DESIGNING INTERACTIVE SONIFICATIONS FOR THE EXPLORATION OF DANCE PHRASE EDGES

Andreas Bergsland
Norwegian University of Science and Technology, NTNU
andreas.bergsland@ntnu.no

ABSTRACT

The paper presents practice-led research where interactive sonifications of dance movements are created so as to have special emphasis on the movement edges of dance phrases. The paper starts out by discussing to what degree interactive sonification of movement and the artistic practice of interactive dance have areas of overlap, and whether their contexts and intentions may be combined to complement each other. A discussion of the concept of salience and how it relates to perceptual edges in general follows, and more specifically to onsets and endings both of movements and musical objects. In this discussion, the author also considers the role of accents as well as different degrees of abruptness of changes. The paper subsequently presents a set of interactive sonifications demonstrating different degrees of salience from very high to very low. Details related to the technical setup, analysis of movement data and the movement-sound mappings are presented, and the results are discussed.

1. INTRODUCTION

In the literature on interactive dance and sonification of movement, there are several mentions of the use of stillness and movement as productive or interesting oppositions [1–5]. For example, in pieces like *Seine hohle form* by Palindrome Dance Company, one can observe how in some sections dance movements are interspersed with stillness to create temporal incisions and accents. [1] In many of the phrase onsets and endings that occur, one can also observe a variation in temporal dynamics, with phrases beginning or ending gradually, abruptly or something in between, with or without accents. This has generated an interest in this author in exploring the dance phrase edges in the interactive sonification of dance movements through a practice-led process, also producing an artistic outcome.

In this paper, I would like to present some aspects of this work, including technical and perceptual issues as well as mapping, and how they relate to relevant research literature. It is not my aim to do a formalized evaluation of the sonifications in this context, but rather to discuss the grounding of core aspects of the sonifications in relevant scientific fields. To do this, I will start by looking at the field of interactive sonifications of body movements, and how it relates to the field of interactive dance before I turn to the concept of salience and discuss how different aspects of this concept can be relevant for the work presented in the paper.

[1] https://vimeo.com/8895552

2. BACKGROUND AND RELEVANT WORK

2.1 Interactive Sonification

In *The Sonification Handbook*, Walker and Nees define sonification as the data-dependent generation of sound where the transformation from data to sound is systematic, objective, and reproducible, and where the data relationships are comprehensible for a human listener [6]. Within this field, the sub-discipline of *interactive* sonification narrows the focus down to situations where humans interact with a system that transforms data into sound [7]. Thus, there seems to be a partial overlap between musical instruments and interactive sonifications, where the main difference is whether the perspective and function revolve around data or information and the conveying of that to a receiver, or whether it evolves around an artistic expression. A further sub-branch of interactive sonification is concerned with human movement as the source of data/information, a branch that Giomi labels *somatic sonification* [8]. Interestingly, he discusses the overlaps and distinguishing features between this branch of sonification and interactive dance, where his main distinguishing features are that sonification "provides information" with a goal of "understanding, exploring, interpreting, communicating or reasoning", whereas in an artistic performance "expressive purposes" and creating an "aesthetic experience" are paramount.

Although the field of sonification thereby seems to be distanced from artistic expressions such as music, it is interesting that aesthetics of sonification is also a part of the discussions in the field. Barrass and Vickers delineate a grey area between art and sonification, where if some data rooted in an extra-musical world in a musical composition is made explicit and the understanding of this can be aided by listening, this can qualify as a sonification [9]. Furthermore, they point to numerous examples from within the field where aesthetic perspectives are not in conflict with the intention of communicating information, but rather how these perspectives could be supporting communication.

2.2 Interactive Dance and Sonification

Interactive dance is a branch of artistic expression often considered to be conceived when John Cage and collaborators made the performance *Variations V* in 1965. Miller, in her in-depth study of this event, writes how with *Variations V* an art form was conceived where "dancers functioned as co-composers, exerting as much influence over the sonic landscape as the musicians who operated the electronic equipment", and where "the interaction of sound and motion was facilitated by a sophisticated technological component" [10]. Covering the more recent practices in the field, interactive dance has been defined as a "performance [...] in which a dancer's movement, gesture, and action are read by sensory devices, translated into digital information, processed by a computer program, and rendered into output that shapes the performance environment in real-time", and where, in the next stage, this output can affect the performers' actions [11]. This "output" might be varied, such as sound, video projections, lights, text, graphics, and robotic movement, but naturally it is the cases where sound is the output that is of interest here. Although the terminology is slightly different, we can recognize several similarities with interactive sonifications of body movements: bodily movements are represented by data (information) and translated (transformed) into sounding output.

