Title:

Changing the landscape of singing research across disciplines with the evolution of VR performance

Exploiting the potential of VR to change the landscape of singing performance research

Abstract

Advancing technology is rapidly changing the landscape of performance research both from a practice-led perspective and performance science. The ongoing developments in VR technology are particularly impactful to this change, widening possibilities of performance and engagement with it. This paper proposes a new multidimensional framework which looks to both develop VR performance possibilities, making group singing accessible across communities, as ell as usVR performance as a tool to improve understanding of performance, through innovative experimental design, in particular to understand the health and well being benefits of group singing. This framework is based on the VIVA system, a VR experience which allows the user to perform with othe singers fully immersed visually and aurally in the performance space. The framework exploits not only current possibilities of VR technology but also the latest advances in sensing technologies to allow direct measurement of biophysical, neurological and psychological parameters whilst singers are preforming. This paper preaents the main concepts of the framework along sue three example case studies of ongoing projects which utilise the framework, with analysis of the challenges and possibilities that exist when utilisi VR in preform acne sciences reaeRch. A multidisciplinary and holistic approach is shown to be essential for the development of VR performance to be successful in the long term and provide entirely new possibilities of engagement.

Section 1: Introduction (HD):

Emerging digital technologies have the potential to completely change our relationship with performance research. As Virtual Reality technology becomes more accessible to researchers and the public, academic communities need to push the boundaries of this technology to develop entirely new ways of conceiving, delivering and understanding performance, rather than simply enhancing existing practice. VR can be used as a tool for understanding ‘traditional’ live performance as well as developing new avenues for engaging with performance in a digital world.

As performance artists and technology companies try to find innovative and exciting ways to engage with emerging digital technologies, there is a danger that the potential for its application is being limited due to an incomplete understanding of how people engage with this new technology. For VR to have an exciting and sustainable future in performance skills and expertise need to be combined: the underlying research must be robust which requires appropriate interdisciplinary approaches.

This essay will outline the research agenda of an interdisciplinary team studying VR technologies and their use in group singing performance through an interactive virtual reality system for ensemble singing, Virtual Performer (ViPer), that has been developed at the University of York. A number of ongoing projects based on this system which illustrate this integrated programme of research and their importance to creating a sustainable future for integrated VR and singing performance are discussed.

Section 2: Virtual Choral Environment (VCE) - an interactive VR system

With engagement with group singing at all levels rapidly growing within communities, it is a natural step to marry this popular trend with the increasing accessibility of VR. Therefore, in order to capitilise on the growing interest in VR technology within the performance and research communities an immersive virtual reality reconstruction of singing as part of a vocal quartet performance was created. The user of the system becomes the fourth member of the singing quartet, hearing and seeing themselves fully immersed in the original environment to perform live with the other three pre-recorded singers. This unique experience allows a user who is physically removed from the original situation to take part in a group singing performance from within the group rather than as an observer.
The system is intended to improve access to group singing situations, and as a tool for data collection to study auditory perception in VR reproduction, performance measures and effects of singing on health and well-being.

Performance Capture and implementation
Recordings were made using a 360 degree Go-Pro camera rig, spherical microphone arrays and headworn DPA microphones in order to create the prototype. In order to allow the user to replace a singer within the group, it was necessary to record each piece four times with the relevant part missing. Ie. one singer was removed from the recording and the Eigenmike and gro-pro rig replaced them within the group. This required the remaining three singers to perform the piece with a part missing but also to ‘interact’ with the camera as though the missing singer was actually there. As semi-professional singers were recruited for the recording this didn’t pose a notable problem, however, it cannot be ignored that they may have been affected by this set-up (especially in terms of a natural interaction with a camera rather than a real person) which could in turn have an impact on the involvement of the singer when engaging with the system.

The data acquisition for the system is time consuming requiring the singers and technicians, as well as the resources (the recording equipment and the space), for half a day in order to record two 3 minute pieces. The need for individual spatial room impulse responses to be recorded from each singer position further increases the resource demand for this project..

The data capture and technical implementation of the VR system are described in full in (Kearney et al 2016).

Success of the system

The singers who took part in the recording of the protype returned to the Audio Lab at the University of York to test the system, performing their part within the virtual environment within an horizontal eight speaker array, wearing an Oculus Rift headset and headworn DPA microphone. In addition to their informal feedback objective measures of engagement and emotion, as well as vocal fold behaviour were recorded using a number of different sensors, which are discussed in more detail in the **section WISHED** below. All four singers reported enjoyment at using the system and found it to be highly realistic, stating that they 'felt like I was really there ' (**SOP) '**forgot where I was**' (?)**… ****INSERT QUOTES HERE**** .** Whilst there was some concern about the lack of peripheral vision provided by the Oculus headset (100 degrees) the singers did not comment on this limitation until it was specified by the researcher, at which point the singers reported that they adapted by moving their heads slightly more than they would normally need to.

Further testing of the virtual environment was undertaken with singers and non-singers who had not performed in the original space or with the original group of singers. This was part of a larger study utilising the system to measure the effects of singing with others rather than singing alone on emotional responses and vocal behaviour. Results again indicate that users engaged well with the system (which at this point had been adapted for HTC Vive for improved peripheral vision to 110 degrees), feeling fully immersed in the environment and mostly reporting that they 'felt they were really there' **RESULTS**

Development of the system

The system has now been enhanced for greater levels of auditory immersion through reproduction over a 50 channel spherical loudspeaker array using higher order Ambisonics soundfield rendering (Fig. X). A headphone based implementation of the system (Fig. X and X) has also been tested and validated relative to the loudspeaker system. The headphone approach utilises binaural sound reproduction and compensates for tonal coloration due to the microphone, headphones and the influence of headphones on the singer's perception of their own voice (Civit, 2017). The latter is particularly important has headphones can not only reduce perception of normal tonal balance of the voice, but can also induce unnatural bone conduction. For this reason circumaural headsets have been shown to be preferable over in-ear headphones. This work has also shown how the use of equalisation filters improves naturalness and provokes closer temporal performance response as well as intonation to that experienced with loudspeaker reproduction.

Fig X. (a) Loudspeaker based auralisation with singer in-situ wearing VR headset and DPA microphone (b) Same scenario with headphone listening (Civit, 2017).

