

Bio-Sensed and Embodied Participation in Interactive Performance

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ABSTRACT

Designing for interactive performances is challenging both in terms of technology design, and of understanding the interplay between technology, narration, and audience interactions. Bio-sensors and bodily tracking technologies afford new ways for artists to engage with audiences, and for audiences to become part of the artwork. Their deployment raises a number of issues for designers of interactive performances. This paper explores such issues by presenting five design ideas for interactive performance afforded by bio-sensing and bodily tracking technologies (i.e. Microsoft Kinect) developed during two design workshops. We use these ideas, and the related scenarios to discuss three emerging issues namely: *temporality of input*, *autonomy and control*, and *visibility of input* in relation to the deployment of bio-sensors and bodily tracking technologies in the context of interactive performances.

Author Keywords

Interactive performances; Bio-Sensing; Audience Engagement; Bodily tracking; Biodata.

ACM Classification Keywords

H.5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous;

INTRODUCTION

The number of readily available body sensor technologies opens up a wealth of new possibilities for interactive performances in terms of audience interaction and interactive storytelling. While bio-sensing has made it into commercial products for areas like health and medical monitoring [22,56,65], entertainment areas are still exploring more readily available scenarios for the use of sensors in performances. Experiments with implementing different types of sensors and embodied interaction in performances are not new [6], and many theaters and play houses have great success in long-running interactive performances both

with and without technology, such as *Sleep No More* (www.sleepnomore.com), *La Mama* (www.lamama.org) and *RATS Theater* (ratsteater.se). As this type of artistic productions are setting out to deploy bio-sensors technologies, a variety of scenarios can be explored to envision different design possibilities exploiting, for instance, audience members' physiological states through heart rate, qualities of breathing [8], or abstractions of emotional states using galvanic skin response (GSR) [26].

By taking advantage of these technologies, participation in interactive performances can evolve from consciously deciding to send a message [12], or moving to a certain location [47], to harnessing the feedback loop of bio-processes. With this move comes a change in the agency of the audience participator. Some bio-mechanical features are easier to control than others, and some are more influenced by the current lived experience of the person being sensed. As the role of the artists can be moved more and more behind the curtain to direct audience peer-production of the content of a piece, the lines between performer, audience member, and director become blurred, and the process of designing and developing experiences changes.

In this paper we use the term “interactive performance” in its broadest sense, encompassing theatre, street performances, dance, and interactive video performances. Interactive simply denotes elements of audience interaction either with (i.e. [40]) or without digital technology. Interacting with a performance through technology can range from sending text [12], physical navigation, physical contact [66], to controlling our breathing [9].

To explore the role of sensor-based interaction modalities in the context of interactive performances, we carried out two design workshops. Participants included choreographers and dancers, interaction designers, engineers, HCI researchers, theatre directors, and actors. The variety of the participants' backgrounds was purposely selected to reflect the diversity of expertise and professional roles required in the design and implementation of interactive performances. The two workshops used techniques of brainstorming [41] and bodystorming [32,33,51] to enable the participants to discuss the embodied aspects inherent in their artistic expression and creation.

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This paper presents five scenarios illustrating five design ideas of interactive performances based on bio-sensing and bodily tracking technologies. We first provide examples of the role such technologies could play in the context of various performance. We then expand our discussion by addressing three main issues emerging from the suggested designs, namely: i) *Temporality of input* – the extent of the feedback loop between audience action and its influence on the performance, ii) *Autonomy and Control* – that is the degree to which audience members, performers and directors can act upon the performance; iii) *Visibility of Input* – that is the degree to which the use of such sensors can make audience’s actions socially visible.

These issues reflect paramount conceptual and interactional aspects inherent in the design and production of interactive performances that creative teams – often characterized by heterogeneous backgrounds and professional skills (ranging from artistic directors to technology experts) – might have to tackle when introducing sensor-based and bodily tracking technologies.

BACKGROUND

Several artists, designers and researchers within HCI have focused on creating interactive performances, both for the value of the performance themselves, but also for studying them for better understanding audience impact [6,28], technology infrastructure [8], and theoretical aspects of interactive theatre [19]. More recently the focus on participation-through-technology in interactive performances has been seen as a way to understand other people and engage in a dialogue with them [12,35]. In the following sections, we introduce previous research on participatory and interactive performances, embodied interaction, as well as investigation of bodily tracking and bio-sensing technologies envisaged to facilitate interactivity. These areas of research constitute the background of our work.