If we return to interactive movement or somatic sonification it is interesting to note that Giomi and Leonard, even if maintaining the distinction between interactive dance as artistic practice and sonification as discussed above, present attempts at combining the two traditions [12]. More specifically, the authors present both others' and their own work, combining the aim for "aesthetically meaningful interactions" with the sonification paradigm and creating sounds that can reflect "objective properties of the movement". In many of these works the authors have aimed for different forms of sensorimotor learning and bodily awareness through sonic feedback, clearly in line with the sonification perspective. An even more radical approach is proposed by Barrass [13] who proposes to facilitate an "aesthetic turn" in sonification dissolving divisions between scientific and artistic methods based on the view that sound is "a naturally affective, aesthetic and cultural medium".

Taken together, interactive sonification of movements and interactive dance have overlapping principles and techniques for translating or transforming data from movements into sound, although there might be differences in the contexts (scientific vs. artistic), and main intentions (informative vs. aesthetic). These contexts and intentions might not be mutually exclusive, but may indeed be combined to complement each other. In the following section, I will present research related to the project's focus on temporal perceptual edges, more precisely dealing with how salience, accents, and segmentation can play a part in music/sound as well as dance, albeit in different ways.

2.3 Salience, Accents and Segmentation

Perceptual salience as a general phenomenon refers to the properties of an object or event that makes it stand out or pop out relative to what surrounds it and therefore likely will capture our attention [14, 15]. The concept is related to other phenomena such as scene analysis, segmentation, chunking, and Gestalt principles, and the key factor here is how perceptual contrasts and marked edges, which might be temporal and/or spatial, separate an entity from whatever surrounds it [16].

As for the auditory domain, qualitative temporal discontinuities in the signal, e.g. between sound and silence, are important, and a source for what Godøy labels *exogenous* (bottom-up) chunking [17]. Such discontinuities would e.g. appear if attacks (onsets) and endings were sufficiently abrupt. More gradual changes, on the other hand, would probably not be perceived as discontinuities [18]. It has to be noted, though, that segmentation/chunking can happen without demarcations of silence, but can happen both due to recognition of familiar musical units or schemata, such as a motif or a metric pattern. This is what Godøy calls *endogenous* (top-down) sources of chunking.

Another related type of high-salience temporal events in music are *accents* [19]. Accents can stand out from their surroundings due to several properties that distinguish them, as Thoresen notes, "most often by being louder; having a more ample mass, a brighter spectrum or a sharper onset quality; and/or being longer than other elements in their context" [20].

Since dance movements most often do not make a lot of sound, of course with several exceptions where body parts audibly touch each other, surfaces, or objects, the perception of another's dancing body is primarily visual. Although the same general principles of perceptual edges and contrast apply in the visual domain, the differences in modality imply a change in the spatio-temporal resolution, i.e. it is known that temporal acuteness is higher for auditory than for visual stimuli [21].

When it comes to the segmentation of dance phrases, top-down factors such as the familiarity of a genre, of specific dance movements, or the structure of repeated sections [22, 23], as well as bottom-up factors related to perceptual temporal edges can play a part. For the latter, analogous to the role of silence in musical segmentation, a period of stillness in between movements will also tend to indicate a boundary. For instance, Glowinski and colleagues found that subjects tend to be able to recognize pauses in a dance sequence when they are longer than 0.4s. of duration [24]. In comparison, most normal-hearing young adults will detect gaps of only 5 ms in a longer segment of white noise [25].

When perceiving dance and music together, one naturally needs to consider how the auditory and visual modalities work in tandem. Whereas the visual modality tends to dominate over the auditory modality in bimodal (audio-visual) spatial perception, the auditory modality tends to dominate over the visual modality in bimodal temporal perception [26]. Also, in experiments researchers have found that sound can 1. increase the salience of visual events, that is, if a sound is added to a visual event, it is more likely to attract attention [27], and 2. audition can affect how visual stimuli are perceived, especially when sharp transient sounds coincide with the visual event [28]. This latter phenomenon is also referred to as auditory capture [29]. These findings might have an impact on the design of sonification of movements in an interactive dance setting.

