comprehension of many kinds of data relevant to behaviour change contexts [9].

1.1. Energy: a domain where most feedback is numerical

Energy use is one of the major issues on which design for behaviour change—more specifically, *design for sustainable behaviour*—has concentrated. Reducing our energy demand, and in turn our carbon dioxide (CO_2) impact, through influencing public behaviour, is a significant research topic across multiple intersecting technological and social science disciplines.

Aside from design work on technology or infrastructure change, such as retrofitting insulation to buildings (thus—

hopefully—leading to reductions in heating use), the majority of work on influencing energy use through behaviour change concentrates on numerical, visual feedback displays for electricity or gas use, in both domestic and commercial environments. There are numerous studies and meta-analyses looking at the effectiveness of different kinds of feedback (real-time, summary, normative, and so on) in this context, and the adoption of these kinds of displays within household life. As technology develops, the opportunities afforded by networked *smart meters*, which enable adaptive pricing changes (as well as providing energy utilities with much more detailed usage data) are also being explored, driven by legislation (e.g. in the UK, it is government policy for all homes and small businesses to have smart meters installed, with displays, by 2020 [31]).

While some influence on behaviour, leading to changes in energy use, has been found from feedback displays [e.g. 10], the situation is complex: simple numerical feedback may not take account of the realities of household life [11, 12, 13] or people's understanding of units and quantities [14], nor link people to wider comprehension of the energy system [15]. Most visual displays require the householder to look at the display—often a small LCD, or a web dashboard—regularly, and actually be able to act on it, for it to have any effect, assuming a model of individual householders as "micro-resource managers" [14], and while there have been some more ambient coloured light-based systems for displaying electricity use, such as DIY Kyoto's *Wattson* and Ambient Devices' *Orb*, and clever use of thermal imaging [16], these are exceptional.

As part of SusLabNWE, a European Living Lab project [17], we have taken a 'research through design' approach to exploring people's relationships with energy in everyday life. Initially, we worked with nine diverse households across London and the south-east, where possible integrating quantitative sensor data with qualitative insights. In this first phase of the project, we visited people at home, investigating stories of daily interactions with heating, lighting, appliances, and electricity monitors, and people's understanding of energy. This was followed with activities exploring themes including metaphors for energy, narrating everyday routines, and addressing 'What does energy look like?' through drawing exercises with members of the public, children, teenagers and energy experts [18].

1.2. Making the invisible audible

We ran a co-creation workshop with our householders, in which—working with designers—they created concepts for new kinds of interface or device which they felt would help them reduce their energy use. This was followed by a 'Home Energy Hackday' at the Science Museum's Dana Centre, bringing together designers, energy experts, and the Internet of Things community to explore new ways of understanding and engaging with energy, building on the ideas from householders.

One of the main themes that emerged was the general *invisibility* of energy in modern life, and its relation to behaviour. Householders' mental models of energy itself, and energy-using systems such as heating [19], together with the relative importance of different energy-using systems in the home, were partly determined by what was most salient—such as lighting—rather than 'hidden' uses such as heating and cooling (this aligns with other research, e.g. [20]).

By people's own admission, much of the energy 'wasted' at home through particular behaviours, such as leaving heating on when going out, or leaving lights on elsewhere in the house, was partly due to its invisibility from the perspective of where they were at the time. People questioned how they could change how they use energy when they can't easily see or feel it, or get a sense of the changing rate at which it is being used. There was confusion with units, for example between kilowatts as a measure of power and kilowatt-hours as a measure of energy. One householder told us:

> "I worked out that through gas and electricity every year, the average house gets the equivalent of a bit over three tons of coal delivered completely silently and without any mess.
> And go back a hundred years ago and everyone would have a really good quantitative understanding of how much energy they used because they had to physically shovel the stuff."

This issue suggested opportunities for visualisation beyond numbers, but also non-visually, for example *sonification* [21] of energy use. In the co-creation workshop with householders, one person suggested that being able to 'listen' to whether appliances were switched on or not, and what state they were in (e.g. listening to a washing machine will give a good idea as to where it is in its cycle), was potentially more useful for understanding how to reduce energy use than a visual display.

Another householder suggested—in response to discussion of smart metering and demand-based pricing changes—that being able to 'hear' the load on the grid (for example, a pleasant background hum could become discordant as the grid's frequency changes due to high demand, or the tick of a clock could become temporarily faster) would be less intrusive than, for example, a text message or a flashing light. There was discussion around the quality of the sound, for example whether a lower-pitched 'rumbling', like thunder, would be more appropriate for greater rate of energy use (i.e. power) than a higher pitch, and whether there could be a music system that somehow 'distorted' what it played when the house's energy use was higher than normal. The thunder-and-lightning theme had also come across in many drawings of 'What energy looks like' [18].

In general, the preference was also for displays which were disaggregated by appliance, or at least by 'function groups' of appliances, since this would enable actual behavioural responses, in terms of understanding where energy was being used, and then doing something about it. Similarly, the preference was for real-time displays rather than solely summaries, although these can also offer useful insights.

There are echoes here of early work in calm technology and ubiquitous computing, such as Natalie Jeremijenko's *Live Wire (Dangling String)* [22], or Anders Ernevi et al's Erratic Radio [23], in which the 'display' fits with the existing daily visual landscape and soundscapes of the office (or home). Sonification of energy use along these lines could enable *ambient comprehension* of energy use with multiple appliances, including pattern recognition and state changes [9].

Relating sound to energy use is not unknown. In explicit data sonification, Opower's 'Chicago in the Wintertime' [24] turns the city's residential electricity use over winter 2012-13 into piece of music; less directly, Foster et al's 'Power Ballads' [25] made use of aversive feedback based around popular UK chart music, automatically posted to the user's Facebook wall,

Figure 3: *Sound of the Office* audio file on SoundCloud: http://v.gd/officesound

based on high levels of electricity use. As part of our Home Energy Hackday, RCA student Ted Hunt demonstrated his ‘audio plug socket’, which uses a small MP3 player hidden within the socket to play provocative spoken word quotes around energy use and political issues such as fracking, when the socket is in use.

2. INITIAL EXPERIMENT: SOUND OF THE OFFICE

To explore energy sonification, we chose CurrentCost electricity monitors, as supplied to many utility customers in the UK, including some of our participating households. The CurrentCost ‘ecosystem’ includes a bridge connecting to a router and posting data to a website, and individual appliance monitors (IAMs) wirelessly connected to the base unit, enabling disaggregated data. CurrentCost has been used in a number of Internet of Things (IoT) academic studies [e.g. 26]. The system can also monitor gas use, if a household has a compatible meter.

An initial energy sonification *parameter-mapping* experiment was carried out in a university office. Three CurrentCost IAMs monitored electricity use of a kettle, a laser printer, and a gang socket for a row of desks, sending data to the CurrentCost website from where it was exported as a CSV file. Data for 12 hours—from midnight on a Sunday to midday Monday—were scaled [27] and manually converted into a three-track 30-second MIDI file using `csvmidi` and Aria Maestosa, with *lower* pitches representing *higher* power, and vice versa, and hourly drumbeat ‘ticks’ [21]. MIDI instruments represented appliances: a tenor sax is the kettle (up to 1.5kW in use); a synth brass is a Kyocera laser printer (background whine of 10W on standby, deepening to 300W-500W in use); and a polysynth is the gang socket, with laptops (15W-50W) plugged in during the day and a charger (1W) otherwise.

