Evaluating Presence in Immersive Virtual Reality Concert Experiences

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***Abstract*—Virtual Reality (VR) concerts using spatial audio offer novel, compelling and immersive ways of experiencing music performances that move far beyond the realms of existing streaming delivery. Evaluating users' sense of presence and immersion remains at the centre of research in virtual environments in general. These evaluations can influence the development of VR experiences when implementing a co-design or user-centred design approach. This design implementation can produce more accessible, enjoyable, and impactful experiences. In this paper, we summarise the development of an existing VR concert experience in the Irish music tradition and propose a survey that investigates and evaluates it from a presence perspective. Our methodology is outlined, and the results show the positive impact of immersive audio design factors on the subjective experience and sense of presence felt by the participants.**

I. Introduction

The advent of virtual reality (VR) has significantly expanded the ways in which people experience all forms of media, including film - or so-called "Cinematic Virtual Reality" (CVR) - [1], [2], interactive games [3]–[5] (particularly serious games [6], [7]) and music [8]–[10]. VR concerts, in particular, offer audiences the ability to experience musical performances from the comfort of their own homes while feeling immersed in a three-dimensional, interactive environment that can significantly exceed the experience of conventional streaming platforms such as YouTube.

In light of the COVID-19 pandemic, which prompted a surge in the popularity[1] of online concerts [11], VR has emerged as a promising solution to maintain the social and emotional elements of live performance in a virtual medium. In the post-pandemic era, the importance of immersive virtual concerts remains strong and offers an inclusive and accessible experience for many who remain excluded or are challenged in their attendance of live performances due to disability, geography, age, or financial constraints.

Immersive technologies also play an important role in the digital preservation and revitalisation of tangible and intangible cultural heritage [12], [13]. Ireland boasts a rich and diverse cultural heritage [14] that includes pre-Christian Celtic sites, arts and crafts; literature in both Irish and English languages [15], [16] and ancient Gaelic games. Irish traditional music is famed worldwide and recognised through several UNESCO designations for its indigenous instruments [17], [18] with the Celtic harp being the official emblem since the establishment of the Irish free state in 1922.

Situating our practice in the context of the cultural and societal opportunities afforded by immersive technologies, in 2023 we designed, developed and presented a VR experience that allowed users to enjoy several performances of music in the Irish tradition [anonymised]. The experience further allowed the participants to virtually move between several well-known and iconic cultural institutions in Ireland, with the recreation of the sonic profile and unique acoustical properties of those spaces adjusting appropriately.

Following refinement of the experience based on informal feedback from our users, in this paper we offer a formal quantitative evaluation of the system and its performance, approaching it from a *presence* perspective. The paper is structured as follows. In II, we define and summarise the phenomenon of presence and examine its influence in the context of musically focussed VR experiences. Section III expands on the technical implementation of Réaltacht in more detail. Section IV details the experimental methodology, and the paper concludes with the results and discussion.

II. Presence

Witmer and Singer introduced their presence questionnaire in 1998 [19], in order to assess the level of immersion, or presence, of a user in a Virtual Environment (VE). Since then, this approach has been used to evaluate the presence of video games, virtual 3D media, educational, and medical training applications. These presence questionnaires quantify the subjective immersive experience through a Likert scale-based system categorised by control, sensory, distraction and realism factors. This method of testing virtual environments has been at the centre of virtual environment testing for the past few decades [20] [21].

The presence questionnaire confines the user to answer only on scale rating, which does apply consistency to the subjective immersive experience but restricts the user from expressing a more complex opinion. This has been adjusted in the Réaltacht questionnaire by adding open-ended questions at the end of each section. These questions are used to acquire a unique perspective of the virtual experience. Presence questionnaires do not have a reference guide to compare one experiment

[1]In the authors' institute alone 400 streaming concerts were produced during the height of the pandemic in 2020-2022

Fig. 1. Green Screen Recording (top) and final VR render (bottom) in the Corner House venue

to another based on presence responses and each presence questionnaire is unique to that individual experiment [22]. Analysing subjective experiences and behaviours allows for broad varied answers and large outliers. This can be due to varied life experiences and varied levels of expertise in the subjective environment [23]. This paper aims to highlight aspects of the VR concert experience that may affect a user's sense of presence.