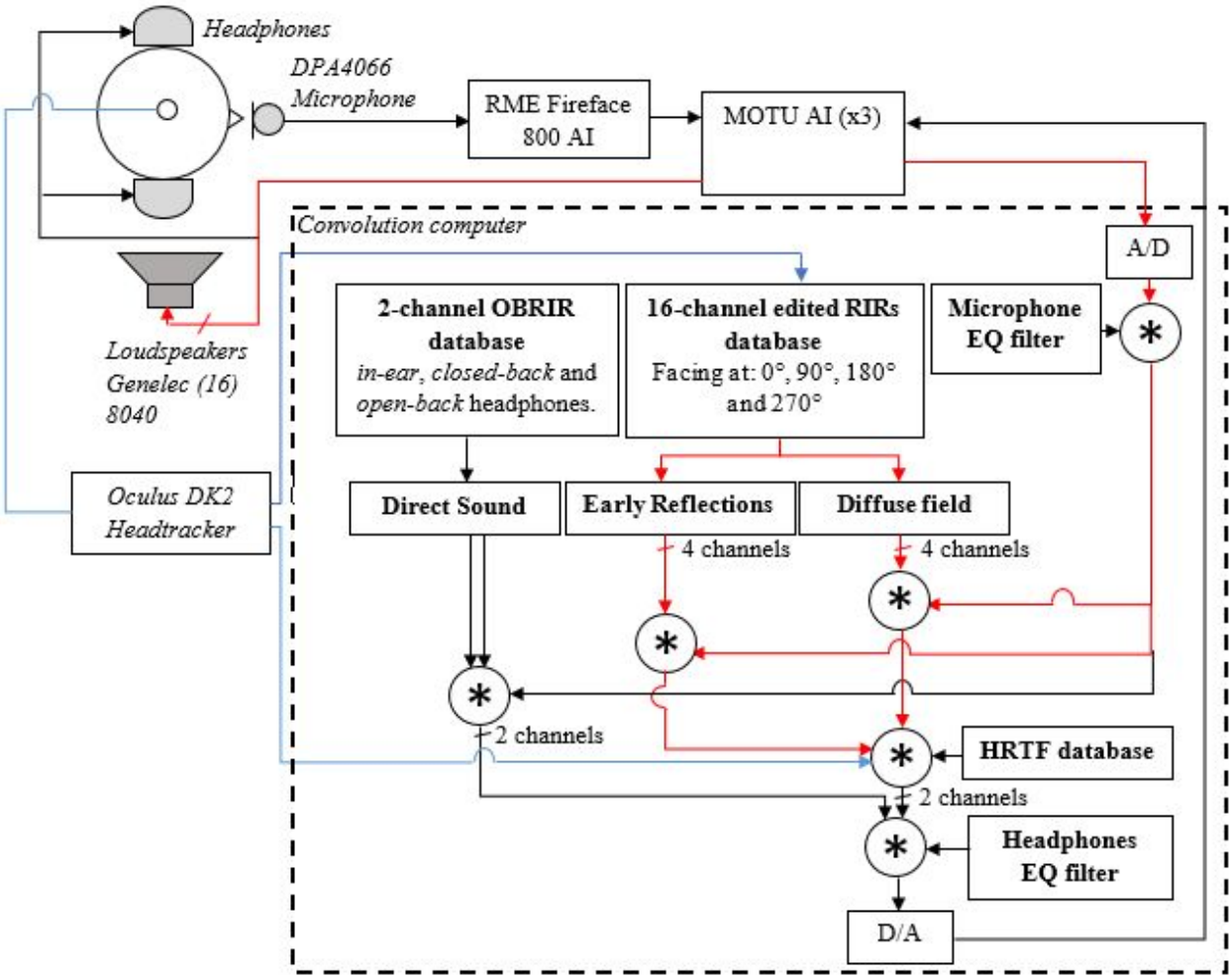


Fig. x Implementation of portable headphone based VR singing system (Civit, 2017).

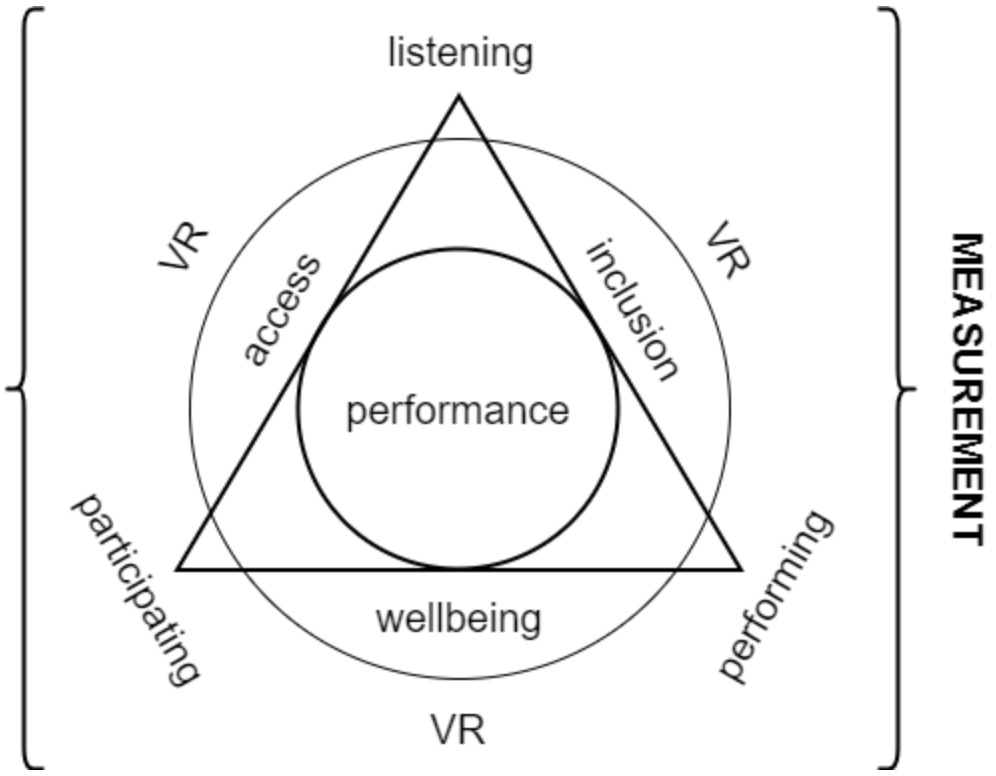
Section 3: Defining a comprehensive programme of singing performance research using VR

The VCE is intended to facilitate creative performance outcomes and performance science research whereby each informs the other: Specifically including, performance, performance analysis, and objective measures of engagement and well being benefits within the activity of group singing. Using VR technology to enable the practice of choral singing, both as an activity in itself and as a tool to engage in experimental research is a new concept and requires the integration of different methodologies and expertise. FIgure * illustrates the research framework that has been developed to this end and how the different objectives inform each other in a multi-directional approach to performance research.

At the centre of the framework is singing performance, with a particular focus within current projects on ensemble singing. WIth performance at its core the diagram highlights the potential

for a bi-directional approach across practice-led research, performance analysis, and measurable physiological and psychological factors. Practical tangible outcomes of the framework include advancing understanding of ‘real’ performance experience, extending performance practices and enabling access in singing performance, as well as pushing the capabilities of VR performance. The individual aspects of this framework, which have mainly been addressed as stand-alone research / performance problems or approaches until now, can be paired with one or several others in order to enhance and maximise outcomes: a multi-dimensional approach which encompasses all elements of the framework with research pathways between them would present a fully holistic approach to VR enabled performance science, capturing and presenting performance from numerous perspectives and for different outcomes.

