How effectively can awe and the Overview Effect be elicited in a Cave Automatic Virtual Environment (CAVE) and what are the resulting impacts of such experiences on one's self-size perception?

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Preface

Presented here is my Bachelor thesis, titled *How effectively can awe and the Overview Effect be elicited in a Cave Automatic Virtual Environment (CAVE), and what are the resulting impacts of such experiences on one's self-Size perception?*

The journey of exploring the fascinating aspects of the Overview Effect and the awe we can inspire through immersive Virtual Reality environments has been truly enlightening. This work not only reflects an academic pursuit but also a deep personal engagement with the subject matter.

I extend my deepest gratitude to Prof. Dr. Max Louwerse, whose guidance, enthusiasm, and invaluable insights have shaped this research profoundly. Special thanks go to Anna van Limpt-Broers, whose assistance in obtaining the questionnaire and background knowledge, were indispensable throughout this process. My appreciation also extends to the entire team at the DAF Technology Lab, whose support and expertise were crucial in facilitating my research.

Additionally, I owe a great deal of thanks to my fellow student, Sherwin Lee, for his role in co-collecting the data necessary for the CAVE experiment.

It is with great pride that I present this thesis, which endeavors to shed light on how effectively awe and the Overview Effect can be elicited through a CAVE system and to explore the transformative potential of such experiences.

Enjoy the read!

Arash Mirshahi
Bergen op Zoom, 21st of May, 2024

Abstract

Experiences that transform our perception of self and the universe are pivotal, often driven by profound emotions such as awe. The Overview Effect, a striking shift in awareness reported during space travel, epitomizes such transformative experiences, prompting sensations of awe and vastness that challenge and expand our worldview. This study explores the effectiveness of a Cave Automatic Virtual Environment (CAVE) and static images in eliciting awe and the Overview Effect among young adults aged 18-25. Utilizing two experimental conditions, the research contrasts participant responses to a virtual spaceflight simulation within a CAVE setup with those experiencing static images of space and natural landscapes. Data were gathered via situational awe and Overview Effect questionnaires alongside pre- and post-experiment drawing tasks. Results reveal no significant difference in enhancing the Overview Effect between the two conditions; however, situational awe scores were significantly higher in the CAVE setting. Further analysis using a general linear model with dispositional awe as a covariate suggests that the CAVE environment, while not statistically significant, potentially provides a more immersive medium for eliciting awe. Additionally, changes in self-size perception measured by drawing tasks were insignificant, indicating limited effects on self-perception related to the Overview Effect. These findings highlight the potential of immersive VR environments like the CAVE in amplifying awe experiences and call for deeper investigation into the factors that markedly influence such outcomes. The study adds to our understanding of how various modalities of awe induction differ in their impact and efficacy.

DATA SOURCE, ETHICS, CODE AND TECHNOLOGY STATEMENT

In the conduct of this study, I am the sole owner of the data collected from human participants who provided informed consent. Data was gathered through surveys administered using Google Forms, ensuring that participants were aware of the research purposes and their voluntary involvement. All tables and flowcharts presented in the thesis were created by me. Images incorporated from other sources, such as open-source web pages and research papers, were carefully chosen and cited to respect copyright laws.

The code for this study was entirely written by me using the R programming language. The libraries and frameworks utilized in the analysis have been explicitly listed in the statistical analysis section (Section 3.4).

For the preparation of this thesis, no external tools or services were used to paraphrase the text. Grammarly was employed to check spelling and grammar, ensuring the clarity and professionalism of the written content. The document was typeset using LaTeX with BibTeX employed for reference management. These tools facilitated the organization and presentation of the thesis, adhering to the academic standards required by the committee.

1 Introduction

Studying awe presents a unique challenge due to its complexity and the difficulty of replicating such profound experiences in laboratory settings (Chirico et al., 2018). Awe often arises in response to vast stimuli or extraordinary events that transcend our understanding, such as natural disasters, expansive landscapes, and remarkable human achievements (Guan et al., 2018: Richesin & Baldwin, 2023). These events are impractical to simulate realistically in traditional research environments. However, Virtual Reality (VR) has emerged as a potent tool for eliciting awe. By creating immersive virtual environments that users can interact with, VR facilitates experiences that feel genuine and closely mimic real-world awe-inspiring scenarios (Quesnel & Riecke, 2018).

One such VR space that has the potential to provoke awe is the Cave Automatic Virtual Environment (CAVE). This environment typically consists of a room-sized area with projections on three to four walls and occasionally includes projections on both the floor and ceiling (Delgado et al., 2023). A CAVE offers an immersive experience by presenting a complete view of the virtual environment that can be shared with other users. Additionally, it allows participants to see their own bodies and those of others within the space, maintaining a sense of presence and interaction (Vasarainen et al., 2021). The SpaceBuzz simulation, developed by the non-profit organization SpaceBuzz, is an ideal candidate for leveraging an extended reality (XR) environment like the CAVE. This virtual spaceflight simulation allows participants and their fellow passengers to experience views of planet Earth, the Moon, and other notable features of our planet, while being guided by a virtual representation of the esteemed Dutch astronaut André Kuipers (Louwerse et al., 2020). Previous studies have demonstrated that viewing the Earth from space via VR can effectively induce intense feelings of awe (van Limpt-Broers et al., 2020; Quesnel & Riecke, 2018; Stepanova et al., 2019b). This sensation is associated with what is known as the Overview Effect (Yaden et al., 2016).

Awe and the Overview Effect have been explored in various environments, both virtual and physical. Studies have induced awe through VR landscapes (Chirico et al., 2018), a SpaceBuzz replica rocket vehicle (Louwerse et al., 2020), photographs (Joye & Dewitte, 2016), and awe-inspiring videos (Bai et al., 2017). Yet, little is understood about the effectiveness of CAVE VR environments in eliciting awe and the Overview Effect. Previous Research primarily focuses on simpler media like images and videos (Pérez et al., 2022).

This study aims to evaluate the ability of the Cave Automatic Virtual Environment at the DAF Technology Lab, Tilburg University, to induce awe and the Overview Effect using the SpaceBuzz simulation. It also examines how these experiences affect self-size perception. To contextualize these findings, a secondary online experiment using awe-inspiring images of natural landscapes and space views will compare the impact of less immersive stimuli (Pausch et al., 1997), enhancing our understanding of different modalities of awe induction.

The significance of this study lies in its contribution to enhancing the ecological validity of CAVE systems in creating immersive experiences that elicit awe and the Overview Effect. Unlike head-mounted displays or single-screen VR setups, CAVE systems provide 360-degree projections that may amplify the intensity of the awe experience (Vasarainen et al., 2021). Although their potential is significant, CAVE systems are underutilized in awe research compared to other VR technologies (Pérez et al., 2022). This research seeks to address this gap by evaluating the efficacy of CAVE systems in generating awe and understanding the subtleties of these experiences.

Additionally, this study explores the implications of awe experiences in managing depression, a prevalent mental condition characterized by persistent sadness and a lack of pleasure

(Hua et al., 2024). With the rising incidence of depression, especially among youth (Ludwig-Walz et al., 2022; Mojtabai et al., 2016; Twenge et al., 2019), and a stagnation in the development of new mental health therapies (Goodwin et al., 2022), alternative therapeutic approaches are needed. Research by Chirico and Gaggioli (2021) suggests that awe can mitigate aspects of depression, although it is not yet a formal clinical intervention. This study will further examine whether awe-induced CAVE experiences can produce positive cognitive changes and contribute to new approaches for depression treatment.

