Sound Through The Rabbit Hole: Sound Design Based On Reports of Auditory Hallucination

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ABSTRACT
As video game developers seek to provide increasing levels of realism and sophistication, there is a need for game characters to be able to exhibit psychological states including 'altered states of consciousness' (ASC) realistically. 'Auditory hallucination' (AH) is a feature of ASC in which an individual may perceive distortions to auditory perception, or hear sounds with no apparent acoustic origin. Appropriate use of game sound may enable realistic representations of these sounds in video games. However to achieve this requires rigorous approaches informed by research. This paper seeks to inform the process of designing sounds based on auditory hallucination, by reporting the outcomes of analysing nearly 2000 experience reports that describe drug-induced intoxication. Many of these reports include descriptions of auditory hallucination. Through analysis of these reports, our research establishes a classification system, which we propose can be used for designing sounds based on auditory hallucination.

Categories and Subject Descriptors
H.5.5 [**Information Interfaces and Presentation**]: Sound and Music Computing – *methodologies and techniques.*

General Terms
Design, Experimentation.

Keywords
Sound Design, Altered States of Consciousness, Video Games, Auditory Hallucinations, Game Sound.

1. INTRODUCTION
In recent years, first-person point-of-view (POV) video games, such as first-person shooters (FPS), have seen increasing levels of complexity with regards to narrative techniques and character development. These can be seen partly as attempts to match the levels of sophistication provided by other mediums such as film. As a result, game characters have become more developed with regards to notions of psychological condition. The need has therefore arisen for game characters to exhibit 'Altered States of Consciousness' (ASC), including states of dream, delirium, hallucination and psychosis. In order to effectively signify ASC within games, game-makers have sought to provide methods through which ASC features can be represented through the use of sound and graphics. Through use of appropriate techniques, it is possible to adapt the representation of the game environment, in order to reflect these alternate perceptual states.

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In previous work Weinel has discussed various examples of games that represent intoxicated states [19]. An early example is *Fantasy World Dizzy* (1989) in which the egg-man protagonist named Dizzy may consume alcoholic spirits, causing involuntary tumbling to ensue. Subsequent titles such as *Death Rally* (1996), *Duke Nukem 3D* (1996) and *Grand Theft Auto III* (2001) have included drugs as 'power-up' items. Demarque and Lima have also discussed 'auditory hallucinations' (AH) in the context of horror games such as *Silent Hill* [5] and journalists have commented on the trend of including hallucinations in various other recent titles [2]. Other related work, which forms a background to this study includes: Weinel's research regarding the composition of electroacoustic music based on ASC [20]; Wale's examples of sound design based on verbal AH [17]; a recent study by Kumar *et al.* in which a participant notated their own musical hallucinations [12]. Our research here builds upon this existing work, but devises a new methodological approach that utilises online experience reports, and focuses on drug-induced AH specifically.

The premise of our work in this area is that rigorous approaches may be effective in establishing systematic ways of representing ASC in games, which do not rely on clichés, but are grounded in the reality of ASC experiences[1]. Such approaches may be established by referring to academic research regarding ASC, such as psychological studies, and accounts of ASC provided by experience reports. It is then possible to identify for various types of ASC, the typical features that characterise these perceptual states, and other relevant factors such as the form and structure of the experience. These features can then be used as a basis for the design of corresponding graphics and sounds in video games, to provide 'ASC simulations'.

Our current work in this area focuses in particular on states of hallucination; those ASC produced by 'psychedelic' drugs such as Psilocybin mushrooms, Lysergic acid diethylamide (LSD) or

[1] The authors acknowledge that such realism may not be sought for all games, since stylised versions of reality are often more preferable and entertaining. Nonetheless, we suppose that value exists in facilitating the tools for such realism; these can then be adapted as required.

Dimethyltryptamine (DMT). These drugs cause various changes to consciousness, including distortions to time perception, the perception of geometric patterns and auditory hallucinations [20]. Those changes that have a visual or auditory component can in principle be imitatively designed using computer sound and graphics. The focus of our discussion here is on AH that involve changes to the subjective perceptual experience of sounds that have an acoustic source in the external environment, and the perception of sounds that have no apparent acoustic origin. For these types, sound can be designed that represents the subjective experience of auditory hallucinations with some degree of realism.

