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CZECH TECHNICAL UNIVERSITY IN PRAGUE

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SIMR

Simulating the phenomena of altered states of consciousness using virtual reality

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Diplomová práce

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SIMR

Simulace fenoménů pozměněných stavů vědomí pomocí virtuální reality

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Školitel: Ing. Josef Kortan

Abstract

TODO

Acknowledgements

TODO thank sci-hub

—Jakub Hlusička

“Not everything that is faced can be changed, but nothing can be changed until it is faced.”

—James Baldwin, As Much Truth as One Can Bear (1962)

Contents

1 Introduction

Contents

1.1 Problem Statement

This thesis is focused on the development of a virtual reality (VR) application that simulates select aspects of altered states of consciousness (ASCs; further defined in 2.1) typically induced by classical psychedelics such as LSD and psilocybin/psilocin. We focus primarily on the recreation of the ASCs' effects on sensory perception using an analytical approach.

1.2 Motivation

Due to their high degree of immersion, VR systems, with head–mounted displays (HMDs) in particular, offer a unique opportunity for recreating certain aspects of ASCs.

1.2.1 Art and Media

ASCs of various forms have had a significant influence on art for millenia. Earliest signs of inductions of ASCs via neurotropic substances have been found possibly as early as 60,000 BC (Guerra-Doce 2015). ASCs continue to be depicted in or influence contemporary popular media.

An analysis and a recreation of certain aspects of ASCs may serve as a reference point for recreating those aspects of ASCs in popular media.

1.2.2 Education

While experiencing a simulation of an ASC is unlikely to be fully representative of the ASC the simulation is modelled after, we propose that the simulation may be significantly less inducive of difficult experiences coloquially known as "bad trips".

This may be a viable alternative form of experiencing certain aspects of ASCs, while the possession or consumption of mind–altering substances is illegal in most countries. The resulting VR application may serve as an educational tool about ASCs which would not require as controlled of an environment as is required in psychedelic–assisted psychotherapy.

1.2.3 Research and Psychotherapy

Aday, Davoli, and Bloesch (2020) make an interesting observation, that psychedelics and VR are utilized in tandem to enhance the experience of recreational users. Moreover, the authors claim that VR could also be used to optimize and tailor the therapeutic setting during psychedelic sessions.

Most importantly, however, the authors state, that:

> [...] VR may be a useful tool for preparing hallucinogen-naïve participants in clinical trials for the sensory distortions experienced in psychedelic states.

Nonetheless, as mentioned previously, care should be taken to ensure that users experiencing the simulation are informed about the simulation not being fully representative of the ASC it is modelled after. While a VR simulation may be suitable for simulating sensory effects of ASCs, other effects, such as the effects on cognition, may be much more difficult, if not impossible, to directly replicate via VR technologies alone. If uninformed, users may gain a false impression about the ASC.

Greco et al. (2021) propose that simulated hallucinations may be used to investigate neural mechanisms of conscious perception without difficulties posed by pharmacologically-induced ASCs — namely the ethical and legal issues, as well as the the difficulty to isolate the neural effects of psychedelic states from other physiological effects elicited by the drug ingestion. The study used *DeepDream* (Mordvintsev, Olah, and Tyka 2015) to generate hallucinations by modifying a video clip.

> [Their] findings suggest that DeepDream and psychedelic drugs induced similar altered brain patterns and demonstrate the potential of adopting this method to study altered perceptual phenomenology in neuroimaging research.

Very recent research (Rastelli et al. 2021) indicates that simulated altered perceptual phenomenology enhances cognitive flexibility and inhibits automated decision making. The study describes cognitive flexibility as “the ability to shift attention between competing concepts and alternatve behavioral policies to meet rapidly changing environmental demands”.

1.2.4 Understanding of the Human Mind

Finally, without any immediate application, the study of the effects of ASCs may help contribute to our understanding of the human mind. Particularly, for instance, analyzing the invariant effects of classical psychedelics on sensory perception may improve our understanding of the visual cortex and the way it functions. Further research involving perceptual phenomena and pharmacodynamics of psychedelics and their mechanisms of action may contribute to our understanding of the significance of certain receptors in processing visual or other sensory information.

The problem of understanding consciousness has long been of interest to philosophers (Block 1993), neuroscientists (Crick and Koch 1990), as well as cognitive psychologists (Dehaene 2014). Recently, with the resurgence of deep neural networks, attempts to contribute to our understanding of consciousness have also appeared in the field of artificial intelligence (AI) (Bengio 2017; Reggia, Katz, and Davis 2020). One such study (Bensemann and Witbrock 2021) examined the effects of implementing phenomenology (in a broader sense of the word, not psychedelic) into a deep neural network.