Participatory Performances

Much of the current participatory live-artwork is body-focused, both in terms of both interaction modalities (e.g. using bio-sensors as input), and of purposes of the art piece (e.g. bodily aesthetic experiences). An example is Loke’s installation, *Surging Verticality* [30]. Here, mediation of a ‘human aide’ and soundscape was used to guide and augment the experience of “feeling gravity through the skeleton”, for the participant. Other works from this project, *Thinking Through the Body* [67], included *Drawing Breath*, visualising the breathing of the audience, and *Cardiomorphologies*, which used their heart rate. Mentis and Johansson’s interactive-improvisational dance performance explored the use of movement as input: A Kinect sensor capturing movement qualities of the audience modified the music, which in turn influenced the dancers on stage [37]. Alaoui et al. [3] and Grønbaek et al. [21] used movement qualities as a modality for interaction to promote a more explorative and expressive experience of artwork.

Embodiment and Interactive Technologies

Embodied interaction can be seen as one’s cyclical, iterative process of action and reaction with one’s physical and social worlds. It influences and is influenced by emotion, space, context, and time. Since the introduction of the concept of embodied interaction [18], we have witnessed a wealth of movement-based technologies [24,53] and practices of designing technology from an embodied perspective [18,38,54]. In the field of performance, and especially interactive performance, we note that the deep and intertwined connection between experience and body – how certain physical states and actions can cause, and are caused by, certain emotional states [63] – can be an important tool in the design of curated performances. Benford et al. for example, in *Breathless* have looked at how negative physical and emotional experiences can be used as building blocks for interaction by “embedding the breath sensors into a gas mask which is used to drive a large powered swing” [9]; in the arts, examples of causing negative emotions are more common [1]. Schiphorst in her *exhale: (breath between bodies)* [50] has combined body movements and wearable technology to design a participatory performance. Feedback from these inputs that are influencing performance is rarely observable as a one-to-one reaction from the performers to the action. Cafaro et al. [11] show that interactive schema that support a 1:1 correspondence between movement and concept (such as those presented in [3,4]) are easy to understand; however, as the complexity of the correspondence increases, the development of the vocabulary of embodied interaction becomes more nuanced, more difficult to understand, and more difficult to design. To ameliorate this scholars have drawn on other disciplines, for example Loke and Robbertson [31] present a method that extends traditional perspectives in HCI of designing from the perspective of the observer and the technology, to a first person perspective. Larssen et al. [27] move past functionality or appearance and explore design with a focus on the tactile dimension and our kinaesthetic sense.

Bodily Tracking

Bodily tracking has been used in a number of fields and is much more prevalent since the introduction of the Microsoft Kinect in 2010, which provided high quality tracking at a low price. From full body gait analysis to measure strides and intervals for health purposes [20] to designing a dance performance [13,37] or creating real time feedback to improve user’s posture or movement habits [62]. In a study more related to everyday life activities, Panger [44] focuses on bodily interaction in the kitchen where different body parts and body gestures can send different commands in order to navigate through the recipe, set the cooking time, and finally play music.

In relation to the performance art and particularly dance we can find several tools and applications [36,46] that can be used for choreography [15] or teaching ballet by combining movement sequences which were performed by ballet teachers and captured with a 3D motion capture system [59].

Bio-Sensing as Input

Sensors that detect the physical state of the body have been around for a long time, but only recently have they been small enough and non-invasive enough to be designed for wearable technologies such as a sensor bracelet [43] that can capture the skin and ambient temperature to diagnose certain medical problems. Recent work by Howell et al. [23] use skin conductance sensor in a form of a dynamic thermochromic t-shirt to detect and display the sudden arousal of the wearer in different social interaction such as embarrassment, joy, or sadness. With this approach as an attempt to engage *affect-as-interaction* [10] with design practice, the authors study the conversations that took place between the participants and used them to frame ‘biosignal’ displays as social cues rather than categorizing them just as bio-sensing technologies. In another domain Simbelis et al. [52] attempt to capture and share the living body with others. They present interactive work, in which a machine transforms and interprets bio data (pulse, movement, etc.) from a participant’s body to a colorful painting.