3. PROCESS AND SETUP

3.1 Process

The work presented in this paper was carried out during a three-month guest researcher residency at the Zürich Hoch-schule der Künste (ZHdK). The residency culminated in a performance of interactive dance in November 2021 carried out as a collaboration between the author and dancer and choreographer Seh Yun Kim. The process leading towards the artistic performance was naturally influenced by the final artistic goal, and has affinities with Borgdorff's conception of artistic research by generating knowledge through an embodied and situated artistic practice embedded in artistic and academic contexts [30]. Moreover, the process has affinities with practice-led research and the author's role as "practitioner-researcher", as described by Grey: "The role is multifaceted - sometimes generator of the research material - art/design works, and participant in the creative process; sometimes self-observer through reflection on action and inaction, and through discussion with others; sometimes observer of others for placing the research in context, and gaining other perspectives; sometimes co-researcher, facilitator and research manager, especially of a collaborative project" [31].

The greater parts of the process, all the way up to the last rehearsals, also had many elements of an iterative design process [32]. As a rule, the work was organized into weekly cycles starting with a period of sound composition and technological development work by the author. This was then followed by a practice session, either in a dance studio or a performance lab with the author and the dancer together. Thus, the iterative work-cycle would typically involve 1) development of interactive instruments, 2) presentation and explanation of new or modified interactive instruments, 3) phase of free exploration with observation and taking notes, 4) reflecting together with dancer and taking notes, and finally, 5) agreeing on the further development of the interactive instruments.

Questions discussed in the fourth point of this cycle were typically:

- What was the general experience of the interaction?
- How do the sounds make the dancer feel?
- How did the dancer's emotions affect her movements?
- Was anything missing, felt awkward or difficult with the interaction for the dancer?

Thus, these questions guided our ideas for how we wanted to develop the instruments further, and this again was fed into the start of the cycle.

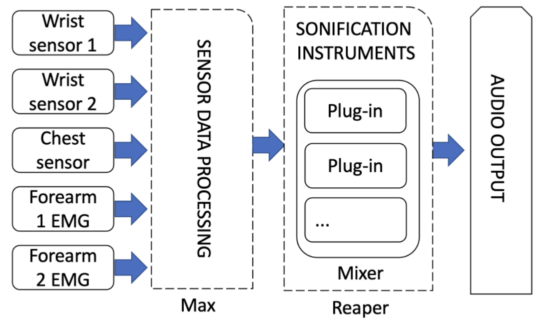

Figure 1. Technical setup used in the project including hardware and software elements.

3.2 Technical Setup and Sensor Placement

The technical setup in this project is shown in Figure 1. The data from the movement sensors was transferred to a computer via Wi-fi and Bluetooth and pre-processed in the Max software environment. The pre-processed data was transmitted over Open Sound Control (OSC) to a second computer running *Reaper*, a Digital Audio Workstation software. The sonifications were implemented as instruments in the sound and music computing system *Csound*, wrapped as VST-plugins with *Cabbage*, and inserted on separate tracks before sent to the audio output.

Several studies have shown how the choice of sensors and their placement on a dancer's body can affect the interaction possibilities and types of movement that an interactive dance system affords [33, 34]. Myo armbands [35] and NGIMU inertial sensors from X-IO [36] were chosen because they were 1) lightweight and relatively unobtrusive, 2) low-latency, 3) robust and reliable, 4) easy and fast to set up, and 5) did not restrict the dancer spatially. Furthermore, the Myo armbands were chosen due to their EMG sensing possibilities.

Although it was originally planned to have sensors on arms, legs, and torso, we ended up having sensors only on the arms and torso, mostly due to time constraints and the extra time implementing sensors and mappings for the legs would imply. This naturally led to a focus on the upper body throughout the process. The placement of the sensors can be seen in Figure 2. The placement of the NGIMUs on the dancer's wrists was seen as a good placement for an expressive use of the dancers' arms and hands, both regarding the choreographic and the musical aspects. The third NGIMU sensor was placed on the central upper chest. This placement was seen as interesting since it would allow for getting both torso direction and angle in a very straightforward way. The Myo armbands were placed on the upper part of the forearms, as devised by the manufacturer, to facilitate the tracking of finger and hand movements, along with the overall tension of the different forearm muscles.

