FEELING LOKI'S PAIN: DESIGNING AND EVALUATING A DIY 3D AUDITORY DISPLAY FOR GEODATA SONIFICATION

PerMagnus Lindborg

SoundLab, School of Creative Media
City University of Hong Kong
Hong Kong SAR
pm.lindborg@cityu.edu.hk

ABSTRACT

Loki's Pain is an immersive 3D audio installation artwork, a sonification of seismic activity. Visitors take the place of Loki, who was punished by the gods and caused earthquakes. We designed an auditory display in the shape of a hemi-dodecahedron and built a prototype with a low-budget, DIY approach. Seismic data were retrieved from the Internet. Location, magnitude, and epicentre depth of hundreds of recent earthquakes were sonified with physical modelling synthesis into a 10-minute piece. The visitor experience was evaluated in a listening experiment (N = 7), comparing the installation with a version for headphones. Differences on eight semantic scales were small. A content analysis of focus group discussions nuanced the investigated topics, and qualitative interpretation strengthened the quantitative findings. Verbal expressions of immersivity were stronger in the installation, which stimulated longer and more detailed responses. Aspects such as audio quality, the structure's physical-visual shape, and multisensorial design evoked both positive and negative emotions, and elicited imagination and memory recall. However, the assumed capacity of the LOKI structure to stimulate a richer social experience than that of headphone listening was not supported by the responses in this study.

1. LOKI'S PAIN

Loki's Pain[a] is an immersive sound installation: a 16-channel 3D audio sonification of seismic activity [1]. Visitors take the place of Loki, who, according to a Norse legend, was "punished by the gods by being chained to three rocks in a cave using the entrails of his dead son, with a venomous serpent poised above his head. When the serpent's poison fell on Loki's head it caused him to shake uncontrollably, thereby unleashing an earthquake" [2]. The artwork aims to remind visitors of the fragility of the Earth's crust and the reality faced by people exposed to the terrifying power of earthquakes and volcanic activity.

To present *Loki's Pain*, we designed and built the 'LOKI structure'. It is a low-cost and relatively portable auditory display for 3D sonic artworks. The structure is suspended from the ceiling, does not touch the floor, and there are no obstructing cables. As shown in Figure 1, the structure envelops the listener and creates an immersive soundscape that may be shared by two visitors. In *Loki's Pain*, they sit on a lightly vibrating subwoofer while listening to the sound of virtual cymbals, created by physical modelling, spatialised according to the geographical location of seismic events, as if they found themselves at the centre of planet Earth. *Loki's Pain* continues the author's work with geodata sonification and the LOKI structure builds on his previous designs of loudspeaker arrays [3], [4], [5], [6].

[a] *Loki's Pain* was commissioned by Indra and Harry Banga Gallery, Hong Kong, and supported by the School of Creative Media, City University of Hong Kong.

2. LOKI STRUCTURE

The LOKI structure is a hemi-dodecahedron and it was designed from scratch with inspiration from [7], [8]. The author and his assistant cut 30x aluminium profiles (T-slot Extrusion, 20 mm wide and 750 mm long), fabricated 160x laser-cut acrylic parts of three kinds, and assembled parts with 140x nuts/bolts and 40x cable ties. The final structure is ~220 cm wide, ~75 cm tall, and weighs ~25 kg. It has four ∩-fittings so as to be suspended from the ceiling grid with adjustable-length hooks and four 1.5 mm coated wires. The total cost of materials and a few special tools was ~4,500 HKD (~800 USD) and took an estimated ~80 man-hours to make.

The structure was fitted with 15 custom-made 'bowl speakers' from a previous project [6]. Audio cables were run from the loudspeakers upwards, so as not to interfere with visitor movement, to a small platform concealed in the Gallery ceiling grid. The platform supports the audio playback system, consisting of two 8-channel fixed-media players (WavePlayer8), two 8-channel custom-built pre-amplifiers, two 4-channel power amplifiers (Pioneer GMX84), and a 12V DC power supply. The purchase cost of this equipment was ~1,600 USD. It took ~20 man-hours to assemble, install, and tune the piece on site. A single AC on/off switch was handled by the Gallery personnel every morning. More information and photos from the construction and installation are available on the project website (http://soundislands.com/2021/01/21/lokis-pain/).