1.3 Related Work

1.3.1 Recreations of Visual Phenomena

In this section, we explore the way ASCs have been depicted in contemporary art and media and recent attempts at recreating aspects of ASCs in the scientific domain.

1.3.1.1 Quake Delirium

In the original paper about Quake Delirium (Weinel 2011), the author divides video games portraying ASCs into two categories:

1. Games which feature literally portrayed dreams, intoxication or hallucinogenic experiences.
2. Games which feature graphical or thematic content which audiences may consider to reflect states of dream, intoxication or hallucination, but without any direct or literal reference to these states.

This categorization is not only useful for examining video games, but also the rest of art and media.

The first category describes media that attempts to recreate ASCs with an explicit reference to a specific induction method, cause or origin. For example, the games in this category, such as Grand Theft Auto: Vice City[1] or Duke Nukem 3D[2], may temporarily portray a character under the influence of a psychoactive drug. However, psychoactive substances are not the only form of ASC induction portrayed in video games. One such exception is LSD: Dream Emulator[3], a game with narrative based on a dream diary and an overall dream-like surrealist aesthetic.

The second category contains media that does not communicate explicitly any ASC method of induction, cause or origin. Despite this, the media that falls into this category may be viewed equally as *psychedelic* or more than that of the first category. This could be considered to be the case of Yoshi's Island[4]. While the creators may not have intended the video game to reflect ASCs, because of it's brightly colored surrealistic visual themes, it may resemble ASCs of games from the first category.

The *Quake Delirium* project itself is a modification of the game *Quake* that makes use of an external digital signal processing (DSP) audio patch for modifying the

[1] Grand Theft Auto: Vice City, Rockstar Games, 2003. PC (Windows) CD-ROM.
[2] Duke Nukem 3D, 3D Realms, 1996. PC (Windows) CD-ROM.
[3] LSD: Dream Emulator, Asmik Ace Entertainment, 1998. Playstation.
[4] Super Mario World 2: Yoshi's Island, Nintendo, 1995. Super NES.

resulting audiovisual output the game produces. The visual effects consist of changes in:

1. field of view (FOV);
2. camera swaying;
3. fog density and color;
4. game speed;
5. stereo vision (for 3D red cyan glasses);
6. gamma;
7. hue.

These visual effects are made available to the DSP patch, the control of which can be automated using multi-track audio sequencing software. This enables the effects to onset slowly and gradually become more severe over time.

The project demonstrates a method of combining multiple partial effects that results in a complex audio-visual effect that is more sophisticated than many of the existing games exhibiting phenomena of ASCs surveyed.

Interestingly, the authors went on to experiment with a dynamic way of controlling the intensity and parameters of the simulated effects in a follow-up study (Weinel et al. 2015). Rather than controlling the parameters using a *pre-determined automation path* via multi-track audio sequencing software, this modification introduced biosensor as a way of influencing the simulation parameters – specifically, they used the commercial *NeuroSky MindWave* electroencephalograph (EEG) device. The study ultimately concludes, that "while the use of EEG to control psychedelic visual effects is conceptually appealing, the current system would also need to be improved to provide a more tangible connection between the headset and the ASC effects in the game."

There is no straightforward way to map EEG signals onto visual effects. The EEG signals need to be interpreted, so that relevant information is extracted. Mapping the extracted information onto specific simulation parameters is then at the artist's discretion. A more sophisticated approach might examine correlations between observed ASC phenomena and EEG signals, then use those correlations to model the mapping from EEG signals onto the visual effects.

1.3.1.2 Crystal Vibes feat. Ott.

Outram et al. (2017) describe *Crystal Vibes feat. Ott.* as a project originally developed to demonstrate the full-body vibrotactile *Synesthesia Suit*, further discussed in 1.3.2.1. The experience places the user into an abstract geometric environment procedurally generated from a soundtrack:

> Crystal Vibes does not use any 3D modelling, 2D design, or hand animation. Instead, the environment is generated using sine and Bézier functions, Bravais lattice structures and Fourier transforms of the audio. Crystal Vibes exploits the innate beauty of 3-dimensional crystal structures, and leverages the artistry of rhythm and form in the music for visual beauty.