Another study [25] using Galvanic Skin Response (GSR) which measures conductivity on the skin influenced by sweat, measured cognitive load and trust of their participants in a text-chat platform. In [61] authors use GSR to measure psychophysiological engagement of their participants in the audience during a live performance as a method to monitor their reaction to different scenes and plots. Unlike the mentioned studies, which tried to detect the audience-participant response, Tennent et al. [57] capture such data from actors, and transfer it to the audience in order to enhance the show and give a richer sense-making experience to the viewers.

METHODS

The work presented stems from two related workshops carried out with six months in between. The aim of the first workshop was to broadly explore the role of novel digital technologies in the context of interactive performances, including theatre and everyday public performances (i.e. commuting as a social act). The second workshop was more narrowly focused on envisioning design ideas and novel interaction modalities for an interactive movie where the main protagonist is a dancer. Both workshops provided a context to reflect on issues emerging from the participation modalities envisioned, and not merely the interactional qualities of the enabling technology. Our material for analysis was the outcome from the workshops rather than the workshop process itself.

In the sections below we detail the procedure of each workshop and how they relate to each other before describing our data collection and data analysis methods.

Workshop one: Envision

The goal of the first full-day design workshop was to brainstorm and develop design ideas for various interactive performances (from theatre to street performance). It was organized by three of the authors of this paper. A total of

twenty people were asked and volunteered to participate in this workshop, thus reflecting a variety of backgrounds including three interaction designers, two computer scientists, eight HCI and media technology researchers, two theatre and movie directors, two professional actors, and three artists. The participants were chosen to represent a wide variety of backgrounds, as well as skills and professional roles that are involved in interactive performances, from designing, script writing, production and actual performance.

The workshop started with an introduction to its goals and methods. In order to gain a common ground, we provided participants with six theme cards highlighting two central aspects of interactive performances: “art” and “technology”. The theme *art* included “participation”, “story-telling” and “temporality”. Participation and story-telling were chosen as two main aspects of interactive performances. These first two themes relate to various modalities enabling members of the audience to contribute to the performance. The latter one encompasses the narrative strategies that can be employed to tell a story. In the context of interactive performances, technology is constitutive of story-telling [7], rather than being an additional layer to the narration. Temporality was relevant as it addresses how technology can redefine the traditional, sequential experience of interactive performance.

The *technology* category included “kinetic interaction” (i.e. responsive material, kinetic actuators, and proximity sensors), “taste and scent interaction” (i.e. edible interaction, smell-based interaction) and “biometrics” (galvanic skin response, hormone levels, and heart rate) as examples of technologies that could be incorporated to design novel ideas of interactive performance. Such technologies were chosen as they are available, but not widely explored in the context of interactive performances (they have however been used in other domains such as fitness [58], wellbeing [43], robotics [64], etc.).

All the themes were briefly presented to the participants with the aid of some concrete examples of each. For the theme *art*, concrete examples of interactive performances were discussed, each one highlighting one of the themes introduced above. In the second case, elements of kinetic interaction, taste and scent interactions and of biometrics were introduced independently of an application area; the potential of the technology was discussed abstractly, while the participants were invited to think of concrete

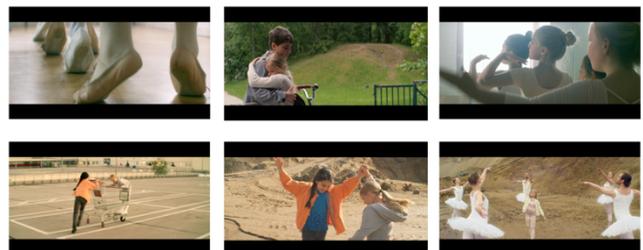


Figure 1: Stills from the movie LIV, shown to participants.

deployments in the context of a performance. During the second phase the participants were divided into three groups, with a distribution of backgrounds and skills in each group. Each group had one organizer as facilitator. Drawing from ideation techniques and brainstorming methods [41], we gathered some simple design tools (playdough, fabrics, pen and paper and etc.) to enable participants to create, sketch and describe their ideas in a hands-on workshop activity. This phase lasted three hours.

During the group activities, participants were asked to first choose and design their performance space, for example if it is an indoor or outdoor performance, a staged or street performance, a play or everyday activity and so on. They were then asked to develop possible interaction modalities in the context of the selected performance space and a relevant example scenario to be presented to the other groups during the final workshop activity.