3. GALLERY EXHIBITION

The LOKI structure playing *Loki's Pain* was exhibited at Indra and Harry Banga Gallery, Hong Kong, between 23 November 2020 and 31 May 2021, interrupted by a 10-week closure due to COVID-19 regulations. The installation was made in a dedicated, semi-secluded partition measuring ~450 cm x ~450 cm, with black carpet flooring and acoustic panels on four walls. A single spotlight gently illuminated the metal structure. In addition to the 15 'bowl speakers' mounted in the structure we placed a subwoofer on the floor at the centre of the LOKI structure. The amplification level and frequency response were adjusted so that visitors sitting on it could feel the vibration rather than hear it.

Figure 1:Two visitors listening to *Loki's Pain* at Banga Gallery, Hong Kong.

Loki's Pain produces sound during ~50 minutes of each hour. The 10-minute sonification (see below) is played four times, interspersed with shorter bits of subwoofer rumbling and silence. The hour-long fixed-media audio is repeated throughout visitor hours. Because all loudspeakers are near-field monitors and placed close to the visitor(s), sound levels can be kept quite low and sound spill to the outside of the installation is relatively unobtrusive.

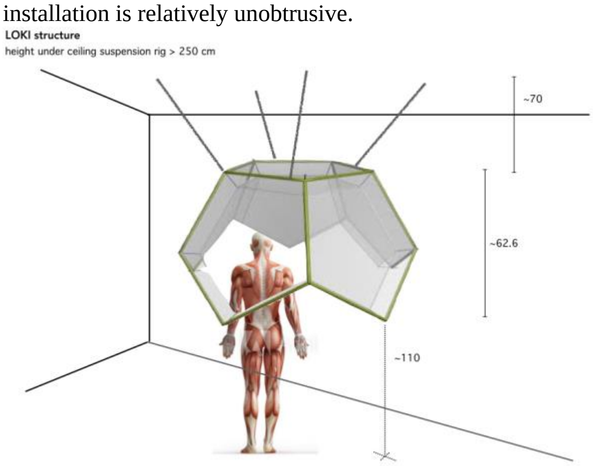

Figure 2: First concept draft of the LOKI structure. Because the ceiling height at *Banga Gallery* is rather low, a solution with visitors seated on a subwoofer was chosen.

A short movie (https://vimeo.com/509611598, 02:03) documents Loki's Pain with a tour and introduction by the Curator at the Gallery opening (23 November 2020).

4. SONIFICATION

The sonification strategy built on [9], [10]. For pragmatic reasons an offline approach was chosen, though in principle the sonification can be made in real-time, as in the author's previous work [4].

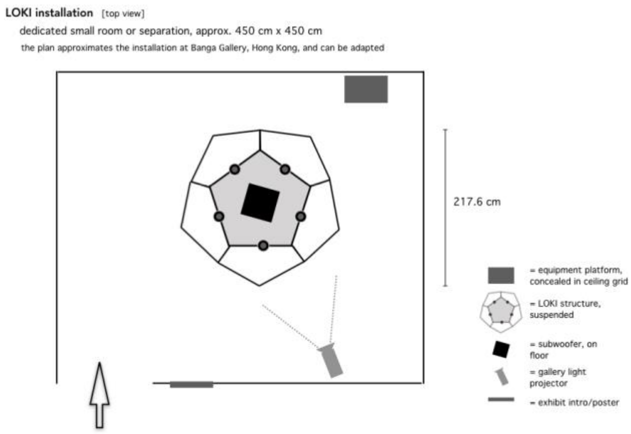

Figure 3: Installation design (top-down view) of LOKI structure and main components.

