Boiling Mind: Amplifying the Audience-Performer Connection through Sonification and Visualization of Heart and Electrodermal Activities

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Figure 1: "Boiling Mind" dance performance, using audience physiological signals as visual/sound elements on stage.

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ABSTRACT

In stage performances, an invisible wall in front of the stage often weakens the connections between the audience and performers. To amplify this performative connection, we present the concept "Boiling Mind". Our design concept is based on streaming sensor data related to heart and electrodermal activities from audience members and integrating this data into staging elements, such as visual projections, music, and lighting. Thus, the internal states of the audience directly influence the staging. Artists can have a more direct perception of the inner reactions of audience members and can create physical expressions in response to them. In this paper,

we present the wearable sensing system as well as design considerations of mapping heart and electrodermal activity to changes in the staging elements. We evaluated our design and setup over three live performances.

CCS CONCEPTS

• **Applied computing → Performing arts**.

KEYWORDS

Interactive Dance performance, Audience engagement, Physiological signals, Embodiment

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1 INTRODUCTION

Live performances can be enchanting experiences for both audiences and artists [3]. However, even if artists carefully follow a strict script, each live performance is different since the involvement of the audience changes. Although the audience is involved, there often is a separation between the audience and the artists on stage. Thus, the connection between the audience and the artists is rather low.

In this work, we are exploring means to strengthen this connection. We present a stage production aiming to integrate the audience into the process of aesthetic creation via physiological sensing. We call this approach "Boiling Mind".

To realize "Boiling Mind", we expressed physiological signals from the audience during the performance via changes in common staging elements, such as projections, sound, and light elements. The reactions of the audience are expressed through these staging elements and become a part of the performance. Additionally, artists on stage adapt their performance to the audience which creates a performative feedback loop. With the projections covering the whole stage performers can see the representation of the audience's physiological data and adjust their movements to create a calmer or more intense atmosphere.

The project is based on the artistic practice and embodied philosophy of Artistic Director Moe Sugawa [47]. The team included a multi-disciplinary artist (artistic director who is a dancer/researcher), one choreographer, six dancers, one composer, one interactive video developer, one interactive lighting developer, three wearable developers, one lighting engineer, one sound engineer, and one stage manager. As a team, we produced a 60-minute dance performance in a semi-democratic process.

This paper focuses on the artistic aspects and concept design rather than data analysis and lab studies. The dataset of the three performances will be published for the research community. This work was conducted "in-the-wild", with a contemporary dance ensemble and audience members (not recruited lab participants). The choreography of the performance and other artistic decisions were made by the choreographer and the artistic team under feedback and discussions with the engineering and design members of the team.

The main contributions of this paper are as follows: (1) We present the concept of "bringing the audience on stage" by mapping physiological signals from audience members to stage elements to amplify the connection between artists and the audience. We detail information about the design process, focusing on sensing heart rate and electrodermal activity (EDA), as well as how these signals are translated to the onstage elements through sonification and visualizations. (2) We describe an open integrated wearable system that consists of a wrist band, back-end processing, and output. Our proposed system enables the capturing and translating of physiological signals into stage design elements. (3) We realized our proposed concept as a proof-of-concept with the performance "Boiling Mind". The performance involved dancers, choreographers, researchers, visual and sound designers in the process. It was performed three times in front of an audience of 57, 37 and 45 people. In each performance, around 30 audience members wore the wearable wrist bands. (4) We conclude with discussing qualitative feedback, interviews and lessons learned from both the audience and artists.

2 BACKGROUND

The fundamentals of our work are based upon findings on *physiological signals*, *audience engagement*, *interactive performances*.

2.1 Psychophysiological Signals

Electrodermal Activity (EDA) is a property of human skin, in particular, changes in the skin conductance level. It can be viewed as a combination of two components: 1) tonic (slow) and 2) phasic (fast). The phasic component is associated with emotions or stress. Despite being over a century old [26], it remains one of the most widespread tools for the measurement of autonomic nervous system responses in psychology and psychotherapy [37, 45]. EDA is a very sensitive marker and is often used to assess emotional arousal [1, 6, 31, 46].