Workshop two: Move:ie

Continuing a longstanding collaboration with a prominent interactive performance director, Rebecca Forsberg, this second workshop focused on design ideas for a performance entailing a short movie. This performance was targeted at children and centered around the protagonist's love for dancing. Thus, unlike the previous workshop in which participants were encouraged to think about different forms of performances, for this workshop we focused on different application scenarios for interacting with a movie.

We chose to employ a more evocative way of brainstorming that used physical artefacts, including body, playthings, textiles, and art and craft material as design resources [31,33,51]. Considering children as one of the target groups of the short movie, we provided probes and tools (toys, playdough, balloons, pieces of a local outdoor game, fabrics, etc.) that could induce creative thinking [15,20] and inspire participants. These probes can encourage and be powerful evocative elements, and suggest novel uses and functionalities in a similar way to Djajadiningrat et al.'s unusual artefacts [16].

For this workshop, we recruited eight participants including three researchers with embodied interaction background, two HCI researchers, one interaction designer, one professional choreographer and the director of the short movie. Similarly, these were chosen to represent a wide set of people engaged in different stages of interactive performances. It was organized by two of the authors, one (the first author) overlapping with the previous workshop.

The workshop began with the organizers introducing the movie and its characters, thus enabling participants to become familiar with the story, and to think of possible themes related to it (Figure 1). After introducing the concept of bodystorming [33,51], participants were divided into two groups with a distribution of backgrounds and skills in each group. Each group had one organizer as a facilitator. The participants' attention was drawn towards the characteristics

of the movie (e.g. playfulness, being together, dance, collaboration, etc.), the space around them, and the probes and artefacts that had been provided. Participants were asked to elaborate on the presented ideas by role playing possible scenario(s) [42]. They were encouraged to think about variations of ideas by changing the rules, artefacts, audience participation and/or performer interaction, the participant's roles, or the method of engagement. For the final step of the workshop, we asked participants to create a video prototype of each finalised idea to present to the other group.

Data Collection

Throughout the two workshops we documented activities by direct and participatory observation. The main data that we collected was video recording, which we made use of for the final idea presentations in each workshop as well as the smaller tasks and exercises. With one organizer always present in each group, we were able to take notes as well as still pictures to document the process and to remember details when discussing the workshops later. We also collected the artifacts generated during the workshops including drawings, paper models and playdough models. Our data for analysis resulted in 5+ hours of video and 50+ still pictures, along with our notes and the artifacts.

Data analysis

Our unit of analysis was the ideas generated throughout the workshops. We used qualitative thematic analysis methods, such as categorization and comparison, to analyse these ideas. The authors conducted several rounds of analysis in which the presentation videos from the workshops were watched alongside the artefacts and notes taken at the time. We started with the authors collaboratively coding and categorising the ideas generated; they were then themed and categorized in terms of several characteristics: 1) if they were temporally bound or not, 2) could work as a game with rules and competition, 3) if they included play objects, 4) could count as performance or be part of a performance, 5) if they involve audience participation, or 6) if the interaction could be categorised as bodily sensing or bio-sensing. We excluded ideas that were not adhering to a broad definition of interactive performance as introduced above. It should be noted that for the purposes of this paper, we have decided to analyse the workshop material to highlight the conceptual and interactional aspects that might emerge from the actual implementation of the designs suggested, rather than the concrete technological issues inherent in them. This is relevant as the issues addressed apply to a variety of interactive performances beyond the concrete use situations instantiated in the scenarios presented.

RESULTS

We begin with the description of five design ideas and the related scenarios produced during the group activities at the workshops. Five scenarios were selected from the 17 presented by participants at both workshops, as exemplars of the range of use of, and interaction with, bio-sensors and