4.1. Data pre-processing

Seismic data were retrieved from the 'Seismic Monitor' website of the Incorporated Research Institutions for Seismology [IRIS], using an R script [11], [12]. IRIS compiles data from a vast network and the website is updated several times a day, typically listing ~750 events over the most recent ~30 days. Each row had time [UTC], latitude, longitude, magnitude, and depth [km], along with location and other information [text]. For *Loki's Pain*, raw data for magnitude and depth were power transformed using a Box-Cox method, trimmed at ±3 standard deviations, and scaled within a range [0…1] [13]. This pre-processing greatly facilitated parameter mappings in Max [14]. See Figure 4.

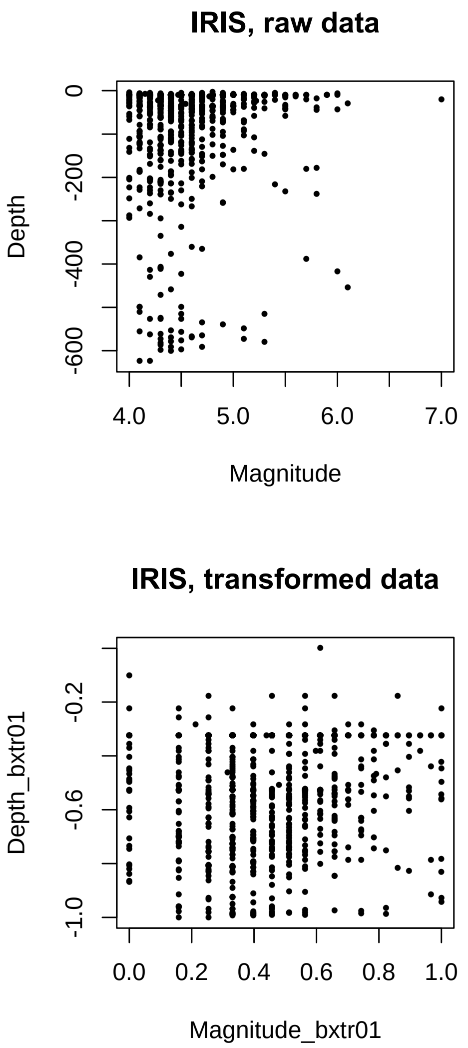

Figure 4: Plots of raw data from the IRIS server [IRIS], and the same data after power transformation, trimming, and scaling.

4.2. Mapping to synthesis parameters

Several audio synthesis methods were explored until we settled on adapting the 'simple cymbal' featured in the tutorial package for Modalys [15]. See Figure 5. This is a physical modelling synthesis of a circular plate that emulates a ride cymbal made of metal and with a raised bell. In the sonification Max patcher, data were streamed from an ftm matrix to a poly~ object with virtual cymbals, defined as in Figure 6. Each seismic event allocated a new poly~ voice instantiation, i.e. a virtual cymbal.

Magnitude and depth were mapped onto synthesis parameters and determined the shape of the excitation signal. All mappings and range limits were carefully tuned heuristically. Recall that *M* [magnitude] and *D* [depth] were power transformed and scaled in range [0…1]. Furthermore, they were coded so that M=1 indicated a very strong earthquake and D=1 indicated a very shallow epicentre (i.e. the opposite of very deep). Equations 1-4 below include *e*, representing the addition of a small, independently

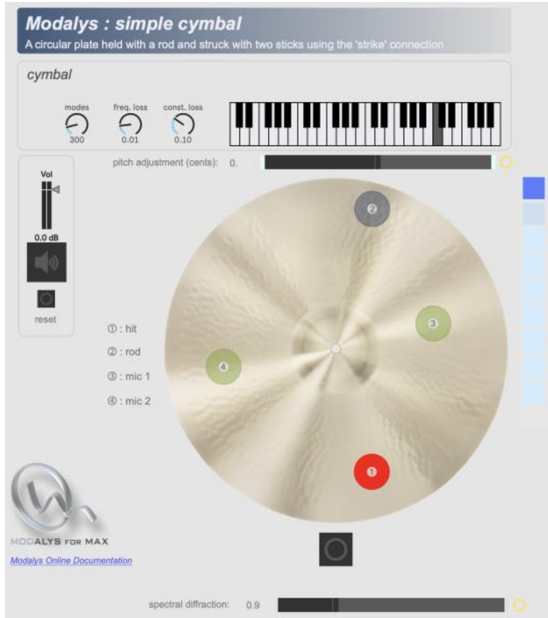

Figure 4: Tutorial patcher for the 'simple cymbal'.

