Conference Presentation

Simulating Auditory Hallucinations in a Video Game: Three Prototype Mechanisms

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Simulating Auditory Hallucinations in a Video Game: Three Prototype Mechanisms

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ABSTRACT

In previous work the authors have proposed the concept of 'ASC Simulation[1]: including audio-visual installations and experiences, as well as interactive video game systems, which simulate altered states of consciousness (ASCs) such as dreams and hallucinations. Building on the discussion of the authors' previous paper, where a large-scale qualitative study explored the changes to auditory perception that users of various intoxicating substances report, here the authors present three prototype audio mechanisms for simulating hallucinations in a video game. These were designed in the Unity video game engine as an early proof-of-concept. The first mechanism simulates 'selective auditory attention' to different sound sources, by attenuating the amplitude of unattended sources. The second simulates 'enhanced sounds', by adjusting perceived brightness through filtering. The third simulates 'spatial disruptions' to perception, by dislocating sound sources from their virtual acoustic origin in 3D-space, causing them to move in oscillations around a central location. In terms of programming structure, these mechanisms are designed using scripts that are attached to the collection of assets that make up the player character, and in future developments of this type of work we foresee a more advanced, standardised interface that models the senses, emotions and state of consciousness of player avatars.

CCS CONCEPTS

• **Applied computing → Sound and music computing** • *Human-centered computing → Sound-based input / output* • *Software and its engineering → Interactive games*

KEYWORDS

Sound design, altered states of consciousness, video games, auditory hallucinations, game sound.

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1 INTRODUCTION

In previous work we have discussed the concept of Altered States of Consciousness (ASCs), in the context of video games [3, 16, 17, 19]. ASCs may include states of dream, delirium, hallucination, meditation or trance (among others), as were discussed in early work by Tart [13]. As capabilities for representing subjective states in first and third-person point-of-view (POV) computer games have increased, we have begun to see representations of ASCs in video games. For example, *Far Cry 3* (2012) and *Grand Theft Auto V* (2013) are two examples of recent games that explicitly use modifications and time-based modulations of graphics and sound in order to reflect states of hallucinations, which occur when the game character consumes intoxicating substances such as psychedelic drugs. Along similar lines, Demarque and Lima [5] have explored horror games that portray auditory hallucinations. Just as games provide improved realism through the use of photorealistic graphics and spatial sound, the possibility has emerged that these 'unreal' experiences can be portrayed with greater levels of sophistication and accuracy than every before. The nature of 3D computer game worlds, in particular, offers the possibilities of not only adjusting the way in which a sound is represented in a game, but affords the possibility of spatial audio manipulations through binaural and multi-channel speaker configurations, that are now a standard feature in such games. This offers the opportunity to bring the experience of an auditory hallucination much closer to being 'inside' or 'around' the head of a listener in a more convincing and immersive fashion.

It is an assumption of our research that by seeking to design ASCs in video games based on research, rather than relying on clichés or intuitive design approaches, that we can provide

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simulations of ASCs in video games that have improved accuracy. Towards this end, in a previous study [18] we carried out a large-scale qualitative study of nearly 2000 experience reports, gathered from the internet site erowid.org, which has a large database of user-submitted experience reports regarding the effects of various intoxicating substances. From these studies we devised a system of categorisation to be used as a basis for sound design. We also created a number of proof-of-concept audio files based on these, which were related to descriptions of auditory hallucinations from the study. Here we extend this work by using these descriptions as a basis for three prototype mechanisms in a video game demo, which we created using the game engine Unity. This paper begins by summarising the basis for these mechanisms from the previous study, before outlining the mechanisms themselves, as we implemented them in Unity. We then offer some concluding comments, outlining further challenges and possible applications for this research.