Measuring presence has been used previously in the evaluation of virtual music concert experiences [24]. This analysis of presence in virtual concert settings is evident in the work by Aguilar et al, and Onderdjik et al [25] [26]. These papers explore what aspects of a virtual concert effect the user's sense of presence in fully rendered 3D environments and 360° concert videos. Quantative techniques for the analysis of VE subjective experience is seen in previous studies exploring theatre productions, [27] [28] and concerts [29].

III. The *Réaltacht* VR Concert Experience

Réaltacht derives its name from the Irish word for 'reality' and is a VR concert experience that presents a virtual performance of fiddle music in the Irish tradition at several iconic cultural institutes in Ireland, including a traditional pub, an historic church converted into a performance venue and Siamsa Tíre, Ireland's National Folk Theatre. The technical implementation is described extensively in the author' previous published paper, [anonymised] but we summarise the key aspects briefly.

Three performances of traditional Irish tunes were recorded by the author's institute traditional music ensemble *Bruach* in a green screen studio environment using an Insta360 Pro 2 360° VR camera and close miking of the fiddle bodies. We then visited each of the cultural venues and captured the locations visually once again using the 360° camera. The acoustic characteristics were captured sonically by recording the responses of swept sine impulses to get a snapshot of the reverberant space. In the final VR experience, the user is able to transport themselves to any of the three venues and the audiovisual experience changes in real-time, as suggested by Figure 1.

360° visuals were coupled with the recordings and impulse responses in the Unity Game Engine, a cross-platform game development engine popular with indie and smaller-scale developers [30]. Unity's built-in support for 3D spatial audio was used to virtually position the sounds in space corresponding to their position in the 3D visual scene. These sounds are mixed with the reverberant characteristics of the space using convolution with the impulse responses. The final prototype was rendered and uploaded to the MetaQuest 2 headset using an APK loader for full VR testing using headtracking.

During the development process, multiple different platforms were explored, including the no-code solution 3DVista.

TABLE I
CATEGORIES AND VARIABLE KEYS OF LIKERT ITEMS

Category	Key	Question
Profile	P-1	How often would you play video games?
	P-2	If you answered yes, how often would you use VR?
	P-3	If yes, how severe were these side effects?
Controls	C-1	How intuitive was the interaction and controls to you?
Presence-Realism	PR-1	How emotionally invested in the experience were you?
	PR-2	How strong was your sense of presence, "being there", in the virtual environment?
	PR-3	How much did your sense of presence change during the experience?
	PR-4	How realistic did the virtual world appear to you?
Sound	S-1	How realistically did the sound sources interact with you as you navigated the virtual environment?
	S-2	To what degree did the sound sources in the virtual room appear to come from specific locations?
	S-3	During the time of the experience, did you often think to yourself that you were in a concert space?

This popular 3D rendering toolkit is frequently used for generating interactive tours of housing properties or 3D scanned landscapes to show potential clients. Although visually compelling and useful for rapid prototyping, we discovered that the audio capabilities are limited and restricted to static stereo recordings only, rather than the full rotational localisation offered by the Unity game engine, a limitation subsequently observed by others [31].

The first iteration of *Réaltacht* was demonstrated to more than 80 staff and students at 4 different campuses of the authors' institute during a month-long programme of events celebrating innovative projects and collaboration. Feedback and responses were largely encouraging and positive, motivating us to develop the formal experimental instrument described in this letter in an effort to understand the impact of immersive audio on presence in VR experiences.