As the audio starts, over the printer’s whine, the kettle comes on as a security guard makes himself a 1.00am cup of tea. Then, early in the morning, the cleaners used the kettle—twice quickly (reboiling?) and then once again. Suddenly, at 9.30am, as staff arrive, the kettle goes on, laptops are plugged in, the printer starts printing and the energetic hubbub of office life appears.

The approach was conceptually similar to Hermann et al’s ‘auditory weather forecasts’ [28]—a summary ‘gist’, presented after the fact. We have subsequently also found Matthew Bay Kenney’s conceptually similar (but much more elegant) work at Penn State on sonifying the energy use of six office appliances over 20 hours [29].

Figure 2: Testing parsing of data from an intact CurrentCost, and triggering audio tracks.

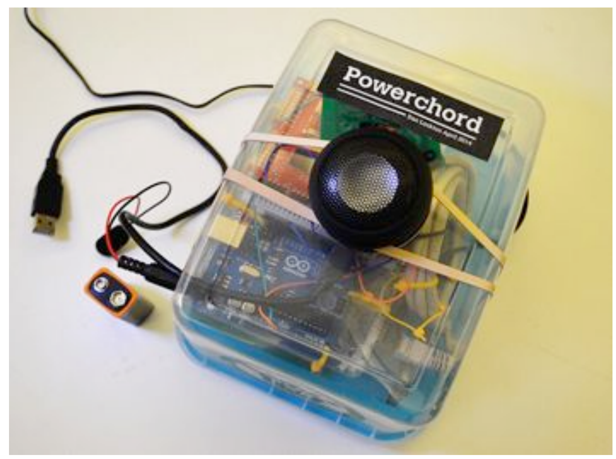

Figure 1: Working prototype of Powerchord.

While summary sonification provided an interesting auditory display of multiple appliance power use over a period—and provoked discussion in the office over the routines of the security guard and cleaners, otherwise ‘invisible’ characters in office life, it was clear that for the household context as explored in the co-creation workshop, (near-)real-time ‘closed loop’ feedback would offer many advantages. A family could use the sound to understand current power use, and change appliance use directly.

3. POWERCHORD (BIRDSONG EDITION)

To achieve near-real-time sonification of electricity use, it was decided to do processing locally rather than online. Building on others’ code [30] for extracting CurrentCost data output, we developed *Powerchord*, an Arduino-based system (Figs. 2, 3 and 4) which parses the CurrentCost’s XML output every 6s, extracting the IAM power figures for individual appliances, and mapping these figures to ranges defined in code. Three IAMs are used, though the system could support up to nine. While the initial proof-of-principle prototype retained the CurrentCost device intact, the next version involved dismantling it and using

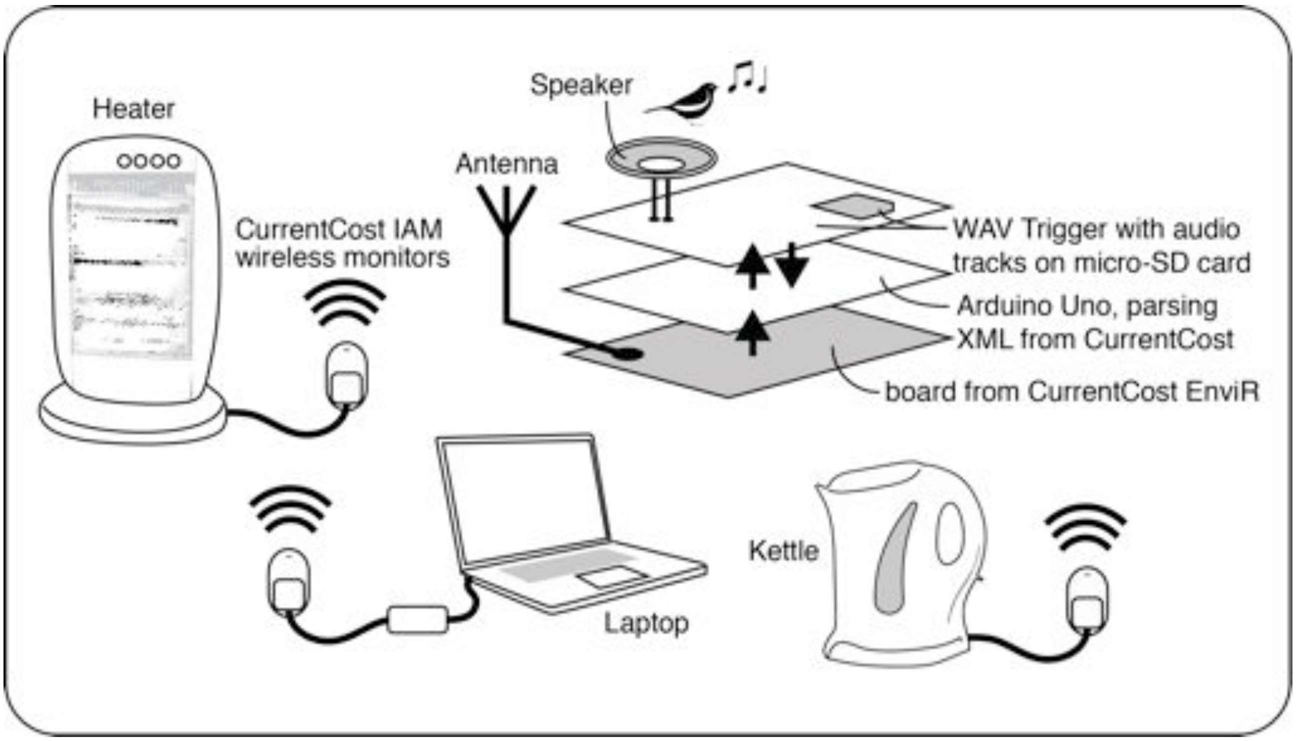

Figure 4: The components of the prototype Powerchord system, with three example appliances.

only the parts which were needed (meaning that the LCD was removed, for example).

Initially we worked with a GinSing synthesizer shield for the Arduino, producing different tones (with various effects) mapped to power ranges, but, lacking experience in composition and sound design, the results we were able to produce were aesthetically unattractive to say the least.

We decided instead to build on the idea from our co-creation work with householders around *fitting into the existing daily soundscapes of the home*—something more like the tick of a clock, or the sound of distant church bells, 'repurposing' them with extra energy information. This meant that recordings of these sounds, suitably modified, and triggered in appropriate circumstances, could be used, rather than tones being generated in real-time. As such, we linked the Arduino to a Robertsonics *WAV Trigger*, enabling polyphonic playback for multiple audio files simultaneously.

Power ranges were defined to match the typical ranges found in household appliances, from <10W for trickle charging, to >2kW for electric heaters. For each power range, for each appliance, the WAV Trigger plays a particular audio track stored on a memory card, and looped until the power range changes. Lower ranges can be set not to result in any sound; the prototype has both a loudspeaker and a headphone socket.

3.1. The affordances of birdsong

For the sounds themselves, the affordances and associations of *birdsong* and bird calls were identified as fitting the model of daily soundscapes, such that rather than being part of the "increasing clutter of beeps and bleeps" [9] of feedback people experience from the electronic devices around them, a natural, largely non-intrusive ambient set of sounds could serve to signify energy usage information.