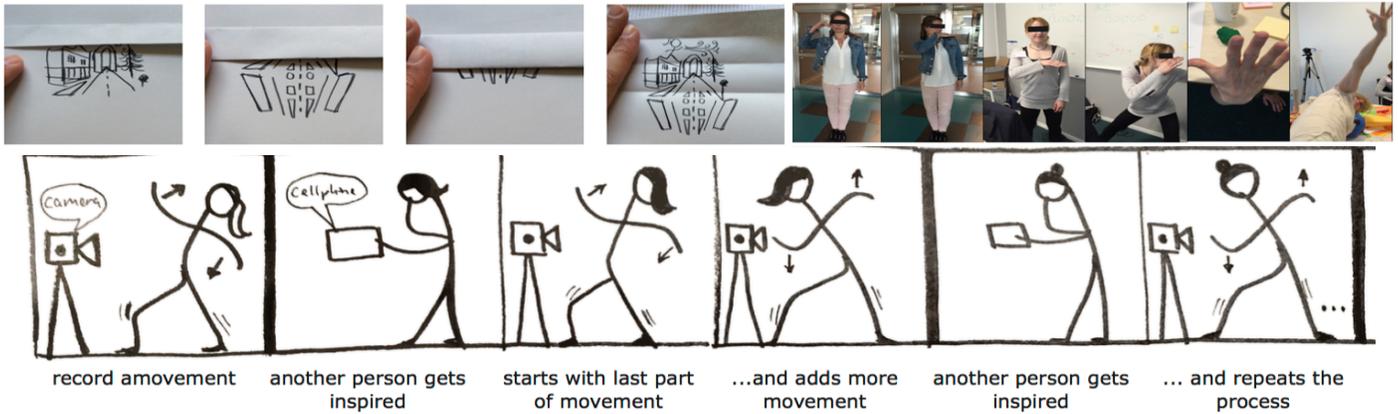


Figure 2: Movement Chain. Top Left: The inspiration, Top Right: Stills from the video produced during the workshop. Bottom: Explanation of the creation of the dance video

bodily tracking envisaged by our participants. These scenarios constitute the base to discuss relevant issues emerging from the influences of bodily sensing and bio-sensing.

Scenario 1: Data Director

In this idea, designed in the first workshop, the navigation through the plot of a movie, or a stage show would be directed, at least partly, by the biometric data sensed from the audience. With certain biological states shown as indicators of psychological ones [29], these could be used as triggers to automatically adjust a performance, or information that a director could take advantage of:

“For example, you have got some sort of argument and you could keep the argument script going and going until you see the heart rate of the audience reached the certain point and then you could break a glass and go to the next scene” Participant3, Workshop1

Possible implementations could employ the detection of heart rate as an indicator of excitement, or the detection of GSR as an indication of the stress levels of the audience. One scenario that was discussed in the group who came with this idea was the horror trope of walking along a dark path with menacing music, just waiting for the antagonist to appear. Using bio-feedback, this tension building scene could be extended until the desired level of excitement was reached by a percentage of the audience, and only then would the footage of the antagonist’s appearance be shown.

This system was not envisaged to necessarily be fully automatic, but could allow for a human director to interpret the incoming data from the audience and either trigger scenes or give direction to the actors on stage. The feedback loop between the performance and the audience’s emotional and physiological states is, in this example, happening in real time. As the director watches the audience calm down during an interlude scene, he can judge the most impactful time to re-engage with the plot, then watch the change this has in the audience to time the next transition. However, the use of previously collected or repurposed data was also considered. For example, by tracking locations as well as physiological

data the director could make assumptions on the community connections and preferences of audience members by locating the tell-tale signals of favourable and unfavourable emotional responses. It was supposed that this could then be used to, for example, play on the fears and assumptions of a suburban audience for whom the less than desirable area of the theatre causes a stressful response.

Scenario 2: Movement Chain

This idea, designed by a group from workshop 2, is inspired by the popular parlour games of additive writing or drawing with limited knowledge of the previous players’ additions, and where the full composition is only revealed at the end.

In this scenario, it is the physical position of the previous player that one must connect with at the start of a turn instead of the final line of the previous player’s story or the bottom edge of their drawing. One player records a movement and the next must start their movement from the final position of the player before them in the chain, adding another phase to the choreography before passing on to another player. The role of the bodily tracking technology in this idea is that of mediator, in the sense that it is used to record the movements of each player and to indicate when the starting position is close enough for the chain to ‘link.’ The final output would be a multi-party dance video which would showcase the combinatory choreography (Figure 2).

Scenario 3: Voice of the City

The Voice of the City was developed while a group of participants in the first workshop was exploring location-based audio stories. In this iteration of a location based story, access to the different parts of the narrative isn’t only restricted by location, but also by the audience member’s physical and emotional state.

