How Are We Connected?
Measuring Audience Galvanic Skin Response of Connected Performances

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Abstract: Accurately measuring the audience response during a performance is a difficult task. This is particularly the case for connected performances. In this paper, we staged a connected performance in which a remote audience enjoyed the performance in real-time. Both objective (galvanic skin response and behaviours) and subjective (interviews) responses from the live and remote audience members were recorded. To capture galvanic skin response, a group of self-built sensors was used to record the electrical conductance of the skin. The results of the measurements showed that both the live and the remote audience members had a similar response to the connected performance even though more vivid artistic artefacts had a stronger effect on the live audience. Some technical issues also influenced the experience of the remote audience. In conclusion we found that the remoteness had little influence on the connected performance.

1 INTRODUCTION

One-Way delivery of live theatre performances to cinemas or other theatres is a relatively recent phenomenon, as well as still relatively small-scale. However, it has already been a commercial success for well-funded companies using expensive and not readily available infrastructure (e.g. satellite communication). For example, the National Theatre in UK often applied NT Live technology to broadcast live performances to digital cinemas (Bakhshi et al., 2010). The long-term vision is that over the next few years, smaller companies will follow suit to reach wider audiences beyond their local community. In addition, we foresee the development of the technology to enable remote audiences to play a much bigger role during live performances. Remote audiences may interact with performers across space and provide feedback, promoting a sense of audience community on a larger scale.

A number of previous studies focused on how to enable connected performances, and how to better engage the audience (Sawchuk et al., 2003; Sheppard et al., 2008; Yang et al., 2006). However, audience response to connected performances has only been investigated in a few papers. Our study was conducted to better understand the effect of remoteness on audience experience during a connected theatre performance. This is a first step in evaluating audience response to connected performances. This paper aims to address the following research question:

How does remote real-time watching compare to being at a performance in person?

To answer this question, an experiment in highly realistic conditions was conducted. Together with a small theatre company, exploratory work was done on synchronous watching (live streaming) of one theatre play, which was called "Styx Boat on the River". It was staged at the University of Falmouth in Falmouth, United Kingdom. The performance was live streamed to another studio located at the same building, which meant that the audiences at the two locations watched the same performance at the same time (Figure 1 and Figure 2). The experience of the audience was captured by galvanic skin response (GSR) sensors, video recordings, and interviews.

The remainder of this paper is structured as follows: The next section is a review of recent relevant research work, highlighting the novelty of our contribution. Then, the methodology employed during the experiments is described and the results are analysed. A discussion concludes the paper.

2 RELATED WORK

Having an exhaustive overview of the previous studies regarding audience experience of theatre performances is beyond the scope of this paper; the interested reader can consult the following surveys (Bennett, 2013; Reason, 2010). A review of the most relevant works is conducted in the following areas: audience response in performing arts and measurement of audience response.

2.1 Audience Response in Performing Arts

In the broadest sense, audience response can be considered as feedback to a stimulus coming from several users, participants, or players (Mandryk, 2004; Chanel et al., 2008; Lunn and Harper, 2010). Different applications define audience response depending on the requirements of the application. Using an online environment as an example, O'Brian and MacLean (2009) regarded audience response as the perceived usability, aesthetics, focused attention and involvement felt.

In other specific application areas like video watching or theatre performances, audience affective states or emotions were also used to define audience response (Ruan et al., 2009; Sauro and Lewis, 2012). According to most psychological models, affective state or emotion includes two dimensions: valence and arousal (Russell, 1980; Bradley et al., 1992; Posner et al., 2005). Arousal has been commonly used to represent audience experience during theatre performance (Dmochowski et al., 2014; Latulipe et al., 2011; Wang et al., 2014). For example, Latulipe and her colleagues (2011) measured both the self-reported arousal and the physiological arousal of an audience member during a recorded performance. They found that the audience self-reports were positively correlated with the audience physiological arousal.

However, previous studies about audience response in the domain of performing arts have been conducted at only one location. For example, Radbourne et al. (2009) conducted a study to investigate the differences in audience response between a live music event and a theatre performance. This study did not find any significant difference.