On a somewhat reductionist level, the fact that we hear birds calling and singing every day—and notice when they are abnormally loud or agitated—yet are usually unable to understand what the sounds 'mean', suggests that birdsong represents an opportunity for this 'unused auditory bandwidth' to be exploited as a channel for information. More poetically, the subjective beauty of most bird vocalisation, such that even birds' alarm calls are usually considered pleasant (and very unlike the alarm sounds generated by most electronic devices), offers a different quality of experience to direct tone-mapped sonification. Connecting people better to the wider, complex systems around them, in which their behaviour plays a part—such as energy use—suggests that 'natural' metaphors may be particularly relevant [18]. One might equally imagine the sound of a river, waterfall, or the sea, or wind in the trees, as being appropriate in this context, or indeed other weather-based sound collections, such as taking further the thunder-and-lightning theme arising from householders' suggestions.

We selected common garden birds whose calls and song would likely already be familiar and potentially part of householders' daily soundscapes—blackbirds and house sparrows—and also, as a counterpoint, the distinctive calls of herring gulls, which potentially evoke seaside memories, but which are not 'tranquil' in the same way.

Using Xeno-Canto, a worldwide Creative Commons-licensed database of bird vocalisations, a number of clips of calls and song of blackbirds, house sparrows and herring gulls were edited in Audacity, such that that different intensities of

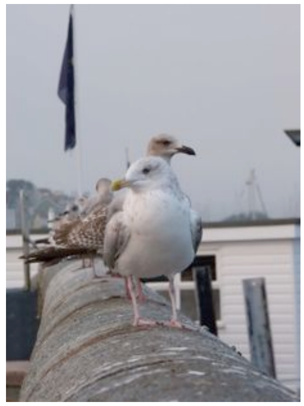

Figure 5: Blackbird, herring gull and house sparrows. Photos by John Stratford, Harriet Riley and Lip Kee, Creative Commons licensed.

call and song (number of birds, agitation level) could map to the power ranges, with different birds for each appliance (e.g. herring gulls for an electric kettle, since it is used intermittently rather than continuously, and the startling sound of the gulls is aligned with the sudden change in household energy use that switching on a kettle normally entails). A video is available—http://v.gd/powerchord

3.2. Testing

This paper reports on work very much in progress: at the time of writing, the prototype Powerchord, with blackbird, house sparrow and herring gull sounds loaded on its memory card, is currently being trialled in one of the authors' homes, to understand how, in practice, it might be used in everyday life, and to refine the design in the light of this—essentially, is it something a family can live with?

Questions under consideration include appropriate volume for the sound output, as well as what power levels ought to trigger particular outputs (should the 'background' electricity use of a house, such as the refrigerator, be monitored or ignored from the sonification perspective?), and whether they should do so continuously or only on edge triggers (e.g. at the point that the kettle or an electric heater is switched on, not all the time that it is switched on). Does the device lose its effect or its salience if it is continuously running?

Powerchord will be on display at the Victoria & Albert Museum's 'Digital Weekend' in September 2014, part of the London Design Festival, to garner further public reaction and suggestions, and improved prototypes will then be installed in three houses over autumn-winter 2014 which are also having their electricity use monitored separately, to understand how, in practice, householders with different lifestyles make use of Powerchord, whether their understanding of the energy system changes, and—although drawing on a very small sample size—whether it has any quantitative effect on electricity use through behaviour change. For example, if a 2kW electric fan heater results in the sound of a loud, angry group of herring gulls, while a smaller 400W heater leads to a subjectively more pleasant chattering of sparrows, does this make it more likely that a householder will choose to use the 400W over the 2kW heater?

The aim is to contribute, in an exploratory way, to energy use feedback work in the emerging 'design for sustainable behaviour' field, as outlined in section 1, through demonstrating the possibilities of sonification and non-visual feedback.

In terms of future research questions, if it is possible to develop Powerchord to the stage of being a relatively reliable platform for triggering particular sound files, polyphonically, in response to electricity (or gas) usage levels, in near-real-time, there are a number of possible avenues to explore, including linking sound to the load on the electricity grid (particularly where this may lead to different pricing per unit), applications in local or community microgrids where generation as well as consumption (and the balance between them) comes into consideration, and, as mentioned earlier, cases where edge triggers could be useful, e.g. to signal when a heating system thermostat switches a boiler on or off. We look forward to being able to report on future research on the project website, http://suslab.rca.ac.uk

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5. REFERENCES

[1] K. Niedderer, J. MacKrill, S. Clune, M. Evans, D. Lockton, G. Ludden, A. Morris, R. Gutteridge, E. Gardiner, R. Cain and P. Hekkert, 'Joining Forces: Investigating the influence of design for behaviour change on sustainable innovation'. *NordDesign 2014: 10th biannual conference on design and development*, 2014, Aalto University, Finland.

[2] T. Djajadiningrat, K. Overbeeke and S. Wensveen, 'But how, Donald, tell us how?: on the creation of meaning in interaction design through feedforward and inherent feedback.' *Proceedings of DIS 2002*, ACM, New York.

[3] B.J. Fogg, 'A Behavior Model for Persuasive Design', *Persuasive 2009: 4th International Conference on Persuasive Technology*. 2009, ACM, New York.

[4] D. Lockton, D. Harrison and N.A. Stanton, 'Choice Architecture and Design with Intent'. *NDM9 – 9th Bi-annual International Conference on Naturalistic Decision Making*. 2009, British Computer Society, Swindon.

[5] D. Lockton, D. Harrison and N.A. Stanton, 'Exploring design patterns for sustainable behaviour'. *The Design Journal*, Vol.16 No. 4, pp. 431-459, 2013

[6] J. Zachrisson Daae and C. Boks, ‘A classification of when to apply different user research methods to support design for sustainable behaviour’. Journal of Cleaner Production, 2014, http://dx.doi.org/10.1016/j.jclepro.2014.04.056

[7] A. Selvefors, S. Renström and H. Strömberg, ‘Design for Sustainable Behaviour: A Toolbox for Targeting the Use Phase’. *Eco-Design Tool Conference*, Gothenburg, Sweden, 2014.

[8] J. Froehlich, L. Findlater, L. and J. Landay, ‘The design of eco-feedback technology’. *Proceedings of CHI 2010*, pp. 1999-2008. ACM, New York.

[9] S. Serafin, K. Franinovic, T. Hermann, G. Lemaitre, M. Rinott, and D. Rocchesso, ‘Sonic Interaction Design’. In Hermann, T., Hunt, A. & Neuhoff, J.G., eds., *The Sonification Handbook*, Berlin: Logos, pp. 87-110, 2011

[10] C.B.A. Kobus, R. Mugge, R. and J.P.L. Schoormans, ‘Washing when the sun is shining! How householders interact with a household energy management system’. *Ergonomics* 56(3), pp. 451-462, 2012.

[11] H. Brynjarsdóttir, M. Håkansson, J. Pierce, E.P.S. Baumer, C. DiSalvo, and P. Sengers, P., ‘Sustainably unpersuaded: How persuasion narrows our vision of sustainability’. *Proceedings of CHI 2012*, ACM, New York.