The article describes in detail the methods employed to simulate audiovisual synesthesia using sound visualization, with an attempt to be “as physically and biologically defensible as possible”. The methods include compensation for the non-linear perception of both auditory and visual information:

> This includes the fact that humans perceive equal pitch differences corresponding roughly to equal differences in the log of audible frequency, that our perception of volume varies over the audible range, and how humans interpret colour from a visible spectrum.

Another technique used to aid in distinguishing different voices of the soundtrack, such as drums and synths, is spatial separation. Each voice would impact a separate region of the visualization. This way, the user can form an association between spatial regions and their corresponding voices.

Finally, the last employed technique of improving the perception of sound via sight is to provide temporal information; instead of only visualizing the current instant of the soundtrack, a roughly 1 second long moving slice of the soundtrack is visualised.

The authors report that users found the visualization compelling, even those who experience synesthesia in their daily lives. Synesthesia is of our interest because it is a prominent phenomenon of some ASCs.

1.3.1.3 Isness

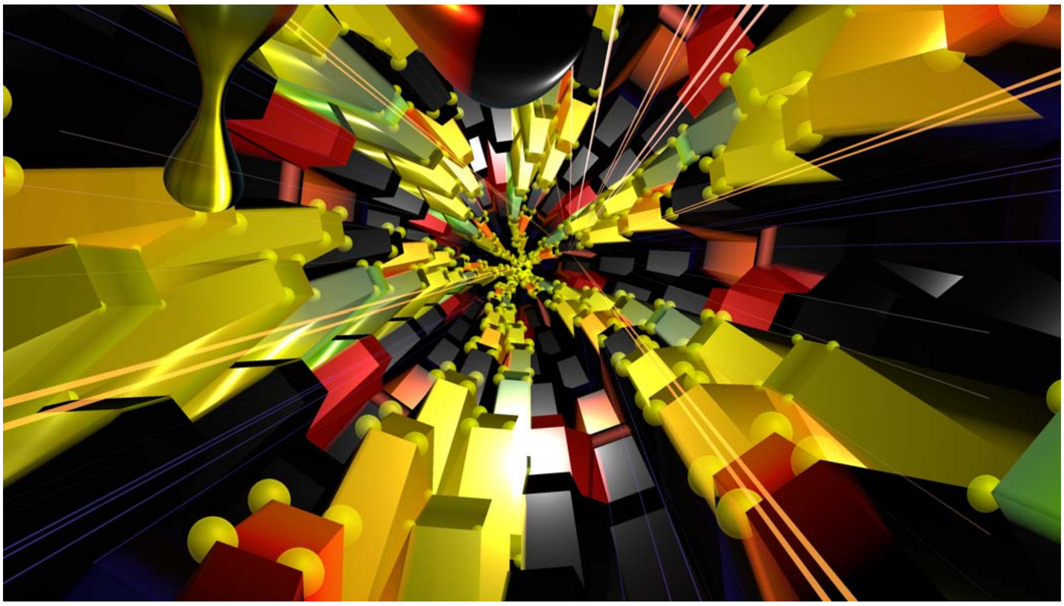
The paper (Glowacki et al. 2020) accompanying the project *Isness* proposes that so-called ‘mystical-type’ experiences (MTEs), that are often experienced under the influence of psychedelic drugs, may also be facilitated by virtual reality. The paper justifies this proposal by conducting a study with 57 participants analyzing participants’ responses to the 30-item revised mystical experience questionnaire (MEQ30), commonly used to evaluate the effects of psychedelic drugs. The results of the study indicated that *Isness* participants reported MTEs comparable to those reported in double-blind clinical studies after high doses of psilocybin and LSD.

The VR application was designed to be used by 4 participants at a time with the *HTC Vive Pro* HMDs. To provide multiplayer functionality, the client/server architecture was chosen, with each HMD being connected to a separate GPU-accelerated server.