The central research question of this study is:

1. How effectively can awe and the Overview Effect be elicited in a Cave Automatic Virtual Environment (CAVE)?

An additional objective that this study aims to explore includes:

1. Does awe, and more specifically, the Overview Effect, significantly impact an individual's self-size perception?

To address these questions, two human-subject experiments were conducted, incorporating questionnaires and drawing tasks. The primary question was explored through a series of statistical tests comparing situational awe scores and changes in Overview Effect scores across both the CAVE and static image conditions. The influence on self-size perception was examined through pre- and post-test drawing tasks, with changes quantified as drawing gains.

For a detailed analysis of the experimental results, please refer to Section 4, *Results*. This section provides comprehensive insights into how the experiments were conducted and the data analysis performed.

2 Related Work

2.1 Awe and the Overview Effect

There are various approaches to defining awe, from detailed analyses to vivid conceptual illustrations. Chen and Mongrain (2021) provide a compelling example of the latter:

> *"One may look up at the night sky and be lucky enough to see a glittering bed of stars and a strip of the Milky Way Galaxy. Is one mesmerized? Speechless? Flooded with feelings of beauty and wonder? Perhaps the best emotion to describe and account for this experience is awe."* (Chen & Mongrain, 2021, p. 770)

A more detailed definition is given by Keltner and Haidt (2003), who conceptualize awe as the resulting outcome from two key appraisals: the experience of vastness and a subsequent need for mental accommodation. Vastness is defined as any encounter in which an awe-inspiring stimulus appears significantly larger than oneself, or the experience transcends one's usual experiences or frameworks. Accommodation follows as both an internal and sometimes external reaction to this profound emotional evaluation, where one's sense of self is reduced (altering the mental framework or schema) and there is a cognitive necessity to adjust to this new information (MacKinnon, 2019).

Viewing Earth from outer space is a quintessential example of vastness, frequently cited as one of the most profound elicitors of awe, often referred to as the Overview Effect (Stepanova et al., 2019b). This phenomenon not only emphasizes the immense scale of Earth and the cosmos but also fosters a deep sense of connection with humanity and the universe. Further illustrating this, Yaden et al. (2016) analyzed astronaut testimonials from around the world, revealing recurrent themes of gratitude, overwhelming emotional responses, and an enhanced sense of unity with both people and the planet.

2.1.1 Eliciting awe and the Overview Effect

Over the past decade, numerous researchers have explored the replication and study of awe and the Overview Effect, particularly through the use of virtual reality (VR) technologies (Chirico et al., 2018; Delgado et al., 2023; Van Limpt-Broers et al., 2020; Louwerse et al., 2020; Stepanova et al., 2019a). One notable study by Stepanova et al. (2019a) developed detailed design guidelines for optimally experiencing the Overview Effect in virtual reality settings. They emphasized that an immersive, first-person perspective is crucial in VR experiments aimed at evoking the Overview Effect, rather than relying solely on verbal descriptions or static images (Stepanova et al., 2019a). As previously mentioned, awe plays a central role in the Overview Effect, with vastness being a fundamental characteristic of most awe-inducing stimuli (Keltner et al., 2003). Therefore, this sense of vastness must be carefully incorporated into the design of VR experiences intended to elicit the Overview Effect (Chirico et al., 2018). A more recent study by Van Limpt-Broers et al. (2020) that adhered to these guidelines investigated the Overview Effect in VR among children aged 10 to 12, focusing specifically on the educational benefits and learning gains associated with experiencing awe. Participants engaged with the SpaceBuzz VR simulation using HTC VIVE Pro headsets, equipped with a resolution of 1,440 x 1600 pixels per eye, a 90Hz refresh rate, and 3D spatial audio, specifications that are ideal for creating a genuinely immersive experience (Çankaya, 2019; Mehrfard et al., 2019). The findings from their study demonstrated that the VR simulation effectively induced awe and the Overview Effect. Their setup shares similarities with my CAVE VR experiment, as both studies utilized the same SpaceBuzz simulation. This body of work is particularly relevant to my study, which also employs the SpaceBuzz simulation but differs in participant demographics (18-25 years old) and setting (CAVE environment), using Volfoni 3D glasses to further enrich the immersive experience.

Beyond virtual reality, videos also serve as a potent medium to elicit awe and the Overview Effect. Researchers have found that videos can offer a visually compelling and accessible way to explore profound experiences (Bai et al., 2017; van Elk et al., 2019; Yan et al., 2024). For example, Bai et al. (2017) demonstrated in their series of six studies that awe-inducing videos effectively diminished the sense of self among participants, measured through self-reports before and after viewing. Comparatively, Kahn and Cargile (2021) evaluated the effectiveness of VR against videos in inducing awe. They utilized a 360-degree video from National Geographic, assigning participants to either a head-mounted VR display or a desktop screen. Results indicated that participants in the VR condition experienced significantly higher levels of awe and presence than those viewing the video on desktops, underscoring VR's higher level of immersion. These findings are particularly relevant to my study, providing a theoretical benchmark for assessing the immersive impact of the CAVE environment on eliciting awe and the Overview Effect. Moreover, this comparison elucidates how varying levels of immersion might affect awe experiences, suggesting that the more holistic and immersive sensory experience offered by CAVE could potentially amplify these effects further (Vasarainen et al., 2021).

Transitioning from dynamic elicitors, static images also play a crucial role as a less immersive, yet profoundly impactful medium for eliciting awe and potentially the Overview Effect (Joye & Dewitte, 2016; Droit-Volet et al., 2024; O'bi & Yang, 2024). Monumental architectural structures are prime examples of man-made awe-inducing images due to their vast scale and height (Joye & Verpooten, 2013; Piff et al., 2015). Research by Joye and Dewitte (2016) indicated that images of monumental buildings significantly enhance awe, with participants feeling more diminished in size compared to when viewing less imposing structures. In contrast, Droit-Volet et al. (2024) demonstrated that natural landscapes trigger a stronger awe response than neutral images and also lead to a perceived elongation of time, indicating deep engagement and a profound awe experience (Droit-Volet et al., 2024; Yaden et al., 2018). In this study, a supplementary online experiment was conducted where participants were exposed to a series of static images to examine the effect of awe in a less immersive medium. This experiment used the same pre-test and a slightly adjusted post-test questionnaire structure as the main study but replaced the CAVE simulation with a slideshow of natural scenes. Following the approach by Joye & Bolderdijk (2015), each image was displayed for at least ten seconds to ensure consistent exposure across participants.

Research on the Overview Effect and awe within CAVE-based VR simulations has been previously explored (Delgado et al., 2023), but it has not been as widely utilized as other methods (Pérez et al., 2022). Elicitation methods such as head-mounted VR displays and CAVE systems offer high levels of immersion (Bernardo et al., 2020; Kahn & Cargile, 2021), essential for inducing feelings of vastness and presence, pivotal in experiencing awe and the Overview Effect (Keltner & Haidt, 2003). The limited application of CAVE technologies suggests a gap in ecological validity and an underutilization of this potent research tool. This study aims to investigate if strong feelings of awe and the Overview Effect can be effectively elicited using a CAVE-based VR simulation facilitated by the SpaceBuzz organization. By exploring how immersive environments affect psychological experiences, this study may provide insights into optimizing VR settings for therapeutic applications. Additionally, a supplementary online experiment with awe-inspiring images has been conducted. This experiment, designed to mirror the CAVE experiment's structure but with less immersive stimuli, serves as a baseline to assess the impact of the CAVE system's higher level of immersion.