[12] S. van Dam, C.A. Bakker, and J.D.M. van Hal, ‘The mediating role of home energy management systems’. *Proceedings of First European Conference on Energy Efficiency and Behaviour,* Maastricht, 2009

[13] T. Hargreaves, M. Nye and J. Burgess, ‘Keeping energy visible? Exploring how householders interact with feedback from smart energy monitors in the longer term’. *Energy Policy* 52, pp. 126-134, 2013

[14] Y. Strengers, ‘Designing Eco-Feedback Systems for Everyday Life’. *Proceedings of CHI 2011*. ACM, New York.

[15] A. Boucher, D. Cameron and N. Jarvis, ‘Power to the People: Dynamic Energy Management through Communal Cooperation’. *Proceedings of DIS 2012*, ACM, New York.

[16] J. Giacomin and D. Bertola, ‘Human emotional response to energy visualisations’, *International Journal of Industrial Ergonomics*, Vol. 46, No. 6, pp. 542-552, 2012.

[17] C. Baedeker, K. Greiff, V. Grinewitschus, M. Hasselkuß, J. Keirstead, D. Keyson, J. Knutsson, C. Liedtke, D. Lockton, T. Lovric, G. Morrison, M. van Rijn, H. Rohn, S. Silvester, W. van Harinxma and L. Virdee, ‘Transition through sustainable Product and Service Innovations in Sustainable Living Labs: application of user-centred research methodology within four Living Labs in Northern Europe’. *IST 2014: 5th International conference on Sustainability Transitions*, 2014, Utrecht.

[18] F. Bowden, D. Lockton, C. Brass and R. Gheerawo, ‘Drawing Energy: Exploring the Aesthetics of the Invisible’. *IAEA Congress 2014: Congress of the International Association of Empirical Aesthetics*, 2014, New York.

[19] K.M.A. Revell and N.A. Stanton, ‘Case studies of mental models in home heat control: Searching for feedback, valve, timer and switch theories’, *Applied Ergonomics*, Vol. 5, No. 3, pp. 363–378, 2014.

[20] S.Z. Attari, M.L. DeKay, C.I. Davidson and W. Bruine de Bruin, ‘Public perceptions of energy consumption and savings’, Proceedings of the National Academy of Sciences, Vol. 107, No. 37, pp. 16054-16059, 2010

[21] B.N. Walker and M.A. Nees, ‘Theory of Sonification’. In Hermann, T., Hunt, A. & Neuhoff, J.G., eds., *The Sonification Handbook*, Berlin: Logos, pp. 9-39, 2011.

[22] M. Weiser, and J.S. Brown, ‘Designing calm technology’, 1995, http://www.ubiq.com/hypertext/weiser/calmtech/calmtech.htm

[23] A. Ernevi, S. Palm and J. Redström, ‘Erratic Appliances and Energy Awareness’, *Knowledge, Technology & Policy*, Vol. 20, No. 1, pp. 71-78, 2007.

[24] A. Tinjum and Y. Ben-Meshulam, ‘This is the sound of Chicago’s energy consumption’. Opower blog, 20 November 2013, http://blog.opower.com/2013/11/power-rock-this-is-the-sound-of-chicagos-energy-consumption/

[25] D. Foster, C. Linehan, S. Lawson and B. Kirman, ‘Power ballads: deploying aversive energy feedback in social media’. *CHI '11 Extended Abstracts on Human Factors in Computing Systems* (CHI EA '11). ACM, New York.

[26] A.F. Smeaton and A.R. Doherty, ‘Persuading consumers to reduce their consumption of electricity in the home’. *Persuasive 2013, 8th International Conference on Persuasive Technology*, Sydney, 2013.

[27] L.M. Brown, S.A. Brewster, R. Ramloll, M. Burton, M. and B. Riedel, ‘Design guidelines for audio presentation of graphs and tables’. *Proceedings of International Conference on Auditory Display (ICAD2003)*, Boston, MA, 2003.

[28] T. Hermann, J.M. Drees and H. Ritter, ‘Broadcasting auditory weather reports—a pilot project’. Proceedings of *International Conference on Auditory Display (ICAD2003)*, Boston, MA, 2003.

[29] M.B. Kenney, ‘Energy Sonification’, available at: http://www.matthewbay.com/portfolio/

[30] C.R. Williams, ‘Arduino CurrentCost Bridge with LCD display’, Available at: http://www.crwilliams.co.uk/

[31] Department of Energy and Climate Change, ‘Helping households to cut their energy bills’, 24 July 2014, available at https://www.gov.uk/government/policies/helping-households-to-cut-their-energy-bills/supporting-pages/smart-meters

SONIFICATION AESTHETICS AND LISTENING FOR NETWORK SITUATIONAL AWARENESS

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ABSTRACT

This paper looks at the problem of using sonification to enable network administrators to maintaining situational awareness about their network environment. Network environments generate a lot of data and the need for continuous monitoring means that sonification systems must be designed in such a way as to maximise acceptance while minimising annoyance and listener fatigue. It will be argued that solutions based on the concept of the soundscape offer an ecological advantage over other sonification designs.

1. INTRODUCTION

In military circles there is debate about whether cyberspace has become the fifth warfighting domain (the others being sea, land, air, and space) [1]. Computer networks are increasingly coming under strain both from adversarial attacks (warfighting in military parlance) and from load and traffic pressures (e.g., increased demand on web services). Another term that has made its way from the military lexicon into the wider world of network administration is *situational awareness*. Endsley [2, p. 36] defined situational awareness (SA) as the

> …perception of elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future.

So, SA facilitates an administrator in becoming aware of a network's current state. The perception phase of SA comprises the recognition of situational events and their subsequent identification. Sonification is a process of computational perceptualisation which Vickers [3] suggested is well suited to the monitoring of time-dependent processes and phenomena such as computer networks. Vickers, Laing, and Fairfax [4] proposed a soundscape-based method for sonifying computationally-derived properties of network traffic in order to monitor in real time the stresses being experienced by a network. Initial results were promising but an important design challenge involving design aesthetics remains to be addressed.

2. THE CYBER ENVIRONMENT

It has been noted that there is debate in military circles about whether cyberspace has become the fifth warfighting domain (following land, sea, air, and space). The central focus of debate is the cyber environment (sometimes known as cyberspace) is a discrete area of operations or whether it is a more pervasive concept that runs through all of the other domains. While land, sea, air, and space are physically distinct and are defined by similar criteria, cyberspace is defined in a different way, existing on an electronic plane rather than a physical and chemical one. Some argue that cyberspace is merely a common component of the four other domains rather than a discrete domain of its own. Indeed, it is easy to see how cyber operations can play a significant role in land, sea, air or space warfare, due to the technology employed in each of these domains [1].

This distinction depends on the way that the various domains are defined. If our definitions are underpinned by a purely physical paradigm, then it is arguable that cyberspace is a very different type of context to the traditional warfighting domains. If, however, our definitions are based on an operational paradigm, then the distinction is less clear. It is possible to conduct entire operations in the cyber environment, made possible by the interconnected nature of the Internet and associated infrastructures. In the same way, it is common to have joint operations operating across multiple domains, including the cyber environment, and the cyber environment isn't restricted to military warfighting scenarios.