Heart rate (HR) and its variability (HRV) are considered to result from the autonomic system (ANS) activities. The neurovisceral integration model describes HRV as the result of prefrontal cortex activities that affect modulation of the parasympathetic (PSNS) and sympathetic (SNS) nervous systems balance [44]. In other words, the neural circuitry that affects HRV goes very deep into our brain and reflects higher-level cognitive processes and emotional states. HRV has been shown to reflect worry and anxiety [9, 25] and emotions [12, 36] among many other characteristics. In this work, we use the ratio Low Frequency/High Frequency (LF/HF) as an indicator of the balance between PSNS and SNS activities, as it is one of the HRV features that is easy to interpret as the excitement indicator [42].

2.2 Audience Engagement

Audiences see active and connected forms of engagement as indicators of performance quality and that this influences the reattendance of a performance [38]. The engagement of an audience is difficult to assess since it is an implicit emotion involving both

valence and arousal[30]. Within this scope, subjective assessments, such as interview results or questionnaires, are general methods to understand audience engagement [7, 33]. To gather information about the engagement of the audience in real-time, the availability of physiological measures which can reflect ANS activity have been explored [2].

Some researchers investigated the possibilities of Brain-Computer Interfaces (BCI) via electroencephalography (EEG) sensing to reveal audience responses. Ramchurn etal. developed an interactive brain-controlled film where each scene's narrative was determined by one audience member's EEG attention data [39]. Furthermore, in Hassib etal. 's research, they extended the use of EEG sensing beyond personal tracking to the aggregation of multiple users' engagement information as feedback to presenters[20]. In our study, we recorded and presented all of the audiences' physiological data as performance elements to provide a comprehensive and close connection between the audience and performance.

Existing literature has also explored the feasibility of using cardiovascular values recorded by an electrocaardiogram (EKG) and EDA to measure audience involvement and engagement. Latulipe et al. have conducted a series of studies to explore measurement for the arousal component of engagement via EDA. Their study indicated EDA related to the performance as interpreted by arts experts and self-reported engagement by audiences, which supported EDA's validity of audience engagement [32]. Lin et al. found that EDA positively correlated with subjective ratings for presence, emotional arousal and engagement but not for HR. In addition, Perttula et al. found that HR measurement could be used to increase the positive event experience when designed properly. However, they also stated that their HR measurement belts need to be placed under clothes which seemed to be at risk of violating audience privacy. In our setup, we offered the audience wristbands to reduce hesitation and insecurity. Instead of using HR directly, we used HRV measurements and EDA together to collect subtle engagement changes in the audience.

2.3 Interactive Performance

Dancing was originally an art where bodies moved in response to unconscious emotions to interact with others in rituals and festivals such as African dance and Kecak [17]. As a co-dependent activity, the connection between dancers and audience has fascinated both researchers and practitioners [5, 16, 24, 38]. Staging elements and empathetic choreography are used to elicit an interpretive and affective response from a passive audience [13].

Throughout the last century, artists like Nam June Paik [18] and John Cage [14] have often relied on interactions from the audience in their art pieces and performances. John Cage considered music arising through both performers and so-called audiences' activity as a valuable element [28]. In Cage's work, the audience can contribute to the performance process by contributing seemingly non-musical sounds such as adjusting their seat or coughing [19].

In recent years, readily available technologies, such as wearable bio sensors and digital media, have enabled artists to drive the performance creation with the support of HCI researchers [4, 7, 13, 41, 43]. Some of them have been exploring the interactions between performers and stage design[10, 27, 40]. There are also attempts to integrate the audiences' senses and feelings into the performance environment, which is similar to the main concept of our study. Klaus Obermaier's team has implemented an interactive system where audience members can co-create the sound environment via the Letterbox smartphone application consciously [34]. Audience's involuntary emotional feelings can also be transformed into messages [11], emotional indicator icons [22] and virtual avatars [8] during a live performance.

In this work, we aimed to build an audience-performer connection across the invisible barrier of the stage by including the audience's emotional feedback as part of the performance. Inspired by previous researches, we designed Boiling Mind, in which all the staging elements including visualizations, music, and lighting changed dynamically based on physiological signals collected by wearable sensors attached to the audience. The audience can contribute to creating and shaping the performance environment as well as the dancers' expressions.

3 CONCEPT DEVELOPMENT

3.1 Concept

The stage design and described setup came out of a collaboration between the performing artists, designers and researchers in a semi-democratic process.