“We decided to see the city as our theatre, where we could be playful, serious and empathetic [...]you can go to some places and you have an app, and you just hear some noise, but if you stand still there you can register what the city is telling you” Participant8, Workshop1

This scenario was perceived as a way to increase the emotive power of traditional location based stories. In one scenario presented by the participants, instead of simply attaching a piece of narrative to a location, the audio would be presented as ‘of the city’ and would only become clear and audible once the listener has waited, still, in a certain place for enough time to move themselves outside the normal flow of the city dwellers. This would be tracked using bio-sensors to encourage a moment of mild meditation in the middle of the city. Expanding this to other narratives, the audience member could be restricted to matching the heart rate chosen by the artist or lowering their galvanic skin response at a certain location. Although it was noted that this may not lend itself to all genres, as a tool for influencing the emotional state of the listener the artists involved saw a number of areas of possible application and an advance over relying solely on location such as in *I seek the nerves under your skin* [34].

Scenario 4: Bob the Blue Ghost

This idea was to enable navigation through the performance individually, rather than something shared by the whole audience as was described in Scenario 1 (Data Director), while still socially attending a performance as part of an audience. Elements of the performance would be hidden from the audience by default, and only shown to them when their bio data matched a certain threshold.

This scenario could take the form of an audio track delivered through headphones or visually, using augmented reality (e.g. a head mounted display). Audience members would then experience the performance differently depending on their physiological readings. The example scenario made by this group, which included a professional actor and a director, can be seen in Figure 3 (left). Bob, a blue ghost that was a figment of the imagination of one of the characters on stage, would only be visible and audible to any audience member when their heart rate was very slow. Described as a ‘window on madness’ the seemingly irrational behaviour of the main character would be explained, to some extent, when Bob was visible. One interesting opportunity the director saw was to use the invisible ghost in a highly emotive way, quickly pushing the audience back out of the head of the main character as their emotions raised their heart rate.

Scenario 5: Magical Dance Keys

The interaction in this scenario centred around providing additional content to the movie described in workshop 2. To increase the sense of connection to the characters in the



Figure 3: Left, Bob the Blue Ghost (and some of his friends). Right, Magical Dance Key being performed

movie, audience members who wanted access to these extra scenes would have to perform the corresponding ‘Key’ in front of a Kinect or similar device at home. These keys, given this scenario’s connection to a movie about dance, were to dance the same steps as the central protagonist.

In expanding this idea, the workshop participants envisaged an alternative, physical installation that would display its content for an amount of time once someone performs the movements, rewarding insider knowledge or fandom in a public setting (Figure 3, Right). Either instantiation was seen as a way to encourage the viewer to watch closely the movements on screen and, through performing and perfecting them themselves, to have a stronger connection to the characters and the story.

EMERGING ISSUES IN BIO-SENSING AND BODILY TRACKING PERFORMANCES

The following sections are structured around three central issues emerging from our analysis that further extend the contemporary discourse on interactive performances, namely; *Temporality of input*, *Autonomy and control* and *Visibility of input*.

Temporality of Input

In traditional interactive performances, and in traditional methods for interacting with systems, the act of providing input is highly temporally bound. The press of a key causes a letter to appear in the word processor in much the same way as sending a text message causes a text to appear on a stage like, for instance, in the performance *Ada* [12]. On the contrary, the passive nature of the input relied upon in bio-sensed and bodily tracking systems gives rise to the possibility of providing input on different temporal scales.

Interactive Sensing

Bodily sensing and bio-sensing have, on the surface, different temporal properties. Bodily sensing, in the way that it was envisaged in the scenarios at the workshops, was immediate. This means, it followed the deliberate movements elicited by the system or performers, and provided output immediately to the user. Bio-sensing was also seen as something to be connected to the ongoing artwork, although the interaction timescales were slower to be in line with the biological limits apparent in the lowering of a heart rate, for example. In using the sensors in this way, the person being sensed still has a large degree of autonomy in that they enter the space where they are being sensed, or put on the wearable provided as part of the installation, and the effect that their input is having on the interaction can be learned through manipulation and experimentation.