2.2 Awe enhances mental well-being

Awe is not only a profound emotional response but also a transformative experience that can significantly enhance mental and physical well-being (Chirico & Gaggioli, 2021; Monroy & Keltner, 2022; Rudd et al., 2012). Monroy and Keltner (2022) outline several pathways through which awe positively impacts well-being, including neurochemical changes, transformation of self-perception, enhancement of prosocial behaviors, strengthening of social bonds, and deepening of personal meaning.

Particularly relevant to this study is the second pathway about the transformation of one's self-perception. Excessive self-focus is often linked to psychological issues such as depression and anxiety, whereas awe can shift focus outward, diminishing self-centric thoughts (Bai et al., 2017; van Elk et al., 2016; Perlin & Li, 2020). This pathway is evidenced by a study conducted by Bai et al. (2017) in Yosemite National Park, where participants depicted themselves as smaller after experiencing awe-inspiring views, suggesting a changed perception of their place in the world (Richesin & Baldwin, 2023).

While this study focuses on the second pathway, the interconnected nature of all these pathways informs the design of the questionnaire used in a previous experiment, which assesses changes in self-perception among other aspects of awe and the Overview Effect (van Limpt-Broers et al., 2024b). The examination of this specific pathway is pivotal, considering its potential therapeutic implications in altering self-perception and reducing depressive symptoms.

2.2.1 Awe and the ”small-self”

In light of the previously discussed drawing tasks, an intriguing aspect of awe is encapsulated in the 'small-self hypothesis' (Bai et al., 2017; Piff et al., 2015). This hypothesis suggests that experiences of immense stimuli can lead individuals to feel small in comparison. This sensation not only reduces one's self-focus but also shifts attention toward larger entities, thereby diminishing the prominence of personal concerns (Perlin & Li, 2020). Defined by attributes such as self-awareness, the use of possessive pronouns, a sense of self-ownership, and the recognition of others' minds (Lebedev et al., 2015), the self plays a central role in psychological well-being. Intense self-preoccupation is often linked to depression and anxiety; therefore, redirecting attention away from oneself through awe may offer therapeutic benefits. This potential makes the exploration of awe particularly relevant in psychological studies, as various researchers have investigated how awe influences cognitive and emotional processes related to self-perception and mental health issues (Bai et al., 2017; van Elk et al., 2016; Monroy & Keltner, 2023; Perlin & Li, 2020).

Bai et al. (2017) investigated the small-self hypothesis through several studies, demonstrating that awe experiences in diverse settings reduce self-focus and enhance social connections. In one experiment involving a drawing task, participants depicted themselves as 33% smaller on average after viewing awe-inspiring landscapes compared to a control group, highlighting awe's significant impact on self-perception. Van Limpt-Broers et al. (2024a) recently utilized a child-friendly adaptation of this drawing task in their study to investigate whether experiences of awe and the Overview Effect lead to reduced sizes in self-drawings made by children aged 10-12.

Given the uncertainty about whether self-size drawings in young adults (18-25) yield results comparable to those in children, this study aims to explore this knowledge gap. Unlike previous research investigating the small-self hypothesis in natural settings (Bai et al., 2017; Piff et al., 2015), this study employs a deeply immersive awe experience – the Overview Effect – within a CAVE environment. The SpaceBuzz simulation, known for its strong elicitation of awe and the Overview Effect (Van Limpt-Broers et al., 2020; Louwerse et al., 2020), is particularly suited for this purpose and integrates effectively into a CAVE setting. Consequently, I hypothesize that the awe and Overview Effect induced by the CAVE SpaceBuzz simulation will negatively impact self-size perception, as evidenced by the drawing tasks.

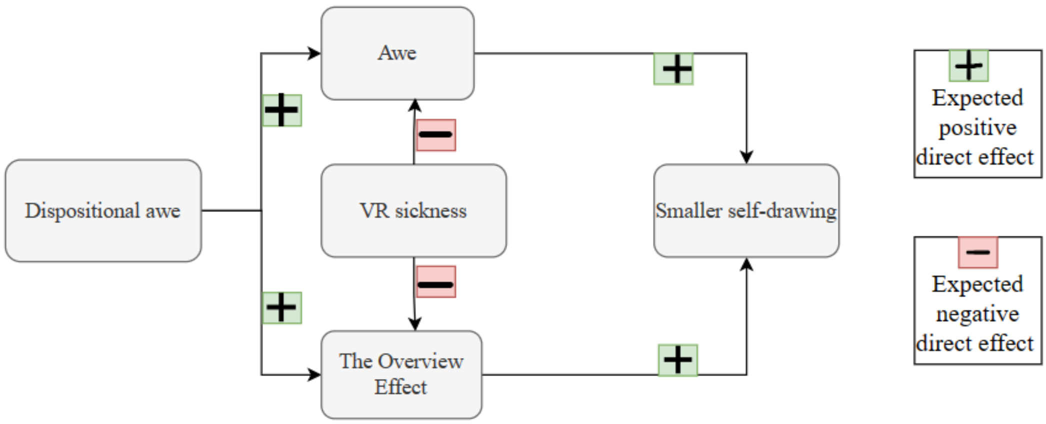
2.3 Current work

Significant research opportunities remain in the areas of awe, the Overview Effect, and immersive VR elicitation methods. Previous investigations of awe have mostly been done through natural settings, which can be regarded as the most effective setting for eliciting awe (Collado & Manrique, 2020), mainly because presence has a high influence on one's ability to feel awe (Chirico et al., 2018). Since it might be costly to investigate awe and the Overview Effect through natural settings, the rise of VR technology offers researchers and designers a valuable tool to explore this elusive phenomenon and create virtual experiences that facilitate transformative change (Stepanova et al., 2019a). Particularly in studying the Overview Effect, one of the most profound awe-inspiring experiences (Yaden et al., 2016), this technological advancement offers a valuable opportunity to make the Overview Effect more accessible to both the general public and researchers. Although current VR technology may not replicate the full intensity of the Overview Effect as experienced by astronauts (Stepanova et al., 2019a), recent studies indicate that it can still induce a lesser yet significant degree of the Overview Effect in

Earth-bound participants (Chirico et al., 2018; Van Limpt-Broers et al., 2020). Since it remains an open question whether a CAVE setting could be effective in eliciting transformative experiences such as the Overview Effect, this study aimed to explore this potential (*RQ1*). Awe and the Overview Effect were elicited using a virtual reality space journey among a group of 18- to 25-year-old young adults within a CAVE environment, assessed through questionnaires and drawing tasks.

In this study, it was mainly hypothesized that the average scores from the situational awe scores (Yaden et al., 2018) and the Overview Effect scores (Kanas, 2020) in the post-test questionnaire of the CAVE experiment would exceed those obtained in the supplementary online experiment that made use of static images as the medium to elicit awe and the Overview Effect. The flow of all variables involved throughout the main study is illustrated in Figure 1.

Figure 1: Flow of variables in the study.



