SONIFICATION OF FLUIDITY - AN EXPLORATION OF PERCEPTUAL CONNOTATIONS OF A PARTICULAR MOVEMENT FEATURE

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ABSTRACT

In this study we conducted two experiments in order to investigate potential strategies for sonification of the expressive movement quality "fluidity" in dance: one perceptual rating experiment (1) in which five different sound models were evaluated on their ability to express fluidity, and one interactive experiment (2) in which participants adjusted parameters for the most fluid sound model in (1) and performed vocal sketching to two video recordings of contemporary dance. Sounds generated in the fluid condition occupied a low register and had darker, more muffled, timbres compared to the non-fluid condition, in which sounds were characterized by a higher spectral centroid and contained more noise. These results were further supported by qualitative data from interviews. The participants conceptualized fluidity as a property related to water, pitched sounds, wind, and continuous flow; non-fluidity had connotations of friction, struggle and effort. The biggest conceptual distinction between fluidity and non-fluidity was the dichotomy of "nature" and "technology", "natural" and "unnatural", or even "human" and "unhuman". We suggest that these distinct connotations should be taken into account in future research focusing on the fluidity quality and its corresponding sonification.

1. BACKGROUND

This study is part of the EU H2020 Project ICT DANCE[1] focusing on investigating how affective and social qualities of human full-body movement can be expressed, represented and analyzed through sound and music. The purpose of the DANCE project is to investigate if it is possible to perceive expressive movement qualities in dance solely through the auditory channel, i.e. to capture expressive qualities of dance movements and convey them through sounds. In a general sense, the ability to translate the finer qualities of some information from one modality to another has many practical implications and use cases. Communicating movement qualities through audition can be of great use, e.g. for the blind. While the DANCE project explores artistic practice, the findings will be useful not only in that domain but also in everyday applications. In this paper, we focus on one particular expressive movement quality belonging to the third layer of the four-layered conceptual framework proposed by Camurri et al. in [2]: *Fluidity*. Third level features such as equilibrium, coordination, repetitiveness, and fluidity "are at a level of abstraction such that they represent amodal descriptors, i.e., the level where perceptual channels integrate" [2]. Fluidity could therefore be considered a meaningful feature for characterizing both audio and movement [2]. Furthermore, fluidity has been found to be one of the properties that appears to contribute significantly to perception of emotions in dance [3], suggesting that it could serve as a meaningful parameter which could be mapped to sound in interactive sonification of bodily movement.

2. FLUIDITY AND ENERGY

The fluidity data used for sonification in this study was extracted using the method described in [1]. In this context of body movement, a fluid movement is smooth and coordinated, such as for example a wave-like propagation through body joints [2]. Here, fluidity is estimated by comparing the mean *jerk* values (i.e. the third derivative of the position) of the shoulders, elbows and hands for both original measurements of a dancer and simulated data of a mass-spring model. The mass-spring model is defined so that each joint of the body is modeled as a mass connected to springs that simulate muscle tension. The human body is thus represented as a set of interconnected masses, where each mass represents a joint. The mass-spring model consists of two types of springs: longitudinal springs *l*, which connect joints, and rotational springs *r*, which impress rotational forces on body segments. By tuning parameters (e.g. mass of the joints, spring stiffness or damping coefficients) this model can be used to simulate very fluid conditions generating very smooth trajectories. By calculating the distance between the jerk of the recorded movement data and the fluid simulated mass-spring model data, an estimate of fluidity of a dance movement can be obtained for a given trajectory segment. This is done by calculating the fluidity index (FI) at frame k of a motion segment recorded with a motion capture system (MoCap) as follows:

$$FI_k = JI_k^l + JI_k^r \tag{1}$$

where JI_k^l is the distance of the overall jerk for the longitudinal spring and JI_k^r the distance of the overall jerk for the rotational spring according to the following equations:

$$JI_k^l = |\dddot{X}_k^{ls} + \dddot{X}_k^{le} + \dddot{X}_k^{lh}| - |\dddot{Y}_k^{ls} + \dddot{Y}_k^{le} + \dddot{Y}_k^{lh}| \tag{2}$$

$$JI_k^r = |\dddot{X}_k^{rs} + \dddot{X}_k^{re} + \dddot{X}_k^{rh}| - |\dddot{Y}_k^{ls} + \dddot{Y}_k^{re} + \dddot{Y}_k^{rh}| \tag{3}$$

where $\dddot{X}_k$ is the third derivative of a set of 3D coordinates measured at frame k for the shoulders (s), elbows (e) and hands (h),

[1] http://dance.dibris.unige.it/

respectively, and $\dddot{Y}_k$ the third derivative of the corresponding simulated set of coordinates for the spring model. After evaluation of FI_k, averaging is done to compute the estimated fluidity. For a more detailed description of the computation of the fluidity estimation and algorithm, see [1].

