Continuous and collective measures of real-time audience engagement

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Abstract

The performing arts are temporal arts. Experiencing dance, music and theatre is a dynamic process that occurs over time and is often shared between groups of people. The continuous and collective nature of the experience of any live performance poses unique challenges to a quantitative or neuroscientific approach to audience research. This chapter reviews the latest methodological approaches and techniques to quantify audience engagement in real-time and across multiple spectators. Three levels of real-time measures of audience engagement are discusses, including continuous behavioural, psychophysiological and brain signals. All three levels can be used to measure what spectators do and feel – both individually and collectively – with a view to providing insights into the neurocognitive mechanisms that are at play when people engage with the performing arts. These measures complement, rather than substitute, traditional methodologies such as qualitative interviews, questionnaires, audience observation and phenomenology. The chapter discusses the chances and challenges of these new audience research tools and reviews key studies that employ these methods across a range of performance situations.

The quantitative empirical methods of cognitive neuroscience are becoming of interest to researchers who study audiences. These approaches can be used to measure what spectators do and feel, and to gather insights about the neurocognitive mechanisms that are at play when we engage with performances. Audience behaviour can be quantified by tracking the bodily motion or eye movements of audience members. Brain activity can be quantified using neuroscience methods, such as fMRI and TMS, and more recently mobile EEG which allows for the study of brain activity outside laboratory contexts. Physiological measures such as heart rate, breathing rate, electrodermal activity and skin temperature measure activity of the autonomic system and affective responses as well as provide an index of excitement and arousal. With careful interpretation, these measures can be used as indirect or implicit measures of spectator cognition and affect paired with their underlying brain mechanisms. Rather than replacing more established qualitative methodologies, these new measures complement qualitative interviews, self-report measures or audience observation and phenomenology.

As physiological and neural measures of audience engagement do not require a conscious or deliberative response from the audience members, they have three distinct advantages. Firstly, they can give continuous measures of engagement that *do not interrupt* an audience member's experience, nor require them to reflect and verbalise it. Secondly, they can be acquired *continuously and instantaneously*, while the performance is happening. A spectator's physiological and brain responses to an ongoing performance happen in real-time, but self-report measures or qualitative interviews are always retrospective and cannot capture the "here and now" of the performance. Thirdly, the measures are less biased by social desirability, which may cause an audience member to refrain from saying something negative about a performance to a researcher, or to feign understanding or enjoyment.

Yet, there are limitations. Physiological and neural measures reflect the activity of highly complex biological systems and produce a signal that evolves over time in response to many factors other than the performance. There is often a danger of reverse inference: assuming that there is a simple one-to-one correspondence between a measure (such as increased heart rate) and an emotion (such as excitement). Moreover, quantifications of audience engagement are correlational rather than causal: a spectators' physiological response to a theatre play may be less affected by the actor's second act *tour de force* than the ice cream they ate during the interval, or the stairs they climbed to get to the balcony. But, in many cases, as we will review in this chapter, these problems can be mitigated with careful interpretation, analysis and experimental design.

More recently, researchers have studied the physiological *synchrony* between audience members. In other words, rather than looking for moments when the average heart rate increases at a particular moment, researchers can quantify the degree to which, collectively, audience members' heart rates move up and down at the same time during the course of a performance. Synchrony occurs at different levels including physiological, behavioural and neural, corresponding to similar bodily responses among group members over a period of time (Ardizzi et al. 2020). Physiological synchrony can be seen in a range of contexts, in established as well as new relationships, and often correlates with a range of psychosocial constructs (Palumbo et al., 2017). A spectator's dynamic engagement with a performance may thus be quantifiable as experiential, psychophysiological and brain synchrony between performers and spectators.

In this chapter, we will discuss three categories of real-time measures of audience engagement. Firstly, we will review studies that use head and body movement as an index of audience engagement. Secondly, we will review studies that collect continuous arousal and engagement across three elements: continuous behavioural measures, physiological measures and synchrony measures including heart rate, EDA (electrodermal activity: index of emotional arousal), and breathing rate. Finally, we will look at studies that employ brain measures through mobile neuroimaging such as EEG (electroencephalography: records electrical activity of the brain) and fNIRS (functional near-infrared spectroscopy: monitors blood flow in the brain). We will distinguish statistical measures of agreement and behavioural coordination from measures of mean engagement, and distinguish between behavioural, psychophysiological and neural synchrony. We will discuss the chances and challenges of these new technologies and critically review recent experimental studies that employ these new methods, across a range of performance situations.