2 AUDITORY HALLUCINATIONS

2.1 Overview

Auditory hallucinations are experiences of sound that occur without acoustic stimulation that arises in a real environment external to the individual. They may occur due to intoxication through various substances such as psychedelic drugs, or via neurological conditions such as schizophrenia. In the latter cases, 'auditory verbal hallucinations' (AVH) are a common phenomenon, during which the individual hears voices that arise internally, with no external acoustic basis. Although in schizophrenia, AVH are the most widely discussed form of auditory hallucination, and may be the most common [15], other types of sound can also be experienced. For example, 'non-verbal auditory hallucinations' (NVAH) are also reported, which may include noise-based sounds [8]. Other types, such as music, are also known to occur [9]. In our previous study of experiences of intoxication, in which we looked at a large number of self-reports (focusing especially on the effects of psychedelic drugs), hallucinated noises were actually more commonly reported than voices [18].

2.2 System of Categorisation

From our previous study [18] we suggested a continuum of auditory hallucinations ranging from unaltered sounds that arise 'externally' from the environment, to wholly hallucinated sounds that originate 'internally' within the brain (Figure 1). According to this continuum, 'normal' perceptions are those that arise via an external environment, and are not abnormally altered in their perception due to intoxication. 'Enhanced' sounds are those that arise externally, but which are perceived as either more, or less, enjoyable, interesting, detailed or intricate than one would normally expect. 'Distorted' sounds similarly arise via the external environment, but are more dramatically altered due to intoxication; for example, individuals may describe hearing sounds that are heard as if processed by filters or effects, such as distortion or echo. Lastly, 'hallucinated' sounds are those that arise internally, with no acoustic basis in the environment. Sounds in this category can be subdivided into different types, including hallucinated music, noise, voices, or silence.

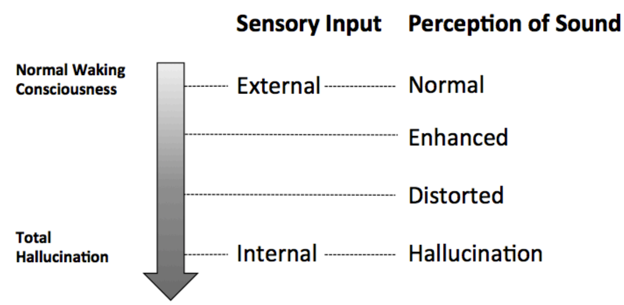

Figure 1: **Proposed continuum of auditory hallucinations**

We placed these sounds on a continuum since, at each progressive stage, we may consider that internal perception (which is present in all experiences of sound), plays an increasingly dominant role in defining the subjective experience of sound. This 'internal perception' encompasses various cognitive systems, including those of attention, memory, and inputs from other sensory modalities such as vision; the latter of which are commonly associated with synaesthesia [4], and have also been demonstrated through phenomena such as the McGurk effect [10]. The concepts of 'internal' and 'external' sensory inputs here are derived from Hobson's [6] work, and his 'Activation, Input, Modulation' concept of consciousness.

2.3 Specific Features

While our system outlines the main types of auditory hallucination, our previous study [18] also assembled a large body of text statements from individuals describing specific experiences of auditory hallucination. From these it is possible to extract statements describing particular kinds of phenomena that we can use as a basis to provide real-time audio mechanisms using computer audio techniques. This approach provides more tangible and focused outcomes when we begin to evaluate technological approaches since they serve as a baseline, which can later be assessed, rather than making abstract interventions based upon the continuum of auditory hallucinations. In this paper we explore three such mechanisms, which we shall first illustrate with reference to the text statements acquired previously.

2.3.1 *Selective Auditory Attention.* The first of our 'features' is 'selective auditory attention'. Selective auditory attention is a well-established concept in cognitive psychology. In early work by Broadbent [2], using 'dichotic listening tests', selective auditory attention was shown, and provided the basis for his proposition of a 'filter theory of attention'. This theory proposes that attention directs incoming auditory inputs, promoting attended sources for higher-level processing, while others are ‘filtered out’ and do not reach awareness. Subsequent studies such as Treisman [14] developed this theory, proposing that unattended sources are ‘attenuated’, and are passed for very limited higher level processing only.