IV. METHODOLOGY

To evaluate the effect of immersive audio on the phenomenon of presence in our VR concert, we designed an experiment to gauge participants' response. This was achieved by conducting a 20-minute session with 35 participants, allowing them to freely interact with the experience, followed by a brief online questionnaire in Google Forms.

A. Experimental Design and Pilot

As discussed in Section II, our instrument builds on the conceptual framework of the presence questionnaire first introduced by Wittmer and Singer, expanded to include specific questions that probe the role and influence of audio (if any). The questionnaire also had the opportunity for personal user feedback through several open-ended questions. This allowed

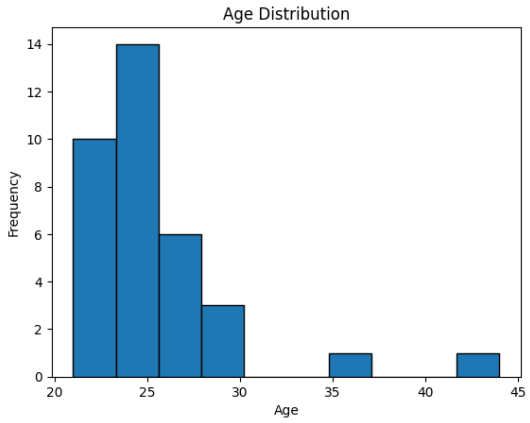

Fig. 2. Age Distribution of Sample

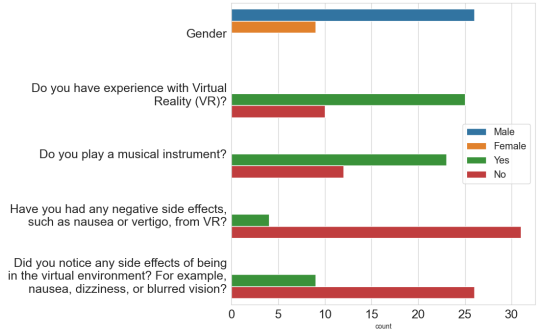

Fig. 3. Responses to Binary Profile Questions

the user to justify their rating, provide clarity, or elaborate on aspects of the test. The Likert questions used are summarised in Table I.

After conducting our literature review and collating our initial question bank, we summarised our plans for the institute's ethics committee, taking care to highlight the specific potential risks and side effects associated with immersive technologies, such as nausea, motion sickness and vertigo [32]. With successful receipt of ethical approval,[2] we were clear to proceed with an initial pilot survey of a small number of colleagues to evaluate the experimental design and data collection process.

The participants' well-being was of high importance during the experimentation process. Each participant was briefed regarding the purpose of the data collection and that they could withdraw during the experimentation process, even after the completion of the experiment. They were reassured that all collected data would be anonymised, and that the analysed data can potentially be referenced in scientific publications.

The pilot survey seemed to be an effective experience for both the researcher and tester. One alteration made to the pilot questionnaire experience was to increase time between experiments to allow for any potential delays.

[2]Approval reference: HREC-FER-23-004

Fig. 4. Data Collection in Studio Environment

B. Data Collection

No major issues were highlighted nor changes required from the pilot survey, so we were able to issue a wider callout through our University and researcher networks (including Science Foundation Ireland) to attract additional interested participants from staff, students, and peers.

1) Test Conditions: Each user entered a small controlled environment that was equipped with a computer for questionnaires and consent forms, the *Meta Quest 2* VR headset, and a set of closed-back over-ear BeyerDynamic DT770 headphones (Figure 4).

Each user was given a brief demonstration instructing how the hand controllers function in the VE. The researcher assisted the user with the correct wearing, positioning, and adjustment of the headset and the headphones. Once the user was comfortable in the VE, the researcher handed the user the Quest controllers.

Once in the VE, each user was informed that in front of them there should be an information text box with a blue 'start' button at the bottom of said box. If a user were to hover over this button and use the right-hand index trigger to select, this would begin the VR concert experience. Directly above the performers three icons dictating different venue settings were visible to the user. If the user hovered over these venue icons and selected a different venue than the one they were currently present in, the scene would seamlessly switch visual and audio profiles. As the users would jump between virtual venues they could notice different acoustics, lighting, reflections, and visual environments.

