Bio Elektron - A Multisensory Approach to Augmenting Dance, Combining: Biosignals, Drawing, Sound and Electrical Feedback

Nuno N. Correia[1, 2], Debora Souza[1], Inês Nêves[3], Jaime Lobato[3]

[1]Tallinn University, [2]ITI/LARSyS, [3]Independent artist Tallinn, Estonia
nuno.correia@tlu.ee, deboracs@tlu.ee, helloineves@gmail.com, jaimelobatocardoso@gmail.com

Abstract

In this paper, we investigate how to augment a dance performance using a multisensory approach in a way that communicates the dancing process as an embodied experience. We collaborated with a dancer and a media artist over an 8-week residency to prepare and present a multisensory dance performance and a spin-off installation. We present related work regarding key areas for this research: dance and technology in general; biosignal sensors; multisensory media (sound, drawing and haptics); and the relation between dance and installation. We also report on the artistic process, which was documented through seven interviews with the artists. Finally, we discuss strategies for drawing and sonification leading to heightened embodiment; approaches for drawing and haptics triggering impressions from the performance; while highlighting the importance of space as a unifying concept in embodied multisensory work. These strategies and approaches can be useful for artists interested in conducting related embodied multisensory work.

Keywords

Dance, Embodiment, Multisensory, Biosignals, Drawing, Sonification, Haptics, Electrical feedback.

DOI

10.69564/ISEA2023-49-full-Correia-et-al-Bio-Elektron

Introduction

There is a long tradition of using technology in dance. Important historical examples of the intersection between these fields are the works of Merce Cunningham in *Lifeforms* (1989), a software allowing to generate new choreography;[25] Mark Coniglio in *MidiDancer* (1989), a wearable device that allowed a performer to control media;[10] and Frieder Weiss in *EyeCon* (2004), a motion-sensing tool which allows movement to control several aspects of a performance.[29]

There is extensive research on using biosignal sensors to reveal body data (such as muscle activity or heart rate) through sound, as presented in a recent review of these approaches.[1] Biosignal sensors have also been used in dance to visualize the inner processes of the dancers.[9] Recent research, involving 10 contemporary dance professionals with experience combining dance and technology, has identified potential in using technology to reveal non-visible elements in a performance—such as the thought process of dancers or their bodily data.[17] However, there is a lack of research in combining these different modalities in dance into a multisensory experience, particularly combining visual, sonic and haptic elements.

Multisensory experience design can transform the way we experience art: "by carefully considering different senses and their possible interrelations it may be possible to design and shape specific human experiences."[28] An example of this approach was the *Tate Sensorium* exhibition at Tate Britain (London). A multidisciplinary team of researchers and practitioners designed the exhibition so that specific sensory elements (sounds, haptics, smells and foods) would augment the experience of four paintings.[28] The possibilities of combining multisensory experiences with interaction design "open up opportunities to explore new experiences for perceiving one's own body, its interactions with the environment and also to explore the environment itself."[2] In terms of performing arts, "the demand for multi-sensory experiences is ever-increasing, given the rise of immersive art and theater in our post-pandemic world."[11]

Zhou et al. have conducted a review of the past twenty years of dance literature in the field of Human-Computer Interaction (HCI).[30] This led to the identification of four main categories of technological approaches for dance: Physiological Sensing; Multisensory Perception; Movement Quality; and Agent Collaboration. Through our research, we aim to combine the first two: the categories of Physiological Sensing and Multisensory Perception.

Our research aims to investigate how to augment a dance performance using a multisensory approach (combining visual feedback and biosignal sensors mapped to sound and haptics), in a way that communicates the dancing process as an embodied experience. To fulfill our research aim, we collaborated with artists Inês Nêves and Jaime Lobato (also co-authors of this paper), and performance space Elektron (Tallinn), in the scope of the Starts.ee research project by Tallinn University. During an 8-week residency, Inês and Jaime prepared and presented a multisensory dance performance (*Bio Elektron*), a spin-off installation, and developed related software and hardware systems. In this paper, we report on this process and its results, while discussing their implications.

Background

In this section we present background and related work regarding key areas for this research: dance and technology in general; input technology adopted (sensors); output multisensory media used (sound, drawing and haptics); and finally, the relation between dance and installation.

Dance and Technology

There has been an increased interest in technology for dance, in parallel to a growing importance of embodied interaction, in the field of HCI. Within the intersection between dance and HCI, Fdili Alaoui et al. classified categories of tools into: Generation (of new choreographic material); Interaction (in real time with performers on stage); Reflection (on choreography); and Annotation (tools assisting the creative process).[13] Raheb et al. categorized dance technologies in a similar perspective: Choreographic tools; Augmented performance; Education; Research and analysis; and Games.[23] Examples of technological approaches in these categories are: development of tools and techniques for annotation [3]; tools for documenting choreographic processes;[6] real time interaction;[14] and choreography generation.[25] Our work is mainly situated in the real time interaction category of tools according to [13], or augmented performance according to [23], with the exception of the spin-off installation.

