Functional Musical Sonification for Chronic Pain Support

Lilly Neubauer[1], Nicolas E. Gold[1], Temitayo Olugbade[2], Amanda CdeC Williams[3], Nadia Berthouze[2]

[1]Department of Computer Science, University College London, UK

[2]UCL Interaction Centre (UCLIC), University College London, UK

[3]Department of Clinical, Education and Health Psychology, University College London, UK

{lilly.neubauer.18,n.gold, temitayo.olugbade.13, amanda.williams, nadia.berthouze}@ucl.ac.uk

Abstract. *Chronic pain causes substantial disability, and people living with chronic pain often use protective behaviours and movements to minimize pain and worry about exacerbating pain during everyday activities such as loading the washing machine. We present work in progress on ubiquitous interactive sonification of body movement to help people with chronic pain to understand and positively modify their movements in clinical and functional situations. The sonification blends informational and aesthetic aspects and is intended for daily use.*

1. Introduction

People with chronic pain experience long-term pain that is not associated with ongoing tissue damage (Raja et al. 2020). This pain can have significant impacts in day to day functional situations. We undertook a survey of people living with chronic pain and respondents (n=37) identified varying extents of difficulty (including total inability) in a range of activities involved in daily life e.g. lifting things, bending, turning while sitting, and ascending and descending stairs. Respondents indicated difficulties in everyday tasks such as shopping, laundry, and cleaning.

Previous work has shown the potential of movement sonification to increase self-efficacy and pain management for people living with chronic pain (Singh et al. 2016, Newbold et al. 2016). It showed that movement sonification could variously increase confidence, relaxation, and self-regulation in individual instances of painful or protective movement. Other work found that music can be effective in reducing pain, depression, anxiety, and feelings of powerlessness in study participants with chronic pain (Guetin et al. 2012, Siedliecki & Good 2006). The distracting power of music was also somewhat evidenced in our survey results: Of the respondents (n=30) who reported that time passes less quickly for them when their pain is more than usual, the majority (n=25) reported that listening to music during this period made time pass the same as or more quickly than on a usual day.

The work we report here is focused on combining generative sonification of body movement with music, to support affective use of the sonification in day to day functional situations. This might be seen as a form of eco-composition (Flores et al. 2009): bringing together agent (the person living with chronic pain), tools (body-worn sensors, mobile phone, headphones, sonification algorithms/apps), and environment (the home). Whilst

the activities (day to day tasks like loading the washing machine or unpacking shopping) are not artistically-focused (e.g. performance, composition (Flores et al. 2009)), the result of using such a sonification in task support will result in 'informational music' created by the user's interaction with the system (the kind of sonic by-product Flores et al. identify, except that here the music itself aims to change the affordance of the environment and activity from which it is being created). Keller et al. (2019) note the potential for well-being and health applications of ubimus technologies, citing the Beathealth project (Timoney et al. 2014) as an example. Like the Beathealth project, our work is not directed primarily at musically-creative outcomes, but aims nonetheless at everyday music-making irrespective of musical expertise (see Keller et al. 2020).

We envisage multiple linked use-cases: in therapeutic situations where an individual is working with a physical therapist to understand, review recordings of, and improve movement confidence and quality; working with a partner to support movement practice; and when alone, drawing on the music and sound developed in these other situations to stimulate and give confidence to tackle functional tasks.

2. Sonification

An initial prototype designed to sonify simple arm extensions was followed by a more complex sonification of a daily task (unloading the washing machine). We used Notch[1] sensors to measure rotation and/or tilt angles of shoulder, knee and chest. Data from the sensors was then downloaded and sonified using SuperCollider[2]. At this stage of our work, the data is simply recorded and replayed to the sonification engine as if in real-time (to minimize the need for participant involvement in each execution and to overcome some current technical limitations). In future we intend the tool to function interactively in real-time to support the range of use-cases identified above.

The sonification design drew on Hunt and Hermann's (2011) criteria for interactive sonifications, considering the system and user as a "closed loop", each influencing the other's reaction and behaviour. We developed four behavioural goals and corresponding sonic mechanisms, drawing on the findings of previous research into chronic pain sonification design (Singh et al. 2017). The result is a multi-layered musical soundscape, with morphing harmonic sounds and individual chiming chords playing over a slow-moving generative bassline. The behaviour-sound mapping is shown in Table 1.

Several videos show the sonification of movement data captured from one of the authors and from study participants. In the first, a series of isolated crouch movements clearly demonstrate the "threshold chimes" when the figure bends their knee past a certain point[3]. The other videos demonstrate the full washing machine task, but with the sonification of "threshold values" taken from different dimensions of movement: knee bend[4]; chest lean forward[5]; and reaching (shoulder extension)[6]. Additionally in each animation, the movement of the band-pass filter frequency and the texture of the ambient melodic sound change as the velocity of the participant's movement changes.