Both researchers and artists contributed to developing the concept during the iterative process to balance research and artistic interests. This process was mainly led by artists, especially the choreographer. Besides the predetermined story and design, the choreographer also created some improvisational sections where dancers could interact with stage elements affected by audience physiological response.

During the performance, the physiological data of the audience was captured using custom built smart wristbands. The physiological data includes heartbeats, EDA, and the LF/HF ratio related to the heart rate variability. The staging elements changed based on the audience's physiological data.

This design aimed to deepen the connection between the audience and the dancers into a collaborative relationship by building a collective experience through the use of physiological data and reactive stage design.

3.2 Design Process

We applied a co-design process. In particular, we developed a dance performance in cooperation with a dance group. The choreographer and the dance group worked in close relations with visualization and sound designers, and researchers in wearable computing, neuroscience, and performing arts. Over the course of a year, we held regular meetings, discussions, tryouts and a test performances, demonstrating each others skills and expertise in a democratic process.

To test our concept, we conducted a proof-of-concept performance. The initial performances involved eyetracking, heart rate, and an electrooculography (EOG) sensing system. We worked together with the performers to test visualizations and feedback mechanisms. From the initial tests (seen in Figure 2) we acquired some insights on how to improve our design:

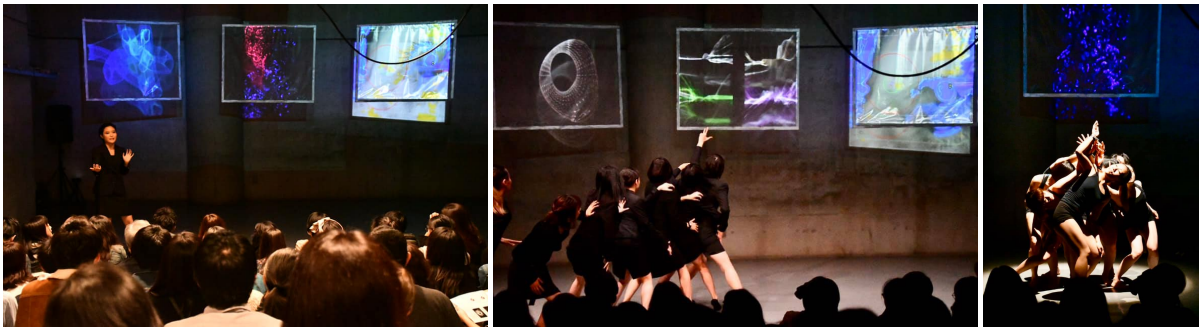

Figure 2: Pictures from tryouts and an initial trial screening mostly with people working in the performing arts sector and theater aficionados.

(1) *Involve more audience members.* Audience members who did not get to use any sensing devices reported feeling left out and wanting to be part of the physiological recording. (2) *Provide a multi-modal experience.* Dancing and all the staging elements need to be designed together. Visuals that were disjointed from the performance were perceived as distracting. (3) *Provide heart related and electrodermal sensing.* EEG and EOG were very noisy in the live performance. Eyetracking and pupil dilation measurements seemed interesting, yet took relatively long to setup and calibrate to be used reliably. Among the test recordings with dancers and audiences, heart rate and electrodermal activity were the easiest to interpret as manifestations of the emotional response.

We also conducted several test screenings to evaluate the sensor data. It was important that the performance could go on even with sensor failures and errors, so we prepared a backup plan using synthetic data which each designed element (lighting, sound, visuals) would use in case the sensor streams were failing.

These three core insights lead to the performance *Boiling Mind* that we describe in next Section. The resulting piece deals with searching and finding your place in society. The choreography aims to excite and stress the audience in the beginning half. The second half is more about reflection and relaxation. Each scene is described in detail later. The goal of the design is to transform the audience's unconscious reactions onto the performance space. The dancers perceive these changes, especially with light and sound, and can adjust their body movements accordingly. The audience can see the dancers' response to changes in the staging elements representing their own unconscious reactions. For example, when the audience's physiological data suggests an increasing level of arousal, dancers can see the reflection of it in the staging elements. In order to take the excitement even further, the dancers will perform even more intensely. This leads the audience to believe that the dancers are reacting to the audience's excitement. Calming and relaxing parts of the performance can be performed in a similar fashion. We decided that the sound and visualization would be the main elements for interacting with the dancers. In case the live streaming failed, we had synthetic streams prepared reflecting the expected reactions from the audience (pre-recorded in test performances).