This research framework will facilitate a better understanding of the complex ways in which ‘immersive’ experiences may mediate people’s experience of Arts and culture more generally. This includes understanding engagement with ‘real’ performance but also the circumstances in which ‘immersive’ experiences contribute to participant wellbeing, as well as when they might they detract from it: Applying the data-driven measurement pathway to different aspects of the framework can function as a tool to inform performance and at the same time provide insight for wider reaching enquiry and impact. Exploring this concept in more detail, the different topics of the framework with examples of pathways across it are considered below.



Access, inclusion and health and wellbeing: measurable factors and impactful benefits

VR implementation of singing performance has the immediate practical potential to improve access to the activity across communities. Populations who are physically unable to attend community choir rehearsals and performances have the opportunity to take part from their own homes, especially as the necessary technology becomes more affordable. By the same means this technology could breakdown barriers of inclusion to group singing activities caused by lack of confidence or ability: as a unidirectional activity, novices can feel free to 'have a go' in a virtual environment with other singers 'live' but without fear of judgement as the other singers are pre-recorded. Of course a limitation of this feature within the current VCE system is that the user receives no feedback to indicate the quality of their contribution: this may be added in the future as a beneficial pedagogical tool.

Existing projects that utilise technology to enable remote musicians and specifically singers to come together in a collective experience demonstrate the enthusiasm for exploiting digital technologies for such performance goals: Eric Whitacre's Virtual Choir has proven to be hugely popular, bringing together singers from across the globe through video recordings. Since its first inception in 2009, Whitacre has worked on several Virtual Choir projects engaging thousands of singers from hundreds of countries (https://ericwhitacre.com/the-virtual-choir/about), with the Live Virtual Choir realised over Skype in 2013. The VCE provides a new dimension to the possibility of shared digital performance, fully immersing the singer in their performance environment.

There is clearly an appetite amongst musicians to enable joined performance across communities. The benefits of improving access and inclusion within choral singing are also linked to the associated health and well being benefits of singing, especially group singing, which are being extolled informally across popular media outlets (Morelle 2013; Burkeman 2015; Eno 2008; Lacey 2013) and are of increasing interest in academic and health communities.

Whilst research in the area is still very much in its infancy, group singing has become popular as an informal complementary treatment for various conditions, with the emergence, for example, of Parkinson's Choirs. Speech therapy, in particular to increase the volume of the spoken voice, is common for Parkinson's patients, attributed in part to a change in auditory feedback (Ho et al., 1999) combined with a symptomatic bowing of the vocal folds (Blumin et al., 2004). Increased jitter and shimmer are also common in Parkinson's patients' spoken voices (Jiménez-Jiménez et al., 1997). Preliminary studies have found benefits of choral singing as a treatment for Parkinson's disease such as Benedetto et al., 2009; Shih et al., 2012; Evans et al., 2012. Singing has been preliminarily explored as an additional form of speech therapy with promising results (Benedetto., 2009). The VCE could provide a valuable tool to maximise community singing as therapy, enabling prolonged and more frequent engagement with the

activity outside ‘real life’ sessions. This applies to mental health and well being as well as physical conditions.

Initial studies indicate notable psychological benefits of group singing, including significant clinical improvements on mental wellbeing for people suffering enduring mental health issues (Clift and Morrison, 2011) and self-endorsed improvement effects in a community chorus (Clift et al. 2010, Clift and Hancox, 2001). Other studies, using qualitative research methods to measure wellbeing in choral singing situations, including in community projects and in aging populations have also indicated a positive correlation (Clift and Hancox, 2001; Hillman, 2002). There are few quantitative studies into the physical benefits of choir singing, however initial findings suggest it has an impact on heart and breathing rate (Vickhoff et al, 2013), as well as cortisol and immunoglobulin levels, all of which are connected to stress levels (Kreutz et al. 2004). Significant reductions in negative affect and increases in positive affect, alongside significant increases in cytokines and reductions in cortisol, beta-endorphin and oxytocin levels have also been reported in choir singing (Fancourt et al. 2016). Whilst progress is being made empirical research in this area is still in its infancy, with an acknowledged need for robust interdisciplinary studies (Glick, 2011; Stacy et al., 2002).

The framework proposed here allows a fully integrated interdisciplinary approach to build on the work in this area, that acknowledges the complexities of applying empirical study to the holistic activity of community singing. In particular, managing confounding variables is a continued challenge for this body of research and one which the VCE could be used to address. The user can interact with the other singers in real time but the other singers cannot respond (it is recorded) enforcing a **one-directional relationship** and thus removing the interactive social dimension of the activity. Exploiting this characteristic of the VCE could therefore lead to a better understanding of the elements of group singing which are beneficial to health and wellbeing, potentially identifying causation beyond the correlations currently reported. In addition to providing a practical tool for engagement with the activity of choral singing for target groups who cannot attend such activities in person but might find it beneficial, the VCE can therefore provide a new perspective to research in the area of singing and health and well being.

It is undisputed that a significant factor contributing to the observed well being benefits of group singing are the social components of the activity. Whilst the VCE can be used to control for this to further understanding on the social phenomena, as understanding increases it can also be used to manipulate these situations to positive effect. If some of the power of the Arts and culture is in their capacity for building social capital and fostering social cohesion (Matarasso 1997; Hallam 2015; Crossick & Kaszynska 2016), the impact that isolating people from other humans in order to have cultural experiences has on the experience itself must also be considered. Specifically, how significant is the experience of ‘interpersonality’ in cultural experience? The phenomenon of ‘entrainment’ is a two-way process (Clayton et al. 2004) – understanding how the experience of interpersonal ‘entrainment’ or ‘resonance’ (Lewis et al.

2001, pp.169–170; Siegel 2011, p.61) might affect cultural experience, will provide insights to develop the system to be able to account for this complex exchange.

If it is possible to isolate the extent to which the presence of other human neurobiology during cultural experience impacts on wellbeing (Siegel 2016), much more informed choices can be made about when, and how, to apply 'immersive' technologies as a strategy for facilitating cultural engagement e.g. for patients with mental health diagnoses experiencing social anxiety, or for singers with mobility issues who could not otherwise participate in certain group singing activities.