In order to inform the design of these sounds, our paper examines the types of auditory hallucination that people typically experience in a range of drug experiences. Through qualitative analysis of nearly 2000 experience reports, across substances such as caffeine, alcohol, amphetamines and various natural and synthetic hallucinogenic substances, a classification for auditory hallucinations is provided. This classification is then used to inform a sound design methodology based on auditory hallucination, with the intention of providing improved realism.

This study discusses a possible method for designing sounds based on the subjective, first-person experience of auditory hallucinations. This method will be of particular relevance to video games, since they are among the most pervasive forms of modern media that make extensive use of first-person POV representations [3]. However, the method discussed could also equally be applied in other situations where first-person representations of ASC are sought; composing electroacoustic music or sounds for cinema, for example.

2. INPUT SOURCES

In previous work regarding the representation of ASC in sound, music and computer graphics [21], Hobson's neurologically-based 'state space' concept of consciousness [8] has provided a useful lens through which to consider ASC. In summary, Hobson provides an 'Activation, Input, Mode' (AIM) model of consciousness, which uses three axes to model how consciousness changes in various states such as normal waking consciousness, non-rapid eye movement (NREM) sleep and rapid eye movement (REM) sleep. 'Activation' relates to the level of brain activity, 'Input' relates to the exchange of information with external or internal sources, and 'Mode' relates to memory.

Of particular interest to our current work is the Input axis. The Input axis describes the way in which different states of consciousness may affect the type of visual or auditory stimulation received in the brain. For example, at the 'external' end of the axis, an individual may be focused on visual or auditory sensory information that is received from the external environment; as is the case in normal waking consciousness, if one gazes out the window (for example). At the 'internal' end of the Input axis, attention may be focused upon visual or auditory simulation that originates in the brain, rather than the external environment. For example, during dreams or hallucinations, vivid images or sounds may be heard which we suppose do not originate in the physical, external environment.

This notion of Hobson's Input axis, and 'internal' or 'external' classifications of auditory or visual stimulus is critical to our discussion here, since they can be used to establish a conceptual understanding of different types of audio input that would be needed, in order to create an interactive system that simulates hallucinatory states. We may therefore state that a system that simulates auditory hallucinations requires:

External Input Sounds: Sounds that represent the acoustic environment of the game world that is external to the game character.

Internal Input Sounds: Sounds that represent auditory experience that the game character subjectively experiences within the game world, which originate internally.

Most first-person games already represent external input sounds. They generally do so through either stereo sound sources that emit from (or close to) entities or specific locations in the virtual game world using '3D sound'[2], or through general background ambient sound that is diegetic ('2D sound').

Internal input sounds are explored in some games to a more limited extent. For example, some games may use imagined sounds or auditory hallucinations that trigger when a game character enters a certain area. These sounds can similarly propagate from specific locations in the game world, or as diegetic 2D Sound.

Through the course of this paper, we will explore auditory hallucinations with regards to both external and internal input sources, in order to establish how more realistic approaches may be achieved through composites of both internal and external sound.

3. AUDITORY HALLUCINATIONS

3.1 Background

A large amount of existing research regarding auditory hallucinations focuses on the 'auditory verbal hallucinations' (AVH) ("hearing voices") experienced in schizophrenia, as described in 70% of cases [18]. However auditory hallucinations may also be experienced in other scenarios, such as in cases of tinnitus, neurological changes such as stroke, or due to drug use [14]. Auditory hallucinations may also consist of hallucinated music [12] or other 'non-verbal auditory hallucinations' (NVAH) such as bangs [9]. In rare cases loud noises may be heard during sleep, as described in the rare condition of 'exploding head syndrome' (EHS) [7]. Sensory deprivation may also induce auditory hallucinations [11].