stochastic value (changing over time according to a Brownian motion algorithm). We defined the mappings from M and D (and *e*) to the six modalys~ synthesis parameters as follows:

$$stick\_pos = \{0.07D + 0.01,\ 6/5\pi + e\} \tag{1}$$

$$rod\_pos = \{0.72 + e,\ 2/5\pi + e\} \tag{2}$$

$$mic\_pos = \{0.6 + e,\ 4/5\pi + e\} \tag{3}$$

$$pitch = -10D + 30 + e \tag{4}$$

$$freq\_loss = -0.38M + 0.4 \tag{5}$$

$$const\_loss = -0.35M + 0.4 \tag{6}$$

Equations 1-3 yield polar coordinates for positions; the values represent relative distance from rim to centre of the cymbal in the range [0…1] and angle in radians. Equation 4 yields a midipitch value in a selected range; the limits correspond to the notes Ab and Gb in the first octave. Note that the virtual cymbal synthesis produces a complex spectrum and there is not really a discernible pitch as such.

We then created an excitation signal by defining four breakpoints. The signal is a 'strike connection' lasting only a few milliseconds. Here, |*amp*| sets the maximum level of the signal and *ts* is the duration of each segment, i.e. from one breakpoint to the next.

$$amp = (-0.02D + 0.04)M + 0.1 \tag{7}$$

$$ts = (M + D)/2 \tag{8}$$

$$excitation(t) = (0, 0),\ (ts, -amp),\ (2ts,\ amp),\ (3ts,\ 0) \tag{9}$$

Finally, we defined a *boost* value (in decibels) applied to the modalys~ output signal, as follows:

$$boost = 14M + 8 \tag{10}$$

Since we wanted rather long-ringing cymbal strikes, we developed an ad hoc method to determine when the level of

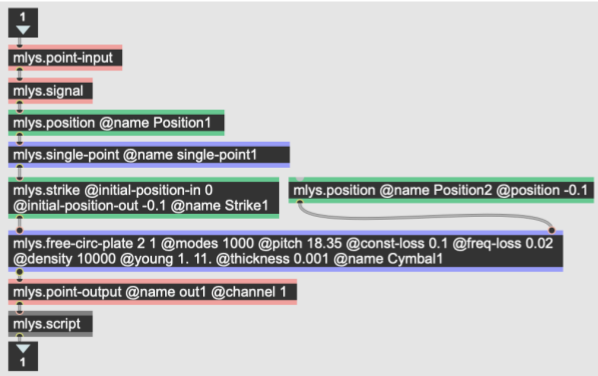

Figure 5: Initialisation of the virtual instrument.

a cymbal voice had faded sufficiently to release it from processing within poly~. This was strictly speaking not necessary given the offline rendering situation but might be crucial in a real-time application such as [16].

The sound of each cymbal strike was spatialised to create the illusion of the visitor being at the very centre of Earth, listening 'outwards'. Latitude and longitude were directly mapped with spat~ using vbap3d panning and with a small amount of room reverberation [17].

In addition to 15 output signals for the 'bowl speakers', a summed and low-passed signal was made for the subwoofer. The 16 channels were rendered to disk and transferred to SD cards for the two synchronized fixed-media players (see Section 2). Simultaneously, a separate spat~ object rendered the same signals to binaural format using a generic KEMAR HRTF profile [16].