The questionnaire format used in this study was originally designed by Van Limpt-Broers et al. (2024b) and was first administered to a group of 41 Dutch-speaking university students. Since the demographics of their study closely resemble those of this study—specifically, young adults—and given that their research also measured awe and the Overview Effect, albeit with different objectives, it was deemed appropriate to utilize this questionnaire for the current study.

Furthermore, in the current study, a pre-and post-test drawing task was administered to all participants of the main experiment to assess changes in self-size perception before and after the virtual spaceflight experience (*RQ2*). Originally, this drawing task was employed by Bai et al. (2017) at Tunnel View Point in Yosemite National Park, involving a large sample of 663 tourists with an average age of 32.46 years. A modified version of this task was later utilized by Van Limpt-Broers et al. (2024a) on a sample of 100 students with a mean age of 11.24. In this version, participants were instructed to draw themselves as astronauts on a grass field, with the sun or moon depicted in the top-right corner. Given the task's relevance to VR spaceflight studies, this adapted version was chosen for use in the current study. This method not only allows for a direct measurement of changes in self-perception, as a consequence of experiencing awe and the Overview Effect, but it also sets the foundation for exploring how these perceived changes might correlate with psychological benefits, particularly in reducing feelings of self-preoccupation (Perlin & Li, 2020), which is often associated with depression and anxiety. Such insights could contribute significantly to alternative therapeutic approaches that utilize awe-inducing experiences (Chirico & Gaggioli, 2021).

The drawing task was not administered in the supplementary online experiment primarily due to the logistical challenges of replicating an interactive and personal activity like drawing in a digital format. Additionally, the nature of this task requires a controlled environment to ensure the accuracy and reliability of the drawings, which is difficult to achieve in an unsupervised online setting.

3 Experimental Setup

3.1 Participants

3.1.1 CAVE Experiment

Participants (N = 13) were recruited from Tilburg University, located in the southern part of the Netherlands. The sample included 13 individuals aged between 19 and 23 years (M = 20.85, SD = 1.07), comprising 7 males and 6 females, all of whose data was considered valid for inclusion in this study. Prior to the start of the experiment, all participants were thoroughly informed about the study procedures and provided their written informed consent.

3.1.2 Online slideshow experiment

For the supplementary online experiment using static images, data was collected by distributing the survey through WhatsApp groups and Instagram. The sample comprised 24 young adults aged between 19 and 27 years (M = 22.29, SD = 2.24), including 10 males, 13 females, and one individual who preferred not to disclose their gender. Before participating, all participants were thoroughly informed about the study procedures, and they provided informed consent within the survey itself.

3.2 Materials

3.2.1 3D glasses & CAVE

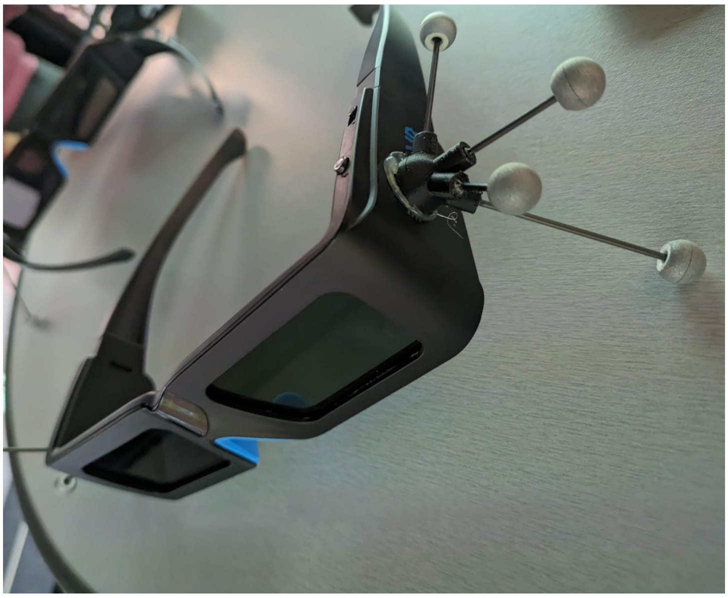
For the main experiment, the virtual spaceflight simulation was projected onto four screens surrounding the participants in the CAVE environment at the DAF Technology Lab at Tilburg University. The front screen served as the primary display for the simulation's content, showing views from the spacecraft's perspective. The screens on the left, right, and rear enhanced immersion by depicting the interior of the rocket ship, consistent with the participant's position within the virtual environment. All participants were required to wear 3D glasses to enable the perception of the simulations as immersive virtual reality experiences projected on the CAVE screens.

Participants used 3D glasses manufactured by Volfoni, specifically designed for immersive virtual reality environments (Fig 2). These glasses are essential for experiencing the full three-dimensional effect of the virtual spaceflight simulation in the CAVE system.

3.2.2 Measures

For measuring the various components associated with awe and the Overview Effect, this study employs the same questionnaire format utilized by Van Limpt-Broers et al. (2024b). This comprehensive instrument is divided into several subscales, each designed to assess distinct aspects of the participant's experience. A breakdown of this questionnaire with all of its subscales and corresponding variables can be found in Table 1.

Figure 2: 3D glasses used in the CAVE



To measure the Overview Effect, A subscale from the *Positive Effects of Being in Space* questionnaire was utilized. Initially employed by Kanas (2020) to explore the prevalence and dimensions of the Overview Effect among astronauts, this questionnaire was later refined by Van Limpt-Broers et al. (2020, 2024b). They selected only the items directly related to the Overview Effect, focusing on sub-scales such as *perceptions of Earth, perceptions of space*, and *changes to daily life*. The questionnaire comprises 13 items, each evaluated on a 7-point Likert scale. The mean Overview Effect score was calculated for both the pre-test and post-test, ranging from a minimum of 1 to a maximum of 7. The difference between these scores was then determined by subtracting the average pre-test scores from the average post-test scores.

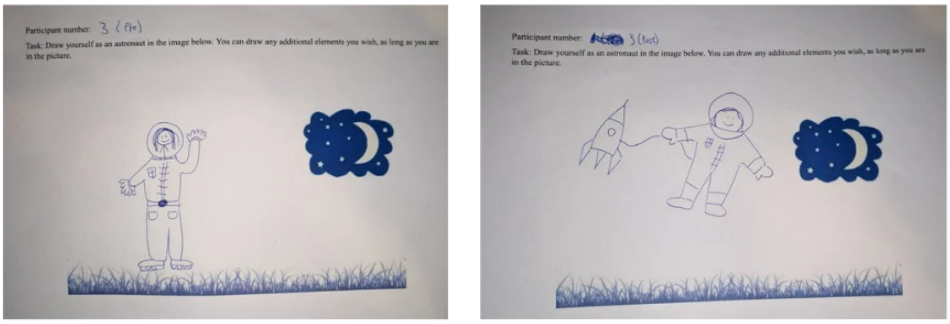
The *Awe-S Scale* (Yaden et al., 2018) was employed to assess situational awe, which quantifies the intensity of amazement and awe in response to the stimulus. The scale includes subcomponents such as *altered time perception, physical sensations, self-diminishment, perceived vastness, connectedness*, and *need for accommodation*. It comprises 30 items, each rated on a 7-point Likert scale in this study. The overall situational awe score is derived by averaging the scores across all items, with values ranging from a minimum of 1 to a maximum of 7.