Head and Body Movements

In the context of studies that use movement as an index of audience engagement, head and body movements can be captured by cameras and image processing systems (Swarbrick et al., 2019; Jensenius, Zelechowska, and Gonzalez Sanches, 2017) or by using gyroscopes that measure acceleration (Casson, Galvez, and Jarchi, 2016). In recent years, wearable acceleration sensors built into smart watches and smart phones have become increasingly sophisticated as low-cost measures of audience engagement in live performance situations, in theatres, and other performance venues.

Using cameras to capture motion, Swarbrick et al. (2019) explored audience engagement during live and recorded music concerts. The authors recorded head movements of audience members while also exploring how their self-reported admiration of a performer, as indicated by a follow-up questionnaire after recruitment, might influence their engagement with the music. Participants included both fans of the band and neutral listeners. Both fans and neutral listeners were invited, at random, to either a live album release concert or a pre-recorded album concert. Both concerts were held in the same venue and the same songs were played in both cases. Head movements were recorded at 90 Hz using a 25-camera motion capture system. The authors quantified both the vigour (average movement speed) of movement and synchronisation of the head movements with the music.

Results showed that head movements were more vigorous during the live performance compared to listening to a recording of the same concert. This effect was stronger for fans of the band. Fans also moved their heads with a higher degree of entrainment ('the ability to synchronise movements with an external auditory stimulus', Swarbrick et al. 2019, 2) in both concerts. Interestingly, songs that produced the fastest or most vigorous movement did not necessarily produce the most entrainment to the music. However, there was one important limitation to this study: in the recorded condition, the songs were played without the same visual information that would be present at a live show. It is therefore possible that reduced head movements in the recorded condition resulted from this lack of expected visual information. Overall, these results suggest that live concerts engage listeners more than listening to recorded versions of the same songs. Moreover, the level of engagement – as measured by the listeners moving to the music – further depends on the listeners' prior affection for the performers.

This example raises other questions: Does music inherently make people move? How might music influence the motion of people when they are trying to stand still? Jensenius, Zelechowska, and Gonzalez Sanches (2017) aimed to investigate this question by reporting a study of music-induced micromotion. 91 subjects were asked to stand still for six minutes (three minutes in silence, three minutes with music) in groups of 5-17 participants. Each participant wore a reflective marker on their head, with the position of the marker recorded using an infrared camera-based motion capture system. As a measure of involuntary sway to the music, the authors calculated the quantity of motion (QoM) of each reflective marker and summed up all differences of consecutive samples to determine the magnitude of the position vector.

The results indicated that, for most participants, the quantity of motion did not change much over time. However, participants who reported more time spent doing physical exercise tended to move more during the experiment, and the more tired a participant felt, the more they moved to music. Beyond this, younger participants tended to move more in both the music and non-music conditions. For the group as a whole, the average quantity of motion at standstill was 6.5 mm/s, and it was found that, on average, subjects moved more when listening to music (6.6 mm/s) as compared to being in silence (6.3 mm/s). These results suggest that listening to music produces 'micro movements' that may not necessarily be noticed by the listener and occur even when they are trying to stand still.

While music does indeed make us move, and even more so in a live concert, does the same apply to other performative contexts? Does more movement always indicate higher engagement or does that depend on the kind of performance that one is engaging with? We can begin to address this question by moving to the area of contemporary dance, with a recent study examining if the movements of audience members during a dance performance indicate their level of engagement with that performance (Theodorou, Healey, and Smeraldi, 2019). To this end the authors studied visible, real-time movements of audiences in four, 20-minute, live contemporary dance performances. The audience movements were recorded with two night vision cameras (1,280 x 1,024 pixels resolution at 45 frames per second) with an infrared light (IR) attached on top of each camera. Additionally, the wrist movement of each audience member was tracked using small reflective wristbands, worn on each hand. A blob detection algorithm (Molinaro, 2010) was used to detect and extract the continuous position of the wrist for each audience member, an optical flow algorithm was used to calculate the visual change in both the footage of the audience and the footage of the dancers, and facial analysis software was used to examine the facial expressions of each audience member throughout the performance.

Not surprisingly, audience members moved more during a moment of applause and in the interludes rather than during the performance itself. The hands appeared to be the most consistently mobile part of the body. Further, the performance rankings were found to be correlated with the overall movements of the audience – with less movement correlating with higher rankings. The second and third performances both had the least amount of movement and were the most and second most preferred pieces to watch. This is in contrast to the first and fourth performances, which both had the most amount of audience movement and were the two least favourite performances. These results also line up with measures of audience engagement. The less an audience moved, the more engaged with a performance they were, and the more they rated it as enjoyable. In contrast, the dancers' movements did not systematically predict audience movement.