5. PERCEPTUAL EVALUATION

Few art galleries are constructed with an acoustic design conducive to sound pieces, and oftentimes visitors may listen to audio works over headphones. At the Banga Gallery, the LOKI structure was set up in an ad hoc semi-secluded partition with a thin carpet and acoustic panels on the walls, which provided some acoustic benefits. To gain a better understanding of the visitor experience, we conducted a listening experiment. The aim was to assess strengths and weaknesses of the LOKI structure as a vehicle to present a 3D sonic artwork. Therefore, we set up a comparison between two different kinds of auditory displays, both playing *Loki's Pain.* In particular, we wanted to know how the installation was perceived in terms of reproducing an immersive soundscape [18], [19]; being a place for shared social experiences [20]; and having a capacity to evoke emotions [21]. These areas of interest led the investigator to define a set of eight topics: sound *spatialization, immersivity, social experience, audio quality, visual imagery, mind wandering, evoked emotion,* and *aesthetic judgement.*

5.1. Materials

We compared two situations (i.e. different auditory displays) through which *Loki's Pain* was presented: the LOKI installation, as described above, and a version for headphones that was set up for the experiment, also in the Gallery but away from the Installation. In what follows, "Installation" refers to listening to the 10-minute piece inside the LOKI structure where it was rendered over 15 'bowl speakers' and a subwoofer; while "Headphones" refers to listening over studio-quality circumaural headphones (AKG K240 MKII) for which the piece was rendered in binaural format (WAV 48 kHz 16 bits; see project website for different versions, at http://soundislands.com/2021/01/21/lokis-pain/). The binaural version was static, i.e. did not compensate for listener movement of the head. Note that the same IRIS data, Modalys synthesis, and basic Spat configuration were used to render the sound for both conditions; what differed was only the definitions of output format for two parallel spat~ objects.

5.2. Participants and procedure

We conducted a pilot study. Seven graduate students (six females, one male) in a class of computer music volunteered to participate in a listening experiment. After being duly informed, each signed a consent form before starting. Two groups were formed by their preferred language: four speaking Mandarin and three Cantonese. One group first listened via Headphones, while the other group started with the Installation. Note that the LOKI structure sits a maximum of two persons at any time, so participants were encouraged to occasionally swap places. One or two persons could stand or move around the suspended structure while one or two others were seated inside of it. The movement this engendered was not considered a problem as it is similar to the normal exhibition conditions and experience of the piece. When two persons were sitting inside the structure, each would inevitably experience a partial acoustic occlusion of the sound-field by the other person's body.

After each round of listening, participants individually filled out a paper/pencil form. It listed the eight topics of investigation (as above), each accompanied by a question to help clarify the construct, and a five-step Likert scale where participants circled one response. For example, the construct "Immersivity" was specified with "To what degree did you feel immersed or enveloped by the sounds?" and the steps were labelled "I felt very immersed - Quite immersed - Neutral – Somewhat immersed - I didn't feel immersed at all". Two versions of the form were used with the eight topics in different order (alphabetical and reverse). They were distributed to the participants at random. Lastly, the protocol invited the participant to write a free-form response with the prompt: "In your own words, describe the listening experience.'

Having finished both listening conditions, the participants gathered for a structured discussion in focus groups [22], [23]. The two groups were formed, led by a Cantonese and Mandarin speaker, respectively. Leaders were given a script with the eight topics (see above) and suggestions for questions and prompts. They had been trained to let the participants discuss freely and only occasionally guide the flow so as to cover all topics. Each focus discussion lasted around ten minutes, and audio recordings were transcribed to English for the analysis.

5.3. Analysis and results

Responses on semantic scales were coded and subjected to statistical analysis in R [12]. A set of within-subjects ANCOVA were conducted, in each case with ratings on one of the eight semantic scales as dependent variable, setup (Installation or Headphones) as the single explanatory variable, and the order of listening (first or second) as a co-variate. Only *Focus* indicated a tangentially significant difference between conditions ($F(5)=6.5$, $p=0.052$), with participants indicating higher degree of *Focus* when listening in the Installation. See Figure 6.