Apart from the fluidity parameter, the sound models described in this paper also make use of kinetic *energy* in the sonification of movement data. Kinetic energy is computed as the product between body joint masses and velocities. Given that we have a three-dimensional space, we define velocity of the *i*-th tracked joint at frame *k* as:

$$v_{ik} = |\dot{X_{ik}}| \tag{4}$$

and then compute the kinetic energy index EI as:

$$EI_k = \frac{1}{2}\sum_{i=1}^{N} m_i \cdot v_{ik}^2 \tag{5}$$

where N is the number of tracked joints of the dancer's body (in our case shoulders, hands and elbows).

3. SOUND MODELS

In previous research on sonification of continuous body gestures, researchers have identified sound properties that can be found in sounds associated to fluent or irregular movements. For example, in a study on the sonification of handwriting it was found that sound models characterized by low frequency components were more suitable for both aiding and communicating fluency of movements, while sound models characterized by high frequency crackling sounds (sounding like small impacts) were suitable for portraying jerky hand movements lacking fluency [4]. In another study in which sound was used for learning movement kinematics, researchers found that sounds which were more noisy or with louder high-frequency components could help users identify motion behavior [5]. These results were taken into account when designing the sound models used in the present study.

As described in the previous section, all sound models were designed to respond to two movement feature parameters: fluidity and energy. In the descriptions below, when *smooth* or *coarse* is used to describe noise, smooth noise stands for spectrally bright and continuous noise, e.g. white noise. Coarse noise signifies more varied and less spectrally even noise, e.g. the noise obtained by randomly switching sample values between +1 and -1, respectively. In all sound models, an increase in energy was mapped to an increase in amplitude, starting from complete silence, given zero energy. All sound models were created using the SuperCollider[2] programming language. The five sound models were:

SM1 An open chord, Eb, in five octaves with one added fifth in the middle of the octave stack, made of saw wave oscillators with variable pitch stability, from perfectly stable to a random modulation of 50Hz centered around the pitch, summed and filtered using a 24dB per octave low pass filter with variable cut off frequency. Increasing the energy increased the filter cut off frequency and increasing the fluidity decreased the amount and speed of the pitch modulation.

[2] http://supercollider.github.io/

SM2 A sinusoidal carrier oscillator with a variable amount of phase modulation from three sinusoidal modulators in intervals of unison, two octaves, and two octaves and a fifth. An increase in energy increased the pitch of all oscillators and the modulation index. A decrease in fluidity injected a white noise component into the sum of the modulators, destabilizing the pitch of the carrier as well as introducing noise in the final output.

SM3 A complex source-filter-model that aims to simulate a wind sound. A mix of noise sources is filtered through a set of band pass and low pass filters that both respond to changes in the energy parameters but also individually vary their cut off frequencies using low frequency random signals. An increase in energy increased the frequency of the random modulations to the filters cut off frequencies as well as their center frequencies. An increase in fluidity resulted in smoother shapes in the modulation signals, as well as a smoother, less coarse, mix of noise sources.

SM4 A simple source-filter-model using a mix of smooth and coarse noise sounds filtered through a 24dB per octave low-pass filter. An increase in energy increased the cut off frequency of the filter. An increase in fluidity increased the amount of smooth noise in the source mix.

SM5 White noise processed by a bank of parallel band pass filters, with variable tuning quantized to semi tone steps in a equal temperament scale, and variable resonance. An increase in energy increased the cut off frequency of the filters, maintaining their harmonic relationship. An increase in fluidity increased the q-value of the filter, making it narrower, approaching a sinusoidal wave. A decrease in fluidity made the filter wider, resulting in a noisier output, and also added a detuning component independently to all filters, making the result less harmonious.