These results support the idea that a central sign of audience engagement, at least in contemporary dance performance, is collective stillness. When comparing this to the previous study by Swarbrick et al. (2019), and as noted above, it becomes clear that the relationship between movement and audience engagement varies across types of performances. While more vigorous head movements were indicators of increased engagement in the context of a live music concert, increased stillness and blank facial expressions were indicators of increased engagement and enjoyment in the context of contemporary dance performance.

Accordingly, different social contexts of live performance trigger specific modes of audience engagement, either moving more or moving less when enjoying the show. For example, when attending a contemporary dance performance in a theatre with a traditional set up, where each individual has an assigned seat, it is custom that the audience will sit relatively still and remain seated for the entire performance. This is in contrast to attending a live music concert in which the audience is standing in front of the stage. If the audience is standing whilst listening, it is custom that they will move to the rhythm of the music. The relationship between audience movement and engagement therefore depends on the level of expected audience participation: In the live concert, more movement is typically a signal of *engagement*. In the traditional theatre setting (or the cinema), more movement is typically a signal of *disengagement*. A further exploration of specific body movements, whether that be the head, hands, or torso, across a range of performances spanning from concerts to contemporary dance to opera can help to more definitively establish what an engaged audience looks like in each of these contexts.

As the examples presented in this section have explored, movement-based measures are an important and reliable indicator of audience activity and therefore engagement. As stated by Theodorou, Healey, and Smeraldi, '…during a live performance overt audience responses matter' (2019, 11). These types of measures are particularly beneficial in uncovering the differences in the expression of audience engagement across performance types i.e. collective stillness during contemporary dance, collective activity during a live music concert. However, these types of measures do not *directly* capture spectator affect or interest in the performance at-hand. Rather, these types of measures are valuable in exploring explicit audience behaviour, but not the implicit physiological, internal, expression of engagement. The use of movement measures paired with continuous behavioural and physiological measures, as will be discussed in the next sections, is one way to overcome this challenge and explore engagement as indicated by the external, physical body in combination with behavioural as well as internal, physiological and synchrony measures.

Arousal and engagement: 1) Continuous behavioural measures

The previous section has explored how engagement during a live performance can be inferred indirectly from body movements of the audience. However, as described above, although movements are a reliable indicator of audience activity, movement measures do not directly capture spectator affect or interest. In order to assess emotional responses during the experience of live performance more directly, continuous ratings of spectator affect can be used. The next three sections examine studies that collect continuous affective judgement and psychophysiological measures of arousal and engagement, divided into first continuous behavioural measures, and later physiological and synchrony measures.

In one of the first studies to use hand-held devices to collect such continuous ratings from audiences during a live performance situation, Stevens et al. (2009) developed the portable Audience Response Facility (pARF): an instrument to record self-reported, real-time audience emotional response, capturing reactions on two dimensions such as valence and arousal at a sampling rate of 2 Hz. The authors conducted two studies, both focussing on affective response during live performance. Their initial study consisted of three adult participants having their continuous responses measured throughout a 60-minute contemporary dance piece. Two dimensions of expressed emotion were recorded during the performance, valence (affective quality: positive-negative) and arousal (level of activity: aroused-sleepy), with participants moving a stylus on the screen. These recordings indicated a correspondence between audience emotional response and structural or expressive aspects of the performance, but were not explored statistically.

Their second study used the pARF with a larger sample of 19 participants during a live dance performance, investigating whether participants make consistent aesthetic responses as measured by an agreement analysis. The authors wanted to identify pieces of the performance where there might be a high agreement among the audience. Agreement varied across the dance performance, with some sections – containing loud music or acrobatics – producing higher agreement among audience members than others. Further, increased agreement was clearer in continuous ratings of arousal (level of activity) than valence (affective quality).

These results show that emotional arousal can be quantified and predicted by both musical and choreographic events during performance in real-time. In this particular study, more activity on stage as well as changes to the music were associated with increased arousal ratings. Changes in valence, on the other hand, do not seem as malleable. While there are a range of possibilities for why this might be the case, the authors suggested that valence could be dependent on more complex factors than surface features of the work, including 'cultural modelling' and personal experience.