Dance and Sensors

Rostami et al. generated five design concepts for interactive performance adopting bio-sensing and bodily tracking technologies [24]. Likewise, Aly et al. reviewed

biosensor modalities for performance from an HCI perspective, discussing the potential of muscular activity to convey rich movement information.[1] The research by Rostami et al. and Aly et al. include not only dance but other performance areas as well (the latter focuses on music). The authors highlight the potential of using biosignal sensors to collect data from the body for performing arts, which was the approach we followed in our work.

Dance and Sound

Researchers have focused on methods and techniques to create music from movement, particularly from dancers. A relevant example on how to extract information from the body is the work of Camurri et al.[4] Another pertinent project studied mappings of expressivity in gesture to sound.[5] These works focus on information retrieval and mappings or similar aspects toward the development of the technology itself. Recently, Masu et al. analyzed the sonic interactions that occur in a dance performance from an ecological perspective.[18] They studied not only the technology and its design, but also the roles of the different actors in the design and implementation process.

Dance and Drawing

There is a tradition of using drawing to visualize and record movement in dance performances. A milestone in this field is Carolee Schneemann's *Tracking* from 1973. Using a rope attached to the ceiling of a train car, Schneemann held a chalk in one hand extended, so that changes in position were marked on the walls and floor it touched.[12] Schneemann would expand this approach in her piece *Up to and Including Her Limits* (1973–1976). In her series *It's a Draw*, Trisha Brown dances while painting on a large paper placed on the floor. By doing so, she collapses four dimensions: "the three dimensions of Brown's movement in the field above, plus the time spent doing it."[12] Haley conducted an extensive review of the use of drawing to visualize movement in dance, while presenting her own piece *Constructions of the Moving Body*, which has as objective "to represent the experience of watching Brown's dance *Accumulation*, and evoke kinesthetic empathy through the drawn image."[15]

Dance and Haptics

There are few examples of use of haptics with dance performances. Mostly, these have dealt with allowing visual or hearing-impaired audiences to experience dance, and with dance education. The *Choreo-haptic* project aimed "to investigate how the kinaesthetic empathy experienced by sighted dance audiences can be also experienced by blind dance audience members."[16] It allowed audiences to feel movement in dance through vibrotactile haptics. Movement data was captured by Microsoft Kinect and then transmitted to a haptic pad (with an array of 6 by 5 motors).[16] A similar system, the *Haptic Cushion*, featured a grid of 8 by 8 vibrotactile actuators fitted to the back of a chair, and was tested with visually impaired audience members.[21] Shibasaki et al. developed a system to allow hearing-impaired audience members to enjoy the performance of tap dancers. The system captured dance data through haptic microphones on the stage, while seating provided haptic information to the audience, using a power amplifier.[27] Another application area for haptics in dance is education. The *Haptic Feedback Ankle Bracelets* "enable learning the footwork for any dance through conditioning the learner to move their feet in accordance to the choreography which follows the beat of the music."[26]

Dance and Installation

There has been an increased interest in adapting performing art pieces to interactive installations. Correia researched converting audiovisual performance pieces to browser-based artworks.[7] Particularly in the field of dance, the choreography *Emotional Landscapes* was transformed into a VR environment, where users can explore a dynamic relationship between the dancer and the virtual world, informed by the original dramaturgy of the piece.[8] *Digital Connection Retrieval* adapts a dance piece into a browser-based installation, using the web camera as an interaction mechanism.[19]

Methods

In the scope of the project Starts.ee, two artists participated in an 8-week art and science residency program, aiming to explore biosignal data in contemporary dance performances. Inês Nêves is a performance artist who assumes drawing as the core of her practice. Jaime Lobato is a multimedia artist, music composer, and independent researcher who uses biosignals as part of his artistic practice. The work took place between November 2021 and February 2022. The 8 weeks of work were not continuous, as there were pauses due to holidays and health issues.

The artists' process was regularly documented through photos and notes. During that time, we conducted seven unstructured interviews (approximately one per week) with the artists about their process, and critical assessment of the work done. The two last interviews

took place after the final show. The interviews were video recorded and transcribed, and then subjected to an interpretivist analysis.[20] The data was analyzed by the second author, and the analysis was double-checked by the first author.

Design Process

The reflections presented in this section stem from the interviews conducted with the artists-in-residence documenting their design process, across three different phases.