Through previous analysis of accounts of drug-induced hallucination, it was noted that NVAH such as hallucinated noises appear to feature prominently. For instance, these appear strikingly in Strassman's studies, in which participants provide accounts of their DMT experiences:

> '...it was quite rare for volunteers to hear formed voices or music. Rather, there were simply sounds, variously described as "high pitched", "whining and whirring," "chattering," crinkling and crunching." Many remarked on the similarity of DMT auditory effects to those of nitrous oxide, where there is a "wah-wah," oscillating, wavering distortion of sounds.' [15]

While various systems for the assessment of auditory hallucinations exist [13], these are intended principally for the assessment of AVH in schizophrenia. At the time of writing we

[2] The definitions of '3D Sound' and '2D Sound' used here are those utilised by the Unity game engine. '3D Sound' is affected by the relative location of the listener, while '2D Sound' ignores spatial processing [16].

are not aware of any large-scale studies that attempt to use these systems to assess and classify the auditory hallucinations experienced in drug-induced hallucinations. Existing academic resources provide a general indication of the type of sounds that may be experienced in auditory hallucinations. However, few of these provide detailed descriptions of the types of sounds heard in drug-induced AH, and those which do (such as Strassman's study) normally describe the experiences of only a few participants.

In order to provide a more detailed impression of the types of sound experienced in drug-induced AH, a review of experience reports was undertaken using an online database of self-reports. The results of this provide us with a large number of descriptions of drug-induced AH, while also providing a general indication of how frequently various types of auditory hallucination are described across various substances. This information is then used to inform our methodology for designing sounds based on drug-induced AH.

3.2 Methodology

The Erowid Experience Vaults database is the primary resource used for the investigation [6]. This database contains over 20,000 English language accounts of experiences that are provided voluntarily by users. These 'experience reports' contain descriptions by individuals of their experiences as a result of consuming various intoxicating substances. The database covers all well-known intoxicating substances, including substances that are both legal such as Caffeine, and illegal such as LSD in most Western countries. It also includes many lesser-known intoxicating substances, such as unusual plants or chemical compounds that have been recently developed, that may have intoxicating properties. From those reports we examined, around ¾ were reports written by men, while ¼ were written by women. Reports appear to predominantly originate from North America, though various other countries (mostly English-speaking) also have a presence.

The premise of the investigation was to analyse the text provided by these reports in order to identify descriptions relating to sound, including normal descriptions of auditory experience, and auditory hallucinations. Due to the large volume of reports contained within the database, and constraints on time, it was decided not to analyse all reports. Instead the investigation explores a list of some of the most well known intoxicating substances, including caffeine, alcohol, amphetamines, opiates, anesthetics and various natural and chemical hallucinogens. For each substance, up to 150 reports were analysed, though for those substances where less than 150 were available, a fewer number were analysed. In total nearly 2000 reports were analysed across all substances under review. Since some reports contain accounts in which multiple different substances have been consumed, the study only looks at reports that list a single substance, where possible.

Reports were processed using the Nvivo qualitative analysis software to provide a keyword search for words related to 'sound', 'audio' and other similar terms. From these reports, each identified phrase that included a keyword was manually examined. Through an initial iterative process, a list of categories was identified, as detailed in the following section. Once this system of categorisation had been established, the analysis of the reports began in full. Each sentence, statement or paragraph related to auditory experience within a report was associated with the relevant category node. Therefore, for each substance analysed, an extensive list was produced containing short descriptions of auditory hallucination (document available in supporting files - see appendix). In addition to the list of substances, basic statistical analysis was performed to show the percentage of reports for each substance containing descriptions of auditory hallucination for each category. This therefore provides a general indication of which substances are most commonly associated with reports of auditory hallucination, and the distribution of those reports across the categories established. This, together with an extensive list of descriptions of auditory hallucinations across the different substances then provides a basis for sound design.

There are some limitations to this approach that should be noted. Firstly, although Erowid carry out basic monitoring of the reports, there are no other methods through which the validity of the reports can be verified. It is entirely possible that the database could contain some fake or fictitious accounts. Perhaps more likely, is that some reports may exaggerate or embellish the truth to make the account more interesting. Additionally, the quantities, quality and method of consumption vary dramatically between reports.

Some reports also lack sufficient detail, or make only vague statements about sound that are hard to classify. In particular, for some examples it is difficult to distinguish the boundaries between inner speech or mentally imagined sounds and hallucinated sound. Additionally, it is rarely possible to distinguish psuedo-hallucinations: in which the person is aware of the un-reality of what they have heard, and true hallucinations: in which the person believes the hallucination to be real [1].