4 IMPLEMENTATION

In the following we describe the stage design and implementation.

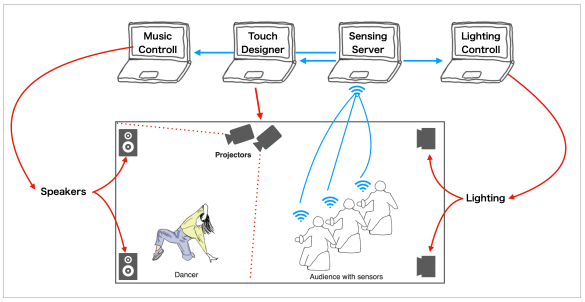

Figure 3: Data Flow.

Figure 4: Wristband with electrodermal, heart activity, acceleration and gyro sensors.

4.1 Setup and Staging

Structure of the setup and the data flow is shown in the Fig.3. The collected physiological data of the audience is transmitted to the server over WiFi. The server re-streams the processed data to other computers controlling each staging element.

4.1.1 ***Sensing Electrodermal and Heart Activity of the Audience.*** For this project we built wrist-worn devices measuring EDA from 2 electrodes on the fingers, and the heart rate using an optical blood volume pulse sensor (See Fig.4). EDA signal was sampled at 4.545 Hz and the heart rate sensor at 50Hz. The server software

Figure 5: Mapping LF/HF Parameters to Colors.

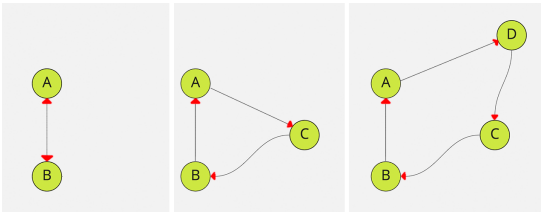

Figure 6: Grouping behavior of the lights, left to right shows group growing and right to left movements

was recording and re-streaming the data to other machines used for staging controls (See Fig.3). Stress tests showed that our system could handle up to 60 devices using a Netgear Nighthawk series WiFi router. Calculation of the HRV parameters such as LF/HF ratio was done on the server side. The aggregated and processed data was sent out to other machines in OSC format over UDP protocol via an Ethernet link.

4.1.2 ***Visualizations.*** We projected the visualizations rendered based on the audience physiological responses. Since the projection was covering the whole stage, it played a significant role in setting the mood and atmosphere. In the design process of the visualisations we had the following considerations and requirements:

(1) Visualisations should reflect audiences' physiological reactions in real-time.
(2) Visualisations have to be easy to understand by both audience and dancers at a glance.
(3) Visualisations have to reflect the atmosphere, tone and story of each scene.

Visualisations were rendered and projected onto the stage using TouchDesigner[1] software. We used 3 projectors so that the visualizations could cover the whole space. We based the visual design around an intuitively comprehensible color scheme. A number of studies indicate that individuals tend to associate red colors with arousal and excitation whereas blue colors are associated with quietness and relaxation [21, 23, 29, 35, 49]. Therefore, in our design we used warm colors such as red to represent arousal and cold colors such as blue to represent relaxation. The LF/HF ratio was mapped to the blue and red extremes of a gradient as shown in Figure 5. The predominant color of the visualisations changed according to either the real-time average LF/HF ratio of the whole audience or one particular spectator's data.

The EDA signal was mapped to the visuals as well. EDA signal interpretation concentrates on the rate of change rather than the absolute values. For each visualization, the rate of change of the EDA signal affected the visualizations' movement speed. That is, the faster the EDA changed, the more intense the movement of the visualizations became. As a result, the audience and the dancers may understand the extent of the audience reaction from the movement of the visualization.

4.1.3 ***Audio.*** The audio setup for this work consisted of 11 speakers: 9 small mono speakers placed on the ceiling, and two large speakers on the floor at the back of the stage. The small speakers on the ceiling were used primarily for supplemental sound design.

These sounds were faded in along with excitement levels of the audience. We decided upon this approach as a way to not only allow the audience data to guide another aspect of the performance, but also to give the dancers a sonic cue of how engaged the audience was during these moments. The upper speakers were also responsible for projecting additional timbral layers in several scenes. Overall, the disbursement of the cumulative soundscapes was divided up with roughly three-quarters of the audio layers assigned to the main speakers and the remaining quarter of the audio layers assigned to the ceiling speakers. This was decided after conducting several trials, in which this balance between consistent audio and supplemental/reactive audio was found to be strongest for the production team and the performers.