(1) Ideation and Prototyping (weeks 1-3)

From the beginning, the artists acknowledged interest in investigating the physical and the perceived space in the artistic performance. Inês commented about the willingness to investigate the implicit aspects of her practice:

"We spoke about exploration of space, on both the physical space and the perceived space. In relation also to the micro movements and how our body moves internally [...] So, we were thinking that the sensor could be there as a significant part of the process." Inês, Interview 1)

The artists identified a common ground connecting their artworks: the relationship to movement and space and how their artworks were influenced by improvisation. Whereby the use of biosensors could bridge their artistic practices, performative movement and sound, while facilitating the communication with the audience. As they mentioned retrospectively at the end of the project:

"One of the motivations of participating in this project was to keep developing my research in this electricity produced by humans" (Jaime, Interview 7)
"I was interested in doing this residency because I thought that biosensors could help to amplify this human quality of visual art by enabling the accessibility to the immaterial qualities of the creator, so me as the performer." Inês, Interview 7)

During their initial exchanges, the artists developed the idea and conceptualization of the performances they wished to create. They set the goal of mapping the body movement energy, using electromyography (EMG) sensors to convert muscle data into sonification layers, which could add on the perception of the performance.

Sound feedback started to be explored using contact microphones, to record the noises of the drawing materials on the large sheet of paper used as a drawing surface. Initially, the paper was placed on a table, later on the floor (on top of a wooden board)—the contact microphones were attached, respectively, to the table and to the wooden board (figure 1).

Figure 1. The photos illustrate the prototyping process. At the left, the initial tests with the sensors and the drawing movements. And at the center and right, the sequence shows the artists attaching the contact microphones.

As Jaime recalls:

"When we were sharing our work, I saw in the last performance that Inês made very interesting sounds [...] And I also remember one piece by the Fluxus group; it's like a written score, and the idea is like to grab a microphone with a piece of paper, and then the microphone amplifies the noise". (Jaime, Interview 2)

By the end of week 2, the artists started playing with the biosignals from the performer's movements to modulate media outputs, exploring ways of allowing the audience to witness the embodied experience of the performer. In other words, to offer a poetic point of view of the inner bodily reactions through the manipulation of the sound.

Jaime brought in an assembled device created by him to collect EMG signals from Inês's movements and they engaged in experiments measuring biosignals of her drawing activity. The EMG signal from Inês's arm muscles was used to apply the average energy amplitude of the drawing movements, as variables to modulate and synthesize the sound output presented to the audience during the drawing performance. The data captured by the EMG sensor was used to process, in Supercollider (https://www.audiosynth.com), the sound of the drawing recorded with the contact microphones. Hence, noises of the drawing act were transformed into a loop of sound effects. As Jaime explained, the resulting sound loops emulated what was happening in the drawing:

"Because in the drawing, you do it through time but, at the end you have this accumulation of gesture, colors and light, so we can have something similar to the sound. I have several variables to switch in the synthesizer." (Jaime, Interview 3)

Installation development

Additionally, the artists designed an installation to explore another sensorial aspect of the perception of the drawings, touch. As the artists pointed out, this idea came up when they were considering the poetic aspects of a haptic feedback loop, making people "feel this variation of electricity [from the performer's activity] as a memory of the movements of Inês's drawings" (Jaime, Interview 2). The idea also refers to a Mexican custom, 'toques', where people clutch two metal rods and allow themselves to receive electric shocks for fun.

The sensorial installation focused on the individual and intimate perception of the art piece. It aimed to allow the audience to feel the electric impulses coming from Inês's arm while she performed the drawing, revealing:

"[...] the movements of my body through these physical impulses and through the encounter of the materials. [By showing that] in an exhibition layout in which we'd have the drawings, and instead of seeing the performance of those drawings, the audience would feel the impulse, to feel the performance of the drawing as they look at it" (Inês, Interview 3)

(2) Rehearsals (weeks 4-7)

In week 4, the artists began the rehearsal process and started exploring the prototype in action, to identify and address possible issues. Testing the prototype during the rehearsals also helped to calibrate the acquisition of the sensor and enhance the quality of the biosignal processing.

Furthermore, their collaboration extended to the shared tasks of assembling the performance hardware and fixing the data collection devices. This built upon Inês's expertise in textile design. Accommodating the design of the wearables was an important aspect in order to attach the sensor to the performer's body, consequentially increasing the reliability of the data collection. It also added an aesthetic quality to the performative act.

One of the emerging challenges was that physiological data acquisition methods are often used in controlled settings, not in dance:

"Wearable prototyping is also a very important proof of concept, because biosignals are not supposed to be taken from the body in movement. So, trying to minimize [signal] noise for a more performatic usage of this technology [...] it's going to be like a proof of concept of taking this [biosignal] amplifier and making it to be a total wireless but also noiseless" (Jaime, Interview 4).