Despite these limitations, the investigation does appear to give a general indication of the types of auditory hallucination that people commonly describe, when under the influence of various intoxicating substances. The categories identified do not conflict with preliminary research or psychological studies where proper experimental controls are in place. Therefore, we presume that the basic categories of auditory hallucination are sufficiently reliable. The study also provides a substantial resource, containing hundreds of short descriptions of hallucinated sound. We propose that these, in combination with the categorisation system are sufficient to support the design of sounds that represent auditory hallucinations.

3.3 Categories of Sound

This subsection details the system of categorisation that was established through analysis of the experience reports:

0. Normal

This category applies for descriptions of normal real-world sounds that seem to be heard as they would normally with no apparent change due to intoxication.

"I awoke to noises of people moving around in the room."

"Upon arriving in my room, I turned on some music and lit up a joint."

"At the main stage mellow progressive psy-trance was playing and lots of people were dancing in the open field enjoying the sun and the music."

1. Normal enhanced

This category applies for descriptions of sound, music or voices that would occur normally in the 'real-world'. The sounds are not described as being qualitatively different in any way, but are

described as having enhanced significance or being more/less enjoyable than usual, with the change seemingly to be due to intoxication.

"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."

"About nine hours into the experience, I gradually started to come down and resumed creative activities, playing each note on the piano with great delicacy and love, music being made an essential aspect of my life."

"The music was enveloping me and I found myself on the dance floor dancing like I had never danced before."

2. Normal distorted

This category describes sounds which would occur normally in the 'real-world', but which are heard as some how different due to intoxication. For example, a person might describe the voices of their companions as seeming to have a flange, reverb or delay effect, which seems to have been caused by intoxication.

"As I sit down my eyes close and visions emerge with the background sound of the TV, audio was now being slowed slightly but not in a scary way, it was pleasant."

"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."

"People were quietly talking… their voices sounded strange, with hissing noises like a broken radio, or sometimes suddenly talking too quickly and high pitched."

3. Hallucinated noises

This category describes sounds that seem to have no real-world origin, but are caused by intoxication. For example, many people describe buzzing noises or similar which are attributed to hallucinogens and may mark the intensification of a 'trip' or transition to a different phase. This category is also used as a generic category for vague descriptions of hallucinated sound.

"Immediately, there is a noise, like an oscillator that starts as a low zoom, going higher and higher, louder and louder."

"Next I remember a frequency noise with lots of chrome silver squares spinning and morphing fast with the noise and the visionary chrome squares getting faster and faster within seconds and I was getting to think if I should be frightened but I lost that thought and a sheer feeling of amazement took over me."

"The auditory hallucinations start. Normally nothing too bizarre, random clicks, small knocks, but some sounds get strong later."

4. Hallucinated music

This category describes hallucinated music that seems to have no real-world origin. An individual may describe hearing music, caused as a direct result of intoxication.

"The sound [in my head] was like the most beautiful music I have ever heard, although it had no melody, just rapidly changing pitches and tones"

"The zooming sounds alone were incredible and seemed like parts of a complex, mystical song that was being composed specifically for me."

"Music began to play. It wasn't from a stereo, it was from my head. I could decide a song, and it played. The Rolling Stones "Paint it Black" began to play in my head. I am not sure why I chose this song, but it began to play and it sounded amazing."

5. Hallucinated voices

This category describes sounds which seem to be entirely of hallucinatory origin (i.e. no entity or person in the real-world is speaking), and which are verbal. This could be either a voice in the person's head or a conversation with a hallucinated being.

"I could hear a thousand voices talking to me at the same time, creating an intense yet soothing buzz, almost like a meditating hum, and at the same time see millions of complicated equations whizzing around me."

"In my visions I see a colourful featureless man holding together the tectonic plates of planet Earth. His soul whispers 'Go inside the man, visit inwards'."

"I could hear thousands of annoying, little demons teasing me."

6. Hallucinated silence

This category applies for situations where due to intoxication there seems to be an absence of sound. For example, the person may describe all sounds seeming to stop (with no apparent cause in the external environment).

"I remember glancing over at my friends as they would walk into the room and see their lips moving as they were trying to talk to me but I heard nothing."