Vicary, Sperling, von Zimmerman, Richardson, and Orgs (2017) studied whether movement synchrony among a group of performers can predict one's aesthetic appreciation of live dance performances. To explore this, a piece of choreography that continuously manipulated group synchrony was developed for 10 professional dancers. This choreography was performed live four times to four audiences in a theatre space. The choreography was task-based, involving primarily pedestrian movements like walking, running and swinging that alternated between moments of highly synchronous and asynchronous movements over time. While the overall structure of the choreography and the movements involved were matched across the four performances, individual performances were never identical, so that 'smaller scale transitions between movements varied, as they depended on specific performer interactions and decisions' (Vicary, Sperling, von Zimmerman, Richardson and Orgs 2017, 4). The dancers wore wrist accelerometers which continuously tracked movement synchrony and acceleration (Garbarino, Lai, Bender, Picard, and Tognetti 2014). The spectators wore the same wrist sensors to measure heart rate and togetherness. Additionally, the authors collected ratings of enjoyment from the audience using tablet computers. The results showed that, across all four performances, movement synchrony among performers predicted audience engagement better than the overall amount of movement of the performers. Yet, there were significant differences between the four performances of the same choreography. One was rated as overall enjoyable, one performance received primarily negative ratings, and two performances received equal amounts of positive and negative enjoyment ratings. There was a good agreement among audience members' enjoyment of each performance, but significant differences between audiences. The authors used granger causality analysis – a statistical procedure that allows to identify temporal patterns in time-series data, i.e. to forecast stock markets – to capture predictive relationships between the performers' movements and the spectators' response to these movements (see also D'Ausilio et al., 2012). Significant predictive relationships among performed synchrony, enjoyment and heart rate existed only for the most and the least liked performances. In sum, the study showed that when watching a group of dancers, the temporal relationship between the performers' movements is more important than how much the group moves. The changes in synchrony among performers are predictive of spectator arousal (heart rate) and engagement (enjoyment ratings).

Continuous behavioural measures like the pARF or other handheld technologies are useful in assessing the self-reported, or explicit, emotional responses of an audience during live performance. The use of these technologies allows one to quantify moments of high and low arousal as well as better predict when these moments might happen in relation to both music and choreography. These measures of arousal may be particularly beneficial in cases where the primary goal is to explore the impacts of specific aspects of the performance on the emotional state of the audience. For example, they can be used by performance makers to study which aspects of a performance are particularly engaging or evoke the most consistent audience response. However, such behavioural measures are limited in that they are subjective, self-report measures and do not tap into the more implicit and spontaneous state of the audience. Nor do they provide insight into the unconscious experience and changes of the live audience. Pairing behavioural measures with physiological or synchrony measures, as seen in the next two sections, provides opportunity to better explore the relationship between explicit, self-report, behavioural measures and implicit, physiological or synchrony measures.

Arousal and engagement: 2) Physiological measures

Physiological measures are able to provide a continuous, non-verbal, and implicit measure of affect, as they capture the activity of the autonomous nervous system which is not under deliberate control of the spectator (Potter and Bolls 2012). For example, changes in heart rate (HR) have been linked to increased information processing demands and/or greater mental effort. But linking heart rate to specific audience responses is not straightforward. On the one hand, heart rates decrease when people focus more on internal information and less on the external environment (Andreassi 2007). On the other hand, heart rates increase during cognitive elaboration and emotional engagement (Papillo and Shapiro 1990). Therefore, if an audience is engaged in a show, it might either decrease their heart rate because they are focused on the external stimulus, or conversely increase their heart rate because they are engaged and aroused by the performance. In this way, measures of arousal can be related to phenomenological distinctions between quiet-attentive and expressive-diverted viewing (Hanich, 2018).

Electrodermal activity (EDA) is an alternative index of emotional arousal (Critchley, 2002; Sequeira, Hot, Silvert, and Delplanque, 2009). EDA is also referred to as galvanic skin response (GSR) and underpins the infamous lie detection using polygraphs. EDA is an index of arousal because when the adrenaline is released in the brain it both enhances autonomic nervous system activity and constricts the sweat glands, increasing skin conductance and indicating arousal (Critchley, 2002).

EDA and HR are both measures of activity in the autonomic nervous system, and so can be taken as indirect measures of arousal. Sadly, no clear answer has emerged as to whether they measure audience engagement equally, or if one measure is more reliable or revealing than the other. EDA and HR certainly have a different time course in their responses. Spikes in EDA may occur in response to a single image within seconds, for example, while changes in heart rate produced by the mounting drama of a play may manifest over seconds or minutes. In a study of neurophysiological signals during learning, for example, Tinga, de Back and Louwerse (2020) found that both HR and EDA correlated with successful learning, but there was some indication that in their paradigm EDA produced a more reliable index. How these results apply to studies of audience engagement is yet to be mapped out systematically.

Though HR and EDA are indexes of physiological arousal, there may be no simple relationship between ‘engagement’ in the sense of felt or reported audience immersion or connection with a performance, and ‘engagement’ in the sense of activity in the autonomic system. This is one aspect of the widely acknowledged problem that ‘engagement’ is a slippery, and multifaceted term (e.g. Beymer, Rosenberg, Schmidt, and Naftzger, 2018; Ellis, Freeman, and Jiang, 2019; Finn and Zimmer, 2012; Fredricks, Bohnert, and Burdette, 2014).