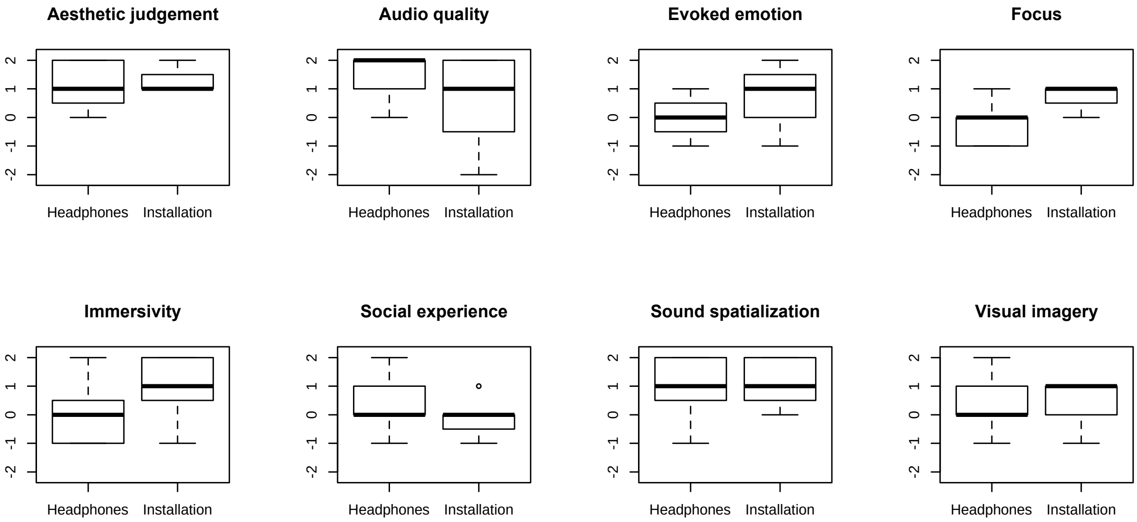

Figure 6: Boxplots of responses (N = 7) on eight semantic scales in two listening conditions. The vertical scale expresses the strength or amount of concepts.

The transcriptions of group interviews were subjected to content analysis [24]. In this qualitative method, text is carefully interpreted so as to identify units of meaning, or frames, that represent concepts that emerge. There is no set number of frames to find for a given text corpus. The two transcripts contained 581 and 734 words, respectively, and the analysis began with taking the eight topics as frames. In a few cases, the author and assistants referred to the original interview recordings (in Mandarin or Cantonese) for clarifications.

The content analysis produced a nuancing of the topics of immersivity and sound spatialization, which were interpreted using three frames: *Sonic Immersivity*, *Immersive Agency*, and *Multimodal Immersivity*. The frame for *Emotion* identified both *Positive* and *Negative* feelings. Furthermore, it was noted that the frames *Focus vs. Distraction* and *Audio Quality* were often connected, that *Imagination or Memory* expressed vivid thoughts in both listening situations, and that *Expectation* and *Social* were of relatively minor importance.

A larger amount of the information content referred to the Installation than to the Headphones: the former had 42 fragments with a total of 375 words, and the latter 22 fragments with 197 words. Another 11 fragments with a total of 135 words referred either to both conditions or were unclear in this regard. We describe the interpretation of content as follows, with select examples:

The Installation was compelling in regards to *Sonic Immersivity*, e.g. "more immersive for me when siting in the installation [M1.III]", or "sound came from various directions… more immersive [M3.II]"), though some participants thought that "headphones made the sound more 3D…spatiality actually felt bigger [C2.I]".

The Installation invited *Immersive Agency* ("can move your head with the sound and the sense of space is different [C1.VI]") to a greater extent than the Headphone situation, which was "more like spectatorship where you listen to whatever is given to you [C1.VI]". Only the Installation conjured *Multimodal Immersivity*: "in the context of installation, when listening… look at the speakers, observe the installation and feel the seat shaking [M4.IV]", and it became a reason for preference "[because] perceptions on multiple aspects [M3/4.VII]").

