Articulating body experiences in reaction to movement sonifications

A workshop strategy for early research inquiries

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ABSTRACT

Auditory feedback of body movement has shown to alter one's body perception. We present a multidisciplinary strategy for articulating how body feelings are affected by movement sonifications. Through a participatory workshop involving methods from design research in HCI and cognitive science, we gathered qualitative and quantitative data revealing contrasting body feelings for two sonifications. Analyses revealed that agility/rigidity, weakness/strength, salience of body boundaries, emotions, and different bodily areas were differently affected. Our findings evidence this paradigm as efficient for distilling qualities altered by sonifications. We discuss its relevance for early stages of the research inquiry and its particular importance in the context of body movement sonifications.

CCS CONCEPTS

• **Human-centered computing** → **Laboratory experiments**; **Auditory feedback**; • **Applied computing** → **Sound and music computing**.

KEYWORDS

Multisensory body perception, mixed methods, sonification, body transformation experiences, body movement.

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1 INTRODUCTION

Multisensory stimulation contributes to the sense of one's body [1, 4], allowing remarkable alterations of body perception. Visual dominance is prevalently used to elicit these changes [4, 7]; however, sound is also a significant contributor to body transformation experiences though relatively less studied [4–6, 8, 10]. For example, transforming the spectra of footstep sounds into lower or higher frequency content respectively produces feeling heavier or lighter [10]. Associations of pitch and height or size [2] or musical mappings have been similarly applied to alter body perception [5]. Additionally, employing material metaphors to sonify body movements can result in e.g., associating the sound of water flow with a perceived increase in speed [11]. Yet, articulating how extensive, complex, and diverse auditory mappings may affect body perception, is a challenging task.

Cognitive neuroscience has articulated the malleability of body perception based on quantifiable constructs such as the sense of body ownership and agency [1]. However, performing controlled statistical studies is a complex endeavor requiring resources often not available for elaborate creative approaches (e.g., sonifications from performance art), or for early steps of the research inquiry. Furthermore, the way each person's body is perceived can vastly vary, providing ample possibilities and valuable nuance that may be overlooked when relying exclusively on quantitative measures [11, 12]. Here, using a series of elaborate movement sonifications created by *Instituto Stocos*, we propose a collaborative and efficient approach for exploring how they alter bodily experience. This participatory approach aims to distill foci of interest and articulate

initial salient changes in body perception in relation to sound. It combines quantitative methods from cognitive science and qualitative design approaches in Human Computer Interaction (HCI). It may be an aid to further research, and support design processes related to sound and body perception.

This approach was articulated as an early effort to explore the bridging of artistic, psychological, and design-oriented perspectives to the research of body perception mediated by interactive technology.

This work is part of a larger multidisciplinary project *BODYinTRANSIT* investigating and designing sensory feedback to create body transformation experiences.

2 METHODS

2.1 Participants

12 people (4 women, 8 men) partook in a workshop consisting of three data collection sections and involving movement sonification technologies employed by *Instituto Stocos*. An HCI expert and main facilitator participated throughout (data gathered only from section 1). 1 facilitator, a composer member of *Instituto Stocos*, oversaw the sonifications and related technicalities (data gathered from section 3 only). Additional co-facilitators were a dancer and member of *Instituto Stocos* (data gathered from sections 1 and 3) and an expert in cognitive science who contributed data throughout the study. 8 additional participants had respective expertise in acoustics, psychoacoustics, HCI and psychology (3 participants), machine learning (data gathered from sections 1 and 3), electronic design and performance art (2 participants).

2.2 Apparatus

The hardware was composed of 4 IMU sensors intended to be placed on both wrists and ankles using straps. Each IMU contained an Adafruit BNO055 9-DOF (3D linear acceleration, 3D angular acceleration, and 3D absolute orientation), a Wi-Fi Arduino MKR100 and a lithium polymer battery. The sensors' data was sent to a Gigabit Router, making latency unnoticeable when involving more than 2 IMUs. Raw sensor signals were processed for jerk extraction, and data was exchanged via OSC. Mappings and models were created in Supercollider. Sounds were presented with a pair of M-Audio BX 8 speakers. The sonifications are described in Table 1 below.