4.1.4 ***Lighting.*** The interactive lighting system consisted of 6 moving head lights on two axes placed around the stage. There were 2 light modes: mode 1 was used in several scenes, while mode 2 was used during one of the performance scenes. In the first mode, 6 members from the audience were selected with their HR data mapped to the intensity of the corresponding light. When more than one person had similar beats per minute (BPM) rate, they would be considered as a group.

The lights corresponding to this group would move to point at each other. When someone's BPM changed to a different value from the rest of the group, the corresponding light would move back to its initial position. The light would then be re-assigned to a different member. All the moving head lights of a given group would keep forwarding to each other (See Figure 6). On the second mode, all the lights were linked to one audience member.

Once a mode was switched on, the lighting can function automatically until switched to a different mode. Thus, the lighting design complements the visualization of the audience as a group or as an individual. In addition, it also affected the dancers by highlighting the inner states of the audience through brightness levels and lighting movements.

4.2 Performance

In March 2020 we conducted three performances. The performances were advertised mentioning that we will be using the physiological signals and a brief introduction of what would be expected to happen during the performance. All the audience members were asked to read through the consent form on their seats (See Fig.4 Left). By signing the form, they agreed to participate in this work and to offer their physiological data. The performance, including the data streaming and recording, was conducted according to the ethics rules and regulations of the ethics board of **university blinded for review**.

[1] https://derivative.ca

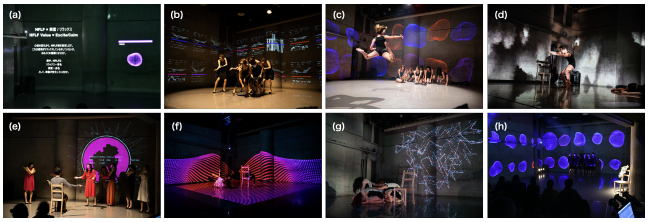

Figure 7: Performance scenes. (a) Introduction. (b) Business Card scene. (c) Bolero scene. (d) Ghostly Amenities scene. (e) Romeo scene. (f) Chaos scene. (g) Loving Animal Companion scene. (h) Ending

Each live performance lasted for about 1 hour and involved 7 dancers enacting the scenes.

a- Introduction (5 minutes): Before the performance started, we introduced the design of the stage elements and physiological sensing to the audience to explain how the stage elements would change depending on their physiological responses (See in Figure 7(a)). We explained how sensors impact the discrete parts of the performances with raw data and stage element examples. We also emphasized the informed consent regarding the sensor data, explaining the kind of data and potential risks with EDA/heartrate recordings. Some audience members could not wear the sensors or decide not to be recorded. As the audience members were informed over flyers and brochures beforehand about the recording, only few opted out completely. The audience members could see raw data and several visualizations based on an individual volunteer and aggregates.

b- Business Card Scene (3 minutes): The performance starts from Ravel's classical piece Boléro. Shortly after the beginning, the 7 dancers blend into the audience and talk to audience members while handing them their own business cards. The physiological data from the audience members of this scene was plotted individually in the form of a real-time graph, with all the audience's graphs displayed side-by-side as shown in Figure 7(b). Each graph contained the heart rate waveform, BPM, LF/HF ratio value, EDA value, and ID of the spectator. The audience was able to see visualizations of their own data reflecting on the stage.As a result of initial tests, many audience members expressed a desire to see how their biometric information changed while watching the dance performance. The act of watching a dance is a very personal experience for the audience, and they are desperate to find common ground between their own experience and what happens on stage. To assist the audience in this quest, we designed the piece to visualize each audience member's biometric information as the key to connecting the audience and the stage. As the emotional response of those who received business cards from dancers spiked drastically, it was also clearly visible in the graphs.

c- Boléro (15 minutes): As Boléro continued to build up, the dancers started moving slowly and quietly, wearing suits and high heels. They gradually took them off and exploded in sync with the rhythm and crescendo of Boléro. As the rhythm of Boléro and the rhythm of the high heels hitting the floor synchronized, the visualization changed to a more abstract representation as shown in Figure 7(c). In this scene, each spectator's data was transformed into an orb that changed color depending on the respective LF/HF value. The shape of this orb was indeterminate, and the speed of its movement depended on the EDA signal changes. Also, Mode1 was used for lighting.