2) Survey Completion and Debrief: When the participant was ready to end the experience, they alerted the researcher to assist with the handover of the controls and the removal of the headphones and headset. As in the pilot questionnaire, the user was asked how they felt and if they were experiencing any side effects. After the user readjusted to reality, they were asked to complete the questionnaire that they had started before entering the VE. Once the user had finished the questionnaire, they were escorted out of the test centre. As they were leaving the building, the researcher would make sure they were not suffering from any lingering side effects.

V. Analysis Tools

Anonymous data collected from Google Forms was downloaded in CSV format and inspected for any errors or incomplete entries, then imported and manipulated in Python using the Pandas [33], [34] package for data analysis and manipulation. Exploratory and descriptive statistics were performed using Pandas and numpy. Inferential statistics were performed using statsmodel [35] and pingun. Plots and charts were prepared using seaborn [36], plotly[3] and Microsoft Copilot[4].

VI. Results

A. Reliability

To determine the internal consistency of the participants' responses to the subjective questions (excluding the profile category which was obviously skewed). To ensure sufficient reliability we used Cronbach's Alpha to report a coefficient of α=0.877 with a confidence interval of which can be interpreted to indicate a reliable response rate in the "good" range according to [37].

B. Descriptive Statistics

1) Profile: Our test subjects were mostly drawn from a convenience sampling of students, staff, and researchers in the university and through outside contacts. This is reflected in the profiles of the students depicted by the age group distribution (Figure 2) and the answers to the binary questions (Figure 3) (26 males, 8 females, mean age m=25.2, ±4.37).

2) Likert Categories: Figure 5 shows the violin plots of the central tendencies and distributions for each of the Likert question categories (Profile, Interaction, Presence-Realism, Sound). The profile category predictably shows the widest diversity of opinion across the questions of video game usage frequency, VR usage frequency, and severity of negative side effects for a subset (n=20), for those who experienced them during test conditions.

In the presence category, there is consistent agreement by the participants with the central value indicating that most felt a level of realism in the virtual world and they considered themselves present and emotionally invested.

In the sound category, participants reported an increased positive response to audio realism when they interacted with the environment (moving their head or switching between the different venues).

C. Inferential Analysis

1) Likert Item Correlation Analysis: To study the links between individual Likert items we estimated the cross-correlation using the non-parametric Spearman's rank coefficient for ordinal scales. Table II shows 14 high scoring correlation scores along with their significant levels ($p < 0.05$ in all cases).