Although selective auditory attention is a phenomenon experienced in normal waking consciousness, under ASCs the reports of intoxicated individuals seem to suggest that the operation of attention is significantly altered. In some cases, individuals seem more susceptible to complete absorption in a particular entity, for instance. Excerpts from the text statements obtained in our previous work illustrate this point:

“During this time I noticed a lot of things that I don't normally pay much attention to, in a serious way. Every single movement of my fingers was palpable, and the vibrations my vocal chords made were so amazingly easy to feel and control...”

“My attention was constantly scanning my surroundings, and so background noises became much more apparent.”

Alternatively, however, in some cases individuals reported a perceived broadening of their attention; that is, they claimed to be able to pay attention to more things simultaneously. For example:

“Listening to 'The Crystal Method'… their music sounds even more amazing than ever. Their music style sometimes has many 'layers' to it, and it feels like my (high-quality) headphones are playing 5 songs at once, and I can enjoy each of them with my undivided attention.”

“I am not hearing with my (attention-limited) ears any longer, but with my whole perception. I can hear a dog barking echoing from the wall over my right shoulder from the window to my left, a truck downshifting on [the] street a block and a half away, hear the dampening effect of the warmer, moister air next to the grass of the lawn as a tangible presence.”

These reports seem to suggest that the narrowing or widening of auditory attention may be a feature of hallucinations, and indeed, this is consistent with classic accounts such as Huxley’s *The Doors of Perception* [7], in which he memorably describes becoming absorbed in the creases of his trousers. In this paper, we focus especially on the idea of intoxicated states causing a narrowing of auditory perception, following Huxley’s account, though further development of this work might also look at ways to represent widening of attention.

2.3.2 Enhanced Sounds. As noted in our system of categorisation, experiences of ‘enhanced’ sound during intoxication are common; indeed, this is the most typical change to the experience of sound that occurs due to intoxication. The following quotes are indicative of the type of change that occurs, which we may reasonably attribute to intoxication:

“My attention then shifted to the music. It suddenly got very loud. The band sounded so good I had no idea how I had missed it before.”

“Music was also amazing, like a wall of sound, with some colours.”

“Music was very effective to hear and she could feel the sound as if it were currents of air moving in the room.”

“The music that was on sounded absolutely amazing. It was shocking! How on earth could they make music that sounded so good?! I wondered if those specific sound waves happened to be tuned to trigger euphoria in the human brain.”

Although individuals often report music being more interesting, enjoyable or meaningful, in some accounts the opposite occurs, and sound seems to be more foreboding or a source of anxiety:

“The music seemed to become metallic and foreboding”

“Noises from neighbours and a tooting on the street made me paranoid…”

Here then, we seem to find a further typical variation in perception, where sound and music can be more, or less, interesting, detailed, or enjoyable, in a way we can attribute specifically to the intoxicated state of the individual. It is also interesting to note that enhancements that are reported can relate to the intensity of sound sources and also to the timbral or frequency content of the stimuli.

2.3.3 Spatial Disruption. Lastly, another phenomena that we noted in some reports, is that of ‘spatial disruption’. In these cases, the individual may perceive sounds that seem as though they are more ‘close’ or ‘distant’ than usual, or otherwise perceive changes related to the spatial experience of sound, as incongruous with the acoustic properties of the environment in which the individual is situated. The following quotations illustrate this effect:

“My hearing began to get messed up. I couldn’t tell which direction sounds were coming from.”

“My perception of space was terribly skewed. The wind, the noise, the movement through space is overwhelming.”

“A car would be about four hundred yards or so down the street, but I could hear them as if they were about to hit me… It was very confusing to see a car very far away but hear it as if it were so close.”