Emotions were *Positive* in the Installation, such as "I felt like I was being purified [C1.II]" and "[prefer installation] because of the overall feelings [M1.VII]". Likewise, "Listening in headphones felt very peaceful [C2.VI]", though it was *Negative* in that "It felt very passive [C1.VI]", and "I started to get bored [C2.V]". One participant was vocal about experiencing a headache in both situations, especially so in the Installation: "my headache was more serious [M3.II]", and this instilled *Negative* feelings so strong that "I wanted to escape from the installation [M3.X]".

In regards to *Imagination & Memory*, the same participant reported vivid thoughts about being "locked in the cage… penalized to be forced to hear the knocking sound in a prison [M3.II]". This 'knocking' sound is featured in *Loki's Pain*, and other participants reacted more calmly towards it, imagining it as "sitting inside an egg and someone was knocking on it [C1.II]", and that it "feels like cathedral/church bells [C1.II]… I didn't visualise it, it just reminded me of the cathedral [C1.III]".

Lastly, some participants deplored the *Audio Quality* in the Installation, identifying a "problem with one speaker which is staticky [M2.I]". By comparison, "Headphone is better due to its clarity [M1/3/4.VIII]", although the "sound was flatter [C1/3.III]".

The technical problem in the Installation revealed itself detrimental to *Focus vs. Distraction*, "[speaker noise] interfered me [M3.VIII]", and the physical structure itself distracted from purely listening to sounds: "distracted visually by the structure and analyzing the speaker set up [C2.V]". In the Headphones situation, distractions appeared to have been internal, e.g. "[after loud sound] I stopped focusing on the sound [C3.VI]…my mind started wandering. It almost felt like I couldn't hear the sounds anymore because I was thinking about other things [C2.V]".

Lastly, the author and two assistants individually evaluated the free-form responses, written by the participants after each round of listening. We rated the degree of positiveness (+1) or negativeness (-1) in relation to the frames that had emerged in the content analysis of the interviews. Scores were scaled for each rater and frame. The frames were taken three by three, to yield scores for *Immersivity*, *Evoked Emotions*, and *Focus/Quality/Social* for each response. As before, three ANCOVAs were carried out, which yielded no significant differences between listening conditions. There was also no difference between conditions in regards to the number of words used in the free-form responses. See Figure 7 for an illustration.

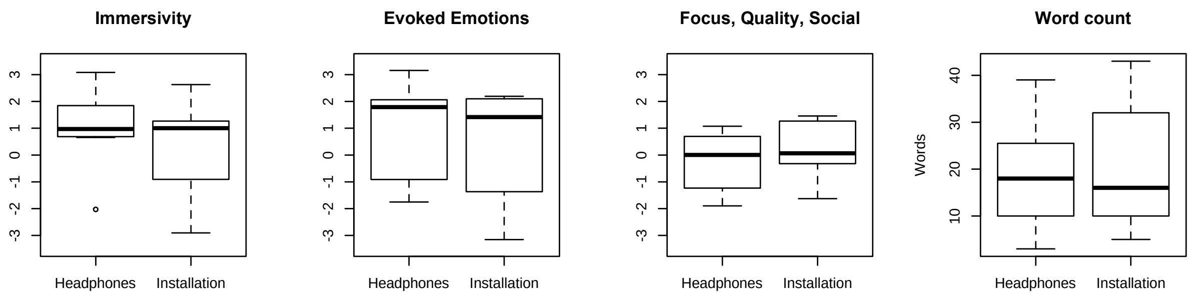

Figure 7: Boxplots illustrating evaluated positiveness-negativeness in three grouped frames of free-form responses (N = 7) in two listening conditions, and word count. The vertical scale on the three panels to the left represent the strength or amount of the concept(s).