"The next step was the elimination of my normal six senses. The last to go was hearing, but the music did eventually fade from my perception. Since I could no longer sense the physical world, it began to dissolve in my mind as well. I entered a stage where I was the only thing that existed."

"Then I noticed that I no longer noticed that noise, but could not hear the music either. I could hear nothing."

3.4 Synesthetic Sounds

In addition to the principle categories identified above, many descriptions also discuss the phenomenon of 'synaesthesia', which involves the blurring of the senses; sounds may acquire a smell, colours assume a taste, etc.

"The psychedelic music inspired images of bright colored snake-like energy patterns moving over me."

"I could have spent the rest of my life lost in the intricacies and combinations of songs and languages of that beautiful moment. Each sound was its own language, with its own purpose and direction. Each sound had its own corresponding color and feeling."

"Otherworldly geometries and angles morphed along with the music in a sort of ancient dance."

In examples such as these, most commonly, sounds appear to trigger associated images. Often the sounds themselves are not described as qualitatively different. Therefore, since our method aims to result in sound that approximates the subjective auditory experience, we do not explore this concept in the current work presented.

However, further developments of this work in an audio-visual context (such as a game engine) will likely take this synesthetic

concept into account, since sounds could be designed to correspond with visual forms, or could be used to trigger associated hallucinated imagery. A significant body of existing audio-visual work already exists that already explores this concept; we discuss this feature in a large contextual review of 'visual music' and associated work elsewhere [22], and use this approach in our own *Psych Dome* project [23].

3.5 Sound Categories in Relation to Input

Each of the sound categories discussed can be considered in relation to Hobson's Input axis. Table 1 indicates how categories can be considered with regards to external and internal inputs.

Table 1. Categories of Sound in Relation to Hobson's Input Axis

Category	Input
0 - Normal	External
1 - Normal Enhanced	External
2 - Normal Distorted	External
3 - Hallucinated Noises	Internal
4 - Hallucinated Music	Internal
5 - Hallucinated Voices	Internal
6 - Hallucinated Silence	Internal

Elaborating on Table 1, it could be argued that categories 1 and 2 represent a shift towards the internal part of the axis; enhanced and distorted sounds both exhibit changes to sound that appear to result due to intoxicated distortions to perception. These changes may be the result of internal subjective interpretations causing changes to the subjective interpretation of sound. Such phenomena may be referred to as illusions, rather than hallucination, but the boundaries are not clearly defined [1]. It is possible then, that auditory hallucinations may be considered on a continuum running from external to internal, where central points consist of external sounds that blend or morph together with internal sounds. For the purposes of our discussion, this may have useful implications for the design of sounds; similar transitions may be created using amplitude fades, dynamic filtering or spectral morphing techniques.

Though we propose that a continuum approach should be adopted, the basic binary categories remain significant, since they distinguish two fundamentally different sources of sound. Sounds can be designed with respect to internal and external sources, which are then subjected to further mixing and manipulation to produce transitions and composites of internal and external source. While the work discussed here explores this through 'fixed' (pre-designed) recordings, Figure 1 shows how we anticipate this might work in a real-time interactive system: internal and external input sources are provided, which then undergo further real-time processing using an 'ASC engine', which is directed by an input parameter.

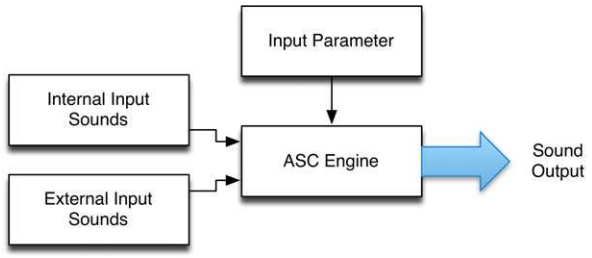

Figure 1. Proposed system for interactive sounds that represent auditory hallucination.