For connected performances, as mentioned above, researchers focused on technical issues, like how to support a connected performance (Yang et al., 2006; Sheppard et al., 2008)) and performance issues, like how to design a high quality connected performance (Gonzalez et al., 2012). For example, Sheppard et al. (2008) and Yang et al. (2006) explored connected dance using a 3D virtual room, where dancers could

Figure 1: The performance: the two photos on the left show the remote location (the performance and the live audience were both displayed on the big screens (top) and the remote audience actively interacted with the actor (bottom)); two photos on the right were taken at the live location (the artist with special effect smoke (top) and the audience watching the play (bottom))

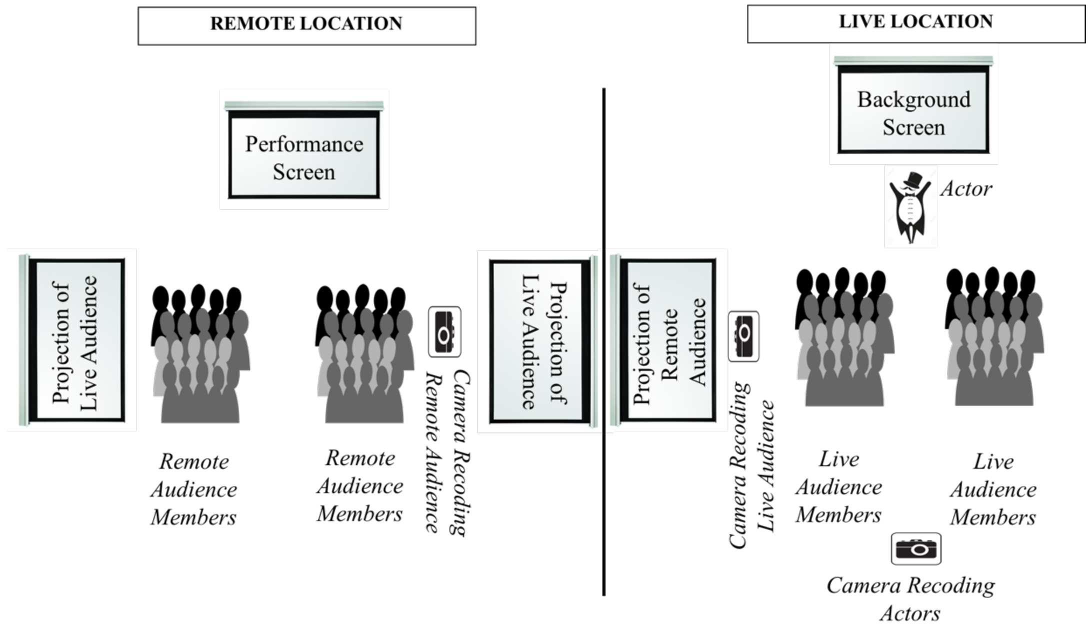

Figure 2: Conceptual sketch of the experimental facilities at each location. Left: at the remote location, there was one screen showing the performance from the live location in front of the audience members. Another two screens, which showed the live audience members, were both on their left and right. One camera at the right of the audience was used to record them. Right: at the live location, the actor was performing in front of the live audience. There was a camera in the back, which recorded the performance. The projection of the remote audience was placed in a screen on the left of the live audience. The camera recording the live audience was on the left side. This set up allowed that audience at both locations felt as if they were in the same space.

interact with each other. Furthermore, in these studies, even though audience response during the performance was recorded, it was only a tool for evaluating the quality of their technologies. So they focused on supporting the performers but not on better understanding the audience response. The current study instead intends to quantify the audience response during the connected performance.

2.2 Measurement of Audience Response

In the past, different mechanisms for quantifying audience response have been employed (e.g., surveys, real-time scaling system, and physiological measurement).

Surveys are the most common method. For example, Gonzalez et al. (2012) used surveys to evaluate how audience responded to different technology-oriented performances. However, this method has some limitations. For instance, surveys are subjective and the result of them can be easily influenced by many other factors, like social pressure and the bandwagon effect.

Besides surveys, Stevens et al. (2009) used a real-time scaling system called “the portable Audience Response Facility” (pARF) to measure audience experience during a performance. There are three drawbacks to this method: First, as with surveys, it is a self-report, which is subjective. Furthermore, before the real experiment starts, the participants have to be trained to use the system to ensure that they can respond using the least cognitive effort. The training procedure is time consuming and inconvenient for both participants and experimenters. Lastly, even though the audience members are trained to use the system, the real-time scaling system still interrupts the audience during the performance.