Performing, participating and listening / observing

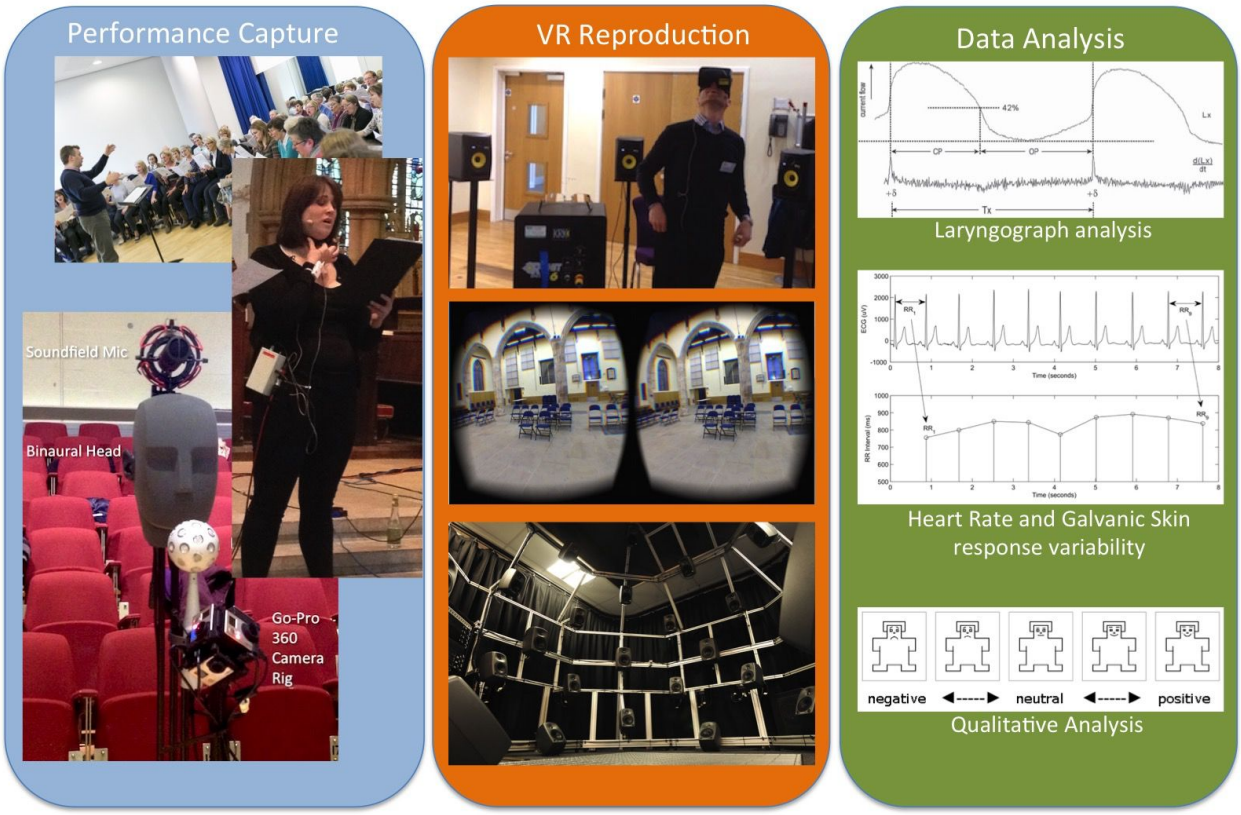
The practical improvements to inclusion and access of singing performance the VCE enables, which are described above, demonstrate the new possibilities of engaging with singing practice (performance or rehearsal) and illustrate a further dimension which the VCE and research framework offer: to blur the boundaries between observing/listening, participating and performing.

VR provides opportunities for an audience to be immersed in a choral performance in different ways, to observe from different perspectives and engage on different levels. This may be to experience a performance from within the choir, or from different physical points within a given space. The aural and visual perspectives may be manipulated either for aesthetic effect or to control variables within an experimental design. This concept extends into the triangular framework of listening, participating and performing as different levels of engagement arise for an individual: they can observe as an 'audience member' immersed in the situation, or they can interact with the system and become part of the 'performance'. In this situation they become, in the real space, the sole performer and audience member, although appear (both visually and aurally) in the virtual space alongside the other performers; this offers an entirely alternative experience to traditional performance attendance. As well as blurring the roles of the individual in terms of observation and participation, the VCE also bridges a gap between recorded and live performance: the VR situation is pre-recorded but the user can participate in real-time, altering the original performance 'live'.

The system therefore has the power to break down boundaries of engagement / performance / observation in novel and exciting ways, but, for its positive impact to be maximised it is important to consider the circumstances under which it might also detract from people's positive experiences of cultural participation. Again this highlights the importance of a holistic view research in this area and the essential role that measurement plays within it.

Using the VCE to change engagement with performance can also be exploited to explore different aspects of performance and influencing factors. Simulated performance environments

have already been used in performance research, and have been shown to be useful in music performance training and in studying performer behaviour (REF Williamon). The Virtual Singing Studio (VSS) at the University of York was developed to allow performers to rehearse in the acoustics of a given venue but from a location remote from the performance space. The VSS, which is based on reconstructed audio but not visual material, has been used to examine singing performance in different acoustic environments (Ref JUDE). The VCE provides new possibilities for this research, providing fully immersive experiences creating further realism for the simulated environments being controlled.



Measurement

Each element of the research framework presented here needs to be robust to ensure reliable outcomes, from the digital outputs to the research methodologies. Both subjective and objective data are needed to build a complete understanding of how users can engage with the system, and how it can be used as a tool to investigate and create different elements of performance.

The physical limitations of a VR system being implemented need to be quantified and considered alongside any research findings. This includes the quality of the visual and audio material, with limitations such as peripheral vision within an immersive setting, and lag of the

auralisation of the system. Understanding how people respond and interact with the VR system is also essential for the media to be used to its full potential. A key intention of this system is for it to be used as a tool to combine ecological and experimental approaches in performance science and performance experience. However, it cannot be presumed that, given a 'good' recreation of a live environment, the user will respond (psychologically, physically, biophysically) as they would in the natural environment. To this end, in parallel with the studies exploring the research framework which are presented as case studies below, there is an ongoing programme of research to analyse the effect of the system itself on the user: that is including the impact that wearing the various sensors involved in a particular experiment, such as the VR headset, the microphone and the headphones where appropriate, have on the user. Establishing a 'natural' environment versus a VR environment baseline is important for any other data to be fully contextualised and meaningful.

Taking these technical factors into consideration, the system can be used to control aspects of the performers' environment, which will novelly contribute to the growing corpus of research into the health and wellbeing benefits of singing as well as providing other insights into singing performance and communication. Established methods across different research areas (e.g. psychology, health sciences, neuroscience) can be employed to collect subjective and objective data related to health and wellbeing and performance.

By conducting a programme of research which explores different avenues of singing performance in parallel (understanding the impact of singing in VR; using VR to measure benefits of group singing; innovating engagement with performance) these areas of research and development can inform each other. The following case studies illustrate some of the research projects that are currently ongoing, which showcase the holistic, multidimensional model for singing research using VR which has been described. In order to make such a programme of research robust, it is essential to have specialised expertise across the disciplines which are encompassed within the framework.

Section 4: Case studies

CS 1: Wellbeing: Investigating Singing Health in Ensembles using Digital Technologies/SWISHED

THis project integrated the first implementation of the VIVA system with the development and piloting of a method for using VR to analyse the wellbeing and health effects of singing in a group. In particular, the aim was to implement a novel experimental protocol quantifying the potential health benefits of group singing using the VIVA to control for interactive social factors.

Four semi-professional singers, a soprano, alto, tenor and bass, took part in both the experiment and the VR recording. Participants performed both as part of a live quartet in the

performance venue of the church and in a virtual setting of the same venue performing the same pieces with the same singers. They performed two pieces a cappella from memory: Amazing Grace in unison and 'If ye loved me' Thomas Tallis in four parts. In both the real and virtual environments measures were taken from the singers which included self-reported stress, arousal and enjoyment levels as well as heart-rate, galvanic skin response, neural activity and vocal fold activity. This required the singers to wear various sensors whilst singing and fill in questionnaires. The experimental data collection in the real environment was performed in addition to and prior to the VR filming as part of the same session. The methods for data collection and their relevance to the framework are described below.