4. MOVEMENT-SOUND MAPPINGS

During the project period and using the described setup, the author in collaboration with the dancer developed a

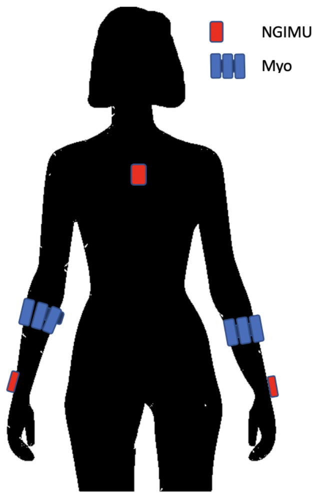

Figure 2. Placement of sensors on the dancer's body

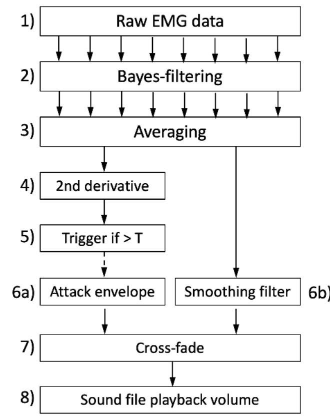

Figure 3. Mapping for clear onsets and smooth continuation

number of movement-sound mappings with special concern for the temporal edges of dance phrases. I will go through three of these in the following, focusing on the most relevant parameters in this context. Video examples of the mappings are provided as links in footnotes, and the reader is recommended to let these accompany the reading of the paper. [2]

4.1 Highly Salient Onsets with Smooth Continuation

The aim of this first mapping was to make abrupt onsets with sharp transients from small finger and hand movements, thereby aiming at high salience for the onsets of small movements. [3] Moreover, we wanted these to make it possible to let a sustained portion of the sound follow these onsets smoothly. In the context of the interactive dance performance, this was seen as a sort of introduction to the interactive paradigm and aimed at making the audience understand that the dancer is actually controlling the sounds, something which is considered important by several practitioners in the field [37].

Figure 3 shows the signal processing steps to achieve a mapping with very abrupt onsets and smooth continuation. The raw EMG data (1) was filtered with a Bayes filter from the *MuBu* package in *Max* (2). The filtered values were then averaged (3). The second derivative (4) was compared to a threshold, which created a trigger if the value was above it (5) that activated an attack envelope (6a). This envelope was cross-faded (7) with the smoothed EMG signal (6b) having a gradual onset. Using this cross-faded value to scale the volume of a sound file playback engine (8) with an arbitrary controllable time pointer made it possible to prolong the sound files indefinitely as long as the muscle activity was held above a certain threshold. [4] When the value dropped below this threshold, a relatively brief fade-out envelope would be imposed on the sound resulting in a relatively instant, albeit not marked, ending of the sound. It was a key point that the sound files had to have sharp transients at the beginning, and therefore clearly articulated stop consonants ([t], [k]) were recorded and used as sound material.

Several movement-sound mappings not directly related to onsets or endings were also applied in this interactive instrument more out of aesthetic concerns:

- Rotation of arm decides the sound file
- Muscle activation moves time pointer through sound
- Muscle activation modulates pitch
- Moving arm gives "chorus" effect
- Long sustained sound with stable pitch generates drone

All in all, this mapping made it possible to have a high-salience onset even from a tiny movement such as moving a single finger, combined with a smooth continuation. This also implies that the joint audiovisual salience of the movement onsets would be considerably increased, giving a heightened focus towards small movements that could otherwise seem to have little significance. In addition, several aspects of the sustained part of the sounds would follow the muscle activation in a way that had the potential to create variation and interest both for the performer and spectators.

4.2 Low and High Extremes of Salience

The second mapping had dual aims. [5] Firstly, to enable close to imperceptible onsets and endings, partly as a sort

[2] A video documenting the whole performance where these interactive sonifications were applied is found here: https://youtu.be/fkOZaT2pS-k

[3] A video demonstrating this sonification can be seen at https://youtu.be/BjW4027YKko.

[4] The playback engine, in this case, was the phase vocoder-based Csound opcode *mincer* which allows independent control of the time pointer that reads the file. For the attack portion of the sound, the time pointer would follow the timing of the original sound file. For the sustained portion, however, the time pointer would be going back and forth in the sustained portion of the sound, with the muscle activity directly controlling the pointer.

[5] A video demonstrating the sonification can be seen at https://youtu.be/Y0FabW2zQNk.