In addition to these subjective tools, objective methods, normally in the form of physiological sensors, have also been used to measure the audience response during a performance. For example, GSR sensors, which measure the users’ electrical conductance of the skin, have been proven to be a valid approach for measuring audience engagement (Picard, 1995). In 2014, Wang and her colleagues conducted experiments in a real theatre studio using GSR sensors. Clustering analysis showed that the audience could be grouped into different engagement levels. They validated that GSR is a valid proxy for quantifying user experience.

Considering the advantages of GSR sensors, such as being an objective and nonintrusive mechanism, in the current study, GSR sensors were used to measure the audience response. Additionally, interviews and behavioural observations were also used for analysing the data.

3 METHODOLOGY

3.1 Participants

All the participants were recruited at the university, and they all were university staff without any visual or acoustic problems. There were 12 audience members in each location (24 participants in total).

3.2 Stimuli and Apparatus

3.2.1 Distributed Performance

The performance for this experiment was carried out by a single actor. The play, called "Styx Boat on the River", was interactive including a number of pieces like singing, effects using theatrical smoke and a vacuum cleaner sound effect. The whole performance lasted 25 minutes.

3.2.2 GSR Sensors

There are several commercial GSR sensors, e.g., BioNomadix Wireless Wearable Physiology from BioPac Systems Inc., GSR 2™ from Thought Technology Ltd., and Q sensors from Affectiva Inc. However, these sensors use Bluetooth as communication protocol, which makes them not suitable for group experiments, where simultaneous readings are needed. We thus decided to build our own GSR sensor using a Jeenode board with a RF12 wireless module, a low pass filter, and several accessories (Figure 3), such as a band to be worn on the user's palm, holding the electrodes. The wireless function of the RF12 module makes it possible to run user studies with a group of users at the same time, which can be carried out during theatre performances. The sensors have been validated through a number of experiments (Wang et al., 2016). All the sensor slaves simultaneously send packets back to the master sink node, which is connected to a laptop. The master node communicates with all the slave nodes by using a polling mechanism. In a lab testing environment, each slave sensor node generated 7 or 8 samples per second (7 Hz or 8 Hz), but in reality the sample rate was reduced to 4 Hz due to in-air collisions. Before we used the sensors in the experiment, the effects of noise in all the sensors were tested, and were validated in different scenarios (i.e., video watching or video game playing). In our case, our sensors are resilient against noise because of the filter. In addition to that, the sensor data distribution was also proved to be in accordance with the typical characteristics of GSR sensor data.

3.2.3 Interviews

Both, actors and audience members were interviewed after the performance. The interview of audience members mainly focused on three parts: the overall evaluation of the performance and the reasons behind their opinions, the closeness they felt to the actors, and the closeness they felt to the audience at the other location. The interview with the actors discussed the overall evaluation of the performance and the reasons behind their opinions, and how they felt with respect to the audience.

3.2.4 Other Apparatus and Software

The performance was live streamed to another performance studio located in the same building, which meant that the audiences at the two locations

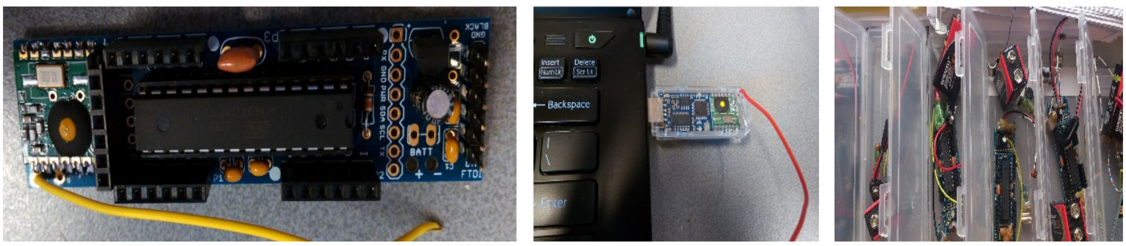

Figure 3: The GSR measuring system: (left) the front side of the sensor board; (middle) the sink node connected with a laptop; (right) the complete sensor sets.

watched the same performance at the same time. The technical research team developed the live streaming system. There were three cameras deployed in total, so that the remote audience could see the actor and the live audience through three projector screens. At the live venue, there were only two projector screens installed, so that the actors could see the reaction of the remote audience during the performance (Figure 2). During the rehearsal, the latency of the live streaming system was measured, to be around 150 milliseconds, so that the audiences at the two locations could hardly feel the influence of delay.