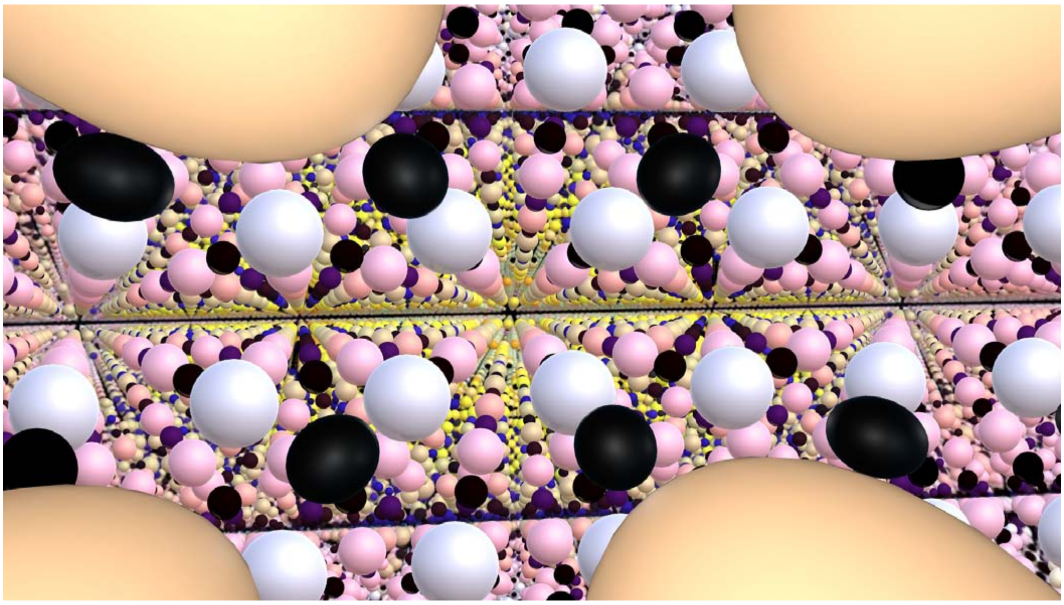
The abstract virtual environments have been designed by defining a set of ‘aesthetic hyperparameters’, each affecting a different aspect of the simulated MTE. The overall *Isness journey* was comprised of a set of states, each of which had some specific time duration. This approach allowed for reproducibility necessary for the study.

Participants were equipped with specially-made ‘Mudra gloves’, which would create a light source within the virtual scene when they made a ‘mudra pose’ by

[5] © Outram et al. (2017), permission for use granted by the authors.
[6] © Outram et al. (2017), permission for use granted by the authors.

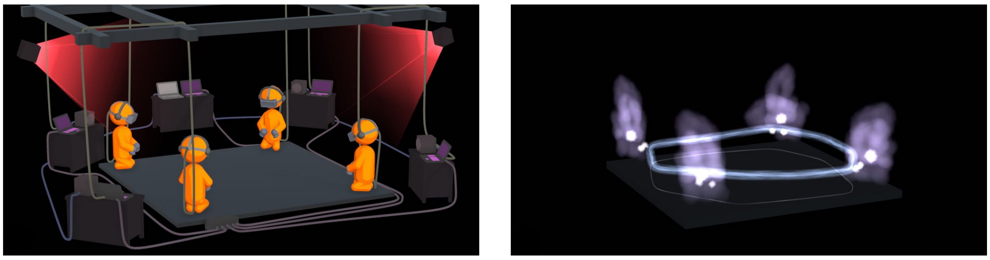


(a) A screenshot from the first main part of *Crystal Vibes*, with an adaptive mesh that envelops the user and responds visually to the music.[5]



(b) A screenshot from the second main part of *Crystal Vibes*, in which sound visualisation in the form of colour flows through an endless lattice of spheres.[6]

Figure 1.1: Screenshots of the *Crystal Vibes* VR application.



(a) *Isness* multi-person VR setup.[7] **(b)** In-world view of an *Isness* state.[8]

Figure 1.2: Design of the *Isness* VR application.

bringing the tip of a thumb to their forefinger or middle finger.

The entire *Isness journey* was divided into 3 phases:

1. Phase 1: Preparation. 15-20 minutes, included information about practical issues (phones off, toilet locations, placing posessions in a safe place), screening, description of the experience, information that the participants could withdraw at any point, and acquisition of verbal and written consent for participation in the study. This phase also included some group exercises to build rapport between participants.

2. Phase 2: Multi-person VR session. 35 minutes with a pre-recorded narrative soundtrack. The VR experience was preceded by a blindfolded, narrated group meditation. Each participant was then fitted with a VR headset and the administrator initiated the VR session, moving through 15 prespecified states, each composed from a set of aesthetic hyperparameters.