The sound models[3] draw on different strategies to express the qualities of the incoming control data. SM1 and SM2 exploits the tension of inharmonicity, chorusing and beating effects to express lack of fluidity, contrasted with harmonicity and stability to express the opposite. SM3 and SM4 both borrow qualities from physical every day interaction, using amplitude and spectral tilt to express energy, e.g. a spectrally brighter and louder sound represents a more forceful and fast movement. Furthermore, they both change their source material to express the presence or lack of fluidity, by varying the coarseness and variability of the source material. In the case of SM4 this is further embellished to approach the realistic sounds of wind gusts, whereas SM3 is decidedly artificial and electronic in its nature. SM5 is a combination of all of these approaches and exploits harmonic pitch sensitivity, physical interpretation of spectral slope and amplitude, as well as a noise generator that can move from coarse, gravel-like sounds, to smoother sound reminiscent of a water stream or light wind. Spectrograms of excerpts of the five sound models are seen in Fig. 1.

The ability of the five sound models to portray fluidity was tested in two experiments presented in the following sections. Our hypothesis was that some of these models would be more suitable than others when sonifying fluidity.

[3] Examples of sonified dance data using the five models can be found at `https://kth.box.com/v/ison2016`.

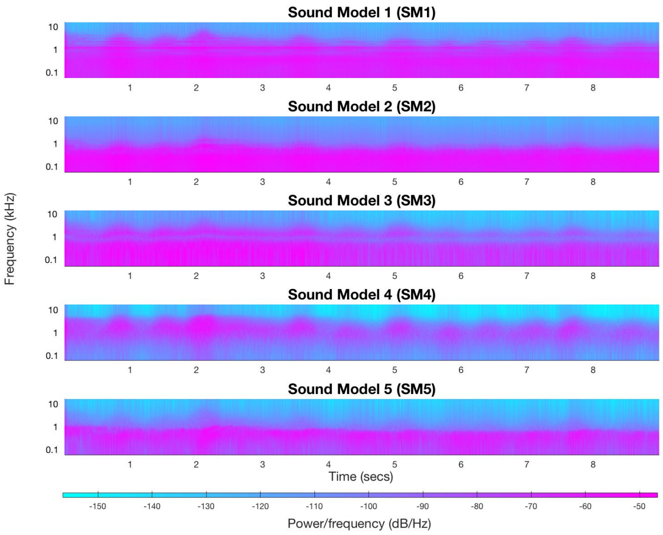

Figure 1: *Spectrograms of 9 second excerpts from sonified movement data using SM1-SM5 in Experiment 1.*

4. EXPERIMENT 1

Experiment 1 was a web-based perceptual rating experiment in which participants rated the presence of fluidity in a recording. In order to avoid bias due to different interpretations of the word "fluidity", participants were asked to rate the presence of the following property (slightly modified from the one suggested in [1]):

"A dancer's energy of movement (energy of muscles) is free to flow between the regions of the body (e.g. from torso to arms, from head to torso to feet) in the same way that a wave propagates in a fluid (such as the wave propagation caused by a stone which is thrown into water)."

The participants listened to sonifications of five segments of movement data, recorded in a studio setting with a dancer, that had previously been rated as very fluid in a previous study [1]. The five different sound models described in Sec. 3 were used, providing a total of 5 sound models times 5 segments of movement data, i.e. 25 stimuli. The stimuli were presented to the participants in a randomized order. For each stimuli, the participants provided their answer to the statement "The above described movement property is present in the sonic representation" using a continuous slider labeled from "I completely disagree" to "I completely agree". The continuous slider was coded in such a manner that "I completely disagree" corresponded to value of 1 and "I completely agree" corresponded to a value of 5 (these values were not visible to the participants).

We collected data from 41 participants (F = 20 and M = 21, Mean = 26.610 yrs, SD = 7.141) from 6 nationalities (the two biggest were Swedish, 76 %, and Italian, 10 %). For all participants, the average rating for each sound model was obtained by calculating the mean of all five segments. A one-way repeated measures ANOVA was conducted to investigate if there was a significant difference in perceived level of fluidity for the different sound models. Mauchly's test of sphericity indicated that the assumption of sphericity had been violated, $\chi^2(9) = 60.468, p = 1.142 \cdot 10^{-9}$, therefore degrees of freedom were corrected using Greenhouse-Geisser estimates of sphericity ($\varepsilon = 0.634$). The results showed that there was a significant effect of sound model on perceived fluidity, F(2.536, 46.878), F = 3.333, p = 0.029. Post hoc comparisons using the Bonferroni correction indicated that the mean score for sound model SM5 (M = 3.274, SD = 0.557) was significantly different from sound model SM2 (M = 2.971, SD = 0.487) and sound model SM3 (M = 2.872 , SD = 0.686). Boxplots of each sound model is seen in Fig. 2, descriptive statistics for each model is seen in Tab. 1.

