Subjective Evaluation of an Olfaction Enhanced Immersive Virtual Reality Environment

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ABSTRACT

Recent research efforts have reported findings on user Quality of Experience (QoE) of immersive virtual reality (VR) experiences. Truly immersive multimedia experiences also include multisensory components such as olfaction, tactile etc., in addition to audiovisual stimuli. In this context, this paper reports the results of a user QoE study of an olfaction-enhanced immersive VR environment. The results presented compare the user QoE between two groups (VR vs VR + Olfaction) and consider how the addition of olfaction affected user QoE levels (considering sense of enjoyment, immersion and discomfort). Self-reported measures via post-test questionnaire (10 questions) only revealed one statistically significant difference between the groups; in terms of how users felt with respect to their senses being stimulated. The presence of olfaction in the VR environment did not have a statistically significant effect in terms of user levels of enjoyment, immersion and discomfort.

CCS CONCEPTS

• **Computing methodologies** → **Virtual Reality** • **Information systems** → **Multimedia content creation**

KEYWORDS

Quality of Experience; Virtual Reality; Multisensory experiences; Subjective Evaluations; Olfaction.

AltMM'17, October 27, 2017, Mountain View, CA, USA
 ACM 978-1-4503-5507-0/17/10…$15.00
https://doi.org/10.1145/3132361.3132363

1 INTRODUCTION

Research on evaluating user QoE has primarily focused on the users perception of audiovisual components and the influence of each individually [1]. With the emergence of Head Mounted Displays (HMDs) such as the Oculus Rift and HTC Vive, a step towards interactive and immersive multimedia experiences is possible. A key aspect to the success of VR is understanding how users perceive quality of these environments. According to [2], QoE is defined as "the degree of delight or annoyance of a person whose experiencing involves an application, service or system. It results from the persons evaluation of the fulfilment of his or her expectations and needs with respect to the utility and/or enjoyment in the light of the person context, personality and current state". User QoE of a multimedia experience is complex and multidimensional as outlined by Ebrahami et al. in [3] and encompasses a number of different factors including technical, social and psychological as shown in **Figure 1**.

More recently, motivated by the need to enhance user QoE beyond what's possible with audiovisual stimuli, and also due to technological advances, research and industry have reported works with respect to sensory experiences [4] or multiple-sensorial media (mulsemedia) [5]. These includes olfaction (sense of smell), gustation (taste) and tactile (sense of touch). Each of these modalities have been used to enhance the traditional 2D media components [6]. Now, an opportunity exists to address the important question of if and how these modalities affect user QoE of immersive virtual reality (VR) environments.

Olfaction is the sense of smell and as a media component, it has the potential to create richer user experiences by enhancing the users sense of reality and diversifying user interaction modalities [7]. In this paper, the user QoE of two independent groups is compared: a VR only group, and a group that experienced olfaction-enhanced VR. The aim was to determine if

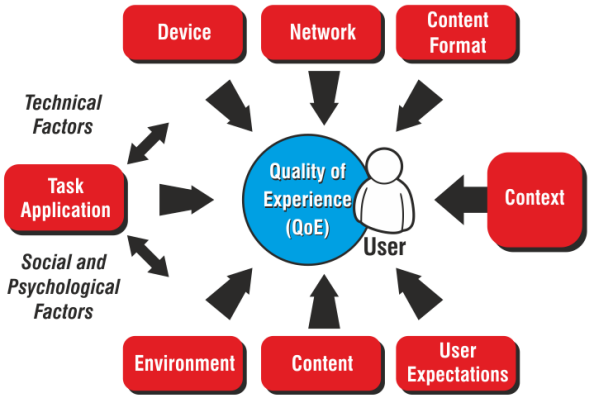

Figure 1: Factors influencing user Quality of Experience, adapted from [3].

the presence of olfaction in a VR environment contributed to higher user QoE.

2 RELATED WORK

Olfactory display systems have been used in virtual environments to try and enhance the level of immersion and the sense of realism. In [8], Jones et al. investigated the use of olfaction in virtual reality environments, and focused on how it impacted the users sense of immersion. Results showed that the addition of olfactory components did not significantly enhance user's immersion in the virtual environment. Another more recent work by Baus & Bouchard [9] analyzed the effect scent had on user experience in a virtual environment, comparing pleasant with unpleasant odours. Interestingly, they reported unpleasant odour had a statistically significant influence on sense of presence, and also that odour didn't have an effect on sense of reality or sense of realism. Nimesha et al. in [10], took a novel and interesting approach by employing olfaction to convey information as part of a game narrative. They also highlighted the potential for olfaction in terms of player cognition and memory as well as in evoking various emotions. In [11] Ishibashi et al. reported a user QoE study of fairness between players in a game which included olfaction. They analyzed the influence of the time it takes a scent to reach a player on fairness. They reported that skew between players less than 500ms has no effect on fairness. Dinh et al. [12] used olfaction in a VR system to conduct a study evaluating a virtual corporate office suite environment. The olfaction was used to try and heighten the sense of presence in the virtual environment. Results strongly indicated that increasing modalities of sensory input in a virtual environment increases the users sense of presence in the virtual environment.