“The sounds in the room of my companions talking quietly around me were echoing, as if I were in a stainless steel vessel, but I was unable to understand what they were saying.”

As with the other features, we may note that the specific effects seem to vary between individuals and instances of intoxication, yet 'spatial disruption' seems to be another common theme, and one that we will draw upon in this paper. As it is spatial, this type of phenomenon broadly incorporates temporal and phase characteristics, coupled with intensity and/or frequency-based elements. Although it is possible that confusion or mismatches over sound localisation can occur even during 'normal' states (for instance, due to acoustic reflections), the scenarios described in the reports suggest that the ASC are the key factor.

The features outlined in this section are by no means exhaustive, as our text statements also illustrate various other features, such as experiences of synaesthesia; for instance, experiences in which sounds and music trigger corresponding visual hallucinations. These other features will remain beyond the scope of this paper, though could also be explored in future work. Here however, we shall focus on the three features outlined in this section, and consider these as a basis for the design of real-time audio systems in a game engine.

3. THREE PROTOYPE MECHANISMS

Having identified three features of auditory hallucination, we can begin to devise specific mechanisms for generating these sounds using real-time audio systems within video games. The benefit of doing so should be to allow improved accuracy in the simulation of these effects for first-person POV video games, and also to allow them to be created more easily by having automated systems that produce these effects, removing the need for sound designers to generate each of these sonic experiences 'from scratch'.

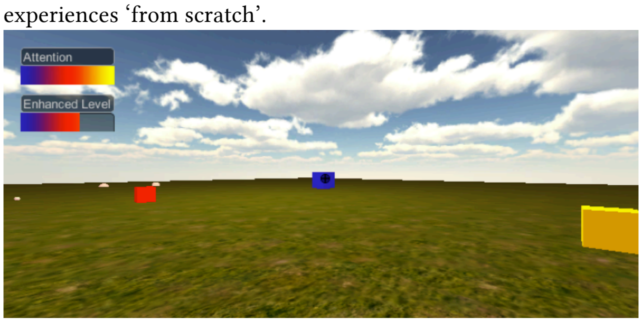

Figure 2: Screenshot from the prototype Unity game. The coloured boxes provide simple sound sources for testing out the auditory mechanisms. The power-meters in the top-left corner of the user interface indicate levels of 'Attention' to a particular sound source, and 'Enhancement Level', respectively.

In order to provide an early prototype of such a system, a simple demo game was created in the video game engine Unity, using basic geometric shapes. The game consists of a grassy plane that forms the 'land', a skybox, and a 'player' asset that allows navigation in first-person POV (Figure 2). Situated on the plane are several coloured boxes (cubes) that represent localised acoustic sources in the 3D world. These are assigned looping 3D sounds with distance attenuation (i.e. sounds that change in amplitude based on their relative distance from the player), such as synthesizer tones utilising a range of frequencies. In an actual game, these might be replaced with any sound emitting sources such as machines, radios, streams or game characters; here however, since we are only interested in modelling processes, coloured boxes that indicate the location of the sound sources are sufficient. This demo game provides a basis for the proof-of-concept audio mechanisms that we shall now describe.

3.1 Selective Auditory Attention

As noted previously 'selective auditory attention' involves the filtering or attenuation of sound sources in subjective perception. In our prototype game we model these as follows:

The attention of the player is taken based on which object the game character is looking at. This is calculated based on the central point of the player's view (or 'crosshair'), which casts a ray intersecting with whatever object the camera is pointing at.

While the player is paying attention (i.e. looking at) one of the sound sources (represented by the coloured blocks), a value for attention increases (Figure 3). This is represented in the demo with a simple power-meter. As this value increases, the other sound sources are attenuated using an envelope function, causing them to fade out. This produces the effect that when the player attends a particular sound source, all others are reduced, representing subjective attention to the one sound source only. Looking away from that sound source reduces 'attention', and all other sounds fade back into hearing. Similarly, looking at a different sound source causes the sound for the new one to be heard while others are faded out. In this way we provide a simple model of selective auditory attention.