The contrast between physiological and experiential engagement was shown recently in a study of audience responses to narratives in audio and video format. Richardson et al. (2020) presented individual participants with either excerpts from audiobooks, or clips from movie or TV adaptations of the same moment in a narrative. As much as possible, these two versions of the narratives were matched for duration and content. While viewing or listening to the narratives, participants' physiological activity was recorded with an Empatica E4 sensor (wristband measuring HR, EDA, temperature and acceleration), and after each, they rated their narrative engagement using a validated scale (Busselle and Bilandzic, 2009). Participants explicitly stated that they felt more engaged by the video narratives. However, their physiology told a contrasting story. While listening to audiobooks, their heart rates were faster and more variable, their EDA was higher, and they had increased body temperatures. These measures concur that physiological engagement was greater for audiobooks than videos. So, why is there a contrast between physiological and experiential engagement? One possibility is that it is due to the imaginative effort required by the audience. The pictures in the listener's mind may not be as vivid and as detailed as those on screen, and so auditory narratives are rated explicitly as less engaging; yet, the generation of those mental images requires greater cognitive and emotional processing, and so they are physiologically more engaging.

Latulipe, Carroll and Lottridge (2011) explored arousal in audience members watching a video of a dance performance. They were interested in further understanding the relationship between audience EDA and self-report measures of audience engagement. 49 participants wore headsets and watched an 11-minute video of a dance performance projected onto a 60-inch projector screen. EDA was recorded using finger wraps on two fingers on the non-dominant hand, while their dominant hand was used to rate their engagement with the performance using a physical slider. Participants were randomly assigned to one of two groups in relation to the physical slider: 1) slider labelled 'Hate it!' at the bottom and 'Love it!' at the top (LH scale); 2) slider labelled 'No Emotional Reaction' and 'Strong Emotional Reaction' (ER scale). In the case of the ER scale, the authors made it clear to audience members that a strong emotional reaction could be either positive or negative. The correlation between average self-report measures of engagement and average EDA collected for that measure was computed. The results indicated a significant correlation between the ER scale, used to report one's emotional reaction, and audience members' EDA. In contrast to this, there was a weakly negative relationship between the LH scale, used to report whether you love or hate parts of the performance, and audience members' EDA. Arousal is therefore more strongly linked to the intensity of an emotional reaction rather than sensory evaluation. Another interesting result was that the absolute value of the LH scale (effectively removing valence information) was more strongly correlated with EDA than the ER scale, suggesting that the LH self-report scale can provide two dimensions of information, valence and arousal. Beyond this, audience members in the LH group were actually able to 'list very specific aspects of the dance performance that they liked or did not like based on the movements and sound score' (Latulipe, Carroll and Lottridge 2011, 1852) while the ER group did not give as many specific details post-performance.

Overall, this study provides support for the interpretation of EDA as a valid representation of audience engagement, at least in the context of a dance performance. Further, the LH scale seems to get at audience engagement more easily, with higher validity (stronger EDA correlation) than the ER scale. This is particularly helpful for developing self-report scales to be used within the context of live performance. Not only was this type of scale easier for audience members to use, but including a scale that is more explicitly focused on valence could be interesting feedback for both the performers and choreographers or directors of the performance at hand.

While we can see that it is possible to measure audience engagement and therefore arousal through a combination of both physiological and self-report measures, how might manipulating certain variables within a performance impact this arousal? Howlin, Vicary, and Orgs (2018) explored how audio-visual congruency might influence continuous aesthetic and psychophysiological responses to a contemporary dance performance. After providing ratings of both their musicality and dance experience, 34 spectators watched a 30-minute video recording of a piece of choreography (Vicary et al. 2017, see above). The performance did not contain any music, and instead a soundtrack consisting of the performers' own steps and voices. Spectators were split into three groups and watched the dance video on a projector in a large lecture theatre and provided continuous enjoyment ratings on a tablet. For the congruent experimental group, movement and soundtrack were presented as originally recorded. The second group watched the video with the soundtrack played in reverse. A third group of people watched the dance video without any sound. The results of this study showed that audio-visual incongruency was rated as more enjoyable than both the congruent or silent conditions. In other words – and as is the case when dance is performed to a musical score (Reason et al., 2016) – an arbitrary relationship between sound and movement was preferred to causal relationship in which it was obvious that the performers made the sounds themselves (Jola et al., 2014; Reason et al., 2016). In fact, spectators in both the congruent and silent conditions effectively disliked the performance. This may be the case within contemporary dance as an arbitrary relationship between the musical score and movement allows the audience to discover correspondences between auditory and visual streams, structuring and segmenting their attention to the movement. Indeed, the authors observed a significant influence of audiovisual congruency on enjoyment. Enjoyment ratings were significantly higher for the incongruent condition as compared to both the congruent and silent conditions. The incongruent condition was the only experimental condition that also elicited an EDA response to the synchrony of the performer's movements. Yet, sound itself was not predictive of spectator arousal, which implies that its influence was indirect, drawing attention to specific aspects of the dance. Thus, incongruencies between the music and movement were actually perceived as complementary and enjoyable in this study.