The software for controlling the cameras, recording the data and networking was written in C and Python. All the data analysis was done using SPSS and Python.

3.3 Experimental Procedures

Before the experiment started, the participants filled an informed consent form. Then oral instructions were provided. After that, the audience members from both locations attached the sensors to their non-dominant palm. At the end of the play, there was a small group interview at each location. Both the audience behavioural response during the whole performance and the performance were video recorded in order to better recall the experiments when analysing the sensor readings.

3.4 Data Analysis

To understand the audience members' GSR response, both the event-related skin conductance (SCR) and the skin conductance level (SCL) were analysed. Before that, the raw GSR data was processed by averaging the results every second.

3.4.1 Data Analysis of Event-related SCR

There are several steps to analyse event-related SCR data (Figure 4) based on Fleureau and his colleagues' (2013) work.

Normally, when humans receive an engaging stimulus, their GSR value will increase fast with a latency of 1-3 seconds, and after reaching a maximum value, it will recover to a value around the baseline. In the algorithm we used, first, a 2Hz ($G(t)$) low-pass filter was applied to remove noise, such as other physiological signals and electrical noise. Then a derivation (from $G(t)$ to $G'(t)$) was applied to calculate the rate of change of the GSR data. This way we know if the GSR value is ascending (positive values) or descending (negative values). After that,

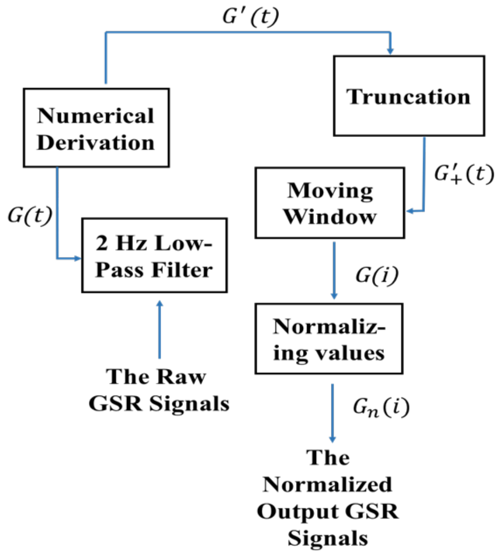

Figure 4: The description of the different steps of the algorithm on the processing the raw GSR signals.

only the positive values were kept, while the negative ones were ignored (from $G'(t)$ to $G'_+(t)$), which means that we only focused on the increasing phases of the GSR signal, because the negative phases only reflect the recovery of the signal to the baseline. The steps above helped us to extract the SCR data.

To temporally analyse emotional flow, we applied an overlapping time moving window with a window size of 30 samples (30 seconds), and an overlap of 15 samples (15 seconds). This step helped us to smooth the data and remove the users' GSR latency. So the mean values of $G'_+(t)$ were converted into $G(i)$ ($1 \leq i \leq k$, k is the number of the moving windows). $G(i)$ is the mean derivative value of one subsample in one specific moving window.

Since each individual may have a different amplitude for the derivative GSR signal when exposed to the same stimulus, $G(i)$ was divided by the sum of the subsampled skin response values (Formula (1)), and the output was $G_n(i)$ ($1 \leq n \leq N$, N is the number of the sample; $1 \leq i \leq k$, k is the number of the moving windows).

$$G_n(i) = \frac{G(i)}{\sum_{i=1}^{k} G(i)} \quad (1)$$

$G_n(i)$ is the individual value in a moving window, which cannot represent the whole group's response, because there is some individual, different from person to person, noise (e.g. body movements). To define whether the group had a significant arousal or not, a statistical test called the bilateral Mann-Whitney-Wilcoxon (MWW) test was used. This test detects whether there is a significant difference between the audience arousal response ($G_n(i)$) and the background noise. We took the lowest 10% of the values in $G_n(i)$ as background noise (Fleureau et al., 2013). $G_n(i)$ of a single time sample was compared to the background noise of each time sample, which means that we used MWW test to compare k times and obtain k p-values for each time sample. The final p-value of each time sample is the averaged value of those k p-values. For final p-values lower than 5%, we considered the response during that time sample to be significantly different from the background noise.

3.4.2 Data Analysis of SCL

The first sensor readings of each participant were used as the baseline, which was then subtracted from the raw data, to remove individual differences. Then, the Pearson product-moment correlation coefficient was used to check whether there was a significant correlation between the responses from the audiences at different locations.