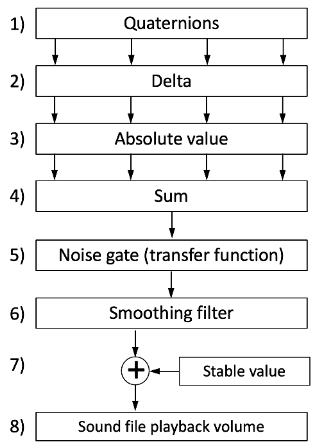

Figure 4. Mapping for gradual onsets and endings

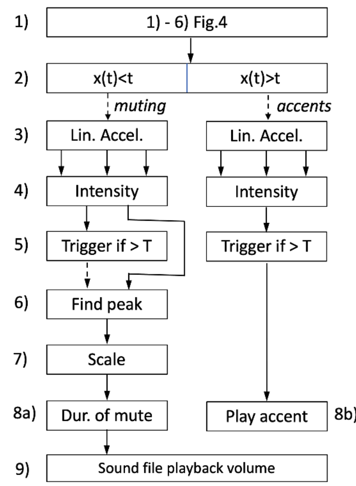

Figure 5. Mapping for alternative endings

of antithesis to the first mapping. Secondly, to highlight high-salience movements with a special effect.

A central strategy for the first aim was to introduce a "carpet" of sound that was always present independent of any movement, and then construct the mapping so very gentle arm movements would bring this carpet gradually to the foreground. In the same manner, as the first mapping, vocal sound recordings were used, but this time with very gradual onsets, and also with three different layers giving a hint of a choral quality, which also added richness to the sound. A playback engine with time pointer control made it possible to prolong the sound indefinitely. [6] For the second aim, a computational model of saliency called the *rarity index* was done based on Niewiadomski and colleagues with a time window of 2.5 seconds [38]. The algorithm was slightly modified to only give high output values when there was a large positive change in input magnitude, i.e. from zero or a lower value to a higher value, and not the other way around.

The mapping for the gradual onset and ending part of this sonification is seen in Figure 4. A general movement intensity or activity value was calculated using the absolute value (3) of the delta (2) of the quaternions (1) from the two NGIMU sensors on the dancer's wrists. These values were summed (4) before being treated with a simple noise gate (5), implemented as a linear transfer function set to 0 up to the noise threshold. This activity value was sensitive even for very low-velocity movements. By adding this to a small constant (7) which was used to scale the volume of the sound file (8), the sound would always be playing. This, combined with the sensitivity to slow movements, made it possible to achieve close very soft, and gradual onsets and endings of the sound, thus exploring the minimal range of salience.

In the second layer of the mapping which was sensitive to high-salience movement events, the rarity index value was mapped to a pitch transposition and spectral arpeggiation effect, including the volume of the effect. This mapping worked as a highly expressive means for the dancer when going from relative stillness to the upper intensity range of her movements. When the dancer produced a sudden burst of activity with her arm, the sounding result was almost like a short phrase played on a flute with a marked timbral and dynamic contrast compared to the relatively quiet vocal layers.

As for the previous mapping, several features were also added with concern for the aesthetic qualities of the sound:

- Brief period of stillness changes one of three sound layers
- Arm horizontal orientation guides time pointer in the sound file
- Salient movements bring forth a pitch modulation and spectral arpeggiation effect

In sum, this sonification explored the high and low ends of movement salience, combining a "carpet" of vocal sounds for the very slow and gradual movements, and more dramatic spectral effects for the highly salient movements.

4.3 High Salience Endings

The third mapping discussed in this paper focused on achieving a rich, complex and varied sonification of dance phrases with two types of high-salience endings. [7] Since the endings are of most relevance here, I will start by describing these in detail, and get back to a few more general traits below. The first type of ending was achieved with a sudden muting of the sound, whereas the second was achieved using an accent sound of the impulse-resonance type according to Smalley's spectromorphological typologies [39].

A simplified flowchart for this mapping is shown in Figure 5. At the outset a calculation based on delta quaternions (1), as shown in points 1-6 of Figure 4 is then sent to

[6] This time a granular playback engine was chosen, the Csound opcode *partikkel*, which gave a slightly more quavering quality to the sound.

[7] A demonstration of the sonification can be found at https://youtu.be/3yd6XDe7zVU.

a switch (2), which will compare it to a threshold value and decide whether to mute or make an accent at the ending of the sound: it will proceed with the left part of the flowchart if lower than the threshold, or the right if higher than the threshold.