Stress Arousal and Enjoyment measures

Whilst singers reported that they felt the same in the virtual environment as in the real venue, the results of the UWIST checklist show that they responded quite differently in the two conditions. In particular, on average, the singers' hedonic tone was generally lower but more stable in the VR condition, stress levels lowered noticeably over the live session whilst they remained high in the VR condition and overall arousal increased over the course of the live session whilst remaining at a relatively low level throughout the VR session. These initial results indicate that the UWIST is a valuable tool in understanding the mood of singers as they perform, as well as suggesting that perceptions of a performance experience may not be truly representative of the mood of the subject.

Heart rate and galvonic skin response

Previous studies have investigated the effects of group singing on heart rate (Vickhoff et al…) and the implications on the activity being useful for stress reduction. In this study a single shimmer GSR+ sensor measuring galvanic skin response (GSR) and blood volume pulse (BVP) was used. GSR signals were measured by attaching two electrodes to the participant's non-dominant hand palmar middle phalanges of the index and middle fingers. And the BVP signal was recorded using a photoplethysmograph that was attached to the same hand's ring finger. The GSR signal allows the extraction of the mean skin conductance level and mean number of skin conductance responses across a longer time period (Boucesin, 2001). From the BVP signal, it is possible to extract the mean heart rate and the amount of sympathetic arousal-induced vasoconstriction. All extracted response descriptions will indicate physiological activation or physiological deactivation that is typically associated with emotional responding (Scherer, 2005), providing biophysical data to complement the UWIST data.

Neurological activity

Vocal fold behaviour

How voices adapt to each other (in terms of vocal fold function and acoustics), is not really understood beyond pitch matching (e.g. Ternström et al., 1988; Ternström, 2003).However,

research into choral singing indicates that when singing together, individual voices have a direct impact on each other in terms of the voice production itself, which could have direct implications on vocal health benefits of group singing. Perceptual factors such as the Lombard effect (the phenomenon that individuals will increase their volume with their surroundings) are known to be relevant in choirs (Tonkinson, 1994). Such perceptual theories could in part explain the improvement observed by Parkinson's patients when participating in group singing activities: singing in a choir provides the same auditory masking that is often simulated in speech therapy (Adams et al.,2002). Vibrato (the periodic oscillations in frequency of the singing voice) has also been shown to synchronise between individuals when singing together (e.g. Daffern, 2016). There are also indications that the vocal folds may adapt their vibratory behaviour based on surrounding voices, with different closed quotient values (time the vocal folds spend in contact during a vibratotry cycle) observed for different voice parts (Howard, 2007).

Electrolaryngographs (electrodes placed externally on the neck) allow measurement of the vocal fold activity of the individuals as they sing, from which measures of pitch (tuning), closed quotient (connected to vocal efficiency) and amplitude can be made. This allows non-invasive measures of individual voices to be taken in real-time whilst singing together where traditional approaches to voice assessment including acoustic analysis and laryngeal scoping are not appropriate.

Head-worn microphones were used not only to record and then auralise the VR environment but also for data capture. Acoustic data is considered alongside Lx data due to the interference of surrounding individual's voice signals (it is not possible to isolate individual singer's voices on an acoustic recording).

Evaluation of the protocol

This pilot was the first step in developing the multi-method design for capturing data across different research areas connected to singing performance using VR and specifically the VIVA system. It considered how intrusive the different sensors might be for the participants, as well as how time consuming and fatigue inducing the questionnaire based data collection might be.

This study focussed on within subject comparisons, in part due to the limited number of participants but also due to the limited resources available at the time: with only one shimmer device available, this data could only be captured for one singer at one time, which provided data for comparison for that singer across conditions, but prevented any cross subject comparison. It showed that VR is a promising tool for investigating singing performance using a mixed method design and provided the necessary background study to allow development of protocols to include a larger number of singers as well as a method that allows study across participants,

In order to minimise the confounding variables it was important that in this experimental design the singers performed with the same other singers in both conditions. This required the

participants to record three VR captures for each piece (with a different part missing on each recording) in order to create four VR experiences, one for each part of the quartet.

One of the biggest challenges in designing a protocol comparing responses in a real and virtual environment is the practical implications of using a VR system. Only one participant can take part in the VR condition at any one time, even if several VIVA systems are available the singers need to be in separate rooms and not coincide at any point in order not to re-introduce the social element which the VR is intended to control. It was desirable to apply a repeated measures design to this study in order to robustify the data, however, working in VR this presented a particular challenge: In the natural environment the singers performed each piece three times, whilst they did the same in the VR condition, only one VR recording was made for each singer and so the repetitions in the VR condition were exact, whilst in the natural condition they varied. This is a feature of the VR which can be exploited for repeated measure experimental design for certain research questions, however in this case when making comparisons between the two conditions the discrepancy between the repeated measures must be acknowledged. It was not practical to solve this problem by making three recordings per singer as it would have impractically lengthened the protocol.

Whilst this study didn't produce robust data across all factors being investigated, for instance due to the lack of Emotiv data in the real condition, the results reveal within subject comparisons that suggest further investigation utilising the framework would be highly valuable. This includes understanding how people's perceptions of their response to a VR system marry with their biophysical and emotional responses as measured using the methods described above, as well as understanding the importance of the interactive, social elements of singing together on health and well being factors.

CS 2: SINGSVR

Objectives

The SINGSVR (Simulating Inclusive Natural Group Singing in Virtual Reality) project extended the protocol developed for WISHED to incorporate a community choir rather than elite singers, and consider the impact of regular singing during rehearsals rathert han taking part in a 'performance'. Two matched groups of amateur singers undertook a longitudinal study across six weeks, in which they were taught six songs, three in reality and three in VR. As a result each group learned the same song under different conditions, providing a direct method of comparison. Singers were taught new, but simple, material in each session, controlling for learning effects, and the same instructor, session format and choir arrangement were maintained for both groups. Singers were fitted with sensors to record physiological data in addition to the UWIST MACL responses which were collected as above. Two indicators of sympathetic and parasympathetic nervous system activity were assessed in all singers using multiple Shimmer GSR+ sensors: galvanic skin response (GSR) and blood volume pulse (BVP). Over a series of multiple natural and virtual choir singing sessions, measurements were taking

during a pre-rehearsal resting period to function as a baseline in later analyses and during the actual singing during the rehearsal. This allows calculation of individual change scores in physiological activation caused by singing. It will then be possible to compare these responses across the two forms of choir singing (in the natural setting or the virtual setting) and see if the virtual choir singing was as stimulating as the natural singing. This method provided objective measures of physiological response to the singing experience in both reality and VR. Furthermore, the extended duration of the study allowed singers to become accustomed to the VR experience, providing information about the potential long-term health and wellbeing benefits of such a system while reducing the influence of disturbance due to the VR equipment.