Though operations in cyberspace are complex, they can be simplified, to some extent, by the cyber operations spectrum. This divides cyber operations into 3 areas [1]:

- **Defence**: Defensive operations take up approximately 80% of cyber activity. This constitutes the work that is (or should be) undertaken by all individuals or organisations. It ranges from simple protection of individual personal equipment to complex security management architectures.
- **Exploitation**: Exploitation is covert activity conducted within an adversaries area of operations. This is generally invisible to the defender (unless compromised by the defender). Exploitation operations range from preparatory activity conducted to enable future activity to protracted information farming operations which are designed to generate intelligence over a protracted period of time.
- **Attack**: The overt phase when effect is brought to bear on a target. There are a wide range of exploits and strategies associated with this phase. It should be

noted that a visible attack may well have been preceded by invisible exploitation operations.

A knowledge of where current operations lie within the cyber spectrum is critical to a clear understanding of the cyber environment. It is also helpful to view the actions of adversaries in this context in order to try to understand the adversarial plan and predict their likely future actions.

Traditional protective strategies were often based on the defence of boundaries and perimeters. Whether defended by technology or, in some cases, complete air gaps, boundary based defence was initially effective until attackers found ways to achieve a breach, whether by compromising vulnerable technology or bridging air gaps, as could be seen, for example, in the Stuxnet attack on the Iranian nuclear processing facility. This boundary-based model is increasingly seen as flawed due to the enormous complexity and granularity of the cyber environment. Increasingly, defensive architectures are seen to be resilient matrices of multiple defensive components. It is no longer credible for organisations to assume that they are completely safe. The sensible security strategy now focuses on raising the bar to reduce the likelihood of a successful attack, but to assume that a proportion of attacks will be successful, but to have the mechanisms in place to identify and manage these events when they occur. Organisations must also ensure that operational architectures are sufficiently resilient to enable them to continue to operate whilst 'under fire' and to be able to accept known levels of attrition. This has resulted in a subtle but tangible shift from purely protective postures to proactive intelligence management within organisations.

In many cases, the compromise of technology is achieved indirectly. This often involves the compromise of people. A wide range of social engineering attacks are employed in order to compromise technology using traditional human weaknesses, including greed, curiosity, insecurity and ignorance. The dependence of cyberspace on people also extends the scope of compromise from direct attacks on target systems, to indirect targeting of social, economic, commercial and financial architectures. The traditional 'high threat club' (those organisations who are known to represent high value targets to attackers) are no longer the only organisations with a requirement for active and dynamic information security infrastructures. Information security is now a critical aspect of corporate governance across the organisational spectrum.

An important driver for the cyber environment is that it effectively becomes an asymmetric enabler. Cyber operations provide a viable attack vector for small nations or influence groups that enables them to directly engage even the largest power bases (military or otherwise) worldwide. One of the effects of the advent of the cyber environment has been to remove much of what von Clausewitz (1873) termed the friction of war. This is exacerbated by the fact that tempo changes are possible, where operations can move rapidly from slow, covert activity to high intensity attack activity with little physical impact.

History has shown that an ability to switch tempo in battle has enormous value in its ability to unhinge adversaries and to compromise their will and ability to fight. This is one of the characteristics that lies at the heart of the 'manoeuverist' doctrine that underpins much of the 20th century warfighting doctrine. Manoeuver warfare is a potentially complex doctrine which is built on simple principles which shape the chosen battlefield through knowledge, understanding and agility. The British Army describes the manoeuverist approach as follows [5]:

> This is an indirect approach which emphasises understanding and targeting the conceptual and moral components of an adversary's fighting power as well as attacking the physical component. Influencing perceptions and breaking or protecting cohesion and will are essential. The approach involves using and threatening to use force in combinations of violent and non-violent means. It concentrates on seizing the initiative and applying strength against weakness and vulnerability, while protecting the same on our own side. The contemporary Manoeuvrist Approach requires a certain attitude of mind, practical knowledge and a philosophy of command that promotes initiative. (Chapter 5)

The cyber environment provides an additional dimension within which agility can be achieved, and initiative seized. It is, perhaps, instructive that the practical application of the manoeuverist approach is broken down into the following components:

- **Understanding the situation**: using information, intelligence and intuition coupled with a sound understanding of objectives and desired outcomes.
- **Influencing perceptions**: planning, gaining and maintaining influence, and the management of key stakeholders.
- **Seizing and holding the initiative**: Ensuring that we hold the ability to dictate the course of events, through competitive advantage, awareness and anticipation.
- **Breaking cohesion and will in our adversaries**: Preventing our adversaries from being able to co-ordinate actions effectively, and compromise their determination to persist.
- **Protecting cohesion and will in ourselves and our allies**: Enabling our own freedom of action and ability to co-ordinate our resources, ensuring that we retain the will and coherence to operate.
- **Enhancing and evolving the approach through innovation**: The approach is enhanced through simplicity, flexibility, tempo, momentum and simultaneity.

All of these components are areas where cyber operations can play a significant part both for the attacker and the defender. In military terms, cyber may be seen as a force multiplier, increasing the effect of existing operational capability. There is, however, another side, in that these principles and components can be applied to operations in the cyber environment and, if applied with flexibility, can provide structure to planning.

Cyberspace is characterised, amongst many things, by a lack of natural visibility and tangibility. Humans have sense-based defensive postures. Sight, smell, feel and sound underpin our innate defensive posture. The challenge of cyberspace is that none of these senses, the core of our sensory toolkits, are effective in the cyber environment without technology and tools. It could be said that we have created an operating environment for which we do not yet have effective sensory perception. We therefore become dependent on these tools, and the way in which they have been developed and configured. This inability to engage our senses in a native manner represents an opportunity for attackers and defenders. In this environment, clear understanding of the current state of the battlespace; situational awareness, becomes a battle winning factor.

To return to the question — has cyber become the new battle space? — whilst the role of the cyber environment as a fully-fledged warfighting domain is open to sustained debate, it is very clear that the cyber environment is one in which it is possible to conduct a range of targeted operations. It is also clear that these operations may be conducted in isolation, or in conjunction with operations in the kinetic sphere (in any of the four principal warfighting domains.)

However we eventually decide to classify this area, we must ensure that we are able to operate within it, at least as effectively as our adversaries are able to. As such, it would be prudent to consider it to be a battlespace, and a high tempo battlespace in which our native situational awareness is limited. It is also a battlespace in which our ability to maintain an agile, proactive posture is critical to our ability to gain and maintain the initiative.

3. SITUATIONAL AWARENESS

As outlined above, terms such as 'battlespace' and 'attack' have become common parlance when discussing the protection of information infrastructures from a wide range of cyber-based information operations, as has another term, 'situational awareness'. The study of situational awareness has its roots in military theory [1]. Situational awareness has the goal of understanding the state of a particular scope and using that understanding to make decisions about how to proceed and respond to events. There are different models and frameworks for situational awareness in the computer networks field, but there is general agreement that at its core lie three levels of awareness (see Endsley [2]):

1. **Perception**: becoming aware of situational events;
2. **Comprehension**: interpreting what is happening to form a situational understanding of the events;
3. **Projection** (i.e., prediction): using the understanding to inform what actions (if any) should be taken to control the network.

When discussing the manoeuverist approach above, we noted that in order to gain and maintain the initiative in a particular area of operations, the first step or component was to achieve an understanding of the area and activity within it. This clearly echoes Endsley's model noting a perception and comprehension of information in order to enable projection; actions to seize the initiative in a particular situation [1].