[3]https://plotly.com/

[4]https://copilot.microsoft.com/

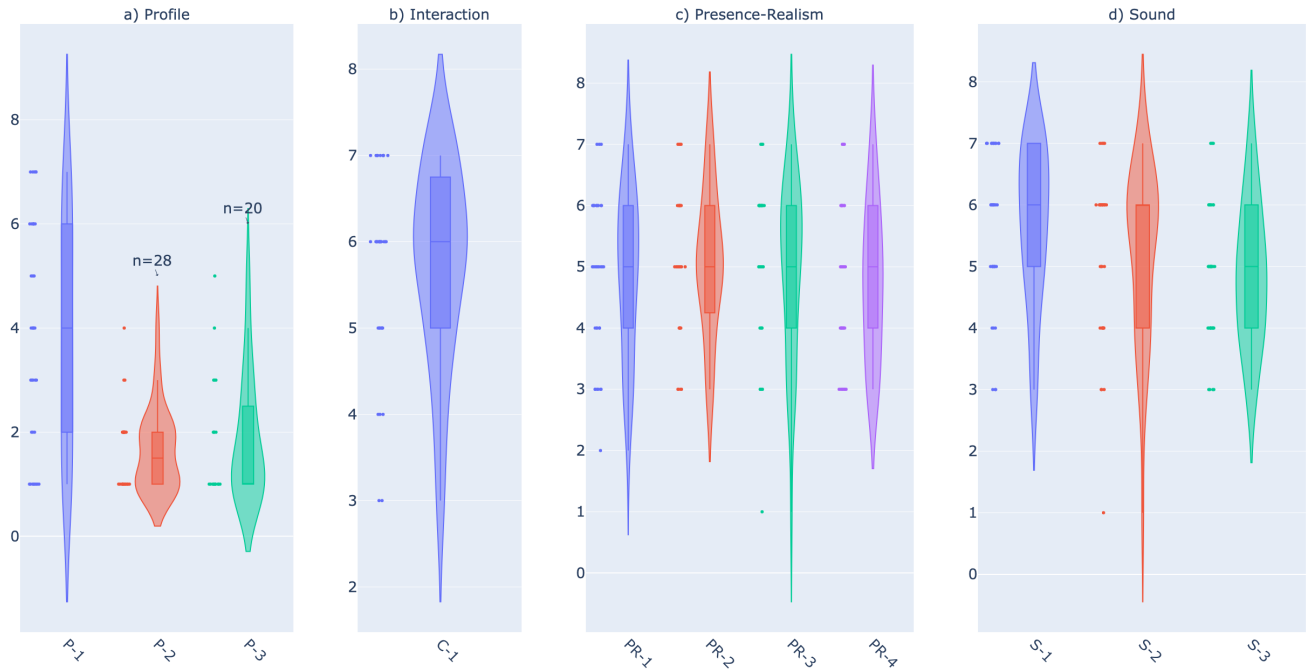

Fig. 5. Violin Plots of Likert Ratings in the 3 Categorical Groupings. **a) Profile**, P-1: *"How often would you play video games?"*. P-2: *"If you answered yes, how often would you use VR?"*, P-3: *"If yes, how severe were these side effects?"*. **b) Interaction**, C1: *''How intuitive was the interaction and controls to you?"*. **c) Presence-Realism**, PR-1: *"How emotionally invested in the experience were you?"*, PR-2: *"How strong was your sense of presence, 'being there', in the virtual environment?"*, PR-3: *"How much did your sense of presence change during the experience?"*, PR-4: *"How realistic did the virtual world appear to you?"*. **d) Sound**, S-1: *"How realistically did the sound sources interact with you as you navigated the virtual environment?"*, S-2: *"To what degree did the sound sources in the virtual room appear to come from specific locations?"*, S-3: *"During the time of the experience, did you often think to yourself that you were in a concert space?"*

TABLE II
HIGHEST CORRELATIONS BETWEEN LIKERT ITEMS

Variable Key			
X	Y	Correlation	P-Value
PR-2	PR-4	0.811	3.447E-09
PR-1	PR-4	0.715	1.404E-06
PR-1	PR-2	0.705	2.312E-06
PR-1	PR-3	0.682	6.377E-06
PR-2	PR-3	0.651	2.323E-05
PR-4	S-3	0.643	3.110E-05
S-1	S-3	0.643	3.129E-05
S-1	S-2	0.621	6.780E-05
PR-2	S-1	0.601	1.355E-04
PR-3	S-3	0.593	1.754E-04
PR-2	S-3	0.567	3.839E-04
PR-3	PR-4	0.559	4.871E-04
PR-3	S-1	0.546	6.975E-04
PR-2	S-2	0.535	9.287E-04

2) Aggregate Correlation Analysis: We also examined the aggregate statistics of the two main categories (Presence-Realism and Sound), by taking the arithmetic mean of each participant's Likert item scores to get an overall Likert Scale summation[5].

Since this is a continuous variable we can use a parametric test like Pearson's correlation coefficient, which we report to be r=0.692 with p<0.05, indicating a moderately strong and statistically significant link between the sense of presence, realism, and the accompanying sound experience.