This project particularly sought to address the questions of whether the community singing experience could be reliably approximated by VR and whether the health and wellbeing benefits were comparable in the two situations, helping to assess whether a VR choir experience would be of long term benefit to those otherwise unable to access a community choir.

Evaluation of the protocol

It was not practical to implement the protocol from WISHED across a larger singing group, whereby a VR recording was made for each singer, as the number of VR recordings would always need to be equal to the number of singers taking part. This was addressed in the SINGSVR project by engaging two choirs with a similar demographic, run by the same director and learning the same repertoire in the same way. One VR recording from within one section of the choir was made and the participants experienced a VR recording from the partner choir. This ensured that they also wouldn't see themselves in the VR experience. This seemed to provide a fair solution, and solved the problem of repetitions that was encountered in the WISHED study: no recording was performed with more than once by each singer and the singers were introduced to repertoire in both the VR and real environments to avoid learning effects influencing the results.

Using 12 strong choirs in this study, with the same data acquisition across all singers (collected in parallel during the real condition and individually as they took part in VR) tested the framework's potential to conduct research with larger groups in a more ecological setting. The main limiting factor for such a protocol remains that of the time it takes to conduct the VR condition as it has to be conducted in isolation from the others. In this case that resulted in the 'real' condition taking 3X rehearsals of 20 minutes X2 choirs = 120 minutes, compared to the VR condition taking 3X reheasals X20 minutes X2 choirs X12 singers = 1440 minutes (24 hours). Streamlining the data acquisiition, in terms of making decsisions as the the content and length of the rehearsals, the number of UWIST checklists and questionnaires, as well as which physiological data whould be colleted was essential, and resulted in this case in the decision not to include eMotiv or Laryngograph data in this study.

Attempting ecological study of the rehearsal process of community choirs requires a substantial length of experiment in order for the experience to mimic that of a 'real' situation. Twenty

minutes was chosen as a compromise between a normal rehearsal length (after discussion it was considered a standard time of a rehearsal to include warmup and work on a single piece of music) and minimising the protocol length considering that the VR condition needed to be conducted one singer at a time.

CS 3: Hills are alive: Combining the Benefits of Natural Environments and Group Singing through Immersive Experiences

The Hills are Alive project aims to increase the accessibility and inclusion benefits of VR choral experiences still further, by allowing participant's virtual access not just to a choir, but to geographically remote and inaccessible cultural locations. This project uses immersive virtual reality technology to bring to life a key moment in the formative history of the UK's National Trust, with the main outcome being an immersive and interactive VR installation at Keswick Museum and Art Gallery. Participants will take part in a group singing event on a Lake District mountain summit, commemorating the 1923 gift of land to the nation in memory of those who lost their lives in the Great War 1914-18. This experience will be captured for VR playback and an immersive experience developed to allow both those who were present at the original recording, and those who could not access it, to take part in the celebration in VR.

The Hills are Alive project is the most ambitious use of the VCE protocol yet, and builds upon the methodology deployed in SINGSVR while incorporating new quantitative measures of engagement using Sensemaker® as a form of 'distributed ethnography' to place participant experience at the heart of the enquiry. A sophisticated phenomenological approach, Sensemaker® captures participants' individual stories as 'micro-narratives' - or fragments of meaning - which the participant subsequently interprets through a process of 'self-signification' to reveal those elements of the experience which have most significance for them. A proven digital methodology for capturing and interpreting the complexity of social phenomena in ecologically valid ways, in this project the Sensemaker® method captures participants' authentic experience of group singing, and translates these into more quantifiable data by a comparative analysis of 'self-signified' responses. Trends in the data appear as 'clusters' of meaning, with an individual story behind each data point available for deeper analysis. Sensemaker® is a genuinely cross-qualiquantitative methodology, accounting the need for phenomenological authenticity whilst identifying trends in the data. We hope that cross-referencing other data with a phenomenological understanding of participant experience will reveal trends, tensions and contradictions in the data which will inform future research design. Whilst the project doesn't allow us to measure any interpersonal neurobiological effect during group singing, the personal 'micro-narratives' of participants will help illuminate the extent to which the social and interpersonal nature of group singing is considered significant by them.

Once installed at the museum, the singers who took part in the recordings, singers who usually attend those choirs but couldn't take part in the live performance, as well as members of the general public will be invited to take part in the VIVA version of the experience. Data will be collected from participants, including the Sensemaker narratives, shimmer and UWIST as described in the previous case studies. Baseline measures will provide a within subject comparison to investigate how participants respond to the system at different levels of engagement, which could be to observe the performance in VR or to take part in the performance in VR. The value and practicalities of presenting VR installations in a museum setting will also be evaluated to inform future engagement with VR performance. This project brings together all aspects of the framework, as data collection, VR experiences, performance and levels of engagement all inform each other: as understanding of how people experience live and VR performance is informed through experimental design, engagement can be manipulated and maximised through performance design informed by that understanding.

Section 5: Discussion

The three case studies summarised above illustrate ways in which the framework has been implemented to explore different research questions and challenges within performance practice and experience. The design of each method presented unique challenges and required careful balancing of data acquisition, VR preparation and capture, ecology of design and resource management. In particular, utilising VR as a tool for investigating singing performance and the potential health and well being benefits of group singing, whilst providing an innovative method for controlling variables, is costly to implement in terms of time: in addition to RIRs being required for any given position within a performance space, and the recording and rendering time, any protocol involving experience of a virtual compared to a real environment requires each participant to experience the VR condition alone. As the technology becomes more accessible and practical to be implemented within the home, which is a key goal for VIVA, more possibilities will emerge for further study of the impact of system on the user. However, in order to conduct controlled laboratory based experimental designs using a VR system, the practical implications need to be considered and written into the design.

Of the preliminary data analysis which has been conducted on the first two case studies, the most notable and promising outcomes have been the positive reactions of users to the VIVA system, with enthusiasm for the concept of the system as a tool for both performance engagement and performance science research, amongst singing and non-singing communities. The apparent discrepancies between the singers' perceived levels of realism with the system compared to their emotional responses as recorded by the UWIST checklist also present very interesting initial findings which show this avenue of understanding performance in VR is an essential avenue of further enquiry within VR performance.

Measuring the possible interpersonal effects of singing in a group on wellbeing is currently un-researched, despite preliminary findings which suggest that the phenomenon of group entrainment is a factor in the experience of group singing (Vickhoff et al. 2013). This framework presents some of the possibilities for utilising VR to improve our understanding of the benefits of group singing, in part by controlling for certain social and interpersonal communications. If the presence of other human neurobiology does affect the experience of singing in a group, this is a complex phenomenon to understand or measure, but has potentially significant implications for group singing in VR. As any wellbeing benefits of interpersonal resonance during cultural activity are not yet fully understood in the 'real world', understanding whether and how they might transfer to virtual environments is an even more complex issue. In the future the use of avataars may enable a multi-directional VR system able to reproduce the acoustic, reflexive and social dimensions of group singing, however, this could still miss the essentially 'human' phenomenon of interpersonal 'attunement' (Siegel 2011). If participants were able to still experience the wellbeing benefits associated with interpersonal 'attunement' during group singing, but without being in the physical presence of other human neurobiology, then this would have profound implications not just for the future of group singing, but for human social life more generally. Employing the framework proposed in this paper, enables all these factors to be considered, understood, and where possible implemented, to maximise the possibilities of engagement and benefits of performance, whether in a live of virtual context.