In addition, a t-test was used to compare the SCL data of live audience members and remote audience members.

3.4.3 Data Analysis of Video Recordings

Several parameters (e.g., eye contact between the actor and the audience, interactions between the actors and the audience, laughter, smile, and applause) from the video recordings were calculated by inspecting the recordings (Roto et al., 2009).

4 RESULTS

4.1 Event-related SCR

The event-related SCR results, extracted from the 24 participants (two groups: 12 live audience members and 12 remote audience members) during the whole performance, are shown in Figure 5 and Figure 6. In

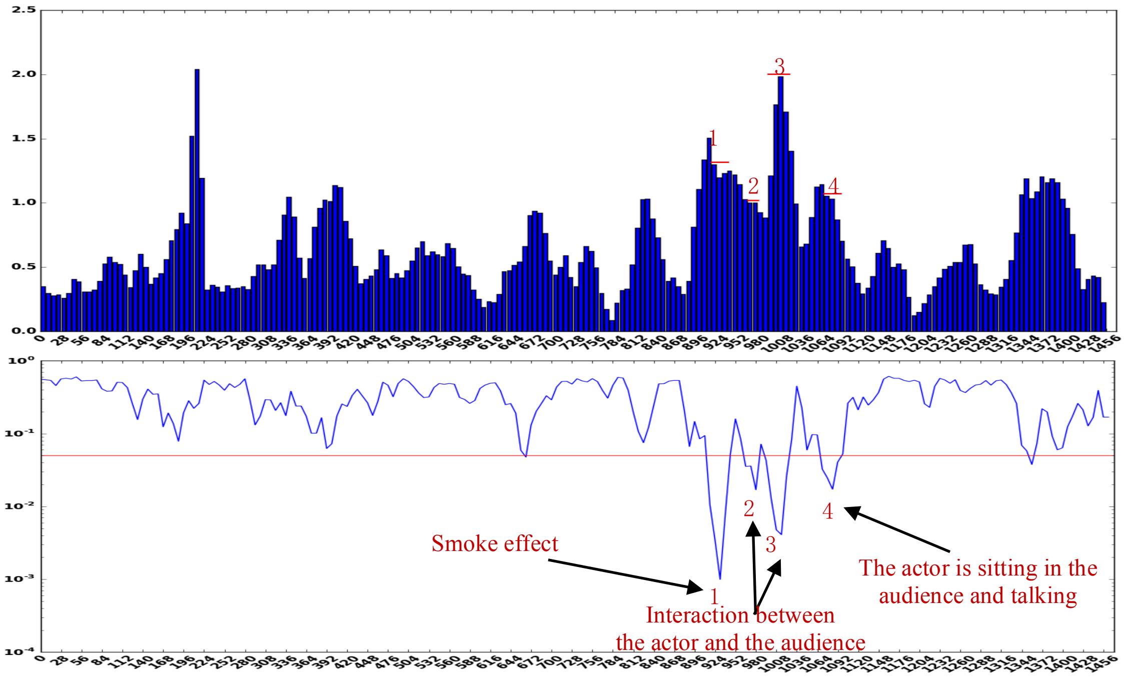

Figure 5: The extracted SCR signals of the live audience members during the performance, where points 1, 2, 3, and 4 are the significantly different SCR responses identified by the algorithm. In the top graph, the y-axis is the mean derivative value. In the bottom graph, the y-axis is the mean p value of the bilateral MWW test. The x-axis of both two graphs is the time in seconds. 1, 2, 3, and 4 are events performed were the live audience SCR response is significantly different from the background noise. 1: the smoke event; 2 and 3: the interaction between the actor and the audience; 4: the actor is sitting in the audience and talking.