d- Ghostly Amenities (10 minutes): Each performer danced with a puppet that represented their alter ego. In the end, the dancers handed the puppet to an audience member. The choreography and music set a mysterious tone in this scene. The visuals were designed to amplify this tone. We used a fluid simulation and created a smoke-filled space. The amount and frequency of appearance of the smoke clouds was varied by means of the LF/HF value. The mean of the EDA values also affected the parameters of the fluid simulation of the smoke. When the EDA data from the audience suggested sedation, there was less smoke, and vice versa (See Figure 7(d)).

The musical score consisted of four movements which were separated and played back depending on the pacing of the choreography. The physiological data from the audience was used as a graphic score guiding the implementation of reverb and a low pass filter (LPF). As the excitement levels increased, the LPF allowed more sub-frequencies into the soundscape. This design was intended to further increase the excitement levels due to the physical nature of the low frequencies, while the reverb was used as an auditory cue for the changes occurring.

e- Romeo (15 minutes): One dancer spoke the line, "If I see your mind, I will dance with it". The phrase and idea came from the lighting technician during discussions leading to the artistic decision to include a more directly linked performance between dancer and audience member. Next, a different dancer picked an audience member and invited him to the stage to play the role of her Romeo. The dancer chose a male spectator from the first row at their own discretion. The spectator needed to have an active sensor and consented to the public data use.

In this scene, the visualization showed the LF/HF and EDA plot similar to Figure 7(a), except the data used was picked up from the chosen Romeo as shown in Figure 7(e). For all three performances, the LF/HF ratio of the Romeo indicated a high level of excitement. For this scene, we linked all the lights to the Romeo audience member using Mode2 lighting.

The dancers could perceive the emotional state of the chosen Romeo based on the color of the visual projection. When it turned red, the dancers would start to improvise and reach out to Romeo, as if saying they were happy to see him here. If he smiled, the dancers would dance with him in a playful way.

f- Chaos (5 minutes): This scene described the conflicting and complex feelings of instability, confusion, and joy that we all experience as we grow from childhood to adulthood. The visualization moved in the form of a wave, with the average LF/HF value changing the color of the wave, and the average EDA value changing the height of the wave as shown as Figure 7(f). Also, Mode1 was used for lighting.

The score for this movement began with a looping drum beat which was then manipulated based on the physiological data. The EDA levels would trigger a stuttering effect which was played back through the ceiling speakers. The LF/HF values dictated the pitch variance in the drum sounds. Lastly, the movements of the solo performer dictated the duration of the drum solo and the entrance

of the subsequent synthesizer passages. Solo dancers improvised to the rhythm of the audience's interlocking LF/HF ratio. As the audience's excitement level increased, the music became disjointed, forcing the dancers to move with unnatural pauses and a complex juxtaposition of tension and relaxation.

g- Loving Animal Companion (15 minutes): One dancer followed another dancer like a playful animal companion (e.g. dog) willingly walking after its owner, clinging to her legs. In this scene, we used particle colors linked to the LF/HF values and particle density linked to EDA as shown in Figure 7(g). The particle effect was rendered to illustrate the change from red to blue as the audience was more sedated, mirroring the slow choreography and aesthetic tone.

The music for this scene was also quite sedated and relaxed. The musical director used the incoming data to guide when various musical layers would enter and exit. In addition to these musical layers, heavily manipulated sounds of high heels were played back through the ceiling speakers as a reference to the earlier parts of the performance. These heel sounds were faded in and out based on the LF/HF and EDA levels.

h- Ending (10 minutes): The music and choreography of the final scene was a reference to the first Boléro scene. The visual design was also the same as in the business card and Boléro scenes. The similarity and references between the ending scene and the beginning scene are purposely delivered to the audience so that they can compare the different states they perceived with the visualization before and after experiencing the entire performance.

To sum up, Boiling Mind was a one-hour contemporary dance performance based on "Boléro" composed by Maurice Ravel. The choreography in Boiling Mind incorporated the mechanism of interpersonal synchrony [15] to create a feedback loop between the audience and the dancers. This was accomplished by sharing rhythms between interpersonal actors in a biosensor-based reactive performance [48]. 57 people attended the first performance, 37 the second, and 45 the third performance. For the 3 performances, we had physiological data related to the emotional responses of 40, 35 and 40 members of the audience used in each respective performance.