3.6 Frequency of Descriptions

Basic statistical analysis was performed on the data collected, which enables us to identify the percentage of reports containing certain types of description. Figure 2 shows the percentage of reports containing descriptions of 'auditory hallucination'. For our purposes here, 'auditory hallucinations' consists of descriptions that relate to categories 2-6 under the classification system described. This system was chosen since these are the categories for which sound is qualitatively different due to intoxication, or is entirely hallucinated; it was also noted that the authors of the accounts often describe distortions to the perception of external sounds as 'auditory hallucinations', so it seems reasonable to place the boundary at this point.

As expected, the substances that are considered to have hallucinogenic properties contain a greater number of descriptions of auditory hallucination. Substances that are not hallucinogenic such as alcohol and caffeine contained fewer descriptions of auditory hallucination. However, these substances do still contain some accounts of auditory hallucination; for example, several accounts describe symptoms of withdrawal from alcohol dependency, which include severe and persistent auditory hallucinations.

Figure 2 also highlights how common descriptions of auditory hallucination are for the main psychoactive substances: ¼ of LSD reports and nearly ½ of DMT reports describe auditory hallucinations. This translates into hundreds of unique accounts of auditory hallucination.

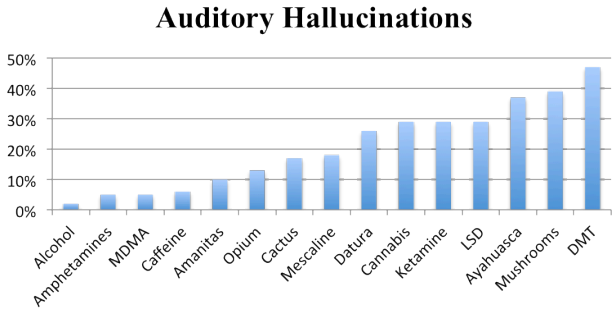

Figure 2. Percentage of reports containing auditory hallucinations.

Figure 3 indicates the percentage of reports for each category of sound, across psychoactive substances only. While a table was produced for each substance indicating the distribution of descriptions for each category, this table is provided as a general, concise indication of what these other tables show: that generally speaking, the most common descriptions of sound are either

normal sound, or enhanced sound. In general, the most common descriptions are of sound and music being more enjoyable as a result of intoxication. Clearly from the reports, this is an effect that is often specifically sought, and many accounts describe the selection and use of various music in order to heighten the experience in combination with the drugs.

Figure 3 also shows that among internal hallucinated sounds, hallucinated noises are the most common, before hallucinated voices. This may seem surprising, since current examples in video games, such as those discussed by Demarque and Lima, focus on voices (AVH). However, the important point to note is that such examples tend to focus on auditory hallucination arising from schizophrenia; essentially used to simulate madness in horror games. Indeed, the research discussed previously confirms that AVH is the dominant form of AH in schizophrenia – so this approach is appropriate. However, what our data may indicate is that a different approach is needed for designing hallucinatory sounds for drug-induced AH, where voices may not be the dominant form.

Hallucinated music was less common, though around 1 in 20 reports still describe this, while hallucinated silence or deafness reports were in the minority.

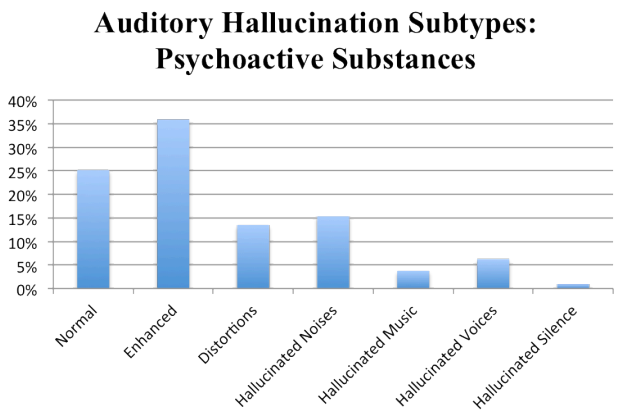

Figure 3. Percentage of reports containing each category of sound, across substances classed as 'psychoactive'.