Physiological measures are able to tap into the less obvious signs of audience engagement that are not voluntarily controlled by the spectator or listener. While in some cases these implicit physiological measures align with explicit measures of enjoyment (Latulipe, Carroll and Lottridge, 2011: significant correlation seen between spectator's EDA and their self-reported emotional reaction) we have also seen that situations requiring greater audience imagination (i.e. listening to an audiobook) result in increased physiological engagement, even though this is the opposite to what was explicitly reported by the spectators. These dissociations between physiological and experiential engagement require further exploration in order to be better understood across specific performance contexts. For example, the results observed in the Howlin, Vicary and Orgs study on contemporary dance may not hold when watching tap dance 'where the rhythmical sound of the dancer's steps is an intrinsic feature of the dance style' (2018, 205). The relationship between musical score and movement might become more or less important depending on the dance style.

Arousal and engagement: 3) Synchrony measures s

Coordination between people is a crucial aspect of human social life (Duran, Dale, Kello, Street, and Richardson, 2013), including things such as how we copy each other's gestures and speech rate, to nodding in time with each other. But coordination goes under the skin too. The degree to which two or more people's autonomic systems are in synchrony can tell us about their emotional relationship, whether positive or negative, to each other (Palumbo et al., 2017). McAssey and colleagues (2013) found that romantic couples who simply sat blindfolded next to each other would synchronize their heart rates, and that this coordination would increase if they looked into each other's eyes. Moreover, in small groups of people, heart rate coordination has been linked to team performance (Henning, Boucsein, and Gil, 2001), trust (Mitkidis et al., 2015) and empathy and liking of each other (Järvelä et al., 2013). Physiological synchrony can also be predictive of outcomes like improved team performance (Henning, Boucsein, and Gil, 2001) or even market performance (Dmochowski et al., 2014).

In recent work, it has been found that physiological synchrony can index the degree of audience engagement. Devlin, Hogan and Richardson (in prep) measured the heart rates of audience members of *Dreamgirls*, a west end musical. They compared heart rates across the performance with participants watching the movie adaption of the show. As well as audience members rating the live show as more engaging, their heart rates were higher, more variable and more synchronized during the live performance. In an unpublished study of heart rates while watching a movie in a cinema (Richardson et al., in prep), the authors also found that levels of HR synchrony were correlated with the social connection that the audience members felt with each other after the show.

Ardizzi et al. (2020) were interested in how spontaneous physiological, implicit synchronization might be related to more explicit ratings of emotional intensity. They investigated this by measuring the cardiac synchrony of spectators watching the same live performance. Using an electrocardiogram (ECG), recordings of cardiac synchrony of 12 actors and 48 spectators were taken pre-performance and throughout the performance. The 48 spectators were split into quartets of 12. The authors calculated the mean cardiac synchrony for each spectator both within their quartet (in-group synchrony) as well as with three randomly chosen spectators from different quartets (out-group synchrony). Post-performance, spectators were also asked to fill in questionnaires explicitly evaluating the performances. The physiological measure of cardiac synchrony was then correlated with the emotional intensity ratings provided by the spectators in the post-performance questionnaires. The results indicated that spectators' cardiac synchrony with each other was indeed correlated with convergence in the audience's explicit emotional evaluation of the performances. Higher in-group cardiac synchrony was found both during rest periods as well as the performance periods. Heightened in-group cardiac synchrony did not correlate with the spectators' individual evaluations of the performance, as measured by the emotional intensity ratings on the questionnaires distributed post-performance, but rather with the degree of convergence of these explicit evaluations with in-group members. In contrast to this, the out-group convergence score was not correlated with the out-group cardiac synchrony. These results suggest that simply being around other people who are also experiencing the same event is enough for spontaneous cardiac synchrony to occur, and this cardiac synchrony will increase 'in function of a shared and coherent emotional experience' (Ardizzi et al. 2020, 6).