Noting that the manoeuverist perspective on situational awareness developed within a kinetic warfighting context [5], it looks in even more detail at information operations, intelligence collection and collation as part of the process to convert perception to comprehension and projection. This is directly relevant to the information space and implies a degree of planning and direction through the acquisition, analysis and dissemination of intelligence. In many contexts, analysis is intuitive and organic, especially in the high tempo information space, however, we must acknowledge its role as an active part of the practical process. It is this transition from information to intelligence which takes us from Endsley's Understanding Phase to the Projection Phase.

Another practical perspective comes from John Boyd. Whilst Endsley's model is useful for understanding the levels of situational awareness, an example from the kinetic sphere readily illustrates how it adds value in a practical context. If we take a brief step into kinetic military doctrine, and view the computer incident response process in the context of Boyd's OODA loop theory (see Angerman [6]), we find a useful model to review the practical relevance of situational awareness in a combat situation [1].

John Boyd was commissioned by the US Department of Defense in 1976 to analyse why US pilots in Korea were so successful despite the fact that the opposing Chinese MiG–15 aircraft were technically superior in many respects. His simple theory, which postulated that certain aspects of the US aircraft design enabled the pilots to react more quickly to the changing battle, has gained much traction since [1].

Boyd theorised that combat pilots made decisions using a cycle comprising four steps: observe, orient, decide, act (OODA). In a contest between two opposing pilots the individual who could complete this cycle the quickest would have the advantage. Boyd suggested that the increased speed at which the US pilots could react and reorient themselves outweighed the technical superiority of the MiG–15 [1].

Refinements have since been made to Boyd's OODA model and it is particularly pertinent in the context of cyber security and the defence of information networks. The information network environment is characterised by high tempo and granularity, coupled with low visibilty and tangibility. Administrators are therefore dependent on complex and granular data feeds for data about what is happening, and must often further translate this view into language that can be understood by decision makers. The use of tools can simplify this complex data picture, but each analysis layer introduces margin for error and adds Clausewitzian friction. Added to this are the practical limitations of our physical and intellectual physiology; it is practically impossible for most people to sit watching complex visual data feeds concurrently with other activity without quickly losing effectiveness [1].

Network administrators require a real-time monitoring tool to facilitate the acquisition and maintenance of situational awareness. Such a tool would assist with:

- Maintenance of security.
- Awareness of anomalous events (e.g., attacks).
- Maintenance of network health through monitoring and tuning.

4. SONIFICATION FOR NETWORK MONITORING

Much work has been done in applying information visualisation techniques to network data for facilitating situational awareness (e.g., see Jajodia *et al*. [7] for a recent overview). However, a particularly striking feature of the three-level model is that the first two levels — perception and comprehension — correspond directly with Pierre Schaeffer's two basic modes of musical listening, ´ecouter (hearing, the auditory equivalent of perception) and entendre (literally 'understanding', the equivalent of comprehension). Schaeffer was writing within a musical arts context but Vickers [8] demonstrated how these modes are applicable to sonification.

Sonification is a branch of auditory display, a family of representational techniques in which non-speech audio is used to convey information. Here, data relations are mapped to features of an acoustic signal which is then used by the listener to interpret the data. Sonification has been used for many different types of data analysis (see Hermann, Hunt, and Neuhoff [9] for a broad and recent treatment of the field) but one for which it seems particularly well suited is live monitoring, as would be required in situational awareness applications. The approach described in this chapter provides one way of addressing the challenges outlined above by enabling operators to monitor infrastructures concurrently with other tasks using additional senses. This increases the available bandwidth of operators without overloading individual cognitive functions, and provides a fast and elegant route to practical situational awareness using multiple senses and an increased range of cognitive ability.

Situational awareness requires intelligence to be provided in real time. A major challenge with live real-time network monitoring is that, with the exception of alarms for discrete events, the administrator needs to attend to the console screen to see what is happening. Spotting changing or emerging patterns in traffic flow would need long-term attention to be focused on the display. Therefore, sonification has been proposed as a means of providing situational awareness.

Monitoring tasks can be categorised as direct, peripheral, or serendipitous-peripheral:

> In a direct monitoring task we are directly engaged with the system being monitored and our attention is focused on the system as we take note of its state. [3, p. 455]

A system to sonify network traffic, on the other hand, would allow monitoring in a peripheral mode. Here,

> … our primary focus is elsewhere, our attention being diverted to the monitored system either on our own volition at intervals by scanning the system … or through being interrupted by an exceptional event signalled by the system itself. [3, p. 455]

Hence, the monitoring becomes a secondary task for the operator who can carry on with some other primary activity. Serendipitous-peripheral is like peripheral monitoring except that the information gained "is useful and appreciated but not strictly required or vital either to the task in hand or the overall goal" [3, p. 456]. Thus, a system to sonify network traffic may allow us to monitor the network in a peripheral mode, the monitoring becoming a secondary task for the operator who can carry on with some other primary activity. Network traffic is a prime candidate for sonification as it comprises series of temporally-related data which may be mapped naturally to sound, a temporal medium [3].

Gilfix and Crouch's PEEP system [10] is an early network sonification example but Ballora *et al*. [11]–[13] developed the idea to address situational awareness. Using an auditory model of the network packet space they produced a "nuanced soundscape in which unexpected patterns can emerge for experienced listeners". Their approach used the five-level JDL fusion model which is concerned with integrating multiple data streams such that situational awareness is enhanced (see Blasch and Plano [14]. However, Ballora *et al*. [11] noted that the high data speeds and volumes associated with computer networks can lead to unmanageable cognitive loads. They concluded:

> The combination of the text-based format commonly used in cyber security systems coupled with the high false alert rates can lead to analysts being overwhelmed and unable to ferret out real intrusions and attacks from the deluge of information. The Level 5 fusion process indicates that the HCI interface should provide access to and human control at each level of the fusion process, but the question is how to do so without overwhelming the analyst with the details.

Kimoto and Ohno [15] developed a network sonification system called 'Stetho' which uses the network traffic as source of sound, based on assumption that the sound will be useful for the network administrator. The music generated by Stetho should be comfortable as music so that changes in network status and exceptional events should be immediately noticeable. Stetho reads commands from the tcpdump packet analyser, then checks and matches them to generate corresponding MIDI events (see http://www.tcpdump.org).

InteNtion (Interactive Network Sonification) is a project targeted at mapping network activity to musical aesthetic. The SharpPCap library is used to analyse the network traffic. The resultant data are then transformed into MIDI messages and sent to synthesisers to generate dynamically mixed sounds [16].

Wolf and Fiebrink [17] designed the SonNet system to help users (artists or people have an interest in network traffic information) to easily access network traffic through a simple coding interface without requiring knowledge of Internet protocols. SonNet acts as packet-sniffing tool and network connection state analyser. It includes an object from the ChucK concurrent music programming language that can be used to generate the required audio (see http://chuck.cs.princeton.edu).

Users typically employ third party packet sniffing applications or libraries such as Wireshark, Tcpdump, or Carnivore. Users have to write code to adjust these tools in order send the network information to a sonic environment in real time. SonNet shortens the process of creating sonifications from network data. With SonNet users do not need to write code to access networking data or write code to track network state information from packet data. SonNet organises the network data into three levels of abstraction: 1) raw packet data, 2) single packet analysis, and 3) accumulated packet analysis [17]. The first level deals with the raw information contained in network packets. By analysing source and destination IP addresses and port numbers level 2 deals with determining the direction of a packet's travel (in or out of the gateway) plus the elapsed time since the previous packet. Level 3 is an aggregation of this analysis and also computes the packet rate over a user-defined time period and the running average packet rate. Thus, the three levels provide different views of the packet data.