Long term Sensing

It is interesting to point out that with an increase in mobile sensing and the growth of personal informatics with movements such as the quantified self [55], it is possible to now sense, or make use of sensed data, from outwith the time of the performance. This leads to possibilities such as the use of audience members’ routines, and the everyday patterns of interactions between them as an input for interacting within

the performance. For instance, the number of times one was in proximity to any other member of the audience before the performance can be calculated from the location traces of the participants, which may be stored by any number of services. However, at the point of interaction and effect, no explicit agency is required from the audience to participate as the actions have already taken place.

With the rise in both the use and the complexity of the sensing of fitness trackers, bodily movement will start to be tracked in the same way as location is currently. This will allow the physical limits of audience members to be known by the system and adaptively pushed by the artist. The yoga instructor may be given a physically different movement to perform than the middle-aged researcher, however the *experience* may be analogical. This also opens the possibility of an audience’s interaction taking place after the performance. With access to behavioural patterns, the current performance could be built upon the behavioural change measured in those who have already been to the installation and shown to those currently visiting.

Autonomy and Control

The scenarios presented above can be used as examples to show the range of influence that the designer of the interactive performance can have on the audience members’ interaction (summarized in Table 1).

Balancing Artist and Audience Autonomy

Action in a traditional interactive performance goes hand in hand with agency and control; the audience member chooses when to interact and how that interaction is directed (i.e. clapping). This is preserved in the bodily movement sensing scenarios; “*Magical Dance Keys*” and “*Movement Chain*”. However, this is blurred in those that are based on bio-data. Even with data collection that is temporally bound to the audience member’s interaction with the performance, as we move towards more passive and bodily sensing the control that participants have over their input drops. Inversely, the control that the artist has over the audience’s input increases, as we see in “*Data Director*” and “*Voice of the City*”. Take heart rate as an example; while there are techniques to regulate one’s heart rate this is much more difficult than pressing a button or changing location. It is also open to more external manipulation – excitement can raise the heart rate or

the beat of a drum can be used to synchronize it [63]. Galvanic Skin Response is becoming a common sensor to include in wearables, something very difficult for the user to consciously control.

As highlighted in *Better than Life* [17] the implicit rules of interaction between performer and audience can be built on-the-fly. These come in part from the understanding built up by audience members through the control they have [49], and where their attention is in the ‘split centre’ of the mixed reality performance (from the stage cue for two actors to have equal prominence, splitting the audience attention) [60]. This provides another axis for artist: the demonstration and transgression of these rules of interaction can be balanced against the understanding of how each audience member can influence the performance.

Visibility of input

The act of giving input to an interactive system is traditionally a physical movement (such as pressing a button) or the production of sound (clapping or voicing commands) [48]. These types of action are well understood in daily life and negotiating their visibility to others is done fluidly [39]. One may move a mobile device out of the visual range of another to type a message, or move oneself out of audible range to conduct a voice search. The individual actions involved in providing input to bio-sensing and bodily tracking systems can have different communicative abilities with respect to the system and others around the user. It is this aspect that reflects on how visible to others the action of interaction is. Drawing on example from the performances and projects that we studied in the background section and the scenarios produced in two workshops, we try to describe and classify them in terms of *Visibility of Input*.

Socially Sharing Highly Personal Data

The interactions included in Figure 5 can be looked at from the perspectives of both the impact each interaction has upon the performance it was directed towards, and also the social investment and the amount of personal performance that is imbued in the act of interacting. We can see the contrast between the personal and mostly non-visible interactions afforded by the bio-sensors (on the left side) with the very visible and, as a result, mostly collaborative interactions using the bodily tracking sensors (on the right side). *Breathless* [9] is one exception, where the normally low-visibility act of breathing is amplified by the system so that it can be heard by the audience, shown as a linear trace on a large screen, and turned into a highly visible physical action – that of swinging on a swing.

This lack of scenarios could stem from the lack of social practices around sharing biometrics. While we all learn to negotiate our visual privacy around our body and our movements, we do not learn to negotiate the sharing of our GSR, heart rate, or breathing in the same way [14,23]. This lack in current practice may be a factor in limiting the interactions around such information to aggregate and hidden ones. As the range of sensed data available to us, and

Bio-sensing	Voice of the City	Bob the Blue Ghost
	Data Director	
Bodily Tracking	Magical Dance Keys	Movement Chain
	<i>Artist</i>	<i>Audience</i>

Locus of Control

Table 1: Classifying scenarios according to who has primary control over the input