Although not involving VR, a study by Murray et al. [13] reported results of a study which looked at users perception of inter-stream synchronization between olfactory data (single and multiple scents) and video. Their results indicated that olfaction before video was more noticeable to users than olfaction after video and users were more tolerable of olfactory data after video

Figure 2: The VR and wearable olfactory display system.

rather than olfactory data before video. Here, a user QoE study of a completely wearable VR and olfactory system is presented. It considers how the addition of multiple scents to an immersive VR environment influences user QoE.

3 EXPERIMENTAL SETUP

This section outlines the immersive multimedia systems (VR and Olfactory display technologies). In addition, it outlines the screening process employed and information on the subjects who participated in the experiment.

3.1 Immersive Multimedia Systems

The HTC Vive HMD, was used to deliver an immersive VR experience as per **Figure 2**. The wearable olfactory device used was from Exhalia. This device features four scent cartridge slots and connects to the PC via Bluetooth. Three scents were used for this experiment; Wood, Coffee, Burnt Gunpowder/Smoke. These scents were presented to the user in sync with the relevant VR content. Each scent was presented to the participant for fifteen seconds.

3.2 Screening process & Participants

The screening process for participants included visual acuity and color perception. Participants were also screened for anosmia which is the inability to perceive odors or the loss of the sense of smell [14]. This screening procedure was executed in adherence to ISO standard 5496:2006 [17]. For visual acuity, a Snellen Test [15] was administered. Red-green color deficiencies were screened using the Ishihara test [16]. Additionally, participants suffering from any illnesses such as epilepsy, were deemed ineligible. Based on the screening conditions, two subjects were deemed ineligible to participate in the assessment.

A convenience sampling approach was used to recruit participants for this study. A total of 61 participants took part in the study with an average age of 25 years. Out of the 61, 35 were male and 26 were female. The distribution of females and males was even between groups.

Table 1: Questionnaire for post experience reporting.

	Question text
Q1	I was immersed in the virtual environment:
Q2	I did not feel like I was physically doing a tour of Athlone Castle:
Q3	I enjoyed experiencing the virtual environment:
Q4	The virtual environment was realistic:
Q5	I would have liked more time in the virtual environment:
Q6	The experience did not meet my expectations:
Q7	I did not feel any discomfort while using the application:
Q9	My senses were highly stimulated during the experience
Q10	I think that these systems are a great way to learn about history:

4 ASSESSMENT METHODOLOGY

4.1 Assessment Protocol

The assessment protocol can be categorized into four key phases: information phase; screening phase; training phase and test phase, and was inspired by [18]. During the information phase, the participant was brought to the waiting room and was provided with the information sheet that described the experiment in full. Any questions the participant had were addressed at this stage. The screening phase assessed the participants' visual acuity, color perception and for anosmia.

The training phase required the participant to sit in the testing room while they were fitted with the HMD and olfactory display. They were then exposed to the virtual scene of a city block for two minutes whilst being presented with one scent. For the testing phase, the participant was strapped into the purposely built segway to stop any risk of the participant falling over. They again had the HMD placed on their head and the olfactory device placed around their neck. The virtual scene lasted five minutes. The participant was brought on a virtual tour around a historic castle and were given information about the castle. The participant did not have any interaction with the virtual environment apart from the freedom of head movement. Upon completion of the test phase, the participant was asked to complete a QoE questionnaire based on their experience.

On average, participants completed the test in 35-40 minutes. Typically, this included: 8 minutes for information phase; 15 minutes for the screening phase; two minutes training phase; 5 minutes for the test phase; and finally, approximately 10 minutes for completion of the questionnaires.

4.2 Questionnaire and Rating Scale

10 questions were developed to evaluate the participants immersion, enjoyment and discomfort. The QoE categories chosen were derived from the QoE model shown in Figure 1 and each of the questions as per Table 1 were designed to align to one of these factors.