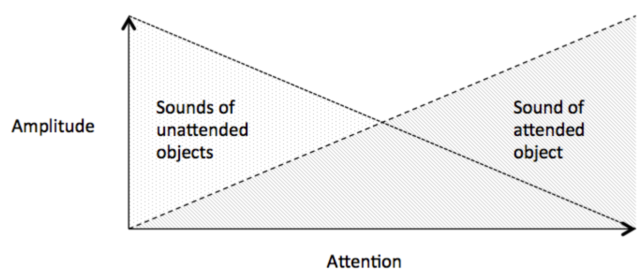

Figure 3: Diagram showing the 'selective auditory attention' function. As the player pays attention (looks at) a sound source, all others fade out, so that only the object of attention is heard.

3.2 Enhanced Sounds

Following our discussion, 'enhanced sounds' occur due to intoxication, and may cause experiences of sound to seem more bright, intricate, detailed, enjoyable or interesting than usual.

In our proof-of-concept game, we modelled this by implementing a value for 'enhancement'. This value is indicated visually with a power-meter graphical display. Changing the value of the bar causes the sound sources to cross-fade between different versions of the same sound loops, which have been prepared in advance with different equalisation and filtering processes. Three versions of each sound were prepared providing 'dull', 'medium' and 'bright' versions of the same sound, which are produced using a graphical equaliser and filters in a digital audio workstation (DAW). The 'dull version' subtracts high frequencies reducing the frequency range of the source material; the 'medium' version is close the original sound; and the 'bright version' boosts frequencies, creating an artificially enhanced sense of the sound spectrum. As indicated in Figure 4, increasing the 'enhancement' slider mixes between the three versions, producing ostensibly brighter sounds in the fully enhanced position, and duller sounds in the lowest position of the parameter.

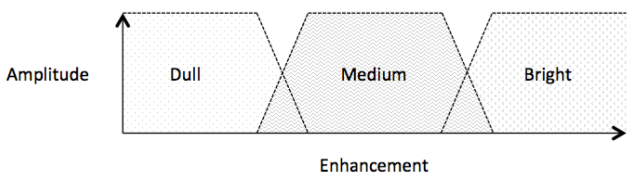

Figure 4: Diagram showing how the 'enhanced sounds' function changes the amplitude of sound sources. As the enhancement meter increases, the source material mixes between 'dull', 'medium', and 'bright' versions of the source material.

3.3 Spatial Disruption

The phenomenon of 'spatial disruption' in experiences of auditory hallucinations describes the experience of sounds that seem to emerge from a location other than where the individual would expect based on the physical position of the acoustic source.

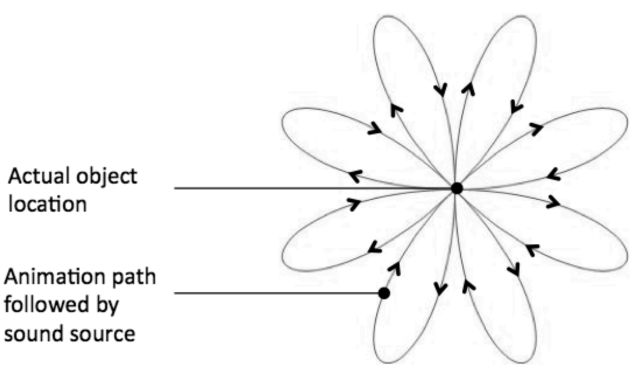

Figure 5: Diagram showing 'spatial disruption'. The sound source moves in an oscillating 'flower' pattern around the central point where the associated object is located in 3D-space.