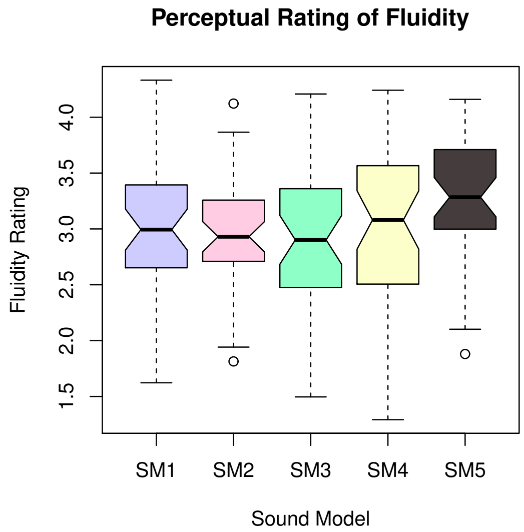

Figure 2: *Boxplots of fluidity ratings for each sound model in Experiment 1.*

Table 1: Perceptual Rating of Fluidity - Descriptive Statistics per Sound Model

Sound Model	Mean	Median	SD	SEM[a]
SM1	2.958	2.994	0.699	0.109
SM2	2.971	2.930	0.487	0.076
SM3	2.872	2.902	0.686	0.107
SM4	2.959	3.080	0.757	0.118
SM5	3.274	3.284	0.557	0.087

[a] *Standard error of the mean.*

5. EXPERIMENT 2

Experiment 2 was an interactive experiment. In total, 9 participants (M=7, F=2, Mean=30.444 yrs, SD=6.697) took part in the experiment. The sound model ranked as the most fluid one in Experiment 1 (SM5) was used to sonify the movement of a dancer performing a fluid movement sequence. This movement sequence was presented in a video that was recorded in a previous study [1]. The synchronized playback of the video and the data that was sonified was done using a custom video playback software written in

C++ using the openFrameworks[4] environment. The sound model was controlled by the energy and fluidity values extracted from the dancer's movement, as described in Sec. 2. The participants were instructed to adjust 6 sliders (with 8 bit resolution) that controlled the following aspects of the sound model in real-time:

- Slider 1: The quantization step of the center frequencies of the band-pass filters, ranging from continuous to steps of a minor third.
- Slider 2: The amount of high frequency content in the noise source.
- Slider 3: Scaling of the fluidity parameter mapping to the bandwidth of the band-pass filters.
- Slider 4: Scaling of the energy parameter mapping to the center frequencies of the band-pass filters.
- Slider 5: The presence of an echo effect.
- Slider 6: Manipulation of the center frequencies of the band-pass filters, ranging from harmonic to inharmonic.

The parameters were chosen so that all parts of the model could be modified, in a bi-polar fashion, from the original parameter setting. The echo effect was added to provide the option of temporal diffusion or smearing to investigate whether distinct clarity over time was a factor in the sonification of fluidity.

Instructions for the experiment were read from a pre-written manuscript. Initially, the participants were instructed to perform two tasks; T1: "Adjust sliders so that the sound corresponds well to the movement performed in the video", and T2: "Adjust sliders so that the sound does not correspond well to the movement performed in the video". Values from the sliders were continuously logged and the audio output was recorded. Each task was finished when the participant stated that (s)he was satisfied with the audible result.

After the real-time adjustment of the sound model (T1 and T2) the participants were given the following task (T3): "You will now see a video of a movement. After the video, try to describe how you believe that a sound portraying this movement would sound. You are encouraged to use metaphors when describing the sound. If you would use your voice to sketch the sound that would portray this movement, what would it sound like?" In task T3 participants were presented with a video of a fluid movement, different from the video used in T1 and T2. Finally, task T3 was repeated, but this time with a video of a non-fluid movement (T4). All videos used as stimuli in Experiment 2 were perceived as very fluid versus very non-fluid in the previous study [1] by Camurri et al. The purpose of including vocal sketching in the study was to allow the participants to explore whatever sounds they thought were appropriate, even if the sound model used wasn't able to produce those particular sounds.