4. DESIGNING SOUNDS BASED ON AUDITORY HALLUCINATIONS

4.1 Overview

As a result of our preliminary investigations, and through the analysis of nearly 2000 experience reports, a system of classification for auditory hallucinations was established, and hundreds of example descriptions were extracted. These outcomes can be used to inform the design of sounds based on auditory hallucinations. While the principle aim of this paper has been to establish the necessary framework for approaching the design of these sounds, it was considered appropriate to put theory into practice by designing a small range of sounds for each category, and exploring methods through which transitions between different simulated ASC may occur, with regards to the auditory components represented. This section therefore describes practice-based research, through which the approaches are demonstrated; enabling us to discuss how the theory presented may lead to actual sounds, using the approaches of computer music.

4.2 Designing Input Sources

Hobson's Input axis provides a useful starting point through which to consider the fundamental categories of sound that are required. All sounds discussed can be derived from either modifications to external or internal sounds, or a combination of the two.

External sounds are created in the usual way; through the acquisition of sounds relating to acoustic sound sources or environmental ambience, relating to a specific location. These can be acquired through sound recordings made in the field, in the studio, through the use of pre-existing sound libraries, or combinations of these.

The source material for internal sounds can be similarly created using the wide range of techniques that are possible with computer music. Generally speaking, source material may be provided via sound recordings, or various techniques in sound synthesis.

While fairly generic, the internal/external categories of sound are of fundamental use at the initial stage when considering how to assemble source materials for further manipulation. Though it is beyond the scope of this paper, these distinctions shall also become significant when developing interactive systems for simulating subjective auditory experienced based on models of ASC.

4.3 Designing Sonic Materials

In this subsection we briefly describe possible approaches for designing sounds based on AH. Sound examples are provided which demonstrate some possible sounds for each category. These sounds are available in the supporting materials that accompany this paper, please see appendix.

0. Normal

Normal sounds can be designed using standard techniques in sound recording and arrangement. Our sound example consists of a short scene, constructed using sound recordings of background ambience, cars and footsteps.

Sound example 1 (0:53)

1. Normal enhanced

Enhanced sounds are not described as qualitatively different to normal sounds. There are therefore two possible approaches: we may either use identical sounds to those used in category 0, or we may attempt to imitate the subjective experience of enhancement, through the use of subtle modification to amplitude, frequencies and separation of sounds. In the sound example below, we adopt the latter approach. The extract uses the same materials as the previous sound example, however the sonic materials have been adjusted in order to reflect the focus of attention on particular sounds. This is achieved through subtle use of envelopes for amplitude and panning, and adjustment of EQ to bring out certain properties of the sounds. For example: footsteps are heard with reduced background noise and enhanced high frequencies (0:12) and the low frequency components of a passing car are emphasized (0:19).

Sound example 2 (0:53)

2. Normal distorted

Sounds in this category may be produced by processing the external source material using suitable DSP processes. Our sound example develops the previous scene by adding artificial reverb to

the footstep sounds (0:15), and adding some distortions to the bass material that was emphasized previously (0:19). These distortions include a combination of filters, EQ and flanger effects, with various parameters automated using envelopes and LFOs. A harmonic comb-filter effect can be heard prominently (0:28).

Sound example 3 (0:53)

3. Hallucinated noises

Hallucinated noises can be created using source material such as recorded sounds and/or synthesis. These can be processed using typical computer music approaches, such as filtering, time-domain manipulations, spectral processes etc. Our sound example consists of metallic sounds which have been processed with granular synthesis and time-stretching effects.

Sound example 4 (0:25)

4. Hallucinated music

Category 4 includes various descriptions ranging from the perception of existing musical compositions by pop artists, to descriptions of choral music and music involving strange noises or tones. Pre-existing musical material could be utilised, providing the necessary copyright persmissions are obtained. Alternatively, music could be specially designed. Some descriptions of 'alien music' or music involving strange noises or tones, could be addressed using compositional strategies associated with electroacoustic music. Our example consists of some synthesizer-based music that includes harmonic, inharmonic and reversed sounds.

Sound example 5 (0:33)

5. Hallucinated voices

Hallucinated voices may be designed using voice actors to provide source material. Using the experience descriptions as a starting point, specific phrases can be designed, as well as ambiguous vocal utterances or whispered voices. The resulting materials can then be processed with granular synthesis, spectral processes, vocoding or other effects. The following sound example was created using student voice actors to provide the source material, with some additional processing and spatialisation. The utterances are based on specific descriptions from the experience reports.