Questions 1, 2, 4 and 9 evaluated user immersion levels. These questions aimed to analyze how the participants felt during the virtual experience in terms of sense on realism, stimulation of

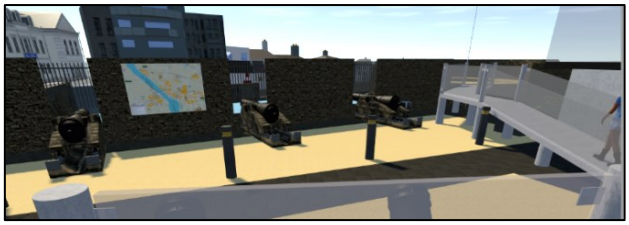

Figure 3: Screenshot of virtual environment.

senses and immersion levels. Questions 3, 5, 6 and 10 evaluated user experience via participant's expectations, enjoyment levels, and interest in spending more time in the virtual environment. Question 7 asked the participant if they did or did not suffer any discomfort during the virtual experience. Question 8 asked the participant to list any symptoms experienced and was derived from [19]. Participants were asked to rate each question using the absolute category rating (ACR) system as outlined in ITU-T P913 [20]. They answered the questions in Table 1 as per the following scale: Strongly disagree, Disagree, Neither agree or disagree, Agree and Strongly agree. Question 8 was open ended and asked assessors to list negative physical symptoms (eye strain, headaches, etc.) experienced (if any) during the evaluations.

5 RESULTS AND DISCUSSION

In this section of the paper, the findings with respect to the subjective data captured during the VR, VR + olfaction experiments are presented and discussed.

5.1 Self-Reported Questionnaire Results

Table 2 presents the statistical analysis and MOS ratings from the post-test questionnaire. An independent sample t-test was performed on the data with 95% confidence level using the IBM statistical analysis software package SPSS.

As per Table 2, of the nine questions that were based on a Likert scale, only question 9 reported a statistical significant difference in the scores between the VR group (M =3.75, SD = 0.645) and VR + olfactory group (M = 4.19, SD = 0.644) conditions; (t (58) = -2.17, p = .011). Question 9 asked participants if their senses were highly stimulated during the experience. Two other questions (Q4 and Q6) had noticeable differences in MOS between the groups, but were not statistically significant. Question 4 asked the participants if they felt the virtual environment was realistic. It is interesting that the VR + olfaction group reported a higher MOS here, as the literature has reported masking effects with respect to visual quality degradations when olfactory stimuli are present. In terms of Question 6, it asked if the experience met the users expectations. Again, the VR + olfaction group reported higher MOS which suggests that multisensory components have strong potential as

alternate modalities in immersive VR systems. Based on the results from the post-test questionnaire, it can be concluded that the addition of olfaction increased participants level of stimulation but did not have a conclusive and statistical effect in terms of the immersion, enjoyment and discomfort factors considered.

Table 2: Statistical analysis of self-reported measures with 95% confidence level.

	VR	VR	VR+Olf	VR+Olf			
	MOS	**SD**	**MOS**	**SD**	**T**	**df**	**Sig. (2-tailed)**
Q1	4.50	.509	4.59	.560	-.46	58	.502
Q2	4.14	.448	4.16	.808	.25	58	.938
Q3	4.54	.508	4.63	.609	-.42	58	.543
Q4	3.86	.756	4.19	.644	-1.45	58	.073
Q5	3.96	.881	4.03	.782	-.62	58	.756
Q6	3.93	.466	4.22	.466	-1.38	58	.082
Q7	4.21	.957	3.97	1.092	.65	58	.361
Q9	3.75	.645	4.19	.644	-2.17	58	.011
Q10	4.36	.621	4.44	.564	-.70	58	.602

5 CONCLUSION

This paper has presented a comparison in terms of subjective ratings of users QoE of an immersive VR and olfaction-enhanced VR experiences. Of the nine questions asked of both groups, only one was statistically significant: when olfaction was presented, assessors reported their senses were highly stimulated. No statistically significant effects were found with respect to levels of immersion, enjoyment or discomfort. These findings are consistent with the literature, who like this work have tried to understand the effect of multisensory components on QoE via self-reported measures. In addition, with respect the VR + olfaction group having higher MOS in terms of realism, this indicates that, the presence of olfaction "masked" any visual quality issues assessors in the VR only group reported. Again, this supports the literature in terms of how users' perceive media experiences that stimulate more than one sense i.e. the user perception of an experience is a combination of the various modalities that are stimulated. In the context of these conclusions,

future work will involve analysis of objective metrics captured as part of this study (heart rate, electrodermal activity and areas of interest). In addition, we will compare the data for the groups reported here with data collected from another group which experienced VR enhanced haptic stimuli.

ACKNOWLEDGMENTS

This research was supported by the Athlone Institute of Technology President Seed fund (grant no. P221-037).

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