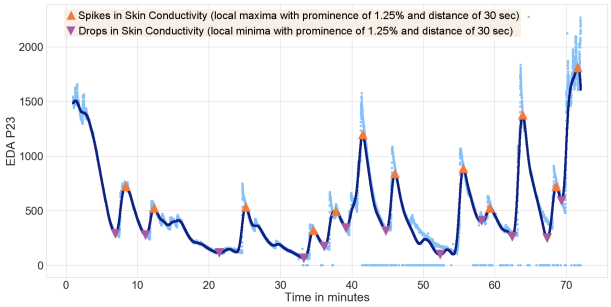

Figure 8: EDA data of one of the participants (performance 3, subject 23). EDA is measured by the change of Skin Conductivity (CS). Light blue - raw EDA data from 12-bit ADC (0..4095 range); Blue - low-pass filtered data; Orange markers - recognized peaks in skin conductivity (local maxima); Purple markers - recognized valleys (local minima). The distribution of phasic peaks suggest that there is a relation between the excitement peaks and the performance scenes.

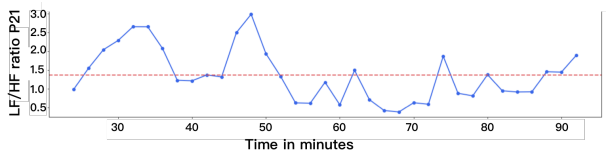

Figure 9: LF/HF ratio data of one of the participants (performance 1, subject 21). LF/HF ratio is a measurement of heart rate variability which represents the ratio between SNS and PSNS activity. Blue - LF/HF ratio data; Red - Average LF/HF ratio of this subject during the whole performance.A high LF/HF ratio indicates sympathetic dominance.The trend suggests the emotional arousal during the unfolding of the performance.

5 FEEDBACK AND DISCUSSION

After each performance, each spectator received an online questionnaire link. We received 35 audience (Female:18, Male: 16, Unknown:1) responses in total. Among 35 audience members, 3 of them attend dance performances every week, 8 of them attend dance performances several times a month, 19 of them attend dance performances several times a year, and 5 of them mentioned this was the first time they attended a dance performance. We also collected informal interviews and feedback from the choreographer, dancers, theater staff and audience members. Additionally, we conducted an online semi-structured interview with five of the seven dancers. Overall, the feedback was very positive.

5.1 Feedback

The online questionnaire covered the following areas: demographic and background questions (e.g. how often do you visit theater/dance performances) and their experience of "Boiling Mind." For the experience enjoyment levels, we used the 1-9 Likert Scale (1 not at all, 9 very much) as well as several open-ended questions about what they liked best/worst compared to other dance performances and general feedback. Almost all the audience members enjoyed the performance and liked the concept of "inviting the audience on stage".

From the questionnaires, 95.6% of the audience members reported they enjoyed the performance and 81.1% reported they felt this performance was more engaging than other performances they attended. We found most attendees considered "Boiling Mind" as an engaging and exciting performance because of its interaction and novelty. 86.5% of them perceived the dance itself as the most impacting factor related to their feelings and emotions. In terms of positive reactions to the staging elements, 56.8% of them noted the audio, 37.8% noted the the visuals, while 21.6% noted the lighting. Overall, most of them (95.6%) specified that they want to see another piece based on the same design concept.

From the free form discussions, we got more detailed responses. An audience member commented that "thinking of combining my heart rate with the stage design made me already excited." 5 audience members mentioned that they enjoyed the Business Card

scene, as they saw the changes in posture of some audience members as well as spikes in heart rate and EDA on some graphs. This connection was something they could relate to and identify. However, we also found some of the audience liked the concept, yet often failed to see a direct effect of their reactions reflected on the stage. 2 members described that they could not really recognize how their heart rate or EDA influenced the dancers and that a direct feedback loop was missing.

The interview with the dancers centered around their overall perceptions of the performances and the audience engagement. We presented them with the graph regarding audience physiological data when dancers and the choreographer reflected on the performances during the interview.