Sound example 6 (0:23)

6. Hallucinated silence

This category can be 'designed' through the absence of sound in relativity to other sounds.

Sound example 7 (0:10).

4.4 Composite Examples

Several audio composites (or miniature electroacoustic compositions) were created which demonstrate the processes described above in combination with both internal and external sounds. These composites demonstrate how the various types of sound may work together in a fixed media form. Developing this work further, systems could be developed which would enable similar composites to occur in real-time within a game engine.

The first of the example composition combines sonic materials discussed previously in sound examples 1-5. It therefore demonstrates various external sounds with varying degrees of enhancement and distortion, and internal sounds in the form of hallucinated noises and music.

Composition example 1 (0:59).

Several further miniature compositions were also created. These present various auditory hallucinations in an external context. Ambient environmental sounds were combined with spot sound effects, and auditory verbal hallucination sounds were created using student voice actors. As each of these miniatures is based on a specific description from the experience reports, a spoken-word introduction has been provided which describes the original account. The composer's interpretation in sound then follows.

Composition example 2: Amanitas (0:38)

Composition example 3: Ayahuasca (1:09)

Composition example 4: Cannabis (1:07)

Composition example 5: Datura (1:29)

Composition example 6: LSD No.1 (1:10) [4]

5. CONCLUSIONS

Through the course of this paper we have demonstrated a conceptual approach for designing the sounds associated with drug-induced auditory hallucinations, by referring to research and experiential accounts. In order to enrich the brief descriptions provided in existing psychological studies, which typically only describe the experiences of a minority of participants, we carried out qualitative research of nearly 2000 accounts from an online database of drug-induced experience reports.

From the reports analysed, and through reference to Hobson's 'state space' model of consciousness, a system of classification was devised. Descriptions of sound including auditory hallucinations were then assigned to these categories, which can also be considered to form a continuum from internal to external Input sources. Through the analysis undertaken, hundreds of example descriptions were extracted, resulting in a sizeable document that serves as a reference that can be used for designing sounds.

Statistical analysis indicating the percentage of reports containing descriptions of hallucinations, enables us to confirm that psychoactive substances provide the most reports of auditory hallucination, and indicates which sub-types of AH are most common. Although this aspect of our work can only be considered as a general marker, it suggests that hallucinated voices are not necessarily the most common type of auditory hallucination for drug-induced psychedelic experiences. Existing examples in games tend to focus on hallucinated voices; this may be appropriate for representation of schizophrenic states. However our research suggests that for drug-induced AH, other types of sound should also be included. Similarly, while our study has focused on drug-induced AH, it may also be appropriate to consider some of these other sub-types when designing sounds for other types of AH.

Although the approach of using online experience reports has some clear limitations, the sheer quantity of reports available may make this approach to gathering information of potential interest for other related work. More generally, we may consider the possible use of online surveys and databases as a means to 'crowd source' information regarding the experience and interpretation of sound. However, the inherent problems identified here may also suggest the need to treat such resources carefully, and consider

cross-referencing with other more controlled sources such as clinical trials.

The systematic method developed here has been demonstrated with regards to some example sounds for each category, and a short example composition provided, to evidence how such sounds might be arranged in combination. The extension of this work in a gaming context will be to develop an interactive system, using a game engine such as Unity. We have outlined a possible framework for such an interactive system. Further development of such a system would also likely take into account systematic ways of dealing with features such as the memory of the game character, in order to construct the contents of the hallucinations. Such approaches may provide improved ways to integrate AH features in the context of game narratives.

Similar approaches may also be applied to other aspects of game design such as computer graphics; indeed, this research forms part of a larger ongoing project related to 'ASC simulations', which explores similar concepts with regards to graphics, and seeks to provide suitable forms of interactivity using biofeedback. The reader may also be aware that the fundamental concepts discussed here with regards to game sound also need not be limited to this area, and could be relevant to other areas such as sound design for film, or electroacoustic compositions based on auditory hallucination.

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8. APPENDIX

Supporting materials for this paper, including the sound examples and a (draft) version of the 'Auditory Hallucinations: Experience Descriptions' document are available online:

http://www.jonweinel.com/media/Weinel_AH_supporting.zip

[Accessed: 28th July 2014]