5.1. Real-time Adjustment

Boxplots of the final slider settings from all participants are seen in Fig. 3. We computed mean values for all sliders for the fluid versus non-fluid condition, thereby obtaining an estimation of slider values for the averaged fluid versus non-fluid sound model [5]. Spectrograms of these two models are seen in Fig. 4. We subsequently

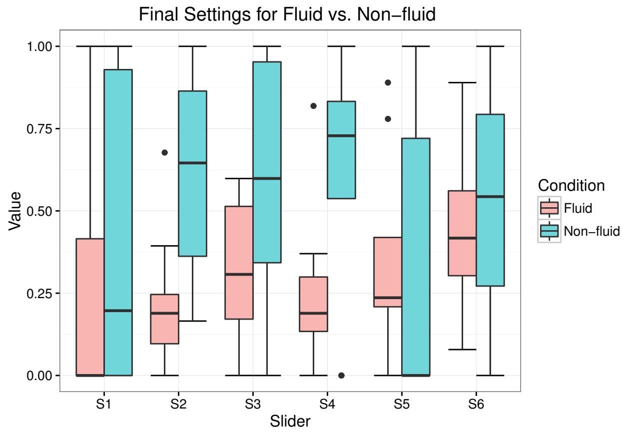

Figure 3: *Final slider settings for the fluid versus the non-fluid condition in Experiment 2.*

conducted a paired-sampled t-test to investigate if the six mean slider values were significantly different for the two conditions (fluid and non-fluid). Rescaling the values of the sliders to 0-1, the paired-samples t-test indicated that values were significantly lower for the fluid condition (M = 0.314 , SD = 0.081) than for the nonfluid condition (M = 0.507 , SD = 0.121), t(8) = -2.829, p = 0.037, d = 0.193.

For each respective slider controlling a certain aspect of the sound, we carried out pair-wise comparisons to investigate if there was a significant difference between the fluid versus non-fluid condition. Data for S1, S4 and S5 did not meet the assumption of normality and was therefore examined using a Wilcoxon signed-ranks test. Since the data for slider S2, S3 and S6 met the assumption of normality, paired-samples t-tests were conducted for these sets. The only observed significant effect for the pair-wise comparisons was for S2: the t-test indicated significantly higher values for the non-fluid condition (M = 0.609, SD = 0.332) than for the fluid condition (M = 0.228, SD = 0.215), t(7) = -2.986, p = 0.020, d = 0.381. This suggests higher amount of high frequency content in the noise source for the non-fluid condition compared to the fluid one.

When examining the recorded sounds[6], we observed that the recordings from the fluid condition were more homogeneous than the recordings from the non-fluid one. In general, the fluid recordings occupied a lower register and were characterized by a darker or more muffled timbre. In contrast, many of the non-fluid recordings were characterized by a high spectral centroid.

5.2. Interviews

After the interviews had been transcribed, the words and phrases used by the participants to describe the observed movements and the imagined sounds were compared and categorized. Below, seven categories are presented together with a few quotes from the interviews that are emblematic of the category. The categories also have a brief description that contextualizes how the participants discussed the sounds and movements in respective condition (fluid or non-fluid). Each category also has a fraction in parenthesis that represents how many of the participants that stated something that

[4] http://openframeworks.cc

[5] Sound examples of these averaged models can be found at `https://kth.box.com/v/ison2016`.

[6] See footnote 3 for sound examples.

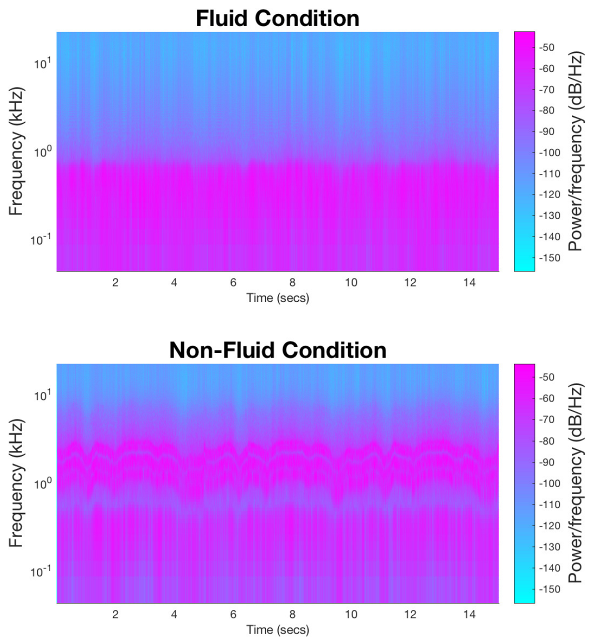

Figure 4: *Spectrograms generated from recordings of sound model SM5 when sliders were set to mean values for the fluid versus non-fluid condition in Experiment 2.*

can be sorted into that category: e.g. a “(9/9)” implies that all participants used words or expressions from the category.