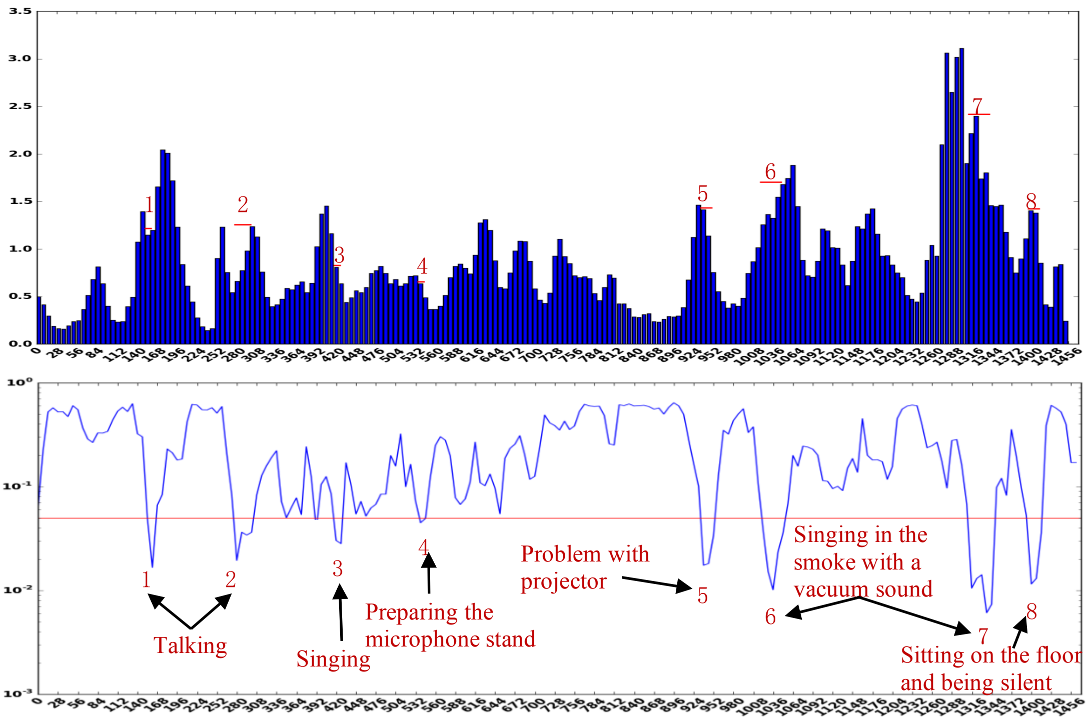

Figure 6: The extracted SCR signals of the remote audience members during the performance, where 1, 2, 3, 4, 5, 6, 7, and 8 are the significantly different SCR response defined by the algorithm. The meaning of x-axis and y-axis is same as Figure 4. 1, 2, 3, 4, 5, 6, 7, and 8 are the events performed while the remote audience SCR response is significantly different from the background noise. 1: the actor is talking with his arms hurling; 2: the actor is talking to the remote audience; 3: the actor is singing; 4: the actor is preparing the microphone holder for singing; 5: there is some problems of the projector and the audience members raised their hand; 6 and 7: the actor was singing in the smog effect with a vacuum sound; 8: the actor was sitting on the floor and being silent.

the top graph of each figure, the blue columns represent the average value of $G_n(i)$ at time ($\overline{G_n(\iota)}$). The red bar means that the p value in this moment is less than 0.05, i.e. significantly different from background noise. The concept is mirrored in the bottom graph where the p-value (blue line) goes below the critical value (red line).

The algorithm detected a number of moments where the event-related SCR signals were significantly different from the background noise, which means that the audience members were more engaged. For example, the significantly different audience SCR response can be seen during the theatrical smoke effect in the graph of the live audience. During the smoke effect, also the remote audience was significantly engaged. The remote audience members were more absorbed when the actor was singing, while the live audience members were more engaged during the interaction event. In addition to that, it is interesting to see that the number of engaging moments of the remote audience members is higher than for the live audience members.

4.2 SCL

First, we compare the SCL data of the audience at different locations during the whole performance. There is a strong positive correlation between the data from the live audience and the remote audience (r = 0.535, n = 12, $p < 0.01$), which indicates that the skin

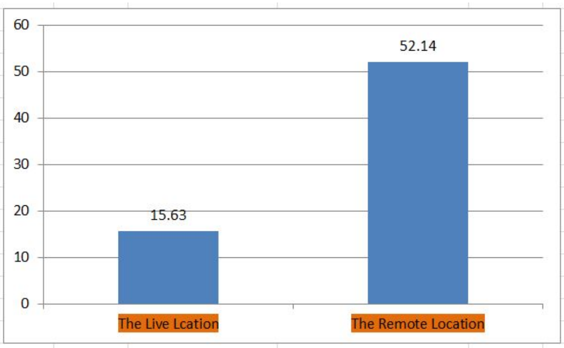

Figure 7: The SCL difference during the singing event.

conductance response pattern at both locations was synchronised. Additionally, the result of the t-test showed that there was no significant difference