Inês kept researching the movements and different aspects of the drawing activity. Additionally, throughout rehearsals, she improved the design of the wearable prototype, to safely hold the sensor hardware, while protecting her body during more abrupt drawing gestures. In parallel, Jaime progressed with the acquisition and processing methods, making the final adjustments in the code, which implemented the performer's biodata as variables for sound manipulation. By the end of the rehearsal phase, he had revised the data acquisition method to reduce signal noise:

"[...] mainly building electronics and writing the software [...] bleaching [soldering] of the connections between the sensors and the Arduino control to have the amplifier working wireless. Inês as well finished the wearable part, so now she can wear the system comfortably." (Jaime, Interview 5)

Installation development

The artists also continued their research on the installation:

"I have been doing some research about how [electricity] works with the body, which is the limit of the secure setup that we can do. Also, I have found very interesting bibliography about the relationship of the body with external and internal electricity" (Jaime, Interview 4)

After developing the installation system, the artists decided to produce the material of the installation beforehand, in order not to compromise the computational process of the live performance in the public show. The EMG data used as the electric stimuli for the installation was recorded from the last rehearsal, in week 7. Naturally, the drawing exhibited in the public show also resulted from that same rehearsal.

(3) Public Show and Post-Performance (week 8)

The final showing was open to the general public and took place on the 6th of February 2022 at Elektron, respecting COVID-19 sanitary measures. It started with the performative drawing (figure 2), followed by a second performative act (out of the scope of this paper). It also included a Q&A session for the audience

to clarify their questions with the artists. Furthermore, the audience had the chance to try out the installation after the performance.

Figure 2. The photo shows the audience surrounding Inês Nêves during the drawing performance.

After the showing, we conducted two interviews with the artists (interviews 6 and 7). The first one was conducted for our own research, the second one also for promotional purposes. Reflecting on the strengths and weaknesses of the work done, both artists expressed that comments from the audience made them consider how the show could have been improved. Jaime recalled the comments by the audience after the show had given him ideas of how to better balance the different sensorial aspects presented to the audience. He also wanted to improve the system's robustness:

"More than the artistic thing, I could improve the sign from the amplifier, putting the wi-fi antenna to incorporate the circuit. It would be more robust [...] maybe less noise would come through." (Jaime, Interview 6)

Inês, on the other hand, expressed her impression about the flow of the performance:

"I think I'd try different materials. I've used what was necessary for the sound but it actually made too much accumulation on the drawing. So, I'd like to try it in different styles." Inês, Interview 6)

Recapping the development of the arts and science residency, the artists mentioned they have achieved their goals with the project about exploring spatial and sensorial dimensions. Including the sensor's data as an artistic variable made them think and perceive their practices on the project differently. Inês commented on her impressions of having an augmented sensorial perception in the performance:

"I have discovered that, what I really appreciate about doing these performative drawings is how, when you see the drawing, [it] comes from the body, and when you see it, you can sort of feel the performer there. [...] it's like, it becomes more physical". (Inês, Interview 7)

Installation development

About the installation (figure 3), Jaime explained how he achieved the setup, recorded from the final rehearsal, clarifying what the audience was feeling:

"It was the record of a full performance. We made it as it happened on the performance, every step as in the official [performance]. I started to record [data for the installation] from the beginning of the drawing until the end. And then the full performance was a loop in the installation. [...] Because there were very rapid peaks of amplitude and I didn't want that strong impulse to get to the public, so I extended that in time." (Jaime, Interview 6)

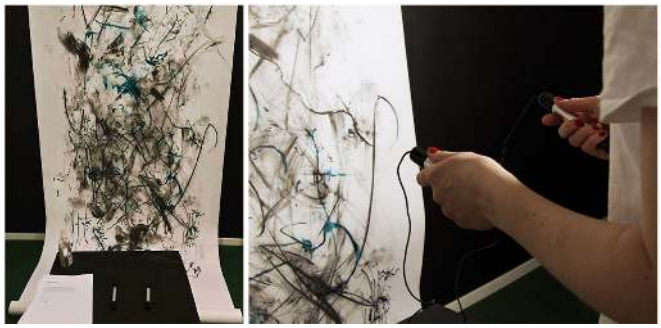

Figure 3. Installation photos. On the left, installation setup. On the right, audience member is clutching two metal rods. The recorded muscle data of the dancer while drawing is being re-played, and conveyed to the audience member as electricity passing through the metal rods. The resulting drawing by the dancer is on display.

In addition, Inês shared her thoughts on the physicality of the experience:

"I think it's so beautiful the idea of being able to feel physically close with someone who is not present now; it's like you can hug or touch a performer that is not there just by looking at the results and how it was crystallized in the electricity and drawing." (Inês, Interview 7)

The artists also reflected on the aspects probed to conceive the installation and their intention to keep exploring how to convey experiences through the skin:

"This is more like a memory trigger, a more poetic way to approach the data we were collecting through the sensors, like the imagination and the poetics of [electricity] as a media itself." (Jaime, Interview 7)

Technical Implementation

For the performance system, Jaime worked with a biosignals amplifier, that is, an operational amplifier (op-amp) calibrated to amplify signals from the human body: muscles (myography), eyes (eye tracker), or heart (electrocardiogram). The op-amp from the beginning of the residency was designed and built by Bruno Eloy Méndez Ambrosio. This circuit has two benefits regarding some commercial sensors: firstly, it has a differential amplifier that assures the user to reduce the noise caught by the ambiance or the electrical system; and secondly, it is open hardware so it is easily connected to any software to use the biosignal in real time.