5. SONIFICATION WITH SOUNDSCAPES

A major challenge for sonification designers continues to be that their work is often perceived as annoying, fatiguing, or both. Whilst annoying and fatiguing sonifications might be tolerable for short tasks, for monitoring tasks (especially those in which situational awareness is the goal) something better is needed. In these situations the environment is unlikely to be a controlled scientific laboratory in which extraneous noises can be removed. For the network administrator, especially one trying to attain situational awareness in a stressful situation such as a cyber attack, the working environment will be sonically uncontrolled. Here sonifications are needed that are not only *not* annoying or fatiguing but which complement the existing sonic environment.

Vickers, Laing, and Fairfax [4] demonstrated their Self-Organised Criticality Sonification System (SOCS) that sonifies meta properties of network traffic data using a soundscape approach (see Fig. 1). The concept of soundscape was introduced by Schafer [18] and is one form of sonic organisation which can be applied to the sonification of a network environment. Pijanowski *et al.* [19, p. 203] observed that sounds

> … are a perpetual and dynamic property of all landscapes. The sounds of vocalizing and stridulating animals and the non-biological sounds of running water and rustling wind emanate from natural landscapes. Urban landscapes, in contrast, are dominated by human-produced sounds radiating from a variety of sources, such as machines, sirens, and the friction of tires rotating on pavement.

A soundscape ecology what is formed by the sounds and spatial temporal patterns as they are created by a landscape's environment [19]. Ecology is studying the relationship between (individuals and communities) within their living environment. Therefore, soundscape ecology is studying the effects of the acoustic environment created by those living with in it due to their responses and behavioural characteristics. The impetus behind it is to recognise imbalances which may have unhealthy or malicious effects.

In principle, a well designed sonification soundscape will either fit in with the existing environment or will sit alongside it in a complementary manner. We are already used to dealing with everyday background sound and quickly deciding what sounds need attending to and what sounds can be pushed to the attentional background. A soundscape offers the sonification designer the potential to leverage this innate information processing capacity in such a way that important changes in the cyber environment become salient in the soundscape.

There have been some notable recent advances in taxonomy for sonification and its relationship to listening (see Tuuri and Eerola [21], Vickers [8], Grond and Herman [22], and Filimowicz [23]). Typically, using Schaeffer's *quatre écoutes* and Chion's causal and semantic listening [24] as a starting point, sonification listening categorisations have been put forward as tools to help in the exploration and understanding of the interactions between a listener and a sonification. For example, Vickers [8] extended Shaeffer's scheme by adding further four listening modes that pertain to sonification. Tuuri and Eerola [21] proposed an alternative three-level taxonomy with eight listening modes. Bringing together these taxonomical accounts and the ecological approach of the soundscape offers the potential to design sonifications that are effective communication channels at the same time as being environmentally compatible and less fatiguing (what Adams *et al.* [20] might call a 'sustainable soundscape'). In the study of natural soundscapes Pijanowski *et al.* state that research "is needed on how natural sounds influence the development of individuals' sense of place, place attachment, and connection to nature" [19, p. 209]. Likewise, sonification research will need to explore how soundscape sonification influences the listener's development of a sense of the information space and their own place within it.

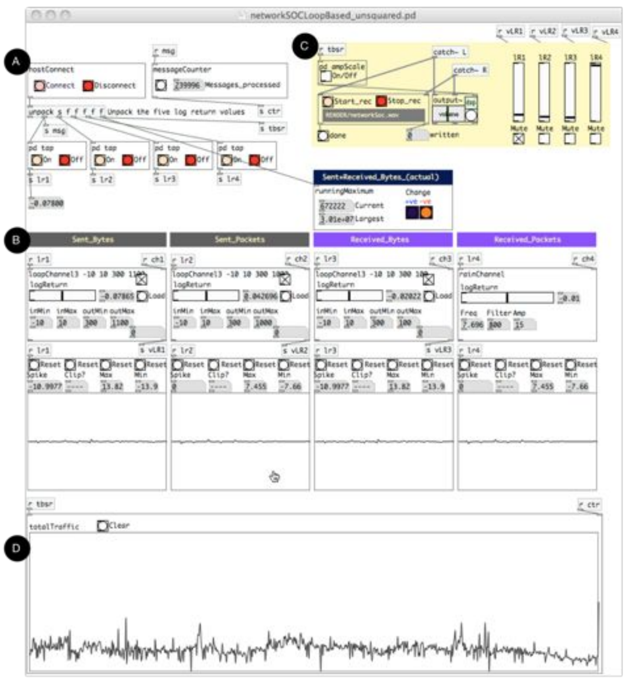

Figure 1: Screen shot of the Self-Organised Criticality Sonification System [4]. Section A receives network traffic from a capture script. Section B shows the voice definitions to which each traffic variable is mapped. Section C mixes the audio streams into a stereo feed. Section D is a combined plot of the variables being monitored.

6. Conclusion

Twenty years ago, Kramer called for collaboration between sonification designers and composers [25]. Despite a few notable exceptions the sonification community seems to have been unwilling or unable to enter into such collaborations (and often with justifiable reticence, for example, see Bovermann, Rohruber, and de Campo [26, p. 240]). However, recently there has been an increasing interest in exploring the aesthetic aspects of sonification (e.g., see Schedel and Worrall's editorial [27]) and the definitional boundary between sonification and music continues to be pushed by sonification designers and composers alike [28]. We now see designers on the one hand who are thinking seriously about the role of aesthetics in sonification design and composers on the other hand who are increasingly interested in using data and sonification schemata in their own aesthetic practice.

It is the goal of our present research to produce a real-time network monitoring system using a soundscape based interactive sonification to enhance situational awareness for network administrators. Such a system will enable them to monitor network activities while performing other administration tasks in order to recognise and identify any patterns of sound that indicate misuse or malicious activity to achieve real-time intelligence about a network environment. The initial SOCS prototype [4] serves as an initial proof of design concept. The next stage will bring together our work on situational awareness [1] and a more formal soundscape approach in a new tool. It is intended to experiment with a range of different naturalistic and artificial soundscapes (e.g., forest, city, sound effects) to see which works best in supporting situational awareness. Modern networks generate a lot of data and it is hoped that a soundscape approach will offer an environmentally complementary solution that is acceptable to users and which minimises annoyance and fatigue.

7. REFERENCES

[1] T. Fairfax, C. Laing, and P. Vickers, "Network Situational Awareness: Sonification & Visualization in the Cyber Battlespace," in *Handbook of Research on Digital Crime, Cyberspace Security, and Information Assurance*, M. M. Cruz-Cunha and I. M. Portela, Eds. IGI Global, 2014, p. in press.

[2] M. R. Endsley, "Toward a Theory of Situation Awareness in Dynamic Systems," *Human Factors*, vol. 37, no. 1, pp. 32–64, 1995.

[3] P. Vickers, "Sonification for Process Monitoring," in *The Sonification Handbook*, T. Hermann, A. D. Hunt, and J. Neuhoff, Eds. Berlin: Logos Verlag, 2011, pp. 455–492.

[4] P. Vickers, C. Laing, and T. Fairfax, "Sonification of a Network's Self-Organized Criticality," *arXiv preprint arXiv:1407.4705*, 2014.