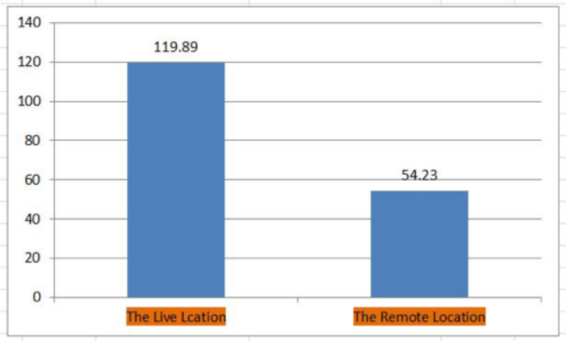

Figure 8: The SCL difference during the theatrical smoke.

Figure 9: The SCL difference during the interaction

between the response from the live audience and the remote audience ($t = 1.18$, $p > .05$).

Although the SCL data at the two locations was similar, we found that the two audiences responded significantly different to different events. These findings may help performers to better understand what kind of effects could arouse a remote audience. When the actor was singing, we found that the remote audience was more absorbed ($t = -4.04$, $p < 0.01$) (Figure 7). Additionally, both the theatrical smoke and the interaction were more engaging for the live audience (smoke effect: $t = 3.35$, $p < 0.01$; interaction: $t = 4.37$, $p < 0.01$) (Figure 8 and Figure 9).

4.3 Interview and Video Recordings

The data from interviews and video recordings is summarised and presented in Table 1. In the video recording, we found that eye contact between the actor and the audience at both locations was constant during the performance. Besides, most of the time, the audience at both locations were smiling. According to the results of the interview, all of the audience members felt connected to both the actor and the audience at the other location. Thus we can conclude that both the live and the remote audiences were similarly immersed during the performance.

Table 1: Summaries of interview and video recordings.

		THE LIVE AUDIENCE	**THE REMOTE AUDIENCE**
VIDEO RECORDINGS	**Eyes Contact**	Constant eye contact	Constant eye contact
	Interactions	6 times	6 times
	Laughter	2 times	3 times
	Smile	Most of the time	Most of the time
	Applause	They applaud at the end of the play	They applaud at the end of the play
INTERVIEWS	**Closeness to the actor**	Being connected	Being connected
	Closeness to another location audience	Being connected	Being connected
	Summarized opinions	The play was interesting and entertaining, and we felt involved as part of the play. We liked the play, because we could interact with the actor during his performance, and it was also funny to see him singing a song with a vacuum cleaner sound as background.	

5 DISCUSSION

In this paper, we reported about a study aimed at investigating the effect that connected theatre plays have on the experience of the audience. Both objective (GSR sensor and video recording) and subjective (interview) measurements were used in this study. We found that compared to the live audience, the remote audience reported a very similar response to the whole performance, and had a similar reaction to the event.

Generally, both the live and remote audience members were engaged, and they had similar response during the whole performance. This suggests that connecting two spaces during a live performance is feasible, and can enable a good experience.

To be more specific, according to the SCL results, the live audience was more engaged during the interaction part and the part with theatrical smoke, while the remote audience members were more absorbed during the singing part, which is consistent with the SCR results. This indicates that remoteness still has some effects on audience experience during connected performances. The reason why the theatrical smoke and interaction were more engaging for the live audience members may be the physical contact. Those two parts were more vivid, which caused higher arousal of live audience members. These results may also help producers to think about how to design a connected performance, which better takes into account both the live audience and the remote audience.

Additionally, it is interesting to see that the remote audience was engaged more often than the live audience, based on the results of SCR data. To explain this, technical issues should be considered. According to the SCR results of the remote audience, they were for example engaged when the projector had problems. This means that when technical problems occur, the remote audience members will pay more attention and the GSR signals will increase. It suggests as well that good control of the technical aspects is crucial for connected performances.

There is a consistency of the GSR data (the SCR and SCL results) and the other results. This demonstrates that GSR is a reliable and valid indicator of audience response.

6 CONCLUSIONS

This paper explores the effects of remoteness on audiences attending theatre plays. Based on the results of all measurements, we found that the remote audience has a similar experience to the live audience, which means that remoteness has little influence on a connected performance. In addition, we can conclude that audience experience of connected performances is also influenced by the physical contact to the audience.

During the experiment, the remote audience experience was heavily influenced by technical problems. So we conclude that adequate technical support plays an important role in a successful connected performance.

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