To assess an individual's predisposition for experiencing awe, the *awe* sub-scale from the *Dispositional Positive Emotions Scale* (DPES) by Shiota et al. (2006) was utilized. This subscale gauges the likelihood that an individual will experience awe. The *disposition for awe* questionnaire comprises six items, each rated on a 7-point Likert scale. The overall score for disposition towards awe is determined by averaging the scores across these items, with possible values ranging from a minimum of 1 to a maximum of 7.

To assess motion sickness within the VR environment, the *Virtual Reality Sickness Questionnaire* (VRSQ) developed by Kim et al. (2018) was employed. This instrument includes nine items, each evaluated on a 4-point Likert scale. The VR sickness score is derived by calculating the average of these item scores, yielding potential values ranging from a minimum of 1 to a maximum of 4. This questionnaire was excluded from the online supplementary experiment since this experiment did not include any VR stimuli.

To quantify changes in perceived self-size, a pre-and post-test drawing task was administered to the participants. Both pre-test and post-test drawing tasks were conducted on A4 paper, which featured a predefined background with green grass at the bottom and either the sun or

Figure 3: Comparison of pre-test (left) and post-test (right) drawing sizes for participant 3



the moon in the upper right corner(see Figure X for an example of pre- and post-test drawings). The instructions for the drawing tasks remained consistent for both sessions: *"Draw yourself as an astronaut in the image below. You can draw any additional elements you wish, as long as you are in the picture"* (see Appendix B for the complete drawing task). I measured the height of each drawn character from the longest leg to the top of the head, including any clothing or hats, in centimeters to one decimal place. To account for variations in drawing size among participants, the data were normalized (see Figure 4). Changes were then assessed by comparing the gains in drawing size from the pre-test to the post-test. Due to logistical constraints, the drawing task was not included in the supplementary online experiment, as replicating this interactive and personal activity digitally proved challenging.

Figure 4: Formula used to normalize the data

$$Drawing\ gains = \frac{\frac{post}{(pre + post)} - \frac{pre}{(pre + post)}}{1 - \frac{pre}{(pre + post)}}$$

3.2.3 Stimuli

In the CAVE experiment, the primary stimulus was a 14-minute and 25-second virtual spaceflight developed by SpaceBuzz. This immersive journey featured a pre-recorded narration by André Kuipers, an astronaut with the European Space Agency (ESA). The simulation was designed to highlight elements crucial for inducing awe and facilitating the Overview Effect (Louwerse et al., 2020). See Figure 5 for some images of the stimuli.

For the supplementary online experiment, participants were shown a slideshow of five images. Three images featured awe-inspiring terrestrial landscapes (National Geographic Staff, 2017), while the remaining two depicted views of Earth from space (NASA, 2022, 2024). For examples of the images used, see Figure 6.

3.3 Design

Participants in the study were allocated into two groups based on the elicitation method used: the CAVE environment and viewing static images. Both groups were exposed to comparable

Table 1: Breakdown of the questionnaire used in this study

Variable	Questionnaire	Likert scale
Overview Effect	Positive Effects of Being in Space Questionnaire: Perception of Earth; Perception of Space; Changes in daily life	7-point
Situational Awe	Awe-S scale	7-point
Dispositional Awe	Disposition Emotions scale (DPES): Awe	7-point
VR Sickness	Virtual Reality Sickness Questionnaire (VRSQ)	4-point

Figure 5: SpaceBuzz simulation in the CAVE

stimuli and completed similar sets of questionnaires. However, participants in the online group did not complete the *Virtual Reality Sickness Questionnaire* (VRSQ), which was specific to the CAVE group. These measures aimed to assess the dependent variables of awe and the Overview Effect, with each condition addressed separately in alignment with research question one (*RQ1*). For reference, Table 1 provides a summary of the questionnaires utilized in this study, noting that the *VRSQ* was exclusive to participants experiencing the CAVE environment. For the complete questionnaires used in both experiments, see Appendix A.

Furthermore, in the CAVE condition, an additional independent variable, perceived self-size, was measured using drawing tasks to address research question two (*RQ2*).

3.3.1 Procedure: Cave Experiment

Before the start of the study, all participants were thoroughly informed about the procedures and provided written consent. Initially, they completed a demographic questionnaire, the *dispositional awe questionnaire* (Shiota et al., 2006), and the *Positive Effects of Being in Space questionnaire* (Kanas, 2020). These were accessed either by scanning a QR code that redirected them to Google Forms on their personal devices or by using a laptop provided by the researcher. Finally, the participants were asked to complete the drawing task, which would be counterbalanced between participants. Upon completion of the questionnaires and the drawing task, participants entered the CAVE to simultaneously experience the SpaceBuzz simulation, although no session reached the maximum capacity of eight people.

Figure 6: Example stimuli used in the online experiment

After completing the SpaceBuzz simulation, the CAVE doors would automatically open, allowing participants to exit. They then proceeded to complete the post-test questionnaires and the second drawing task, which was identical to the first. The post-test included the Positive Effects of Being in Space Questionnaire (Kanas, 2020), the Awe-S scale (Yaden et al., 2018), and the Virtual Reality Sickness Questionnaire (Kim et al., 2018).

3.3.2 Procedure: Online slideshow experiment

Similarly to the CAVE experiment, participants in the online experiment were informed about the study and provided consent before proceeding. Instead of the physical interaction with the CAVE environment, participants in this experiment engaged with a slideshow of five awe-inspiring images, comprising natural landscapes and views of planet Earth from space. Each image was viewed for a minimum of ten seconds. The pre-test questionnaires were the same as those used in the CAVE experiment, including the *dispositional awe* (Shiota et al., 2006) and *Positive Effects of Being in Space* (Kanas, 2020) questionnaires. However, unlike the CAVE setup, the online experiment did not involve the drawing tasks. Following the slideshow, participants completed the same post-test questionnaires as in the main experiment, excluding the *VR sickness* measure (Kim et al., 2018).

3.4 Statistical analysis

For the statistical analysis, R version 4.3.3 was utilized. Data handling and preprocessing were conducted using the *dplyr* (Broatch et al., 2019) and *readr* (Mailund, 2022) packages. Statistical tests were performed using functions from the base R *stats* (R Core Team, 2021) package. The conventional alpha level of 0.05 (5%) will be used to determine the statistical significance of all tests.

3.4.1 Comparing both experimental conditions

To evaluate the effectiveness of a Cave Automatic Virtual Environment (CAVE) in eliciting awe and the Overview Effect, a series of statistical tests were conducted.

First, the assumptions of normality and homogeneity of variances had to be calculated for the Overview Effect difference scores across both conditions. This was done by using the *leveneTest* function from the *car* (Fox & Weisberg, 2018) package.

Following verification that the assumptions of normality and homogeneity of variances were satisfied, an independent samples t-test (Liu & Wang, 2020) was conducted to compare the changes in Overview Effect scores between the CAVE experiment and the static images experiment.

Since the situational awe data was not normally distributed in both conditions, a Mann-Whitney U test (McKnight & Najab, 2010) was conducted to compare the changes in situational awe scores between the CAVE experiment and the static images experiment.

Further analysis incorporated a General Linear Model (GLM) (Myers & Montgomery, 1997) to assess the impact of dispositional awe on the situational awe scores. This model included experimental condition and dispositional awe as predictors, allowing me to control for individual differences in awe predisposition and better understand their influence on the observed awe responses across different experimental settings (see Figure 7).