The first three steps (3)-(5), are similar for both paths: The linear acceleration (3) values from the NGIMU sensors on the wrists are sent to the *intensity* object in the Max software. [8] If this value is above a threshold, it will produce a trigger according to the chosen path. For the muting path, the peak intensity (6) will be scaled (7), and used to set the duration of the muting (8a) before being applied as an envelope of the sound file (9). For the accents path, it will simply trigger a sound file with an accent sound.

As for the general design of this sonification, it is a form of granular concatenative synthesis based on the author's earlier work [2]. The sonification uses a great number (200+) of short sound files, in this case, recordings of different metal objects, organized to make up a perceptual continuum. These sound files are triggered by a metronome whose frequency is controlled by the delta quaternion-based intensity parameter (implemented as in 4, pt.(1)-(6)). The horizontal orientation of the NGIMU-sensor on the torso will then select which sound file is played back. The result is a rich and complex sonification with expressive potential.

Taken together, it has to be admitted that the aim of designing endings with high salience was only partly successful for this sonification. This might have to do with the high degree of variation and timbral richness in the general design of the sonification, which somehow slightly reduced the effect of the sudden muting and the accent. It might also be that for the accents, the impulse-resonance sounds that were chosen could have been even more salient without the resonance part, thereby articulating the contrast to the following silence in a temporally more acute way. Moreover, the technical implementation relied on an increase of intensity of an ending gesture, but such an increase of intensity can also happen without the movement ending, thus producing muting or accents without any actual movement phrase ending. Therefore, to be effective, this sonification demands some training to get the desired effects at the right moments and consistency on the part of the dancer in using it for movement endings.

5. DISCUSSION

The three sonifications presented in this paper were all originally developed for an artistic project, implying that compositional ideas, structures, and developments through the different sections of the work made sense from an aesthetic point of view. Nevertheless, the focus on beginnings and endings, especially regarding salience as perceptual edges, segmentation, and accents involving both movement, music, and sound, has been an important backdrop for the work.

[8] The algorithm is a part of the RIoT Bitalino package and is based on taking the delta of each of the values, squaring them, smoothing the result with a first-order IIR filter, scaling, and finally summing the values.

The sonifications in this project have suggested different ways of giving high salience to movement edges, thereby both providing heightened temporal resolution to these movements through the auditory modality and potential of putting a special focus on aspects of a movement that in other settings would have been lost.

The role of salient temporal edges for segmentation can also prove useful. Making onset and ending points salient may assist chunking operation and thereby create a clear phrase structure. This can probably be of assistance in movement learning and memorization, whereas in other cases a familiarity with genre and repertoire is needed [22]. Using some of the techniques of sonification presented in this paper, one could e.g. speculate that dance phrases could have been segmented with a lot shorter pauses than the 0.4 seconds that Glowinski and colleagues found in their study [24]. Using sonifications with high salience edges could also be important if one wishes to set movement phrases in relation to other temporal phenomena, synchronize, create a rhythmical temporal response, etc.

There can also be motivations for the design of interaction with low temporal salience, as presented in the second sonification here with the always present vocal layers. Fleeting experiences with few or no temporal incisions can create a high orientation towards the present, or an "out-of-time" experience, which e.g. can be paramount to let the user relax or in a state of flow that can be useful in therapy, rehabilitation, and more.

Lastly, for all the sonifications in this paper, aesthetic issues have been crucial in the design. Creating variation in the sound material while retaining a sense of coherence and continuum, has been one of the core design principles of this author. This has included the use of recorded sound samples, often in large numbers, organized in perceptual continua. It is the author's experience that this has resulted in interactive sonifications that have created engagement, playfulness, and enjoyment for the user and avoided annoyance and irritation. While sound sources like sine tones and white noise are easily reproducible and might represent certain types of data more objectively, their uniformity can imply a risk of annoyance and listener fatigue, which variation can counteract [9].

6. CONCLUSIONS AND OUTLOOK

During this paper, I hope I have shown that set of movement-sound mappings presented in this paper are sonifications based on providing information about the temporal dynamics of the movements, with special emphasis on the onsets and endings. While they have had many aspects that were designed with an aesthetic motivation, this might accommodate the user in receiving the information, simply by making the sonification more engaging to use and less prone to annoyance. The precise mechanisms involved will still have to be verified by an empirical evaluation in the future. Moreover, while several of the mappings presented seemed to have clear high-salience as well as low-salience events, further details of the landscape in between remain to be explored.

Acknowledgments

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