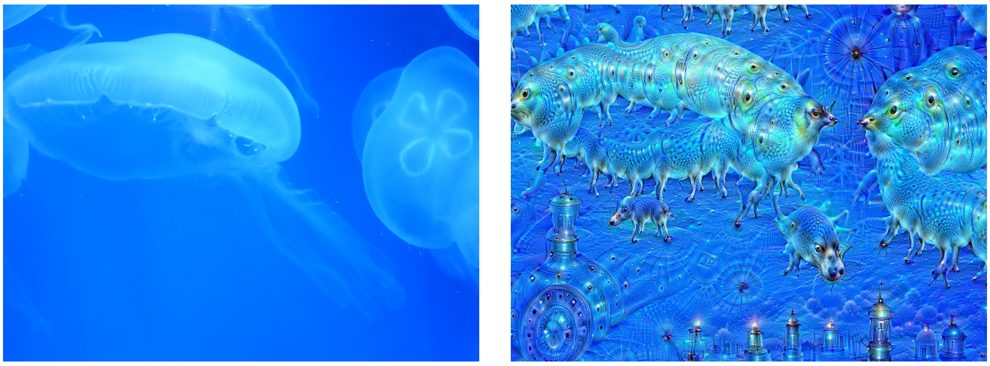
3. Phase 3: Integration. The HMDs were taken off. Breath exercises and group exercises followed. Participants were then invited to share in a 10-15 minute facilitated discussion, after which they were provided a blank piece of paper for reflective writing, along with a blank MEQ30.

It is fair to say that the *Isness* project focuses mainly on the replication of MTEs, whose characteristics include a sense of connectedness, transcendence, and ineffability; specifically the effects of ASCs on emotion and cognition, rather than the effects on sensory perception, as is also evident by the MEQ30 questionnaire used in the study. This can be seen in the emphasis on the narrated structure of the *Isness journey*, the inclusion of a meditation session, as well as in the multiplayer design of the overall experience, that encourages interaction between participants.

That is to say, the *Isness journey* has been effective in creating a memorable, subjectively meaningful experience comparable to ASCs induced by psychedelic drugs.

[7] A cropped version with label removed of "Isness multi-person VR setup" released by Glowacki et al. (2020) under the CC BY-SA 4.0 license. © Glowacki et al. (2020).

[8] A cropped version with label removed of "In-world view of an Isness state" released by Glowacki et al. (2020) under the CC BY-SA 4.0 license. © Glowacki et al. (2020).



(a) Original image.[9] **(b)** Image altered by *DeepDream*.[10]

Figure 1.3: Example result of applying the *DeepDream* technology to an image.

1.3.1.4 Hallucination Machine

Hallucination Machine (Suzuki et al. 2018) makes use of the *DeepDream* (Mordvintsev, Olah, and Tyka 2015) technology to alter spherical panoramic video. The altered video is then viewed through a HMD. The usage of *DeepDream* successfully simulates the sense of an increased ability to recognize patterns during certain ASCs.

While it is a compelling concept, there are many drawbacks to this approach.

1. The alteration caused by *DeepDream* is heavily dependent on the source data the deep convolutional neural networks (DCNN) is trained with. If, for example, the DCNN is trained with images of puppies, the alteration by this DCNN will result in *hallucinated* puppies.
2. The panoramic spherical videos are not stereoscopic, hence the sense of depth is lost.
3. Finally, the fact that the *DeepDream* technology is computationally demanding may have resulted in the choice to use pre-recorded videos rather than real-time footage. This, however, limits the applications of the solution.

However, what the *DeepDream* technology does well is the simulation of the sense of an increased ability to recognize patterns, otherwise known as pareidolia, characteristic of certain ASCs. For this reason, it has found popular use in research as a way to simulate hallucinations (Greco et al. 2021; Rastelli et al. 2021).

1.3.1.5 Lucid Loop

Lucid Loop (Kitson, DiPaola, and Riecke 2019) is a proposed VR application that makes use of an EEG device (along with other biosensors) for biofeedback. The application is a proposed training aid for maintaining awareness during lucid dreaming, a state reached when a person becomes aware they are dreaming.

[9] Released by Martin Thoma under the CC0 1.0 (public domain) license.
[10] Released by Martin Thoma under the CC0 1.0 (public domain) license.

The application makes use of a HMD to display *DeepDream*-altered (Mordvintsev, Olah, and Tyka 2015) content with the intensity of alteration corresponding to the current brain wave distribution of the wearer — as higher frequency brain waves dominate, the displayed content becomes less affected by *DeepDream*, resulting in more clarity; as lower frequency brain waves dominate, the displayed content becomes more affected and is interpreted as more dreamy and abstract.