Categories describing *fluid* sounds and movements

Water (6/9)

The flowing qualities of water itself, but also the way things underwater move, constantly affected by their surroundings.

- “The movement makes me think of sort of liquids.”
- “Seaweed in the ocean.”
- “A sound for water.”
- “Like waves.”
- “A flowing sound.”

Pitch (5/9)

On the qualities of pitch and related metaphors such as vertical position and speed.

- “Connected to the floor, heavy and slow, [. . .], something stable that always comes down to the ground.”
- “Pitched, not very noisy.”
- “I feel that it is pretty low, [. . .] like a melody that is easy to listen to.”
- “Varying pitch.”
- “Not a high pitch.”

Wind (3/9)

Air and wind, and how an air stream sounds and feels.

- “Something airy, [. . .], it sounds like wind.”
- “An airy feeling, like you feel when you move your arms around yourself, you feel the air.”
- “Looks like the movement of the wind.”

Natural (3/9)

Actions and sounds that are expected, natural, and follow some logic of uninterrupted flow.

- “Something stable.”
- “A flow and continuum.”
- “Comfortable, natural.”
- “Flowing, [. . .] a comfortable movement.”

Categories describing *non-fluid* sounds and movements

Friction (6/9)

The creaks and scrapings of rusty joints or old doors.

- “Something very creaky, like a creaking door.”
- “It is like some rusty door [. . .] metal, the shaft parts, the connection parts.”
- “Creaking sound that shows how the joints may sound if they are so hard to move.”
- “Friction and strong interaction between parts that dont really want to interact.”
- “Like wood creaking.”
- “The sound of an old metal thing that needs to be greased [. . .], a joint that needs oil.”

Unnatural (5/9)

A category where technology, industrial machines, and robots are put in contrast to nature and an idea of natural behavior.

- “The movement reminds me a bit of a robot, [. . .], something more industrial [. . .], a factory line.”
- “A bit robotic.”
- “Abnormal, [. . .] robotic movement, but not a proper robot, a normal robot would not move like this.”
- “Unhuman, coarse, metallic.”
- “A very unnatural movement, [. . .], [a sound] you don’t expect to come from a human.”

Effort (4/9)

A struggle against constraints, containment, weight.

- “Something that feels restricted to some extent [...] it is more confined.”
- “It is like he is stuck, and can’t move properly.”
- “The person is unable to move, and he or she is trying very hard to move legs and hands”, ”probably [. . .] the sound that comes when you move your bones, something like the bones cracking.”

- “A strained feeling.”
- “Struggling and making a real effort.”

In general, the participants spent more time talking about the non-fluid sounds and movements, and they seemed to have a harder time finding the words to describe the fluid movements. The fluid movements were seen as “natural” and somehow appropriate and were therefore hard to pinpoint (they were as things “ought to” be). The non-fluid movements on the other hand evoked a set of rather well defined metaphors of the “industrial”, “unnatural” and images of painful struggle and malfunctioning machines.

To summarize the results, the ideal sound to express fluidity is continuous, pitched and maybe even melodic, in a comfortably low register and pleasing to listen to. The ideal sound to express non-fluidity on the other hand is creaky, metallic, unhuman and robotic. By taking the opposites of the qualities connected to fluidity and non-fluidity and adding them to the other category, we can also add organic (opposite of metallic) and smooth (opposite of creaky) to fluidity, and stuttering, non-pitched, and high pitched to non-fluid (the opposites of continuous, pitched and low-pitched, respectively).

5.3. Vocal Sketching

Vocal sketching can be effective when describing sounds that don’t have clear agreed upon symbols in language (e.g. when the source of the sound cannot be identified), or when communicating characteristics of a sound that are ambiguous, such as pitch or temporal qualities (e.g. how low is “low”, how fast is “fast”) [6, 7].