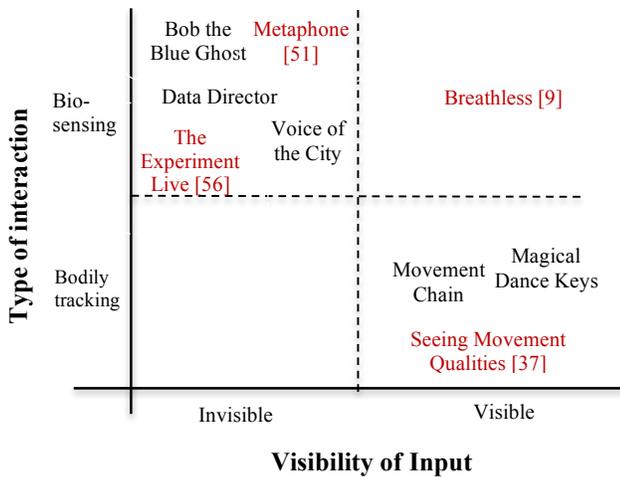


Figure 5: Classifying scenarios and example performances (projects and performances from the background in red)

thus available for sharing with others, increases, so will our social practices around them deepen. Now that they are in genesis and flux exploring them with art would be timely and produce interesting, impactful results. One avenue of future work we hope to pursue is design work focused on this emerging field leading to the production of performances and installations to expose the general public to these issues.

Reconfiguring boundaries

The ideas presented, and the technology upon which they are based, all in some way alter the boundaries between the creative team and the audience. On one hand, it could be said that the act of interaction by an audience member within an interactive performance is already under the control of the creative team to a greater (i.e. Stage Hypnotism) or lesser (i.e. improvisational theatre) extent. The environment, emotional cues, and information on the plot and characters are all under the control of the artists and are used in the manipulation of the emotional and psychological state of the audience – traditional interaction can then be seen as both a means to probe the effectiveness, and further the impact of this manipulation.

Asking the audience to ‘boo’ the protagonist is an act that is socially obligated in situ, reinforces the emotional commitment to the hero, and at the same time provides a window on the engagement level of the audience for the artists. By changing the act of interaction from active, as in the example above, to passively being sensed these three aspects of interaction can be disconnected from each other. It is this disconnection between action and reaction, between cause and effect, that opens the possibility for the artists to manipulate, blur, and play with boundaries between traditional roles. For example, in the *Bob the Blue Ghost* scenario, each audience member takes part of the role of director by directly influencing through their bodily functions the modalities of the experience they are able to perceive, but the director still has influence through the choice of triggers and thresholds, as well as through

traditional means of influencing the psychological, and as result the physiological, state of the audience.

Tracking Invisible Bodily Movements

The least populated areas of the graph in Figure 5 are those where the inherent visibility of the input is challenged. Opportunities to take advantage of low-visibility physical movements exist, but they are technologically more difficult to harness than larger movements. Designing systems that respond to micro-expressions [45], the involuntary, short, and small movements in facial muscles that signal emotional states, is hampered by the current need to have a high quality, well lit video of the face of the users. The current need for high quality video in the detection of fidgeting [2] and other small bodily movements at a distance similarly limits the current application of these types of movement as an input. However, as both the quality and quantity of cameras that can be trained on an audience increases alongside the complexity and robustness of algorithms to detect such small movements the inclusion of low-visibility bodily movements will become viable. What is interesting here is that the concerns around autonomy and control with bio-sensed data are echoed and, because of the short time scale of the actions being detected, amplified.

CONCLUSIONS

In this paper we have presented five design ideas and related scenarios for interactive performance systems centred on bio-sensing and bodily movement interaction modalities. The ideas were generated during two design workshops which various experts in digital technology and interactive performance participated in. These ideas provide a base for the exploration of novel opportunities for audience participation in interactive performances. We use these ideas to present three key issues concerning such interactive performances; *the temporality of input, the audience’s degree of agency and control, and the visibility of the interaction itself*. At a time when the deployment of sensor-based devices is quickly making its way into a range of use applications (i.e. including health and medical monitoring), this paper draws attention to potential developments and issues that might emerge when designing for artistic experiences. The issues discussed constitute three paramount conceptual and interaction aspects inherent to triggering reflection on the role of the audience (i.e. from spectator to participant), and on the reconfiguration of boundaries between members of the audience, creative production teams, and performing artists.

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