In keeping with this, though in a different performative setting, Konvalinka et al. (2011) investigated the physiological effects of synchronized arousal in a Spanish fire-walking ritual between both active participants and related or unrelated spectators. The authors examined heart rate data from 38 participants including fire-walkers (those performing the ritual), related spectators (individuals related in some way to the fire-walkers), and unrelated spectators (individuals witnessing the ritual with no connection to the fire-walkers). Continuous heart rate data, examined as the average heart rate over 5 second intervals was recorded using a chest belt sensor. Each fire-walk lasted to 4-5 seconds. The authors analysed heart rate for 30 minutes 2-3 hours before the ritual and 30 minutes during and after the ritual. Cross-recurrence quantification analysis (used to quantify dynamic relationships between two time series; see Coco and Dale 2014, von Zimmerman, Vicary, Sperling, Orgs and Richardson, 2018) on pairs of participants data was conducted. Interestingly, an examination of raw pulse data showed striking qualitative similarities during the ritual between the heart rate of fire-walkers and heart rate of related spectators, but *no* apparent similarity to unrelated spectators. The recurrence rates of fire-walkers and related spectators were similarly characterized by abrupt changes in the dynamics at the start of the ritual and during the fire-walking. This is in contrast to the recurrence rates of fire-walkers and unrelated spectators which did not reveal these similarities. Overall, related pairs of individuals were shown to have more shared dynamics, indicating that psychophysiological coupling between performers and spectators, is modulated by kinship.

An important benefit to synchrony measures is their ability to tap into the relationships and social dynamics at play between and among audience members or groups. As we have seen, simply sharing in the experience of an event can be enough to produce physiological synchrony. However, as recommended by Ardizzi et al. (2020), it is important to consider context when evaluating physiological synchrony. A systematic review by Palumbo et al. (2017), makes it clear that synchrony results vary depending on the context being examined. So, it isn't as straightforward as being in the same space or having a relationship with someone that then results in synchronisation. Do situations where the group or audience members have a chance to interact and socialize pre-performance enhance the level of synchrony? Do previous relationships among audience or group members more reliably lead to increased synchrony? Does '… group convergence, and the related increased cardiac synchrony, … play a role in the aesthetic experience of collective forms of art'? (Ardizzi et al. 2020, p 6). Future research should explore these questions in relation to different performative contexts from dance performance to live music to theatre to better understand how these variables interact and affect the outcomes of synchrony measures.

Brain Measures: EEG and fNIRS

This final section examines recent advances in mobile brain and body imaging (Jungnickel and Gramann, 2016) which have made it possible to collect neural data outside traditional lab settings, using for example mobile EEG, TMS and fNIRS devices.

While not in a performative context, Dikker et al. (2017) conducted a group EEG study in a classroom setting with a goal of identifying markers of group engagement in the context of teaching. EEG was recorded from 12 pupils simultaneously in 11 sessions across a semester during regular classroom activities. The study measured neural coherence in the group. Neural coherence was computed by decomposing each student's EEG signal into frequency bands between 1 20 Hz, and calculating the sum of the inter-brain coherence between pairs of students within each frequency band. The authors observed significant relationships between alpha band coherence (8 - 12 Hz) and student appreciation ratings of different teaching styles as well as social closeness during class interactions. Students preferred watching videos and engaging in group discussions as compared to listening to the teacher reading aloud or lecturing. Further, the higher the post-semester student ratings, the stronger the student-to-group synchrony. Brain-to-brain synchrony is suggested to be driven by a combination of stimulus properties and individual differences with the highest pairwise synchrony seen with each student's face-to-face partner. The authors suggest that brain-to-brain synchrony is a possible marker for joint attention during social interactions. It seems important to explore whether these results replicate in the context of live performance.

With transcranial magnetic stimulation (TMS; non-invasive stimulation of the brain), one part of a study conducted by Jola, Abedian-Amiri, Kuppuswamy, Pollick and Grosbras (2012) examined the impact of visual experience on corticospinal excitability when watching live dance performance. 32 participants without prior formal dance training were included in the study and made up three groups based on their previous visual experience of watching dance: 1) Indian dance spectators (visually experienced in watching Indian dance), 2) ballet spectators (visually experience in watching ballet), 3) novices (no visual experience of watching dance). All participants were invited to watch three live solo performances, each 5 minutes long, at the Scottish Ballet company's rehearsal space in Glasgow. The three performances were in the styles of Indian dance, ballet and non-dance. Prior to the start of the performances as well as throughout the performances, TMS was used to measure participants' corticospinal activity via motor-evoked potentials (MEPs) induced by the TMS in the arm and the hand. These body parts were specifically chosen given their use in both ballet and Indian dance techniques.