Additionally, an Analysis of Covariance (ANCOVA) (Culpepper & Aguinis, 2011) was employed to predict post-test Overview Effect scores, with pre-test scores used as a covariate to control for baseline levels. This analysis was used to further examine the differential impact of the two conditions on significantly enhancing the Overview Effect.

3.4.2 Drawing gains

To further understand changes in participants' perceived self-size, drawing tasks were administered both before and after the CAVE experiment. The pre-and post-test sizes were calculated and then normalized using the formula depicted in Figure 4. Given that the data from the drawing sizes were normally distributed, a paired t-test (Hsu & Lachenbruch, 2014) was utilized to analyze the changes.

3.4.3 VR motion sickness

Given that VR motion sickness can potentially influence outcomes in the CAVE experiment, it is crucial to thoroughly examine this variable. The analysis will begin with descriptive statistics to understand the distribution and central tendencies of the VR sickness scores. Subsequent correlation analysis (R Core Team, 2021) will explore the relationships between VR sickness and post-test situational awe scores. Since the static images condition did not involve a VR environment, VR sickness analysis will not apply to that group.

4 Results

4.1 Effectiveness of the CAVE

To assess the effectiveness of the CAVE in eliciting awe and the Overview Effect (*RQ1*), several analyses have been conducted, including a two-sample t-test, a Mann-Whitney U test, a General Linear Model (GLM), and an ANCOVA model.

4.1.1 Two-sample t-test

Initially, the distribution of the *Overview Effect Change* scores was evaluated using Shapiro-Wilk tests, with results indicating that the assumptions for normality were sufficiently met for both conditions (CAVE: W = 0.89199, p = 0.1038; Static Images: W = 0.97895, p = 0.8758). Levene's test (Fox & Weisberg, 2018) for equality of variances showed homogeneity between groups (p = 0.5429), supporting the use of a two-sample t-test (Liu & Wang, 2020). The test revealed that the mean increase in Overview Effect scores was higher in the CAVE group (M = 0.249, SD = 0.386) compared to the Static Images group (M = 0.013, SD = 0.387), although this difference was not statistically significant (t(35) = 1.7708, p = 0.0853). The medium effect size (Cohen's d = 0.61) suggests a moderate practical impact (Gignac & Szodorai, 2016), which, while not statistically significant, could be meaningful in applied settings. The 95% confidence interval for the difference in means, ranging from -0.035 to 0.509, includes zero, indicating that the differences might be due to chance.

4.1.2 Mann-Whitney U test

For the average situational awe scores, the data was not normally distributed in both conditions (CAVE: W = 0.81079, p-value = 0.009183; Static images: W = 0.89951, p-value = 0.02102). Given the non-normal distribution in both groups, a Mann-Whitney U test (McKnight & Najab, 2010) was used to compare the medians of the situational awe scores between the CAVE and Static Images conditions. The Mann-Whitney U test indicated a significant difference in situational awe scores (W = 234.5, p-value = 0.006517), with the medians being higher in the CAVE condition. To quantify the magnitude of the difference between conditions, *Cliff's Delta* from the *effsize* package was calculated, which measures the effect size for ordinal data (Fox & Weisberg, 2018). The delta estimate was 0.503, classified as a large effect size (Macbeth et al., 2011). The 95% confidence interval for Cliff's Delta ranged from 0.1498 to 0.7426, indicating a robust effect across the range of possible true effect sizes. This large effect size supports the conclusion that the CAVE environment significantly enhances situational awe compared to static images, suggesting that the immersive nature of the CAVE may play a critical role in eliciting stronger awe responses.

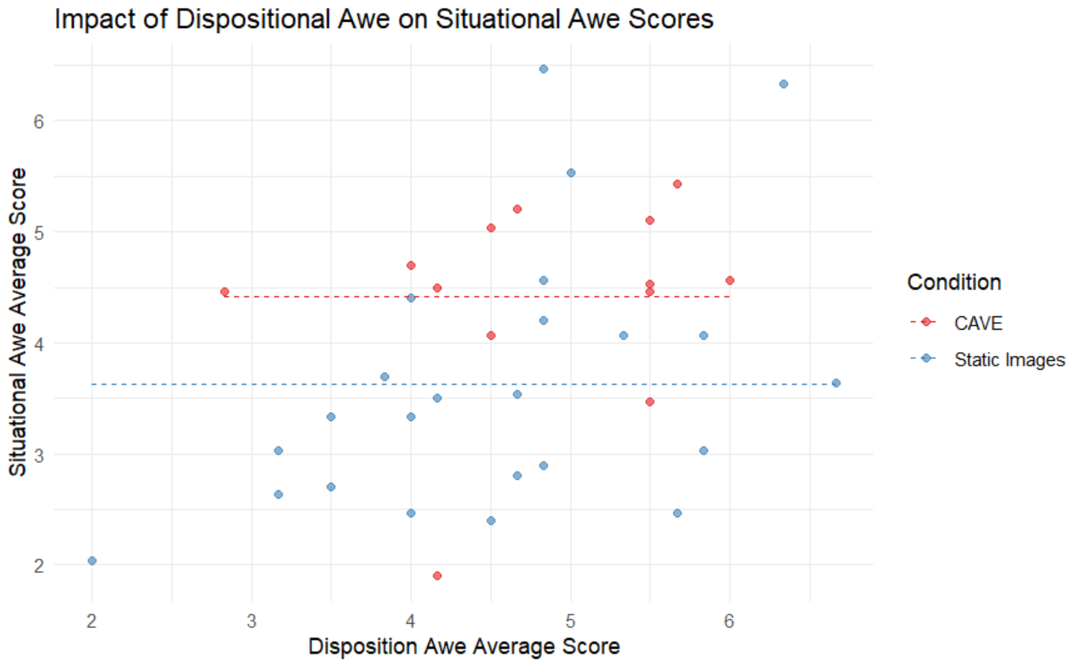
4.1.3 General linear model

To better understand the differences in situational awe scores between the two conditions, a linear regression model was constructed, taking into account participants' dispositional awe. This model used situational awe scores as the dependent variable, with experimental condition (CAVE as the reference category) and dispositional awe scores as predictors. The inclusion of dispositional awe as a covariate aimed to control for the baseline propensity of individuals to experience awe, thereby allowing for an assessment of awe scores that goes beyond personal predispositions.

The findings revealed that situational awe scores in the static images condition were lower by an average of 0.6795 points compared to the CAVE condition, though this difference approached but did not reach conventional levels of statistical significance (p = 0.0636). This suggests that the CAVE environment may be more effective at eliciting awe. Additionally, the analysis indicated that each one-point increase in dispositional awe score was associated with a 0.4165 point increase in situational awe scores across conditions (p = 0.0180), highlighting the significant role of individuals' inherent awe predispositions.

Overall, the model explains approximately 24.76% of the variance in situational awe scores, with an adjusted R-squared of 0.2033. In Fig 7 below you can find a visualization of the results, created in R using the *ggplot2* library (Wickham, 2016). The relationship between dispositional awe and situational awe scores is depicted, stratified by experimental conditions. This scatterplot with fitted lines further illustrates how individual predispositions to awe (dispositional awe) influence the experienced intensity of awe (situational awe) across the two different experimental setups: the CAVE environment and the static image viewing.