Table 1: Description of sonifications used in the workshop

Name(s)	General description
Drawing with Air & Apollo	Both are implemented through an extended waveguide synthesis model simulating waves moving through a tube. They produce a palette spanning from wind instruments, to more natural airy textures such as wind travelling through a glacier or breathing. The parameters (air breath, tube feedback, and mouthpiece feedback) and their mapping to both low-level movement data and higher-level data (jerk) enable the individual control of noisy transients or air/breath pulsations, and more stable pitch components. Each parameter is differently affected by movement. E.g., the air breath (noise) that feeds the simulated tube is 70% controlled by jerk and 30% controlled by acceleration. From this model, two variations were derived: *Drawing with Air* maps gentle fluid movements to produce airy sounds of undefined pitch while jerkiness gives rise to more defined pitched and dense harmonic content, even tending to multiphonics in some cases. *Apollo*, in contrast, changes pitch and exaggerates spectral content, thus resembling a didgeridoo or a bass flute/clarinet.
Ataxia	Subtractive synthesis model recreating metal percussive sounds. Designed for the control of three fundamental rhythmic aspects: accents, durations, and timbre which are controlled by linear and rotational acceleration, and joint absolute rotations. It has several mapping modes, to control e.g, the attack (with more energy more pulses coalesce into a mass) or the degree of disorder of an isochronic pulse (the beat) using gaussian distributions.
Synthetic Voices	Extended vocal synthesis model based on a traditional Formant-Wave-Function synthesis but integrating several intermediate layers of stochastic and waveshaping functions to add liveness. In the used model (for four joints and for voices), the joint vertical orientation controls pitch traversing multiple tessitures (soprano, tenor, alto, bass); acceleration controls amplitude, brightness and low pass filtering; while jerk controls vibrato (minimum jerk no vibrato and vice versa).

2.3 Procedure

2.3.1 Warmup and sonification playground. For this first section, participants stood in a circle and were instructed to perform a mirror exercise: each person led movements while the others followed as closely and immediately as possible (see Figure 1a). After approximately 10 to 20s they would pass on the leadership to the next participant until everyone had taken the leadership role. To acquaint participants, this was first completed silently without any sonification. The whole round was then performed once for each of four different sonifications (i.e., Drawing with Air, Apollo, Ataxia, Synthetic Voices, see Table 1) while the device was worn by a professional dancer. This ensured better responsiveness to others' movements and optimized the process for the large group (i.e., instead of switching turns with the device). A series of body feelings were portrayed on signs equidistantly positioned throughout the room. After each round, everyone positioned themselves under the sign that most closely resembled their body feelings. People under each dimension were counted to assess the collectively most salient changes followed by a short discussion to express why and how the sound affected them.

2.3.2 In depth exploration. For this 2nd section, the sonifications Drawing with Air and Apollo were selected (see details on sound selection in Section 3.1) and presented in that order. Participants were split into two groups to experience the sonification in turns (see Figure 1b). In the experiencing group, each participant had a minute to wear the device and explore the sonification by moving while the others listened with their eyes closed. Everyone filled-in keywords describing their experience as listeners (not analyzed here). The device would then pass on to the next participant until everyone

had repeated the procedure. The whole group would afterwards complete a questionnaire on body perception (see Supplementary Materials) and a body map [12] (see Figure 1c for details), while the next group explored the sonification. This was repeated for both sonifications.

2.3.3 General discussion round and analysis. At last, the group sat in a circle and shared significant aspects of their experience throughout. A first round focused on general highlights while a second on methodological reflections.

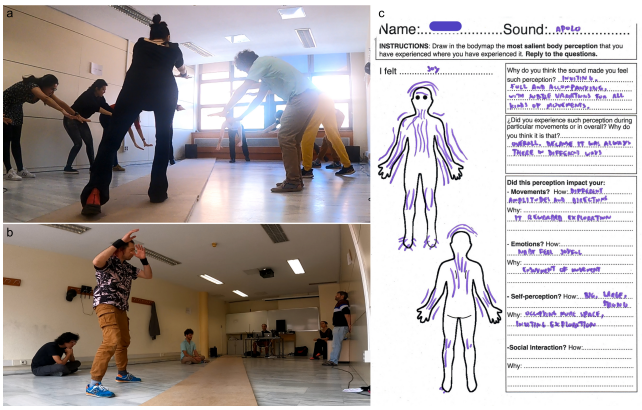

Figure 1: Participants' movement explorations in sections 1 (a) and 2 (b) and an example body map (c).

2.4 Data analyses

Participants selecting each category after each sonification in the 1st section were directly counted to assess the most salient body feelings for most participants (Figure 2.a). The questionnaire results were analyzed statistically. Aware of the small sample, we consider these results as preliminary to serve as a pointer of differences between the two sounds. The body maps sheets and the final discussion were analyzed following an open, inductive coding approach to qualitative data to identify tentative trends in people's experience [9]. Video data from the workshop was revised using an approach loosely inspired in Video Analysis [3] to find further empirical grounding for the questionnaire's results and to identify other potentially relevant insights.