Section 6 Conclusions

The VIVA system of singing in a group situation in VR which has been developed at the Uni of York, provides a novel and useful tool to allow people to engage in and with singing performance in different ways. The research framework which has been presented utilises VIVA as a tool to investigate singing performance science with particular examples of investigating the health and well being benefits of group singing, controlling for social elements of the activity, as well as exploring ways that the boundaries of performance engagement can be blurred through VR performance. This framework has the potential to change our approach to performance science research and performance practice (both virtual and real) through its multi-directional approach whereby the different levels of the framework necessarily inform each other. Using this framework to better understand the elements of group singing which contribute to enhanced well being could in turn better inform performance practice, including future developments of the VIVA system to maximise the health and well being benefits of group singing: beyond making the activity accessible across wider communities it can provide a knowledge base form which to tailor the activity to maximise its use as a 'therapy' across target populations.

Acknowledgements

FUnding: UoY Creativity fund; Centre for Future Health; AHRC; Singers

References:

Civit, P, An Investigation and Design of a Binaural Virtual Singing Studio for Home Applications, (2017), Master's Thesis, Department of Electronic Engineering, University of York.

Kearney, G., Daffern, H., Thresh, L., Omodudu, H., Armstrong, C. and Brereton, J., (2016) Design of an Interactive Virtual Reality System for Ensemble Singing, Interactive Audio Systems Symposium, York, United Kingdom.

Scherer, K. R. (2005). What are emotions? And how can they be measured? *Social Science Information*, *44*(4), 695–729. http://doi.org/10.1177/0539018405058216

Boucsein, W. (2001). Physiologische Grundlagen und Meßmethoden der dermalen Aktivität [Physiological Bases and Measurement Methods for Electrodermal Activity]. In F. Rösler (Ed.), Enzyklopädie der Psychologie, Bereich Psychophysiologie: Vol. 1. Grundlagen und Methoden der Psychophysiologie [Encyclopedia of psychology, area psychophysiology: Vol. 1. Basics and methods of psychophysiology] (pp. 551–623). Göttingen: Hogrefe.

References from Dave

Burkeman, O. (2015). Want to be happy? Join a choir. *The Guardian*. [Online]. 18 December. Available from: http://www.theguardian.com/lifeandstyle/2015/dec/18/why-singing-makes-people-happy-oliver-burkeman?CMP=share_btn_fb. [Accessed: 20 December 2015].
Clayton, M., Will, U. & Sager, R. (2004). In Time With The Music - The concept of entrainment and its significance for ethnomusicology. *ESEM CounterPoint,*. 1. p.pp. 1–84.
Clift, S., Manship, S. & Stephens, L. (2017). Further evidence that singing fosters mental health and wellbeing. *Mental Health and Social Inclusion*.
Clift, S. & Morrison, I. (2011). Group Singing fosters mentsl health and wellbeing: findings from the East Kent 'singing for health' network project. *Mental Health and Social Inclusion*. 15 (2). p.pp. 88–97.
Clift, S., Morrison, I., Skingley, A., Page, S., Coulton, S., Treadwell, P., Vella-Burrows, T., Salisbury, I. & Shipton, M. (2013). *An evaluation of community singing for people with COPD (Chronic Obstructive Pulmonary Disease)*. Conterbury Christ Church University.
Crossick, G. & Kaszynska, P. (2016). *Understanding the Value of Arts and Culture: The AHRC Cultural Value Report*. [Online]. Swindon: Arts & Humanities Research Council. Available from: http://www.ahrc.ac.uk/documents/publications/cultural-value-project-final-report/.
Eno, B. (2008). *Singing: The Key To A Long Life*. [Online]. 23 November 2008. Available from: http://www.npr.org/templates/story/story.php?storyId=97320958. [Accessed: 10 April 2014].

Fancourt, D., Williamon, A., Carvalho, L.A., Steptoe, A., Dow, R. & Lewis, I. (2016). Singing modulates mood, stress, cortisol, cytokine and neuropeptide activity in cancer patients and carers. *ecancer*. [Online]. 10 (631). Available from: https://www.researchgate.net/publication/294873196_Singing_modulates_mood_stress_cortisol_cytokine_and_neuropeptide_activity_in_cancer_patients_and_carers.
Hallam, S. (2015). *The Power of Music: a research synthesis on the impact of actively making music on the intellectual, social and personal development of children and young people*. International Music Education Research Centre.
Kreutz, G., Bongard, S., Rohrmann, S., Hodapp, V. & Grebe, D. (2004). Effects of Choir Singing or Listening on Secretory Immunoglobulin A, Cortisol, and Emotional State. *Journal of Behavioral Medicine*. 27 (6). p.pp. 623–635.
Lacey, A. (2013). *Belting out a tune 'helps those struggling to breathe'*. [Online]. 8 December 2013. Available from: http://www.bbc.co.uk/news/health-25231910. [Accessed: 8 December 2013].
Lewis, T., Amini, F. & Lannon, R. (2001). *A General Theory of Love*. Reprint. New York: Vintage Books.
Livesey, L., Morrison, I., Clift, S. & Camic, P. (2012). Benefits of choral singing for social and mental wellbeing: qualitative findings from a cross-national survey of choir members. *Journal of Public Mental Health*. 11 (1). p.pp. 10–26.
Matarasso, F. (1997). 1 873667 57 4. *Use or Ornament? The social impact of participation in the arts*. Stroud: Comedia,.
Morelle, R. (2013). *Choir singers 'synchronise their heartbeats'*. [Online]. 9 July 2013. Available from: http://www.bbc.co.uk/news/science-environment-23230411. [Accessed: 11 July 2013].
NICE (2015). *Older people - independence and mental wellbeing*. NICE Guidelines. [Online]. London: National Institute for Health and Care Excellence. Available from: http://www.nice.org.uk/guidance/ng32/resources/older-people-independence-and-mental-wellbeing-1837389003973. [Accessed: 24 January 2016].
Shakespeare, T. & Whieldon, A. (2017). *Sing Your Heart Out: community singing as part of mental health recovery*. [Online]. Norfolk: University of East Anglia. Available from: https://ueaeprints.uea.ac.uk/65446/1/Accepted_manuscript.pdf.
Siegel, D. (2011). *Mindsight: Transform Your Brain with the New Science of Kindness*. S.l.: Oneworld Publications.
Siegel, D.J. (2016). *Mind: A Journey to the Heart of Being Human*. New York: W. W. Norton & Company.
Skingley, A., Clift, S.M., Coulton, S.P. & Rodriguez, J. (2011). *The effectiveness and cost-effectiveness of a participative community singing programme as a health promotion initiative for older people: protocol for a randomised controlled trial.* [Online]. 28 January 2011. Available from: http://www.biomedcentral.com/1471-2458/11/142. [Accessed: 9 April 2014].
Snowden, D. (2016). *Ethnography Part II*. [Online]. 10 February 2016. Cognitive Edge. Available from: /blog/ethnography-part-ii/. [Accessed: 18 January 2018].
Snowden, D. (n.d.). *SenseMaker®*. [Online]. Cognitive Edge. Available from: http://cognitive-edge.com/sensemaker/. [Accessed: 20 December 2016].