The concept is promising, but the choice of *DeepDream* might prove to be challenging to implement effectively, as the intensity of the *DeepDream* alteration of displayed content is dynamic. The *DeepDream* algorithm would either have to be applied in real-time, which is problematic due to the algorithm's high computational demands, or an optimization scheme would have to be used. One such optimization scheme, assuming spherical panoramic video as displayed content, might pre-render the video as altered by *DeepDream* for several levels of intensity, and then during usage, would interpolate between the pre-rendered videos.

Finally, while the tool is supposed to aid in helping maintain awareness during lucid dreaming, I find it to be a missed opportunity, that the paper does not address the event that high frequency brain waves, while perhaps corresponding to greater awareness, might also cause the dreamer to wake up. A possible improvement of this tool might take this into consideration and also provide biofeedback for this event, such as fading the displayed content to white as the user becomes "too aware".

1.3.1.6 Other AI–based Approaches

Schartner and Timmermann (2020) develop two models for generating image distortions reminiscent of verbal reports from clinical trials of *N,N*-dimethyltryptamine (DMT).

In the first approach, the authors employed the *StyleGAN* algorithm (Karras, Laine, and Aila 2019) and modified it such that no noise input was added during the generation process, according to a hypothesized brain mechanism. This resulted in smoother, painterly look of the images.

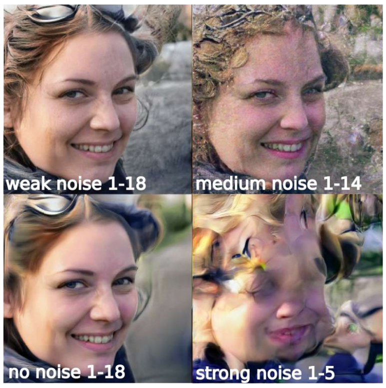
In the second approach, the authors used the *Fast Neural-Style Pytorch Implementation for Artistic Style Transfer* (Johnson, Alahi, and Fei-Fei 2016). This method allows for the depiction of nearly any report of a visual hallucination, assuming one can find a matching content and style image.

1.3.2 Tactile Stimulation Interfaces

VR interfaces provide a way to replace sensory information with information provided by the VR application. Different kinds of interfaces have been developed

[11] A cropped version of "NVIDIA's generative model with noise perturbation and analogous hypothesized brain mechanism" released by Schartner and Timmermann (2020) under the CC BY-SA 4.0 license. © Schartner and Timmermann (2020).

[12] "Example output of a style-transfer network" released by Schartner and Timmermann (2020) under the CC BY-SA 4.0 license. © Schartner and Timmermann (2020).



(a) Effect of *StyleGAN* with varying levels of noise.[11]

(b) Effect of a style transfer network with varying levels of bias.[12]

Figure 1.4: Results from the modification of *StyleGAN* and the usage of a style transfer network.

since the conceptualization of VR, but among the most practical and commercially available is the HMD, which includes stereoscopic screens for visual information, and usually provides a way to substitute auditory information as well, either by providing built-in headphones or an audio connection to connect external headphones to. The main purpose of these interfaces is to provide (or improve the amount of) immersion within the virtual scene.

Among other VR interfaces, *tactile stimulation interfaces* deserve a special mention, because of their relevance to the simulation of ASCs, in particular, the simulation of haptic and auditory synasthesia, and because of their past usage in related projects. In this section, we mention several of these interfaces.

1.3.2.1 Synesthesia Suit for Rez Infinite

The *Synesthesia Suit* (Konishi, Hanamitsu, Outram, Minamizawa, et al. 2016; Konishi, Hanamitsu, Outram, Kamiyama, et al. 2016; Synesthesia Lab 2016) is a full-body suit that provides haptic sensation via 24 actuators, all of which can be independently controlled. The suit has been developed for the VR game *Rez Infinite* (Enhance Experience Inc. 2016). The aforementioned VR game *Crystal Vibes feat. Ott.* (see 1.3.1.2; Outram et al. (2017)) has been developed to demonstrate the capabilities of this suit.

Figure 1.5: The *Synesthesia Suit.*[13]

In the game *Rez Infinite*, the suit would provide feedback for interactions like shooting, hitting, and warping. The suit would respond to collisions in the virtual world, as well as to the in-game action and sounds.

The design of the *Synesthesia Suit* was later improved by *Synesthesia Wear* (Furukawa et al. 2019), which adds wireless connections and improves user intuitiveness and customizability in the placement of the actuators.