Figure 7: Visualization of the GLM



4.1.4 ANCOVA model

An ANCOVA model was constructed to predict the post-test Overview Effect scores, using pre-test Overview Effect scores as a covariate. The analysis revealed a significant effect of the experimental condition on the post-test Overview Effect scores, with participants in the CAVE condition exhibiting more pronounced changes compared to those exposed to static images ($p = 0.00153$). This finding supports the primary hypothesis regarding the enhanced effectiveness of the immersive CAVE environment. Additionally, the pre-test scores proved to be a strong predictor of post-test scores, suggesting that initial levels of the Overview Effect significantly influence the results following the intervention ($p < 0.001$). The residual plots used to check the model's assumptions confirmed that the model fits well, satisfying the necessary statistical prerequisites for conducting an ANCOVA (Culpepper & Aguinis, 2011) .

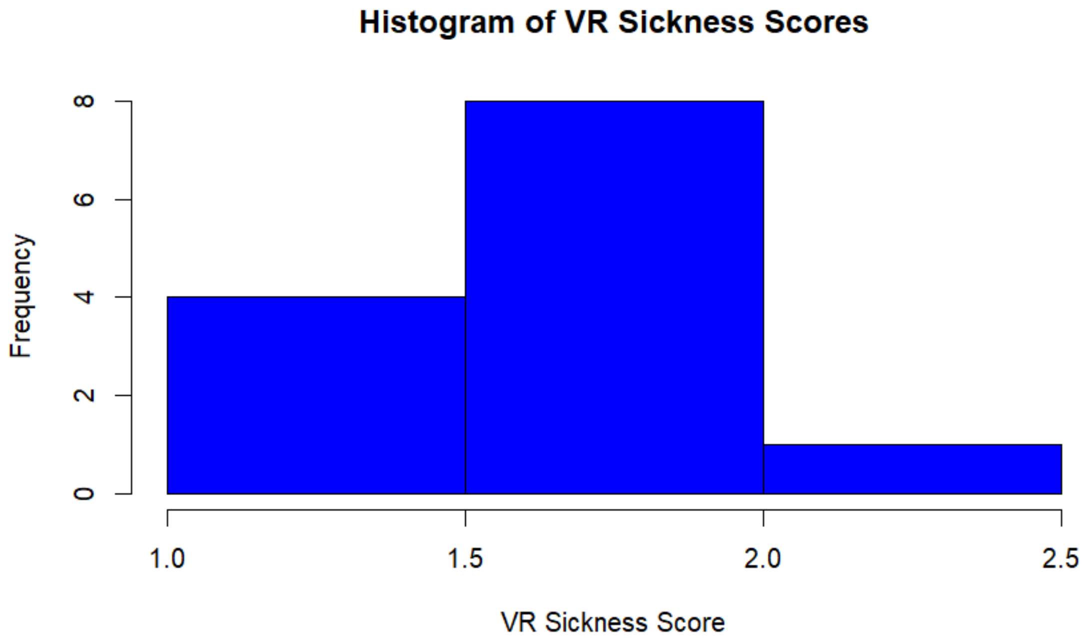
4.2 Perceived self-size

Given that the differences in drawing sizes from pre- to post-tests were normally distributed, as confirmed by both histogram inspection and a Shapiro-Wilk test ($W = 0.98584$, $p = 0.9967$), a paired t-test was conducted to assess the changes in perceived self-size based on these drawing tasks. The test did not reveal statistically significant changes ($t = -1.4055$, $df = 12$, $p = 0.1852$). The mean difference, calculated by subtracting the post-test drawing sizes from the pre-test drawing sizes, was approximately -0.569. This indicates that, on average, participants' drawings of themselves were larger in the post-test compared to the pre-test. Despite this increase, the difference was not statistically significant, suggesting no substantial change in perceived self-size after the experiment. The calculated Cohen's d was 0.344, indicating a small to medium effect size (Gignac & Szodorai, 2016).

4.3 Correlational analyses

In the CAVE condition, which utilizes a virtual environment, understanding the impact of motion sickness is crucial. Descriptive statistics reveal that the majority of VR sickness scores cluster around the lower end of the scale, indicating that most participants experienced mild to moderate VR sickness (refer to Figure 9 for the histogram). For the correlation analysis, the *Hmisc* (Harrell, 2024) library was used. The results indicate a negative correlation of -0.2935366 between VR sickness and situational awe. However, this correlation is not statistically significant (p = 0.3303578), suggesting that while there is a slight inverse relationship, VR sickness does not substantially affect the levels of situational awe experienced by participants.

Figure 8: Histogram of VR sickness scores



5 Discussion and Conclusion

The primary aim of this study was to evaluate the effectiveness of a Cave Automatic Virtual Environment (CAVE) in eliciting awe and the Overview Effect, comparing its efficacy against less immersive static images. This research contributes to understanding how varying exposure modalities to awe-inspiring stimuli can affect participants' cognitive and emotional responses, particularly their self-size perception.

The findings indicated that while the CAVE environment did not significantly enhance the Overview Effect more than static images, the medium effect size observed (Cohen's d = 0.61) suggests that even minor enhancements in awe might have practical implications in applied settings. This aligns with Stepanova et al. (2019b), who emphasized the need for strong immersion to experience the vastness of awe-inducing stimuli, a requirement potentially better met in more traditional VR settings, or in actual natural settings where the true vastness of these stimuli can be experienced. On the contrary, the Mann-Whitney U test demonstrated a significant difference in situational awe scores, with higher medians in the CAVE condition. With a large effect size (Cliff's Delta = 0.503), this supports the idea that these environments do differ in terms of immersion and presence, which is an important component for the enhancement of situational awe (Chirco et al., 2018; Vasarainen et al., 2021). These findings combined, not only highlight the subtle differences between the two mediums used in this study but also demonstrate that experiencing the Overview Effect requires a higher sense of presence compared to only experiencing awe (Yaden et al., 2016).

In the further analysis of situational awe scores, the GLM provided an opportunity to understand how dispositional awe (Shiota et al., 2006) influences awe experiences in different experimental conditions. Importantly, the model accounted for approximately 24.76% of the variance in situational awe scores, as indicated by an adjusted R-squared value of 0.2033. An explained variance of 24.76% is considered moderate in behavioral sciences (Cohen, 1988), suggesting that while the model captures a significant portion of the factors influencing awe responses, a substantial amount of variability remains unexplained. This could be due to other unmeasured variables that might also impact awe experiences, such as individual differences in sensory sensitivity (Ward, 2019), prior exposure to similar stimuli (Dijksterhuis & Smith, 2002), or even the specific content and design of the awe-inducing stimuli used in each condition. The non-significant difference in awe scores between the CAVE and static images conditions, after controlling for dispositional awe, suggests that while the CAVE environment may offer a more immersive experience, the effect of this immersion on situational awe is not overwhelmingly strong. This could point to the potential for static images, when used effectively, to evoke comparable awe experiences, especially in individuals with a high disposition for awe.

Unexpectedly, participants' perceived self-size did not decrease following the CAVE experience. This outcome diverges from findings within natural settings (Bai et al., 2017) where vast environments typically induce a feeling of being smaller. This discrepancy may stem from the virtual settings not fully replicating the expansiveness of natural environments, especially when it comes to the Overview Effect(Yaden et al., 2016). It may also stem from the simple fact that drawing tasks often resonate more with younger participants (children), who are generally more inclined to express their feelings and thoughts through drawings (Johnson et al., 2012). An alternative interpretation of these results could be that while observing an awe-inspiring stimulus might diminish self-size perception (Bai et al., 2017), the depiction of self-figures in drawings could vary based on cultural influences (Yap et al., 2022).