Stacy, R., Brittain, K. & Kerr, S. (2002). Singing for health: an exploration of the issues. *Health Education*. 102 (4). p.pp. 156–162.
Tenovus (n.d.). *Join a Choir*. [Online]. Available from: http://www.tenovuscancercare.org.uk/how-we-can-help-you/join-a-choir/. [Accessed: 19 December 2014].
Vickhoff, B., Malmgren, Helge, Astrom, Rickard, Ekstrom, S.-R., Engwall, M., Snygg, J., Nilsson, M. & Jornsten, R. (2013). *Music structure determines heart rate variability of singers*. [Online]. 9 July 2013. Frontiers in Auditory Cognitive Neuroscience. Available from: http://www.frontiersin.org/Auditory_Cognitive_Neuroscience/10.3389/fpsyg.2013.00334/abstract. [Accessed: 11 July 2013].

DUMP

As the current resurgence of VR technologies seems set to be a success as a commercial enterprise, it is to be expected that the performance arts are embracing the new digital potential that the medium brings. Initial engagement with the newly accessible technology of VR focussed on enhancing experiences (e.g.s making fantasy worlds in video games fully immersive; performance art experience?). There is now a need to push the boundaries of this technology to develop entirely new ways of conceiving and delivering performance, rather than simply enhancing existing practice, if digital technology is to have a sustainable and exciting future.

As performance artists and technology companies try to find innovative and exciting ways to engage with emerging digital technologies, there is a danger that the potential for its application is being limited due to an incomplete understanding of how people engage with this new technology. Current direction of engagement with digital technologies suggests that the future will involve greater culmination of different disciplines and mediums for the delivery and production of performing arts, and it is therefore essential that the underlying research is robust and also calls on the appropriate interdisciplinary expertise.
Music performance analysis

In what ways does a singer's performance change between the real and virtual environments? Can they sing effectively in an ensemble considering factors such as eye-contact, body motion, acoustic plausibility and 360 visualisation?

The project will also enable us to develop a stronger understanding of the complex ways in which 'immersive' experiences may mediate people's experience of Arts and culture more generally i.e. in what circumstances do 'immersive' experiences contribute to participant wellbeing, and when might they detract from it? The system has the power to break down boundaries of engagement / performance / observation, but under what circumstances might it also detract from people's positive experiences of cultural participation? If some of the power of

the Arts and culture is in their capacity for building social capital and fostering social cohesion (Matarasso 1997; Hallam 2015; Crossick & Kaszynska 2016), what impact does isolating people from other humans in order to have cultural experiences have on the experience itself? Specifically, how significant is the experience of 'interpersonality' in cultural experience? The phenomenon of 'entrainment' is a two-way process (Clayton et al. 2004) – understanding how the experience of interpersonal 'entrainment' or 'resonance' (Lewis et al. 2001, pp.169–170; Siegel 2011, p.61) might affect cultural experience, will provide insights to develop the system to be able to account for this complex exchange. Whilst the project doesn't allow us to measure any interpersonal neurobiological effect during group singing, the personal 'micro-narratives' of participants will help illuminate the extent to which the social and interpersonal nature of group singing is considered significant by them. If we are able to isolate the extent to which the presence of other human neurobiology during cultural experience impacts on wellbeing (Siegel 2016), we can make much more informed choices about when, and how, to apply 'immersive' technologies as a strategy for facilitating cultural engagement e.g. for patients with mental health diagnoses experiencing social anxiety, or for singers with mobility issues who could not otherwise participate in outdoor mountain-top group singing.

, in health practice, with the emergence of choirs for health (Tenovus n.d.; Livesey et al. 2012; Shakespeare & Whieldon 2017; Skingley et al. 2011; Stacy et al. 2002) and in research where studies are trying to better understand with relationships between the activity of group singing and health and well being outcomes with a limited number of controlled trials now published (Fancourt et al. 2016; Clift et al. 2017; Clift & Morrison 2011; Clift et al. 2013; Kreutz et al. 2004; NICE 2015; Shakespeare & Whieldon 2017).

The benefits of music on wellbeing are relatively well-documented and empirically investigated (Clift et al., 2006; Macdonald et al., 2012; Västfjäll et al., 2012).

There is further preliminary research, which suggests community singing is beneficial to clinical groups such as cancer sufferers (Young, 2009, Fancourt et al. 2016).

From section 2

Questions with the development of the system
Does the rendering of the virtual environment present a plausible reconstruction of the original performance space? Which parameters detract from the experience and which are perceptually irrelevant in a virtual performance scenario? What is the effect of immersive visual cues on the

rendered audio? Objective audio-visual measurements in both the real and virtual environments as well as subjective analysis are needed.

Form case studies

In addition to the filming for the VR experience, - objective measures of VF engagement emotion taken during filming (as separate session so all singing together (when taking ‘audience position). Did solo and ensemble.. Diff measures below… When they came back to try the VR Emotiv was added…. Compare real vs. virtual…

Our recent research has utilised the UWIST in our experimental protocols. One particular project, Singing in Virtual Environments (SIVE), monitored subjective mood throughout a singing protocol where participants would sing (both solo and in a group) as well as listen to live performances in VR. Irrespective of the condition order, participants reported stress reduction throughout the protocol - suggesting an element of getting used to the headset and the protocol. Furthermore, there is more stress associated with singing rather than listening, and more physical arousal associated with singing rather than listening. Hedonic tone levels appear to be high throughout the protocol, indicating an overall enjoyment of singing or listening to music.

From hauke moved

GSR signals were measured by attaching two electrodes to the participant’s non-dominant hand palmar middle phalanges of the index and middle fingers. And the BVP signal was recorded using a photoplethysmograph that was attached to the same hand’s ring finger. The GSR signal allows us to extract the mean skin conductance level and mean number of skin conductance responses across a longer time period (Boucesin, 2001). From the BVP signal, we will be able to extract the mean heart rate and the amount of sympathetic arousal-induced vasoconstriction. All extracted response descriptions will indicate physiological activation or physiological deactivation that is typically associated with emotional responding (Scherer, 2005).

Conclusions removed

Huge potential for impactful research - bidirectional approach integrates impact from the onset.

Problems
Time it takes to create a VR system (RIRs, filming) especially if needing to create multiple recordings (e.g. diff parts, avoiding seeing yourself in VR, repetitions).

Challenges for the future

All elements developing together (i.e. the technology, the experimental methodologies,

Next steps for the system

Real time multi directional engagement (i.e. not with a recording)