1.3.2.2 Synesthesia X1 - 2.44

Synesthesia X1 - 2.44 (Synesthesia Lab 2021) is a seat with 2 speakers and 44 vibrotactile actuators. While it has been presented without a HMD, the possibility of using a HMD while seated is available, but the design of this tactile interface as a seat makes it impossible for the user to move around. Still, it might be suitable used for the development of a more passive VR experience.

1.3.2.3 Subpac

Commercial wearable subwoofers, such as the *Subpac* (SUBPAC 2013), are able to have a significant impact on immersion (Drempetic and Potter 2017) even for non-VR content.

The *Subpac* has been used in *Longing for Wilderness* (Zimmermann, Helzle, and Arellano 2016), a VR experience that "takes you from the noisy city through the slowly transforming forest towards a calm and airy landscape". The sound design of the application has been specially made with the device in mind.

[13]© Konishi, Hanamitsu, Outram, Kamiyama, et al. (2016), permission for use granted by the authors.

1.4 Contributions

We develop a VR application for HMDs that simulates select aspects of ASCs. We perform a study in which we measure the influence of the created VR application on the human mind. This measurement is done via the 11-Factor Altered States of Consciousness Questionnaire (11-ASC; Studerus, Gamma, and Vollenweider (2010)), that is used in clinical studies of psychedelic drugs and in studies of other kinds of ASCs.

2 Background

Contents

2.1 Altered States of Consciousness

Ludwig (1966) define ASCs as „any mental state(s), induced by various physiological, psychological, or pharmacological maneuvers or agents, which can be recognized subjectively by the individual himself (or by an objective observer of the individual) as representing a sufficient deviation in subjective experience or psychological functioning from certain general norms for that individual during alert, waking consciousness."

This term is meant to encompass phenomena such as sleep, dream states, day dreaming, hypnosis, sensory deprivation, hysterical states of dissociation and depersonalization, pharmacologically induced mental aberrations and so on, and provide a framework for further analysis of these phenomena.

With regards to psychedelics specifically; ASCs induced by psychedelics are mainly characterized by profound alterations in sensory perception, mood, thought including the perception of reality, and the sense of self (Preller and Vollenweider 2016).

2.1.1 Phenomenology of Psychedelic States

The psychedelic experience The main component of the psychedelic experience is the concept of the *phenomenological ego* and the way it is influenced throughout the experience.

> According to Metzinger (2009), the ego is the content of a self-model; this conscious self-model constructed by the brain allows us to interact with our internal world as well as with the external environment in a holistic manner. In a broad sense, the self encompasses features such as a first-person perspective, feelings of agency, ownership ("mineness") and immediacy ("nowness"), spatial perspective, autobiographical memory, emotions, perceptions, thoughts and acts of will, as well as the feeling of being embedded in our bodily sensations (Metzinger 2009; Northoff 2011).
>
> Another function of the ego serves is to help control and plan our behavior and to understand the behavior of others. By representing the process of representation itself, we can catch ourselves in the act of knowing. Ultimately, the subjective experience of the ego arises from dynamic self-related information processing, which is the result of a self-organizing brain system interacting with its environment, because no such things as selves exist in the world (Metzinger 2009).
>
> (Preller and Vollenweider 2016)

According to Masters and Houston (2000), modified by Preller and Vollenweider (2016), the suppression of the *phenomenological ego* during the results in distinctive stages of the psychedelic experience, with alterations at:

1. the perceptual level,

2. the recollective-psychodynamic level,
3. the symbolic existential level, and
4. the deep integral level of self-transcendence.

See figure 2.1.