3 RESULTS

3.1 Warmup and sonification playground

Quantitative results (N=11) are depicted in Figure 2.a. Two sonifications, Drawing with Air and Apollo, were chosen due to consensus in their influence on body perception. This was more pertinent to the present study compared to changes in e.g., motivation or rhythmicity, which were reported for the other sonifications. Additionally, for these two sonifications, all participants experienced clear effects in one of the given categories, unlike for Ataxia where participants experienced multiple 'other' effects of the sound. Synthetic Voices was not considered despite homogenous responses since these were reported as more negative in valence.

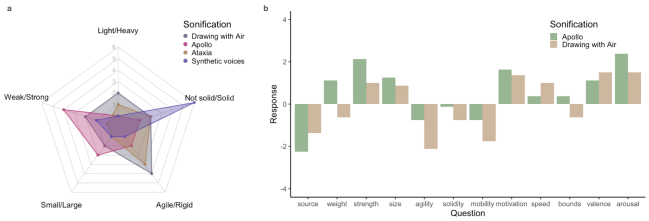

Figure 2: Data visualization of (a) 1st phase, participants reporting a clear change in one category are depicted. Those indecisive or that selected "other" are excluded. (b) 2nd phase, Barplot for each question ranging between -3 and 3 except for valence and arousal from -4 to 4.

3.2 In-depth exploration

3.2.1 3.2.1 Quantitative results. Results for the questionnaire data (N=8) are depicted in Figure 2.b. Wilcoxon paired tests revealed a significantly greater sense of bodily strength for Apollo compared to Drawing with Air ($W = 15$, $p = 0.048$, $r = -0.7$) as well as a trend for greater agility ($W = 25$, $p = 0.066$, $r = -0.65$) and a trend for a greater sense that the sound emanated from one's body ($W = 0$, $p = 0.053$, $r = -0.68$). Additional non-significant statistics are described in the Supplementary Materials. These results should be cautiously considered due to the small sample size and the relative lack of experimental control. In any case, they are not intended as final evidence but as proof of concept that our methodology enables the selection of sonifications eliciting measurably distinct qualities of bodily experience.

3.2.2 Qualitative results. The body map sheets (see Figure 1c for an example) revealed a variety of feelings on the upper limbs with Drawing with Air for most participants. One of them felt their upper limbs as plastic and elongated ('like chewing gum'), attributing this feeling to the high-frequency sound. Another reported feeling "free", as if flying; and another felt smaller and lighter since moving appeared easier. One felt in control of their body because the sound matched their movement speed. In contrast, another participant reported feeling strong because the sonification didn't allow for gentle gestures while intense movements produced corresponding sounds. Varying impacts on movement were reported: some said that Drawing with Air prompted them to move so as to create more sounds, while another participant reported moving more lightly and fluidly because of the sound's airy quality. Nearly half of the sample reported emotional experiences, e.g.: feeling happier because of the feeling of freedom, lack of perceived body boundaries, and enjoying producing the sound. Others reported feeling more relaxed or aroused. Some reported being negatively impacted. One attributed annoyance to the incapacity for gentle movement.

The Apollo's effect, in contrast, was felt throughout the body. Nearly half of the participants reported that the low frequencies affected their body perception: some felt powerful; others bigger and stronger as if the sound made them take more space. Their movement was impacted too, prompting slower motions attributed to feeling heavier. Emotionally, nearly half of the sample stated feeling happy, free, energetic, joyful, or powerful because they felt comfortable, in control, calm, or simply enjoyed moving. A few

others reported feeling serious, or angry; and one reported feeling scared and sad.

3.3 General discussion round

The following themes were derived from this section.

3.3.1 Body perceptions and movement. A few participants reported that when the sonification stopped, it felt as if their body missed something. Similarly, when others' sonification ended, their gestures seemed bleak. The technical facilitator noticed how each sonification prompted a different set of movements, whether gentler or stronger, depending on the jerkiness and thresholds for each configuration. Aligned with this, one participant noticed that Drawing with Air had more degrees of freedom and clear control while the Apollo seemed more fixed, prompting a different motor palette. According to several participants, Drawing with Air noticably elicited fuzzy body boundaries, while Apollo did not affect them, this was attributed to either a lack of linguistic reference or no effect on this perceptual quality for the latter sound.