In this part of the study, the authors found that those with visual experience of watching ballet exhibited larger MEPs in the extensor carpi radialis (ECR) muscle of the forearm when they were watching the ballet solo as compared to watching the non-dance or Indian dance performances. These results are particularly interesting given that the participants had no formal dance training and instead were simply avid watchers of ballet. So, physical training was not necessary for the corticospinal excitability to be present and the visual experience of watching this specific dance style was enough for the participants to imagine or simulate these visually learnt movements in the mind.

Using functional near infrared spectroscopy (fNIRS) (Hamilton, Pinti, Paoletti and Ward (2018) studied brain activity of actors while performing. Full-body motion capture suits that are able to capture location of head and limbs were worn by two actors while performing scenes. One of the two actors wore 18-channel functional near-infrared spectroscopy (fNIRS)-based headgear to record the activation patterns on the prefrontal cortex at 5 Hz. The 20-minute recording included synchronization, control actions, scene demonstration, and scene performance.

Recurrence analysis identified the moments where the actors repeated the scene performance. It was found that the activation of the prefrontal cortex increases as the scene develops and further peaks when characters make eye contact for the first time. Yet, research using fNIRS in performance situations is in its infancy; to date no study exists that has used fNIRS to study audience engagement.

The development of portable, wearable technologies that are tolerant to movement (Pinti et al. 2020) such as fNIRS expands the possibilities for the contexts in which we are able to scan the brain. Rather than being restricted to the lab, these technologies can be taken into the real-world and could be a breakthrough in terms of visualizing the brains of audience members as well as performers in live performance contexts. Being able to explore the synchrony between and among brains as well as the patterns of brain activity while watching a live performance is an exciting possibility, particularly in combination with the other behavioural, physiological and synchrony measures we have discussed. These measures in conjunction would allow for a bigger picture to be captured and to explore how the brain reacts and changes when viewing live performance. Given the relative newness of these technologies in the realm of live performance, they have yet to be used to their full potential. It is important that future real-time audience research apply fNIRS and other technologies including mobile EEG and TMS to move the field forward.

Conclusion

Continuous measures of audience engagement provide insight into the implicit effects of performance. Without requiring a conscious response from a spectator in the moment of their experience, these measures are capable of detecting audience engagement and avoid the influence of social desirability. A sophisticated smart watch today can monitor your physiology at the gym, tell you how intense your workout was, and rate the success of your exercise regime. It might be tempting to imagine a smart watch of the future that can produce a read out of how engaging you found a theatre performance, or predict the commercial success of a play.

Desirable or not, this possibility is remote. Physiological signals require layers of interpretation within a particular context. On their own, psychophysiological measures are not specific enough to explain what spectators are engaging *with*. Implicit indexes of engagement need to be grounded, at some point, in explicit reported judgements. This requires cross-validation with other behavioural measures such as continuous self-report survey methods following the performance, or recordings of eye movements. For the reasons we have outlined throughout this chapter, physiological measures are unsuited to the job of measuring *absolute* levels of audience engagement or enjoyment of a performance. Rather, their strength is in framing, generating, and answering more subtle, *relative* questions.

Moreover, psychophysiological and neural measures are noisy signals that require careful correction for artifacts such as movement or temperature of the environment. As an example, skin conductance may increase because the theatre gets warmer over the course of a performance, rather than due to rising engagement with that performance. These measures can also be subject to large individual differences such as a spectator's general fitness level. Therefore, an individual spectator's heart rate needs to be compared to the same spectator's resting pulse in order to be meaningful when exploring data from different participants. It is important to consider and minimise these potential outside influences through careful design of the study, data preprocessing and data analysis. To do this requires relevant expertise and specialist knowledge.

It is also important to articulate clear theoretical positions and hypotheses before using indirect, quantitative measures as these types of measures are less useful as exploratory tools and require careful interpretation. Without pre-specifying what aspects of audience engagement one is looking for, it is easy to get lost in the many possibilities of interpretation. For example, in order for acceleration measures to be useful in the case of using movement as an index of audience engagement, we need to know not only what kind of performance is being viewed but also what kind of *viewing* we are examining, i.e. quiet-attentive or expressive diverted viewing (Hanich, 2019). Further, when exploring synchrony measures, it is important to establish and operationalise a specific quantification of the measurement. Indirect, quantitative, physiological measures are only as good as the theory that motivates using them.

Continuous behavioural, psychophysiological and neural measures can complement retrospective self-report, observational and phenomenological approaches to understanding how audiences engage with the performing arts. These qualitative analyses, from both artists and spectators, are essential tools to establish the concepts to be studied within the quantitative analyses and are a prerequisite for collecting interpretable and meaningful quantitative data. The ability to get underneath audience experience, informed by explicit ratings and performance theory, is the promise of neurophysiological methods that is, as yet, largely untapped.

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