Despite concerns, VR motion sickness was predominantly mild and did not significantly detract from the overall effectiveness of the CAVE environment. However, the slight negative correlation observed between VR sickness and situational awe, though not significant, aligns with previous studies suggesting that discomfort may undermine the depth of awe experiences (Chirico et al., 2018; Stepanova et al., 2019a), warranting further exploration in future studies.

The study's limitations include its small sample size and participant homogeneity, which may affect the generalizability of the findings. Future research could benefit from exploring diverse participant groups and varying the VR content to more comprehensively assess the CAVE's potential. Further investigations might also focus on interactive elements (contrary to this study using a seated SpaceBuzz simulation) within the CAVE to enhance engagement and the resultant emotional responses, potentially overcoming the limitations observed in this study. Specifically for the second experiment with static images, the lack of significant results may stem from the unsupervised way it was designed, as it was an online study.

In conclusion, while the CAVE environment effectively elicited situational awe (*RQ1*), its impact on the Overview Effect (*RQ1*) and self-size perception (*RQ2*) was inconclusive, highlighting the complex interplay between immersion levels and psychological outcomes. These findings pave the way for future research to optimize immersive technologies for enhancing human emotional and cognitive experiences, particularly in therapeutic contexts.

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Appendices

A Awe and Overview Effect Questionnaires

A.1 CAVE experiment

A.1.1 Pre-test

1. What is your age?
2. What gender do you specify with?
3. Have you experienced VR before?
4. I often feel awe.
5. I see beauty all around me.
6. I feel wonder almost every day.
7. I often look for patterns in the objects around me.
8. I have many opportunities to see the beauty of nature.
9. I seek out experiences that challenge my understanding of the world.
10. I have a strong appreciation of the Earth's beauty.
11. I appreciate the fragility of the Earth.
12. I realize how much I treasure the Earth.
13. I am, or want to be involved in environmental causes.
14. I have a strong sense of wonder about the universe.
15. I am excited about space exploration.
16. I have an appreciation for the boundlessness of the Cosmos.
17. I am interested in the possibility of life on other planets.
18. My relationship with my family is strong.
19. I have a strong appreciation for the unity of humankind.
20. I am inspired to express my creativity.
21. I want to be, or am involved in political activities.
22. I think that differences in political ideology are arbitrary.

A.1.2 Post-test

1. I sensed things momentarily slow down.
2. I noticed time slowing.
3. I have a strong appreciation of the Earth's beauty.
4. I felt my sense of time change.
5. I felt a sense of communion with all living things.
6. I have an appreciation for the boundlessness of the Cosmos.
7. I felt my sense of self become smaller somehow.
8. I felt that I was in the presence of something grand.
9. I am excited about space exploration.
10. I experienced the passage of time differently.
11. I perceived something that was much larger than me.
12. I have a strong sense of wonder about the universe.
13. I felt my jaw drop.
14. I had goosebumps.
15. My relationship with my family is strong.
16. I experienced a reduced sense of self.
17. I think that differences in political ideology are arbitrary.
18. I had the sense that a moment lasted longer than usual.
19. I am interested in the possibility of life on other planets.
20. I experienced a sense of oneness with all things.
21. I realize how much I treasure the Earth.
22. I had chills.
23. I felt my eyes widen.
24. I gasped.
25. I appreciate the fragility of the Earth.
26. I felt that my sense of self was diminished.
27. I am, or want to be involved in environmental causes.
28. I felt my sense of self shrink.

29. I perceived vastness.
30. I have a strong appreciation for the unity of humankind.
31. I found it hard to comprehend the experience in full.
32. I felt small compared to everything else.
33. I felt challenged to mentally process what I was experiencing.
34. I had the sense of being connected to everything.
35. I felt challenged to understand the experience.
36. I felt in the presence of greatness.
37. I am inspired to express my creativity.
38. I felt closely connected to humanity.
39. I struggled to take in all that I was experiencing at once.
40. I had a sense of complete connectedness.
41. I want to be, or am involved in political activities.
42. I experienced something greater than myself.
43. I tried to understand the magnitude of what I was experiencing.
44. Indicate how much you experienced the following symptom during the VR experience: General discomfort
45. Indicate how much you experienced the following symptom during the VR experience: Fatigue
46. Indicate how much you experienced the following symptom during the VR experience: Eyestrain* (*Eyestrain may include feelings of tired eyes, difficulty focusing, or slight discomfort around the eyes.)
47. Indicate how much you experienced the following symptom during the VR experience: Difficulty focusing
48. Indicate how much you experienced the following symptom during the VR experience: Headache
49. Indicate how much you experienced the following symptom during the VR experience: Fullness of head* (*Fullness of head can refer to sensations of pressure or a slight heaviness in the head.)
50. Indicate how much you experienced the following symptom during the VR experience: Blurred vision
51. Indicate how much you experienced the following symptom during the VR experience: Dizzy (eyes closed)

52. Indicate how much you experienced the following symptom during the VR experience: Vertigo* (*Vertigo refers to a feeling of dizziness or spinning, as if the environment around you is moving or swirling.)

A.2 Static Images experiment

A.2.1 Pre-test

1. What is your age?
2. What gender do you specify with?
3. I often feel awe.
4. I see beauty all around me.
5. I feel wonder almost every day.
6. I often look for patterns in the objects around me.
7. I have many opportunities to see the beauty of nature.
8. I seek out experiences that challenge my understanding of the world.
9. I have a strong appreciation of the Earth's beauty.
10. I appreciate the fragility of the Earth.
11. I realize how much I treasure the Earth.
12. I am, or want to be involved in environmental causes.
13. I have a strong sense of wonder about the universe.
14. I am excited about space exploration.
15. I have an appreciation for the boundlessness of the Cosmos.
16. I am interested in the possibility of life on other planets.
17. My relationship with my family is strong.
18. I have a strong appreciation for the unity of humankind.
19. I am inspired to express my creativity.
20. I want to be, or am involved in political activities.
21. I think that differences in political ideology are arbitrary.

A.2.2 Post-test

1. I sensed things momentarily slow down.
2. I noticed time slowing.
3. I have a strong appreciation of the Earth's beauty.
4. I felt my sense of time change.
5. I felt a sense of communion with all living things.
6. I have an appreciation for the boundlessness of the Cosmos.
7. I felt my sense of self become smaller somehow.
8. I felt that I was in the presence of something grand.
9. I am excited about space exploration.
10. I experienced the passage of time differently.
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15. My relationship with my family is strong.
16. I experienced a reduced sense of self.
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18. I had the sense that a moment lasted longer than usual.
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28. I felt my sense of self shrink.

29. I perceived vastness.
30. I have a strong appreciation for the unity of humankind.
31. I found it hard to comprehend the experience in full.
32. I felt small compared to everything else.
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39. I struggled to take in all that I was experiencing at once.
40. I had a sense of complete connectedness.
41. I want to be, or am involved in political activities.
42. I experienced something greater than myself.
43. I tried to understand the magnitude of what I was experiencing.

B Self-size perception - Draw yourself as an astronaut

Instructions: *"Draw yourself as an astronaut in the image below. You can draw any additional elements you wish, as long as you are in the picture"*

Figure 9: Default drawing field version 1 and 2