The dancers expressed their enthusiasm for the performance piece and their willingness to create similar performances in the future. They could recognize the staging elements' differences for each performance, especially the audio and color changes in projections and lighting effects. However, they wanted more clarity on what the changes in staging elements represent and how they should react to them.

Moreover, they would like to deliver more physical interactions to respond to the audience's physiological data. For example, one dancer said when she saw several projections of audience states turning blue, she tried to increase her movement speed and intensity to engage the audience more. However, it may not be easy for dancers to engage with the staging elements all the time as for some part they are preoccupied with the story line. Regarding that, some dancers suggested adding more improvisational scenes allowing them to perform accordingly to the change of staging elements to strengthen the communicative flow between dancers and the audience.

5.2 Lessons Learned

"A more direct feel on how I influence the stage" A criticism from several members of the audience (4) was that they cannot recognize how their own data changes the stage elements. For some it's quite disjunctive. 2 of them also remarked that they didn't recognize any difference compared to a standard dance performance. One remedy could be to play with the sense of agency. Since direct control for large audiences is very difficult, one could devise interactions that give the audience a feeling of control.

"Don't dismiss Raw Data as a visual" Related to the first insight, several participants (5) mentioned that they enjoyed the Business Card scene, as they saw the posture reactions of some audience members as well as spikes in heart rate and skin response on some graphs. They could relate to them. We thought that raw time series data might not be optimal, yet "Keeping it close to the raw signals" for visualization seems to be one take away. In our scenario with 40 simultaneous streams it is definitely feasible, though beyond that there will be scalability issues.

"Best Practices on How to Dance to Biometric Visualization" Four of the dancers still mentioned that they didn't know how to respond to the biometric data from the audience directly. They recognized changes in their behavior (e.g. dancing more erraticly when the visualization showed that the audience was not engaged in a part of the performance that was supposed to be stressful); yet they mentioned that they need more practice to acquire physical techniques to respond to the audience's biometric data. We need to create better practices and training routines surrounding this concept.

Post-Performance Insights When the dancers and choreographer reflected on the performances, we also presented them with the graph regarding to audience bio data. Dancers discussed reasons why some scenes had the audience more engaged than others such as Romeo while referring to the summarized audience bio feedback. They especially liked comparing different performances and could identify individual dance variations that seemed to have an impact on the audience.

"Even tighter Co-Design between Artists and Technical Staff" Even though the dance, visualizations, sonification, and lighting were co-designed together with dancers, choreographer, designers and researchers, we need an even tighter loop including the physiological sensing more in the process. Given the limitations, we had just a couple of training sessions with 2 or 3 test subjects posing as audience. For dancers to have a better grasp of what the visualization changes mean, new forms of co-design (e.g. training with a small audience) have to be created.

6 CONCLUSIONS AND FUTURE WORK

This paper introduces Boiling Mind, a novel interactive performance approach that breaks the fourth wall between the audience and performers by using sonification and visualization of heart beats and EDA data. We have developed a system to reflect physiological data collected from a large number of sensors to stage elements in real time, and have investigated a method to enhance audience engagement and participation in the performance.

From an initial data inspection, the data seems sound and captured the intended effects from the audience (stress versus relaxation). Yet, this paper focused on the design process and providing the dataset to the community in general (with video recordings of the performance). The analysis of the data is future work and will give more quantitative insights into how to design these experiences.

Although the reception of the three performances was very positive, the intention of creating a seamless feedback loop between audience and performers is still not fully achieved. For future work, we will add the dancers' real-time recording for the whole performance. This will allow us to audio-visualize how Audience-Performer physiological data interacts with and influences each other. We will also focus on improving the connection between the data and stage design elements to let the audience feel more influence over the stage. For example, the audience can play with the stage elements to increase their sense of agency and control over the staging elements before the performance starts. Since implementing a system that gives a sense of control to a large audience is very difficult, one could guide the audience to perform some synchronous actions that would give the audience a feeling of control over the staging elements. In addition, we believe this approach can be applied in the field of remote performances in which the audience is physically separated from the performance space.

In order to create stronger "continuous feedback loops" between audience and performers, stage elements and maybe dancers themselves could be physically affected by the audience biometeric data. For example, as the audience's heartbeat increases, the floor on the stage starts pounding, or artificial muscles will provide the rhythm directly to the dancers body.

We hope this research can inspire/help performers and designers to explore novel methods by developing more interactive works.

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