While all participants carried out some vocal sketching, the sounds produced varied from a few seconds to up to a minute for different participants. Some participants felt uncomfortable doing the vocal sketching, while others didn’t give it a second thought. However, even when taking this into account, some general characteristics can be observed in the sketching across most participants.

The vocal sketching of fluid movements was continuous, somewhat softer and sometimes lower pitched than the one of non-fluid movements. It used an uninterrupted air flow, whistling, whooshing and whispering sounds, and tended towards darker timbres. The vocal sketching of non-fluid movements was louder, strained, used vocal creaks and often contained bursts of sound, or short series of completely separated staccato sounds. Generally, it contained much more high frequency energy than the vocal sketching of fluid movements.

Even though the material collected in this study was too small and varied to serve as a basis for any conclusions on its own, it is evident that the vocal sketching supports the analysis of the interviews presented above.

6. CONCLUSIONS

In Experiment 1, we observed a significant effect of sound model on perceived fluidity, with sound model SM5 being perceived as significantly more fluid than SM2 and SM3. We believe this to be a result of SM5 representing a complex and layered approach that combines several strategies to express the variations in fluidity.

In Experiment 2, when the participants manipulated the internal parameters of SM5, they tuned the model in significantly different ways in the fluid and non-fluid conditions. This indicates that the parameter space provided offered distinctly different sonic possibilities. In general, significantly larger values were found for the non-fluid condition compared to the fluid one for slider S2 (which controlled the high frequency content in the noise source). Nevertheless, as described in Section 3, all parameters had a complex interdependent relationship and one should take into account that the combined slider settings influenced the extent to which adjustment of the S2 slider had an effect.

The main conclusion drawn from examining the logged data in Experiment 2 is that participants managed to create two distinct sonic representations. In general, the fluid recordings occupied a lower register and were characterized by a darker or more muffled timbre, whereas many of the non-fluid recordings were characterized by a higher spectral centroid and more noise.

In the qualitative interviews in Experiment 2, the participants conceptualized fluidity (both in movement and in sound) as a property related to water, pitched sounds, wind, and continuous flow. Non-fluidity on the other hand had connotations of friction, struggle and effort. However, the biggest conceptual distinction between fluidity and non-fluidity was the dichotomy of nature and technology, natural and unnatural, or even human and unhuman. We believe that it is important to take these distinct connotations into account when performing perceptual studies focusing on the fluidity parameter.

Some general differences could also be observed in the vocal sketching in the fluid and non-fluid conditions: fluidity was expressed using continuous, softer, and lower pitched sounds with a darker timbre; non-fluidity was vocalized with louder, more strained, creaks and bursts of sound, with more high frequency content. The vocal sketching served two important functions. Firstly, it corroborated the analysis of the interview. Secondly, it provided a possible explanation for the heterogeneity in the resulting audio recordings for the non-fluid condition, as the participants sketched sounds that simply were not possible to arrive at given the possibilities offered by SM5.

Finally, the participants tendency to interpret fluid/non-fluid as natural/unnatural meant that they generally had a harder time providing descriptions or sketches of fluidity as it was seen as the “correct” way of moving and sounding. It was the internalized natural state and therefore somewhat invisible. On the other hand, by connecting non-fluidity to otherness and the unnatural, it could be more clearly described, being something external that could easily be pointed to.

7. FUTURE WORK

One disadvantage of the approach employed in Experiment 2 was that only a small set of actual videos (not point-light displays), were used as stimuli. During the qualitative interviews, it was evident that some of the descriptive key words used related more to the dancer’s personal impersonation of the movement property, i.e. to the theatrical aspects of the dance performance, rather than the properties innate in the actual high-level movement feature. We propose future investigations involving a larger data set. Furthermore, building on the findings from the vocal sketching, we suggest a follow-up experiment in which the parameter-space of the sound models is expanded so as to allow exploration into both fluid and non-fluid sounds.

8. SUPPLEMENTARY MATERIAL

The movement data, the source code for the software that reads the movement data and generates the sonification, as well as examples of sonified movement data using the five models can be found at `https://kth.box.com/v/ison2016`.

9. ACKNOWLEDGMENTS

The work presented in this paper was funded by the European Unions Horizon 2020 research and innovation programme under grant agreement No 645553 (DANCE).

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