As part of the residency, Jaime added a potentiometer in order to move the offset of the signal, as it was digitized with Arduino and there was the need to have only positive numbers. He also developed software with analysis tools such as: Signal averaging; True Root Mean Square (TRMS); Heartbeat signal damping; Heartbeat signal isolation; and 2nd order Butterworth filters.

An extra module was added for real time connectivity. It can send the raw signal and all the analysis indexes from the user to any software by MIDI, OSC and serial protocols. The information can be recorded as CSV format for deferred time analysis. The work was centered in finding critical biomarkers in the time series associated with physiological responses, which could be turned into experimental animations and data sonification or data-driven composition.

During the performance, the biomarkers were used in real time. There was a wooden board (where the drawing was attached to) with 4 contact microphones, which were mapped to each of the 4 loudspeakers in a quadraphonic arrangement. This wrapped the performer and the audience. Thus, the sound could be specialized with the performer's movements. Also, a myograph was placed in the arm of the artist as controller for a sound loop station, emulating the drawing process as an accumulation of sound.

In the installation, the biomarkers were used in deferred time. The TRMS information of the artist's arm was recorded during the performance. Jaime adapted a Steren 'toques' box (see section Ideation and Prototyping) to receive this data. He swapped the mechanical potentiometer of the box for an electrical one, so the public could feel the electric variations of the performer as it happened in the performance, while watching the drawing produced. By holding the left and right 'toques' rods, the user was able to perceive the electrical voltage produced by the dancer's muscles while dancing and drawing. The drawing from the corresponding rehearsal was displayed on the wall next to the 'toques' hardware. The user could thus re-imagine the drawing process, and the energy behind it, based on the muscle data being conveyed through electrical current.

Discussion

In this section, we will discuss the multisensory approaches followed, and related perspectives derived from the work.

Drawing and sonification leading to heightened embodiment

According to Inês, the multisensory aspects of the performance (movement and associated drawing, both producing sound) led to an added perception of the dancer's body: "it becomes more physical". The multisensory approach has been successful to heighten to presence and bodily impression of the dancer. Jaime's design approach toward sonification of movement was tightly coupled with the process of drawing and its cumulative nature: "you have this accumulation of a gesture, colors and light, so we can have something similar to the sound." He achieved this by recording and then looping segments of sound, which were then reprocessed based on biosignal data from Inês. The co-existence of the resulting multiple layers of sound echoes the accumulation of the multiple layers of drawing on paper. This relates to Eleey's description of collapsing four dimensions in performative drawing: three dimensions of movement, plus time.[12] In this case, both drawing and sound led to the collapse of the four dimensions. Inês also highlighted the importance of the choice of drawing materials for producing interesting sounds. But this should be balanced with the need to avoid excessive accumulation: "I've used what was necessary for the sound, but it actually made too much accumulation on the drawing".

In summary, we argue that there are important factors for sonifying drawing-producing gesture, leading to heightened sense of embodiment: 1) to mirror the process of drawing, and its accumulation, with sound; 2) to use data from the movement itself (e.g., biosignals) to affect sound; 3) to use interesting sound-producing drawing materials; and 4) to carefully balance all these elements in order to leave 'space' in the visual and auditory domains, that is, to avoid saturation of sound

and of drawing. When using haptics as part of a multisensory approach in dance, this should be also harmonized with the other multisensory aspects.

Drawing and haptics triggering impressions from the performance

Another important multisensory approach of the work was the combination of haptics and drawing. The haptic element of the installation aimed to trigger in the audience impressions from the act of drawing, when combined with the stimuli of viewing the resulting drawing. The haptic aspect consisted in conveying the muscle energy of the performer (EMG data collected in the performance) to the audience through electrical impulses, by holding two electrical metal rods in both hands. The piece creates an energy link between performer (muscle energy captured) and audience (muscle energy conveyed through electric signal). As Inês stated: "I think it's so beautiful the idea of being able to feel physically close with someone who is not present now (...) looking at the results and how it was crystallized in the electricity and drawing." Jaime calls it "a memory trigger" of a performance, allowing the audience to perceive it through the combination of traces it leaves (the drawing and the corresponding performer's energy). To allow the audience to better experience peaks and variations of electrical impulse, Jaime extended the data time span of, from 18 minutes to one hour. Thus, the audience experienced the energy from the drawing in a slowed-down pace, for better perception of the nuances in the data.