We also took aggregate mode statistics for the Presence-Realism and Sound categories, and performed a Spearman's Rank cross-correlation along with the Control Likert item 6. The 0.62 statistic between Presence-Realism and Sound supports the previous Pearson's coefficient finding. There is also a medium and statistically significant correlation between Interaction and Presence-Realism.

3) Effects of Binary Questions: To test the effects of the binary questions on the aggregate scores a t-test was performed to determine any difference between the group subsets. All of the tests were statistically insignificant except for the mean presence-realism scores of males (m=4.673, ±1.124) versus females (m=5.583, ±0.707) with $t(35)$=-2.266, p=0.03).

This was reiterated when the non-parametric Mann-Whitney-U test was applied to median scores each of the individual ordinal Likert items. All independent and dependent variables produced statistically insignificant results apart from two questions. Firstly, males (med=5) scored lower than females (med=6) on "How emotionally invested in the experience were you?" (U=62.5, p=0.036). They also scored lower (med=5 versus med=6) on "How strong was your sense of

[5]https://www.stat59.com/blog/2022/8/analyzing-likert-scale-items-group/

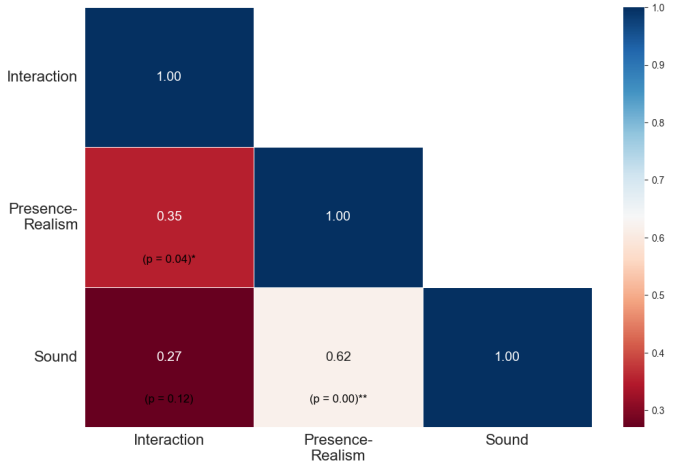

Fig. 6. Correlation Heatmap between Aggregate Likert Scores

TABLE III
MANN-WHITNEY U TESTS BETWEEN PARTITIONED INDEPENDENT GROUPS

Independent		Dependent				
Key	Median	Key	X Mode	Y Mode	Stat	p_value
C1	6	PR-4	4.5 (n=12)	5.0 (n=23)	880.5	0.00125
C1	6	S-3	4.5 (n=12)	5.0 (n=23)	868	0.00205
S-1	6	PR-4	4.0 (n=14)	5.0 (n=21)	857	0.00334
S-1	6	S-3	4.0 (n=14)	5.0 (n=21)	842.5	0.00569
C1	6	PR-1	4.5 (n=12)	5.0 (n=23)	835	0.00708
C1	6	PR-2	5.0 (n=12)	5.0 (n=23)	821	0.01145
S-1	6	PR-1	5.0 (n=14)	5.0 (n=21)	815	0.01483
C1	6	PR-3	4.5 (n=12)	6.0 (n=23)	809	0.01694
S-1	6	PR-2	4.5 (n=14)	5.0 (n=21)	795.5	0.02688
S-1	6	PR-3	4.0 (n=14)	6.0 (n=21)	791.5	0.0309

presence, "being there", in the virtual environment?" (U=60, p=0.025).

4) Partition Effects: The final approach adapted was to partition the data according to the median profiles on an independent variable of interest (*med*=6.0 in each case), then repeating the Mann-Whitney U test on the modes of the dependent variable in the partitioned groups (labelled X and Y). Table III shows the top 10 statistically significant effects when running this procedure.