5.4. Summary of evaluation

A study was conducted with seven participants who compared the listening experience between two situations, the LOKI installation and a headphones version. Differences in scores on most of the eight semantic scales were small, with the exception that *Focus* was felt to be higher in the Installation, i.e. there were fewer internal or external distractions. Scores for *Immersivity* and *Evoked Emotion* were slightly higher in the Installation but failed to reach significance level. A content analysis of focus group discussions nuanced the investigated topics, which were reformulated as nine content frames. Qualitative interpretation strengthened the quantitative findings. Furthermore, the content analysis revealed that participants were distracted by a technical problem in the Installation (an intermittent buzzing noise) that led to negative evaluations of *Audio Quality*. While one participant reported negative physical reactions (e.g. headache) and imaginations (e.g. like being in prison) in both listening conditions, but more strongly in the Installation, other participants evidenced calmer imagery overall, yet occasionally vivid (e.g. like a cathedral; or raindrops on the head). It was noted that although the participants had knowledge about the poetic and real-life contexts of *Loki's Pain*, no reference was made to either the Norse myth or to seismology in the free-form responses or group discussions.

6. DISCUSSION

Overall, this study could not reveal any significantly different perceptual aspects between Installation and Headphones versions of *Loki's Pain*. Future work should increase the number of participants and control for possible covariates, such as musical sophistication and expectation.

The placing of a relatively large subwoofer inside the LOKI frame restricted the freedom of movement for visitors. One of our initial ideas was to suspend the structure so that its centre is at ear-height for a person standing, as in the concept draft in Figure 2. However, we had to adapt to the conditions of the venue, which has limited height under the ceiling grid. We therefore opted for a situation where the structure is mounted lower, and visitors are seated instead of standing. This idea suggested the use of a subwoofer as a stool with serendipitous sonic possibilities, which were explored in the finalised version at the exhibition.

The custom-built DIY loudspeakers were chosen mainly because of the limited budget available, but also for sentimental reasons. The Author wanted to reuse material from a previous work [6] because it seemed aesthetically suitable for a low-cost prototype work as well as being in the spirit of the poetic subject matter. The audio quality of the 'bowl speakers' is not high but good enough to reproduce the chosen sounds. The 'buzzing noise' that annoyed some of the participants in the evaluation was upon inspection found to be due to a bad cable connection for one single speaker. It was easily fixed. Nevertheless, the negative impression of the installation's audio appears to have influenced other aspects of the evaluation as well. It goes to show that exhibition visitors expect a level of perfection that is hard to maintain in this kind of artwork.

For future work with the present LOKI structure we aim to upgrade the DIY speakers with a set of commercial mini-loudspeakers. It would also be of interest to create a larger, yet still portable structure, that can be suspended from the ceiling in a (larger) gallery space. A hemi-dodecahedron structure that is two to three times the size of LOKI could be sturdy enough to support loudspeakers weighing a few kilograms each. AES67-enabled speakers powered over PoE+ is an attractive option [25].

Sonification of seismic records has a long but relatively sparse history. Significant projects have had different purposes. In 1961, Speeth trained a small group of students to discriminate between underground nuclear blasts and natural earthquakes by listening to seismograms speeded-up into a normal hearing range [27]. This discovery-oriented approach relying on listening, was pursued by Dombois [26]. Meanwhile, Saue and collaborators developed sonification methods of seismic recordings aimed at facilitating oil exploration [28]. Their approach, which was systematic and sensitive to psychoacoustic conditions, later integrated interactive techniques as well, such as 'audio zooming', and identifiable (i.e. semantic) sound objects [29]. In sonic artwork, Roden created "ear(th)" (2004), an installation music piece where an automatic Glockenspiel plays "an image of an earthquake" [30]. Perhaps other forms of geodata, such as those describing climate change, have garnered more attention amongst sound artists than seismic activity [31], [3], [6].

With our present work, we have attempted to create a sound art installation with the same degree of systematicity, transparency of translation, and reproducibility, as might be required for a scientifically purposed sonification. We believe it represents a small step on the long road of bringing aesthetic and utilitarian sonification approaches closer together.

7. ACKNOWLEDGMENT

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