The installation presents a novel approach to haptics, compared to related ones presented in our Background section (which do not use an electrical signal as output). The haptic approach followed allows one to experience in deferred time a performing art piece, using electrical current to convey the energy behind the process of drawing. This, coupled with visualizing the final drawing resulting from that process, can have an evocative effect. The strategy followed, conveying to an audience the energy impulse of a performer through electrical signals, possibly in combination with other sensory elements, can be an inspiring approach to other artists (either in deferred time, as in our case, or even in real time).

Space as a unifying concept in embodied multisensory work

This project demonstrates that when carrying out embodied multisensory work, it is key to be mindful of the body's relationship with space. It is through the interaction between our bodies and space that we build our knowledge about the world, an idea supported by Merleau-Ponty's thoughts on human perception and cognition. Merleau-Ponty stated that we comprehend the world through our 'body schema': a general awareness of our existence within the "inter-sensory world."[22] He also defined space as what connects all things, instead of where they merely lay.

Following these reflections, in this project we used space to generate dynamic connections between the fields of drawing, movement, and sound, as well the performer's and the audiences' sensory experience. The use of contact microphones, sound spatialization and bio-sensors allowed the performer to sculpt sound in space with her movements. Alternatively, the sound produced shaped how she drew and moved in space.

This method for using space to intersect different disciplines could be a beneficial framework for other embodied multisensory work. Additionally, working within an expanded space could also allow a higher variety of embodied experiences (e.g., wider and smaller gestures, more impulsive and more controlled movements). Space and time are also connected dimensions in terms of accumulation of drawing. A longer performance requires a larger sheet of paper, to avoid excessive accumulation, rendering the drawing illegible.

Challenges of appropriating wearable sensors for performing arts

The sensors used in this work combine the knowledge of Jaime and his associates in terms of sensor and amplifier design, and Inês's knowledge in textile design. The latter allowed her to create a wearable housing for the sensors, which was gradually improved in terms of comfort and robustness. Biosignal sensors are not normally designed to be used for artistic purposes, let alone for the demands of dance performance. Dance creates strains in terms of noisy signals, discomfort of use, and connectivity issues. The necessary adaptation requires skills in appropriating sensor and wearable design for performance purposes.

Conclusion

Our research aim was to investigate how to augment a dance performance using a multisensory approach (combining visual feedback and biosignal sensors mapped to sound and haptics), in a way that communicates the dancing process as an embodied experience. In the Discussion section, we present how

we achieved this research aim, materialized into: strategies for drawing and sonification leading to heightened embodiment; approaches for drawing and haptics triggering impressions from the performance; while highlighting the importance of space as a unifying concept in embodied multisensory work. These strategies and approaches can be adapted and replicated by artists interested in conducting related multisensory projects. Our work is novel, particular considering augmenting performative drawing with sonification and haptic approaches. The latter allows extending the performance into an installation, in deferred time, using an innovative electricity-based approach.

The main limitation of the research is that our practice-based approach could have been complemented by audience studies, to assess the effectiveness of our multisensory approaches from an audience perspective. In terms of future work, we would like to adjust the installation to display in real time the data collected in the performance. We would also like to explore alternative models of interaction with the public by using the audience's biosignals as an extra input for the performance. This would disrupt the hierarchy between artists and audience, while allowing us to close the biosignal loop between them.

Acknowledgements

We acknowledge the support of Starts.ee project, of Elektron and of LARSyS (Project - UIDB/50009/2020) to this research.

References

1 Luís Aly, Hugo Silva, Gilberto Bernardes, and Rui Penha, Appropriating biosensors as embodied control structures in interactive music systems. *Human Technology: An Interdisciplinary Journal on Humans in ICT Environments* 17, 1, 2021, 45–80. DOI:https://doi.org/10.17011/ht/urn.202106223978

2 Maryam Bandukda, Aneesha Singh, Catherine Holloway, Nadia Berthouze, Emeline Brulé, Ana Tajadura-Jiménez, Oussama Metatla, Ana Javornik, Anja Thieme, Rethinking the Senses: A Workshop on Multisensory Embodied Experiences and Disability Interactions, In *Extended Abstracts of the 2021 CHI Conference on Human Factors in Computing Systems* (CHI EA '21), Association for Computing Machinery, New York, NY, USA, 2021, 1–5, DOI:https://doi.org/10.1145/3411763.3441356

3 Diogo Cabral, Urândia Carvalho, João Silva, João Valente, Carla Fernandes, Nuno Correia, Multimodal Video Annotation for Contemporary Dance Creation, In *CHI '11 Extended Abstracts on Human Factors in Computing Systems* (CHI EA '11), ACM, New York, NY , USA, 2011, 2293–2298, DOI:https://doi.org/10.1145/1979742.1979930