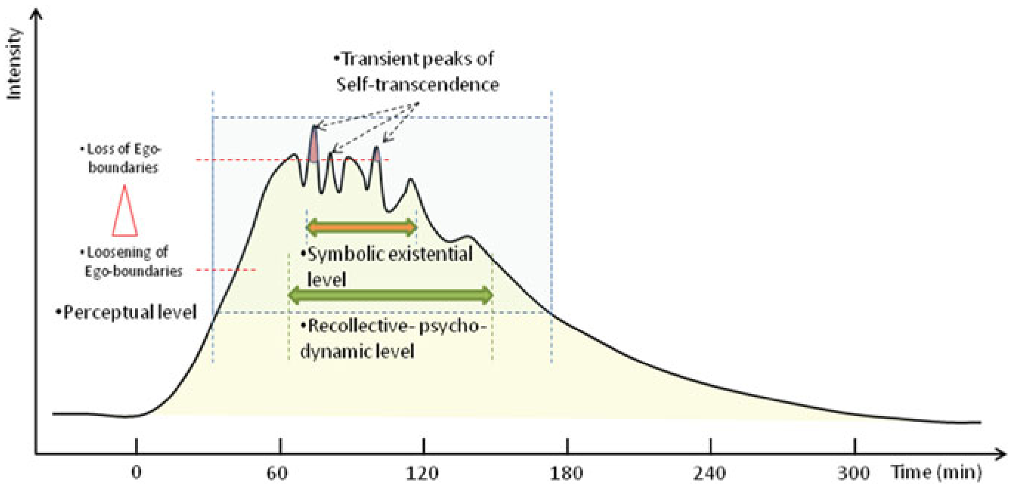


Figure 2.1: Temporal dynamics and stages of a psilocybin-induced psychedelic experience. Adaptation by Preller and Vollenweider (2016) of the original by Leuner (1962).

2.1.2 Aspects

For the purpose of this thesis, we define an *aspect* of an ASC as a single, distinctive phenomenon of an ASC. An *aspect* does not describe the entirety of the ASCs, only a particular part of it. In order to model ASCs, we analyze them and break them down into their respective *aspects*.

An example that is common for ASCs induced by psychedelics is the distortion in the perception of time.

2.1.3 Replications

Replications are recreations or simulations of one or more aspects of ASCs using various forms of media (audio, video, tactile, etc.) with the intention of communicating the experience of ASCs. Many examples are described in section 1. Various artistic *replications* may be viewed at PsychonautWiki (2022).

For the rest of this thesis, *a replication* will refer to a recreation or simulation of a *single* aspect of ASCs. Furthermore, a *complex replication* will refer to a combination of *replications*.

A *replication* of time perception distortion may be simulated via the augmentation of the playback speed of a videoclip using non-linear resampling, or via the augmentation of the simulation speed (timestep) of a VR application. This augmentation may be performed by replacing the original sampling function $s\colon \mathbb{R} \to \mathbb{R}$ by

$s'(t) = s(t) + f(t)$ where $f : \mathbb{R} \to \mathbb{R}$ is a function for sampling procedurally generated noise, such as Perlin noise (Perlin 1985) or Simplex noise (Olano et al. 2002).

2.2 Psychometric Evaluation Methods

Psychometric evaluation of ASCs are generally performed via questionnaires, of which there are many available. Schmidt and Majić (2018) and Figueiredo et al. (2016) performed an analysis of 9 such questionnaires and recommends the 11-Factor Altered States of Consciousness Questionnaire (11-ASC) and the Phenomenology of Consciousness Inventory (PCI) questionnaires for general assessment of ASCs.

The 11-ASC was chosen over the PCI due to the popularity of the 11-ASC in the evaluation of psychedelic-induced ASCs, and because of the complete lack of VR-related studies using the 11-ASC.

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(Fischer et al. 1970)

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List of Acronyms

11-ASC 11-Factor Altered States of Consciousness Questionnaire: A version of the *Altered States of Consciousness Rating Scale* psychometric questionnaire, which is based on the hypothesis that ASCs have a common core independent of the induction method which distinguishes them from the waking conscious state (Figueiredo et al. 2016; Studerus, Gamma, and Vollenweider 2010).

AI artificial intelligence

ASC altered state of consciousness: See section 2.1 for a complete definition and related terms.

DCNN deep convolutional neural networks

DMT *N,N*-dimethyltryptamine: A classical hallucinogenic drug first synthesized in 1931 (Manske 1931), a psychoactive compound of Ayahuasca, the ceremonial spiritual medicine used by Amazonian natives for shamanic purposes and to bond socially in a casual setting (Mark Hay 2020).

DSP digital signal processing

EEG electroencephalograph

FOV field of view

GPU graphics processing unit: A specialized extension module providing acceleration for computer graphics computations and other parallelizable tasks.

HMD head–mounted display

LSD lysergic acid diethylamide: A classical hallucinogenic drug first synthesized in 1938 from ergotamine, an alkaloid of the ergot rye fungus (Albert Hofmann 1969).

MEQ30 30-item revised mystical experience questionnaire

MTE ‘mystical-type’ experience: Subjective experiences whose characteristics include a sense of connectedness, transcendence, and ineffability.

PCI Phenomenology of Consciousness Inventory: A psychometric questionnaire based on the hypothesis that different states of consciousness can be characterized in terms of phenomenological dimensions which can be quantified in terms of their intensity. The resulting pattern is assumed to be typical of a particular induction method and can be observed consistently (Figueiredo et al. 2016).

VR virtual reality

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