Our Unity demo models this spatial disruption using sine operators, which allow us to variably modulate the distance of the sound source from its origin in time. This approach was conceived as a way to retain an approximate sense of where sound sources are located with regards to their associated objects, preserving some salient features of the acoustic scene, while also causing disruption. As indicated in Figure 5, this causes oscillations of the location of the sounds in 3D space, while the actual object (the box that you can see) stays in a fixed location. In a version of the prototype, additional spheres were attached to the moving sound sources, allowing us to observe and verify their path around the associated object.

4. STRUCTURAL DESIGN

The concept of 'ASC Simulations' that the prototype game is based on, presumes that eventually game engines could provide pre-designed packages for modelling the subjective conscious states of avatars, offering parameterised features that modulate graphics and sounds based on the conscious state of the game characters with minimum effort. For example, as discussed in previous work [17], we could provide an 'input' parameter that modulates between internal and external sources of sensory information. Similarly, the emotional states of a video game character could be defined according to valence and arousal models of emotion such as Russell's 'circumplex model of affect' [12].

Following this view, our Unity prototype places the scripts for the respective auditory mechanisms as features within a group entitled 'ASC Engine', which is located within the group of objects that make up the first-person POV game character (this larger group also includes assets such as the camera that represents the vision of the game character). We argue that this is the most logical place to locate the code, and indeed, eventually we could conceive of an 'ASC Engine' group of scripts being attached to multiple game characters as a way to modulate their functionality based on different states of consciousness. Figure 6 illustrates the structural location of the scripts in Unity.

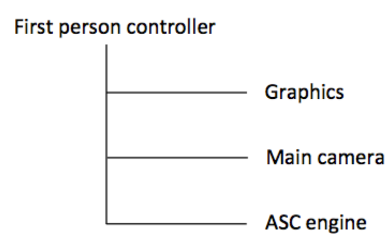

Figure 6: Diagram indicating structural design in Unity. The 'ASC Engine' provides the prototype features, and is located a subgroup attached to the main 'first person controller' group.

We propose that this structural approach is essential in order to make the principles we begin to outline in this paper scalable. Though the demo project we provide here has only a few assets, it would be straight-forwards to add many more, and achieve similar effects by adjusting the perceptual parameters of the player avatar, within the 'ASC engine'. This would allow the mechanisms outlined here to be applied to much larger and more complex scenes that have a greater number of sound sources. Critically, this is not the type of approach used in other examples we have looked at, which tend to trigger sounds of auditory hallucination when a player enters a specific location (e.g. walking down a dark corridor). The avatar-centred approach that we propose here offers improved scalability for a variety of situations. We propose that modeling features of subjective perception for avatars, through general parameters, will be an essential part of sound design for first-person POV media such as games in the near future.

5. INITIAL OBSERVATIONS

This project is a very early prototype, and for a further development we would aim to provide a formal evaluation of the auditory mechanisms based on a group of participants through a user experience study, potentially using a repertory grid or Likert evaluation process, as described in our earlier evaluation of ASC in games [3]. Such mechanisms would provide useful insight into the experience that users have of the auditory design mechanisms and how they can be evaluated. A challenge in doing so is in ensuring the users have a suitable benchmark or set of metrics that they can use to evaluate ASC experiences, since they may never have experienced these in real life. This presents a potential barrier to the validity of any validation study. To help mitigate for this, our work in [3] created a series of scales for ASC sound, synthesised from group norms that capture the broad sensory evocations. Similarly, providing users with a series of words or descriptions, such as those exemplars in Section 2 of this paper, and asking participants to match and weight those to aspects to their experience of the simulation, would be another approach for evaluation. Similarly, more traditional observational studies of users playing through the simulation, as in computer game user experience research [11], offer potential. Nonetheless, here we offer some initial observations on the system.