4 Antonio Camurri, Barbara Mazzarino, Matteo Ricchetti, Renee Timmers, Gualtiero Volpe, Multimodal Analysis of Expressive Gesture in Music and Dance Performances, In *Gesture-Based Communication in Human-Computer Interaction* (Lecture Notes in Computer Science), Springer, Berlin, Heidelberg, 2004, 20– 39, DOI:https://doi.org/10.1007/978-3-540-24598-8_3

5 Ginevra Castellano, Roberto Bresin, Antonio Camurri, Gualtiero Volpe, Expressive control of music and visual media by full-body movement, In *Proceedings of the 7th international conference on New interfaces for musical expression* (NIME '07), Association for Computing Machinery, New York, NY, USA, 2007, 390–391, DOI:https://doi.org/10.1145/1279740.1279829

6 Marianela Ciolfi Felice, Sarah Fdili Alaoui, Wendy E. Mackay, Knotation: Exploring and Documenting Choreographic Processes. In *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems* (CHI '18), ACM, New York, NY, USA, 2018, 448:1-448:12. DOI:https://doi.org/10.1145/3173574.3174022

7 Nuno N. Correia, Interactive Audiovisual Objects, Doctoral thesis, Aalto ARTS Books, Helsinki, 2013, Retrieved April 12, 2020 from https://aaltodoc.aalto.fi/handle/123456789/11341

8 Nuno N. Correia, Stephan Jürgens, Raul Masu, Jochen Feitsch, Ivana Druzetic, Performative Virtual Scenes: A Dynamic VR Environment Design Approach. In *Entertainment Computing – ICEC 2021* (Lecture Notes in Computer Science), Springer International Publishing, Cham, 2021, 100–114, DOI:https://doi.org/10.1007/978-3-030-89394-1_8

9 Nuno N. Correia, Raul Masu, William Primett, Stephan Jürgens, Jochen Feitsch, and Hugo Plácido da Silva, Designing Interactive Visuals for Dance from Body Maps: Machine Learning and Composite Animation Approaches, In *Designing Interactive Systems Conference* (DIS '22), Association for Computing Machinery, New York, NY, USA, 2022, 204–216, DOI:https://doi.org/10.1145/3532106.3533467

10 Scott deLahunta, Isadora 'almost out of beta': tracing the development of a new software tool for performing artists. *International Journal of Performance Arts and Digital Media* 1, 1, January 2005, 2005, 31–46, DOI:https://doi.org/10.1386/padm.1.1.31/1

11 Gabrielle Di Raddo, Haptic Feedback: Feeling the Dance You Cannot See, *Arts Management & Technology Laboratory, CMU,* Retrieved November 13, 2022, https://amt-lab.org/blog/2022/4/haptic-feedback-feeling-the-dance-you-cannot-see

12 Peter Eleey, If You Couldn't See Me: The Drawings of Trisha Brown, In *Trisha Brown: So that the Audience Does Not Know Whether I have Stopped Dancing*, Peter Eleey and PhilipBither (eds.), Walker Art Center, Minneapolis, 2008, Retrieved October 30, 2022, http://walkerart.org/collections/publications/performativity/drawings-of-trisha-brown/

13 Sarah Fdili Alaoui, Kristin Carlson, Thecla Schiphorst, Choreography As Mediated Through Compositional Tools for Movement: Constructing A Historical Perspective, In *Proceedings of the 2014 International Workshop on Movement and Computing* (MOCO '14), ACM, New York, NY, USA, 1:1-1:6. 2014, DOI:https://doi.org/10.1145/2617995.2617996

14 Sarah Fdili Alaoui, Christian Jacquemin, Frédéric Bevilacqua, Chiseling bodies: an augmented dance performance, In *CHI Extended Abstracts*, ACM, Paris, 2915–2918, 2013, Retrieved

October 20, 2020, https://doi.org/10.1145/2468356.2479573

15 Rochelle Haley, Constructions of the moving body: drawing and dancing, *Studies in Theatre and Performance* 38, 3 September 2018, 289–301, DOI: https://doi.org/10.1080/14682761.2018.1506966

16 Sophia Lycouris, Wendy Timmons, John Ravenscroft, Mark Wright, Choreohaptic Experiments (2012), Retrieved November 13, 2022, https://www.research.ed.ac.uk/en/publications/choreohaptic-experiments

17 Raul Masu, Nuno N.Correia, Stephan Jurgens, Ivana Druzetic, William Primett, How do Dancers Want to Use Interactive Technology? Appropriation and Layers of Meaning Beyond Traditional Movement Mapping, In *Proceedings of the 9th International Conference on Digital and Interactive Arts* (ARTECH 2019), Association for Computing Machinery, Braga, Portugal, 2019, 1–9, DOI:https://doi.org/10.1145/3359852.3359869