This reveals interesting perspectives on the role that sound design, and user interaction design, plays in creating a convincing sense of presence and realism in immersive environments. This correlation between sound design and a user's sense of presence is reinforced by the work of Park et al, and Shilling [38] [39]. Contrary to being merely "purely cosmetic", as stated by Shilling, sound design plays a far more crucial role in virtual presence - a key focus of our research.

D. Qualitative and Textual Analysis

The participants were also given the chance to expand on their Likert responses through several open-ended questions which provided some additional qualitative analysis.

Fig. 7. Wordcloud for responses to question: "What are you expecting from a VR experience?"

1) General Feedback: The participants were initially asked "What are you expecting from a VR experience?" to gauge their expectations, particularly those who have never used VR before. The participants overwhelmingly responded that they wanted an 'experience' and to feel 'immersed', as indicated by the word cloud in Figure 7.

In the post-interview stage after concluding the experience, the participants were asked the follow-up question "How did your experience differ from the expectations you had mentioned in the Precursor Question Section?". Here, opinion ranged from negative, for example, due to perceived lack of realism.

- *It was immersive but maybe not as immersive as I thought it would be*
- *It was an interesting VR experience but the lack of video quality prevents from me from truly engaging in the VR experience*
- *Experience was rather immersive, although the slightly lower background definition took slightly*

Other opinions were more neutral, emphasising that the experience was *"very similar"*, didn't differ *"... very much"* or *"not all that much"* to their preconceptions. In two cases, this was due to some participants' prior familiarity with VR:

- *It didn't much considering that I have used VR headsets in the past and this felt no different but it was still really cool.*
- *Not too different as i have used vr before but still really enjoyed*

Computational sentiment analysis was performed using TextBlob/NLTK[6] on the responses to produce Positivity/Subjectivity scores for each of the participants (Figure 8). The polarity ranges from -1 to 1, suggesting a negative or positive sentiment centred at neutral 0. Four highlighted responses in grey black are considered unreliable false positive predications, but the overall summary is positive. Subjectivity relates to the level of opinion (use of personal pronouns, emotions, etc.) and is clearly correlated in this case with increased positivity (0.62, p $<$0.05)

[6]https://textblob.readthedocs.io/

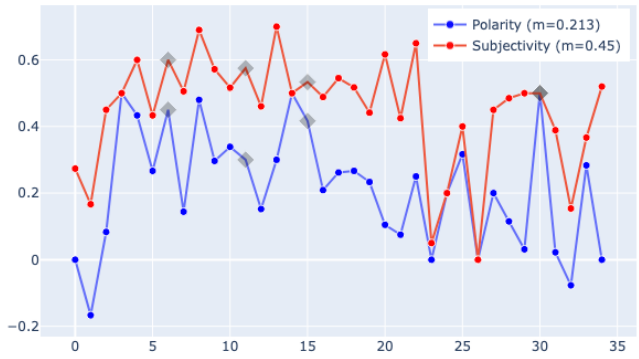

Fig. 8. Sentiment Analysis of User Responses for "How did your experience differ from the expectations you had mentioned in the Precursor Question Section?"

2) Side Effects: In the pre-questionnaire stage, 4 participants reported experiencing negative side effects during previous sessions with immersive technology. This included *"minor nausea"*, sensations that were *"a bit dizzying"*, *"motion sickness"*, and *"Slight nausea after long use and lots of in game movement."*.

After concluding the experiment, participants were again asked did they experience negative side effects and the degree of severity as indicated in Figure (5). 7 participants indicated they experienced minor to moderate side effects (<4). Interestingly, only 1/4 of the participants who reported prior negative side effects in other experiences also suffered side effects in this experiment.

3) Experience Interaction: We were interested in gauging descriptive responses to the interaction aspect of the experience as participants transitioned between each virtual venue. Overall, there were favourable remarks regarding the audio aspect, particularly the noticeable effect of the reverberant spaces and their effect on the intimacy of each venue. Some of those who had visited the venue(s) previously confirmed the accurate response and characteristics.