Considering first the 'selective auditory attention' mechanism, the manner in which we predict the attention of the user is an obvious limitation. For now, the mechanism of ray-casting based on the direction the player camera is pointing is adequate to illustrate the concept, but there is evidently room for improvement. An advantage of the current method is that it would translate well to virtual reality (VR) applications, where a limited field of vision necessitates turning the head towards objects to observe them, and thus may give a useful rough indication of attention. It could also be developed further by using eye-tracking technology, which may provide more accurate predictions of attention that do not require turning of the player's viewpoint. However, this still presumes a relationship between sight and attention that is not an accurate reflection of how attention actually occurs in the real world, since we know that auditory attention is not necessary related to what we are looking at. More sophisticated techniques could perhaps be devised based on biofeedback; for example, using Auditory Event-Related Potentials (ERPs) it is possible to register auditory attention using Electroencephalography (EEG), and this has been demonstrated effectively with consumer-grade EEG headsets such as the Emotiv EPOC, which is sold as a low-cost biofeedback device for gaming [1]. Such equipment might then provide a way to register the attention of the player to different sound sources in a gaming environment.

With regards to the 'enhanced sounds' mechanism, clearly a functional limitation is the need to pre-process sound sources. This would be very time consuming for a full game, and would require 3x the data for the audio assets, which could present problems as audio files are among the largest assets of a game already, and storage constraints remain an important concern for developers. A more practical solution would be the real-time processing of sound sources, and this could easily be achieved using modern game engines; it is a limitation of the 'free' version of Unity that we created the demo with, that meant we did not have access to such features. However, full-featured engines would be able to undertake such processing and variation without significant processing overheads and there is the potential to make this part of the design process simpler for the sound designer by including such steps in the manipulation of game audio events being designed in middleware packages, such as WWise or FMOD.

Lastly, the 'spatial disruption' feature was too dramatic and incoherent to be of practical use in its current form. We were using the in-built Doppler effect of Unity, which at the time did not offer a good quality spatial impression. With improved spatial algorithms, or by fine-tuning the Doppler shift parameters, this could be a much more interesting effect. For example, it is easy to image that this could provide an effective way to generate interesting psychosis effects in VR horror games, which disorientate the player through sound. Most likely for such purposes, slower oscillations would be preferable than the ones used here. Also, other patterns of disruption could be used, which move sound along various Lissajous curves, or other more randomised, non-periodic, paths of movement. Additionally, other acoustic properties of reverberation or echo could be modulated, allowing these to make spaces seem larger or more compact at times, imitating the 'drink me' distortions described in Lewis Carroll's *Alice's Adventures in Wonderland.*

6. DISCUSSION

The three prototype mechanisms for simulating auditory hallucinations discussed here represent an early foray into a novel area where more research is needed. Based on the data from our previous research, we have suggested three possible mechanisms for representing specific features of auditory hallucinations. These were chosen selectively, and eventually we would like to see these form part of a larger, comprehensive system for modelling conscious states and ASCs of game characters. Such systems will allow more accurate modelling of the cognition of game characters and avatars that are controlled by a player. The systems discussed here require further development, and in due course we would also aim to undertake a formal evaluation of them using empirical methods.

Work in this area can be associated with a growing field of activity where VR is being used to create experiences that represent or induce ASCs, either by inducing heightened states of fear as entertainment (e.g. *Affected the Manor,* 2016; and *The Hospital: Allison's Diary*, 2016, on Samsung Gear VR), or by producing relaxing or meditation experiences (e.g. *Zen Zone,* 2016; and *Guided Meditation VR,* 2016, also on Gear VR). Research is needed to explore how such experiences can be designed effectively; to demonstrate what effects they have on their users; and to ensure that they are used in ethically sound ways. If we can do this, the potential is there to alter consciousness ethically in range of ways that may be entertaining, and even therapeutic for the user, depending on the aims of the software and its successful realisation.

A APPENDIX

The source code, and several demonstration videos of the project discussed, are available in the supporting zip file available here: http://www.jonweinel.com/media/ASC_Sim_Supporting.zip [Accessed: 7th June 2017]

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