18 Raul Masu, Nuno N.Correia, Stephan Jurgens, Jochen Feitsch, and Teresa Romão. 2020. Designing interactive sonic artefacts for dance performance: an ecological approach. In *Proceedings of the 15th International Conference on Audio Mostly* (AM '20), ACM, Graz, Austria, 122–129. DOI:https://doi.org/10.1145/3411109.3412297

19 Raul Masu, Hanna Pajala-Assefa, Nuno N.Correia, Teresa Romão, Full-Body Interaction in a Remote Context: Adapting a Dance Piece to a Browser-Based Installation, In *10th International Conference on Digital and Interactive Arts* (ARTECH 2021), Association for Computing Machinery, New York, NY, USA, 2021, 1–4, DOI:https://doi.org/10.1145/3483529.3483747

20 Katrina Mc Chesney, Jill Aldridge, Weaving an interpretivist stance throughout mixed methods research, *International Journal of Research & Method in Education* 42, 3 May 2019, 225–238, DOI: https://doi.org/10.1080/1743727X.2019.1590811

21 John Mc Cormick, Mohammed Hossny, Michael Fielding, James Mullins, Jordan Beth Vincent, Mostafa Hossny, Kim Vincs, Shady Mohamed, Saeid Nahavandi, Douglas Creighton, Steph Hutchison. 2020. Feels Like Dancing: Motion Capture-Driven Haptic Interface as an Added Sensory Experience for Dance Viewing. *Leonardo* 53, 1 February 2020, 45–49, DOI:https://doi.org/10.1162/leon_a_01689

22 Maurice Merleau-Ponty, Taylor Carman, *Phenomenology of Perception* (1st edition ed.), Routledge, Abingdon, Oxon, New York, 2012.

23 Katerina El Raheb, Marina Stergiou, Akrivi Katifori, Yannis Ioannidis, Dance Interactive Learning Systems: A Study on Interaction Workflow and Teaching Approaches, *ACM Comput. Surv.* 52, 3 June 2019, 50:1-50:37, DOI:https://doi.org/10.1145/3323335

24 Asreen Rostami, Donald McMillan, Elena Márquez Segura, Chiara Rossito, Louise Barkhuus, Bio-Sensed and Embodied Participation in Interactive Performance, In *Proceedings of the Eleventh International Conference on Tangible, Embedded, and Embodied Interaction* (TEI '17), Association for Computing Machinery, Yokohama, Japan, 2017, 197–208, DOI:https://doi.org/10.1145/3024969.3024998

25 Thecla Schiphorst, A case study of Merce Cunningham's use of the LifeForms computer choreographic system in the making of Trackers. Master of Arts, Simon Fraser University, 1993, Retrieved February 21, 2022, https://www.semanticscholar.org/paper/A-case-study-of-Merce-Cunningham%27s-use-of-the-in-of-Schiphorst/a0f9abc63c77db0f84a5a1de8601b6fc9a7e0720

26 Navid Shaghaghi, Yu Yang Chee, Jesse Mayer, Alissa LaFerriere, SwingBeats: An IoT Haptic Feedback Ankle Bracelet (HFAB) for Dance Education. In *Intelligent Technologies for Interactive Entertainment* (Lecture Notes of the Institute for Computer Sciences, Social Informatics and Telecommunications Engineering), Springer International Publishing, Cham, 2021, 82–101, DOI:https://doi.org/10.1007/978-3-030-76426-5_6

27 Mina Shibasaki, Youichi Kamiyama, Kouta Minamizawa, Designing a Haptic Feedback System for Hearing-Impaired to Experience Tap Dance, In *Proceedings of the 29th Annual Symposium on User Interface Software and Technology* (UIST '16 Adjunct), Association for Computing Machinery, New York, NY, USA, 2016, 97–99, DOI:https://doi.org/10.1145/2984751.2985716

28 Carlos Velasco, Marianna Obrist, *Multisensory Experiences: Where the senses meet technology,* OUP Oxford, New York, NY, 2020.

29 Robert Wechsler, FriederWeiß, Peter Dowling, EyeCon -- a motion sensing tool for creating interactive dance, music and video projections, In *Proceedings of the Society for the Study of Artificial Intelligence and the Simulation of Behavior (SSAISB)'s convention: Motion, Emotion and Cognition*, Society for the Study of Artificial Intelligence and the Simulation of Behavior, Leeds, 2004, Retrieved January 17, 2018, 1–7, http://www.palindrome.de/content/pubs/leeds.pdf

30 Qiushi Zhou, Cheng Cheng Cheng Chua, Jarrod Knibbe, Jorge Goncalves, Eduardo Velloso, Dance and Choreography in HCI: A Two-Decade Retrospective, In *Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems* (CHI '21), Association for Computing Machinery, New York, NY, USA, 2021, 1–14, DOI:https://doi.org/10.1145/3411764.3445804