[5] Ministry of Defence, *Army Doctrine Publication — Operations*. 2010.

[6] W. S. Angerman, "Coming Full Circle with Boyd's OODA Loop Ideas: An Analysis of Innovation Diffusion and Evolution," Airforce Institute of Technology, Wright-Patterson AFB, Ohio, USA, 2004.

[7] S. Jajodia, P. Liu, V. Swarup, and C. Wang, Eds., *Cyber Situational Awareness: Issues and Research*. Springer Verlag, 2010.

[8] P. Vickers, "Ways of Listening and Modes of Being: Electroacoustic Auditory Display," *Journal of Sonic Studies*, vol. 2, no. 1, 2012.

[9] T. Hermann, A. D. Hunt, and J. Neuhoff, Eds., *The Sonification Handbook*. Berlin: Logos Verlag, 2011.

[10] M. Gilfix and A. L. Couch, "Peep (The Network Auralizer): Monitoring Your Network with Sound," in *14th System Administration Conference (LISA 2000)*, New Orleans, Louisiana, USA, 2000, pp. 109–117.

[11] M. Ballora, B. Panulla, M. Gourley, and D. L. Hall, "Preliminary Steps in Sonifying Web Log Data," in *16th International Conference on Auditory Display*, Washington, DC, 2010, pp. 83–87.

[12] M. Ballora, N. A. Giacobe, and D. L. Hall, "Songs of Cyberspace: An Update on Sonifications of Network Traffic to Support Situational Awareness," *Proc. SPIE*, vol. 8064, p. 80640P–80640P–6, 2011.

[13] M. Ballora, N. A. Giacobe, M. McNeese, and D. L. Hall, "Information Data Fusion and Computer Network Defense," in *Situational Awareness in Computer Network Defense: Principles, Methods and Applications*, C. Onwubiko and T. Owens, Eds. IGI Global, 2012.

[14] E. P. Blasch and S. Plano, "JDL Level 5 Fusion Model: User Refinement Issues and Applications in Group Tracking," in *Proc. SPIE*, 2002, vol. 4729, pp. 270–279.

[15] M. Kimoto and H. Ohno, "Design and Implementation of Stetho — Network Sonification System," in *Proceedings of the 2002 International Computer Music Conference*, Göteborg, 2002, pp. 273–279.

[16] R. Giot and Y. Courbe, "InteNtion–Interactive Network Sonification," in *Proceedings of the 18th International Conference on Auditory Display (ICAD 2012)*, 2012, pp. 235–236.

[17] K. E. Wolf and R. Fiebrink, "SonNet: A Code Interface for Sonifying Computer Network Data," in *NIME'13 — 13th International Conference on New Interfaces for Musical Expression*, Daejeon + Seoul, Korea, 2013, pp. 503–506.

[18] R. M. Schafer, *The Tuning of the World*. Random House, 1977.

[19] B. C. Pijanowski, L. J. Villanueva-Rivera, S. L. Dumyahn, A. Farina, B. L. Krause, B. M. Napoletano, S. H. Gage, and N. Pieretti, "Soundscape Ecology: The Science of Sound in the Landscape," *BioScience*, vol. 61, no. 3, pp. 203–216, 2011.

[20] M. Adams, T. Cox, G. Moore, B. Croxford, M. Refaee, and S. Sharples, "Sustainable Soundscapes: Noise Policy and the Urban Experience," *Urban Studies*, vol. 43, no. 13, pp. 2385–2398, 2006.

[21] K. Tuuri and T. Eerola, "Formulating a revised taxonomy for modes of listening," *Journal of New Music Research*, vol. 41, no. 2, pp. 137–152, 2012.

[22] F. Grond and T. Hermann, "Interactive Sonification for Data Exploration: How listening modes and display purposes define design guidelines," *Organised Sound*, vol. 19, no. Special Issue 01, pp. 41–51, 2014.

[23] M. Filimowicz, "Peircing Fritz and Snow: An aesthetic field for sonified data," *Organised Sound*, vol. 19, no. Special Issue 01, pp. 90–99, 2014.

[24] M. Chion, *Audio-Vision: Sound on Screen*. NY: Columbia University Press, 1994.

[25] G. Kramer, "An Introduction to Auditory Display," in *Auditory Display*, vol. XVIII, G. Kramer, Ed. Reading, MA: Addison-Wesley, 1994, pp. 1–78.

[26] T. Bovermann, J. Rohruber, and A. de Campo, "Laboratory Methods for Experimental Sonification," in *The Sonification Handbook*, T. Hermann, A. D. Hunt, and J. Neuhoff, Eds. Berlin: Logos Verlag, 2011, pp. 237–272.

[27] M. Schedel and D. R. Worrall, "Editorial," *Organised Sound*, vol. 19, no. Special Issue 01, pp. 1–3, 2014.

[28] P. Vickers, "Sonification and Music, Music and Sonification," in *submitted to The Routledge Companion to Sounding Art*, M. Cobussen, V. Meelberg, and B. Truax, Eds. Routledge, 2015.

SONIFICATION DESCRIPTIONS

4-channel sonification of EEG-data

Tilo Schmalenberg, Berlin (Germany)

My ambition with this artistic approach is to show the room of the brain with the cerebral processes as a room of sounds. In other words, to listen someone's thinking.

The EEG-data has been read approx. every 5th number resulting in broken line of data which is better for musical reasons in order to have bigger intervals than smaller steps or glissandi. Although as a lot of data is eliminated the shape of the graph from the data and the resulting "melody" becomes clearer.

Each channel of the EEG-headset has its own representation as a channel in sound. The forehead channels have more higher frequencies and the occipitals more lower frequencies. The stereo panorama also depends on the channel points of the headset as well.

The raw data sounds are made only of sinusoidal waves. The resulting accords demonstrate clearly the interrelation of the brain areals. When the accords are changing it often seems to be in a 3/8 rhythm and the brain seams to dance. Higher brain activities are more melodic or sound as a sudden higher sustained note. The left hemisphere sounds are much lower frequencies.

The Emotion data are composed under sound design for artistic reasons. 'Excitement' is represented by more vibrant sound, the drone stands for
'boredom' and drone with slow rhythm for 'engagement'.

This 2-minute piece is a cut-out of the time section from 13:52:30 to 13:54:30 with unchanged tempo. The piece starts with the emotion-sounds then at 0:30 the raw data is producing more "natural based" sound. At 1:30 gradually both sound-sections are mixed together.

Tilo Schmalenberg

BrainWaves.

By Dimitris Maronidis [Ph.D]

The piece was composed by elaborating EMOTIV data retrieved from soniHED website. I used the "Engagement" field to control the onsets of the events. "Meditation" data were used to control the durations and modulate the frequencies of the events (scaled to fit in two minutes and expanded to cover the auditory hearing range) while "Frustration" and "Boredom" data controlled the amplitude envelopes of the sonic events. Finally, "Excitement" data used to control the Amplitude Modulation and some aspects of spatial distribution.

I was imagining the encephalic signals, traveling across the human brain, as imaginary musical strings vibrated by stimuli of the real world (as if the brain would be a musical instrument itself).

The piece was implemented in OpenMusic (IRCAM) and Cmix (Princeton University) programming languages. Special patches/algorithms were developed to make the sonification of the data possible and meaningful. The process was completed after many experiments in a "trial and error" process.

Dimitris Maronidis [Ph.D]
Composer