---

[1] https://wearnotch.com
[2] https://supercollider.github.io
[3] https://youtu.be/RPhH8NTUhyI - Video of isolated crouch movements
[4] https://youtu.be/JuNyJpaPLcY - Unloading the Washing Machine, Study Participant, knee bend
[5] https://youtu.be/Mv3TuWPIGhE - Unloading the Washing Machine, Study Participant, lean forward.
[6] https://youtu.be/TEp66ysbIKo - Unloading the washing machine, researcher

Table 1. Sonification Design Factors

Goal	Rationale	Sonification Design
Reduce anxiety	Movement can exacerbate pain leading to significant anxiety about movement.	Generative, slow-tempo, ambient sounds with long attack/release times provide a foundation to reduce anxiety.
Foster feelings of achievement/progress	People living with chronic pain can benefit from an awareness of progress in range of motion over time.	"Positive" (major, chiming) sound triggered when reaching a pre-defined movement threshold (set by the user and/or therapist in advance). Thresholds can be set to reflect gradual changes in range of motion.
Objective self-monitoring	Agency over the sound is needed, thus some sonification elements must directly map to movements.	1. Angular velocity is mapped to the frequency of a band-pass filter (100Hz-3kHz) applied to a pink noise generator, to indicate when motion is taking place. 2. The "energy function" (see Fod, Matarić & Jenkins 2002) of a user's movement is mapped to the trigger rate, grain duration, and amplification parameters of a granular synthesizer, resulting in the texture (smooth vs. grainy) of the sound varying in response to the dynamism of movement.
Promote exploration	To motivate continued use, the soundscape should encourage playfulness and creativity.	The integration of the sonic layers is designed to promote fidelity of sonic outcome in response to movement but remain interesting to the user.

3. Conclusion

This paper has reported work in progress on a musically-oriented movement sonification to support people with chronic pain. Future work will include empirical evaluation of the sonification in a range of settings to investigate the balance between information and musical coherence, investigating more advanced movement recognition, and considering possible applications beyond chronic pain.

This work is funded by the EU Horizon 2020 FET Proactive project "EnTimeMent", grant number: GA824160. Ethics approvals: UCL 5625/001, UCLIC/1516/012/Staff Berthouze/Singh; NRES Committee - 11/0514, UCL 5095/001.

References

Flores, L. V., Pimenta, M., Capasso, A., Tinajero, P., & Keller, D. (2009). "Ubiquitous music: Concepts and metaphors". *XII Brazilian Symposium on Computer Music*, p. 139–150.

Fod, A., Matarić, M. J., & Jenkins, O. C. (2002). "Automated derivation of primitives for movement classification". *Autonomous robots*, 12(1), p. 39-54.

Guétin, S., Giniès, P., Siou, D. K., Picot, M. C., Pommié, C., Guldner, E., Gosp, A. M., Ostyn, K., Coudeyre, E., & Touchon, J. (2012). "The effects of music intervention in the management of chronic pain: a single-blind, randomized, controlled trial". *The Clinical journal of pain*, 28(4), p. 329–337.

Hunt, A., & Hermann, T. (2011). "Interactive sonification". In Hermann, T., Hunt, A., Neuhoff, J.G. (Eds.). *The Sonification Handbook*. Logos Verlag, Berlin, Germany, 2011 p. 273-298.

Keller, D., Schiavoni, F., & Lazzarini, V. (2019). "Ubiquitous music: Perspectives and challenges", *Journal of New Music Research*, 48(4), p. 309-315.

Keller, D., Messina, M., & de Oliveira, F. Z. N. (2020). "Second Wave Ubiquitous Music: Collaboration, Automation and Knowledge Transfer for Creativity (Editorial)", *Journal of Digital Media & Interaction*, 3(5), p. 5–20.

Newbold, J. W., Bianchi-Berthouze, N., Gold, N. E., Tajadura-Jiménez, A., & Williams, A. C. (2016). "Musically informed sonification for chronic pain rehabilitation: Facilitating progress & avoiding over-doing". *Proc. CHI 2016*, p. 5698–5703.

Raja, S.N., Carr, D.B., Cohen, M., Finnerup, N.B., Flor, H., Gibson, S., Keefe, F.J., Mogil, J.S., Ringkamp, M., Sluka, K.A., Song, X.J., Stevens, B., Sullivan, M.D., Tutelman, P.R., Ushida, T., Vader, K. (2020). "The revised International Association for the Study of Pain definition of pain: concepts, challenges, and compromises". *Pain*. Sep 1;161(9) p. 1976-1982.

Siedliecki, S. L., & Good, M. (2006). "Effect of music on power, pain, depression and disability". *Journal of advanced nursing, 54*(5), p. 553-562.

Singh, A., Piana, S., Pollarolo, D., Volpe, G., Varni, G., Tajadura-Jiménez, A., Williams, A. C., Camurri, A., & Bianchi-Berthouze, N. (2016). "Go-with-the-flow: tracking, analysis and sonification of movement and breathing to build confidence in activity despite chronic pain". *Human–Computer Interaction*, 31(3–4), p. 335–383.

Singh, A., Bianchi-Berthouze, N., & Williams, A. C. (2017). "Supporting everyday function in chronic pain using wearable technology". *Proc. CHI 2017,* p. 3903-3915.

Timoney, J., Lazzarini, V., Ward, T., Villing, R., Conway, E. & Czesak, D. "The Beathealth project: synchronising movement and music". *Fifth Workshop on Ubiquitous Music*, Vitorià (Brazil): Oct 29 - Nov 1, 2014.