3.3.2 Roles. Participants clearly distinguished the experience of sonifying versus listening. For Apollo, four participants mentioned feeling oppressed or even scared while listening to others, while in contrast feeling powerful while using the device themselves. They found the former distressing; however, three other participants found the listening role for this sound pleasing, which points at the heterogeneity of reactions and the difficulty of generalization.

3.3.3 Social aspect. Some noted that seeing others differently approach the same sonification expanded their movement palette. A few noted that each participant produced a distinct sound, suggesting that the devices pick-up nuances of personal gestures. However, one participant noted a limitation for attempting to follow and improve others' approach rather than exploring more personally. While the social aspect was generally valued, some noted that experimenting on their own with headphones and for a longer period could have allowed a more thorough exploration.

3.3.4 Methodology. The lack of control of our experimental design was noted by one participant. A few were surprised by the selection of the sonifications for the 2nd section of in-depth exploration, as they would have selected others.

3.3.5 Technical, artistic, and design considerations. Some noticed frustration for lack of control or understanding of the mappings, linking this to a lost sense of agency. The composer highlighted that participants' reactions confirmed his intuitions, both those previously articulated and also some implicitly known that had not been put into words. The dancer highlighted how putting into words in contrast to her usual movement practice was insightful.

3.3.6 Clinical and ethical considerations. Notably, one participant with previous psychiatric history mentioned that one sound triggered a traumatic war memory, reporting symptoms of dissociation in reaction to it.

4 DISCUSSION, LIMITATIONS, AND FUTURE WORK

Despite the clear effect of sound on body perception [5, 6, 8, 10], methods usually rely on visual dominance (e.g., involving virtual reality [4, 7]) which is not ideal for in-the-wild settings or for sustained periods of time. In contrast, sonifications may be used in these scenarios, for instance, in combination wearables [11], which opens a great potential for their application in everyday life. However, given the great variety of potential sonifications, it's difficult to articulate what qualities of body experience may be related to which sounds and auditory-motor mappings. Here, we tested a collaborative multidisciplinary approach for an initial assessment. Our methodology combines artistic, quantitative, and qualitative methods, for an early exploration of the influence of movement sonifications on body perception. We highlight the relevance of this methodology for distilling foci of interest and articulating salient changes in body perception in reaction to sound. Controlled experimental work in cognitive sciences requires significant resources and while important, it might not be optimal for early steps of the research agenda or when working with a great diversity of stimuli and mappings (as is the case of potential sonifications). Our preliminary findings provide an initial articulation of the distinct qualities of body experience that may be altered through sonifications, confirming its viability and potential applicability in future work.

With this approach, we show qualitative and quantitative differences in body perception between two sonifications. Drawing with Air and Apollo were selected for their influence on agility/rigidity and weakness/strength, respectively. Results from the in-depth exploration and the general discussion highlighted distinct body dimensions affected by each sound and replicated findings from the initial inquiry. Significant quantitative differences in perceived strength were found between the sounds and trends for perceived agility. While this is not confirmatory evidence, it provides a path for future work. Qualitative analysis on the body maps revealed distinct emotional effects of each sound, and a greater influence on the upper extremities for Drawing with Air while Apollo influenced the whole body. Changes in body boundaries were highlighted in the discussion, and a statistical trend for whether the body was the source of the sound was found. Having tools to influence these experiences may be relevant for fundamental research [1, 4] and applications on mental health or exertion [6]. These findings can inform future controlled studies targeting specific bodily qualities.

Despite evident limitations such as the small sample size and relative lack of control, our exploration intends to provide a compass for early inquiry. Future work might involve additional implicit measures that do not hinder the workshop's pace, e.g., a task involving response time as an implicit measure of agility/rigidity to move beyond participants'reports. Keywords describing the experience of listening to others were excluded due to our current focus, however they may be reported in future work. Additional feedback to our methodology highlighted the relevance of having different roles and a social setting for articulating the experience. This accentuates aspects that may be lost in non-participatory contexts, and the relevance of joining qualitative and quantitative approaches. It should be noted also that our study highlighted the importance of

considering clinical history and informed consent in sonification research, since one participant reported a distressing experience triggered by sonifications.

Beyond the direct evidence pointing at our methodology being relevant for early articulations of body transformation experiences in realtion to sound, academically articulating this type of interdisciplinary and early dynamics might bring forth better methods that involve participants' own expertise. In the field of body perception, often it's not clear where the idea to use one type of stimulation rather than another derives from [e.g, [7, 8]]. Publishing these processes might improve transparency, further a relevant conversation, and nourish mixed methods approaches.

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