- *Fairly seamless transitions between spaces. From being at gigs in similar venues, the sound felt fairly accurate*
- *The pub environment felt and sounded very intimate as opposed to the larger venues like the Triskel and Siamsa Tire where you could both feel and hear that you were in a larger, grander space*
- *Each room/setting had a very different "feel". The Siamsa Tíre felt extremely open, almost to degree of anxiety while looking at the expansive room (and it felt like I was on stage on own, suddenly unprepared for a performance that I didn't know was scheduled. The corner house had an intimate and cozy feel to it. Since the Triskel Arts Centre was the only place that I recognised, as soon as i switched to that room i couldn't help but be impressed by the realism.*

One participant didn't notice a perceptual response to the directionality of the performers which is unusual, and warrants a follow-up session to study further: *"Audio wise, quite a lot. Interesting to hear the different room tones. However, would have liked if the audio reacted to the direction I was facing."*. Another participant didn't report an emotional response - *"I did not have much emotion from scene to scene"* - but didn't expand on the perceptual effects.

Negative feedback was largely attributed to the visual limitations of the prototypical experience, and one conclusion we can draw from this experiment is that many users are willing to forgive this given a sufficiently rich, convincing, and interactive audio implementation. In addition, the unnatural lack of audience members, particularly in the large purpose-built venues, contributed to a sense of unease and loneliness, echoing a phenomenon in digital animation and virtual environments known as the "uncanny valley" [40].

- *The changing of the room sound really added to the experience. The lack of shadows in Triskel did bring me out of the experience as the floor was so light in colour it definitely looked more fake than real.*
- *Found the middle session (the pub) to feel very appropriate. The experience was appropriately intimate. However, for the first (the concert) found the lack of an audience is a bit jarring...*
- *...not too much but I wasn't expecting to be up on stage and experience it like that so that was cool but at the same time i think it felt kind of lonely and lacked atmosphere if you were to go in that direction*

VII. Discussion and Future Work

In this paper we offered a comprehensive survey that evaluated a VR concert experience with spatial audio from a presence perspective. Building on established experimental methodology from general VR evaluation, we tailored the approach for the investigation of an existing VR concert performance in the Irish music tradition.

35 participants were selected from a convenience sampling of the authors' institute and invited to spend some time in the headset, experiencing the musical performance and selecting 3 different virtual venues in which the musicians were positioned. Afterwards they completed an online Google Forms survey gauging their reaction to the experience from a presence perspective through a series of 7 point Likert scale questions along with some open-ended feedback.

Our initial descriptive statistical analysis revealed a positive subjective response to the experience, particularly for the realism of the sound sources during transitions through the environment and the intuitiveness of the interactions/controls, frequently a challenge in the design of VR environments.

Digging deeper with the hypothesis testing and inferential statistics outlined in Section VI-C, we noted moderate to strong, statistically significant correlations with the Presence-Realism factors and the Sound category using a variety of approaches. Partitioning based on an independent variable of interest reiterated findings that sound design and user interaction are important in producing a sense of presence and realism in immersive environments. The influence of profile

factors such as prior VR and musical experience, and existing experience of side effects was mostly insignificant. Participant gender revealed differences in emotional response and presence. As Figure 3 indicated, the sizes of these individual groups were often quite small and imbalanced. For future experiments, we plan to draw a larger, more diverse sample size from the population to produce more conclusive results.

Finally, qualitative analysis of the open-ended questions using manual and automatic analysis also highlighted positive responses to the experience, with frequent mention of the sonic design. Negative feedback was mostly confined to limitations in the visual scene.

In terms of future work, we are already in the design and development stages for a new VR experience that builds on *Réaltacht*, but extends to other musical styles including rock and pop. The findings from this experiment support the validity of our approach; by addressing as much of the feedback as possible, we will conduct a similar survey that can be compared and contrasted with this work. The methodology outlined in this paper could also function as a framework for additional research into virtual concerts and the study of audio in virtual environments.

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