RESPIRA: fractal dimensions as an immersive interactive training for diaphragmatic breathing.

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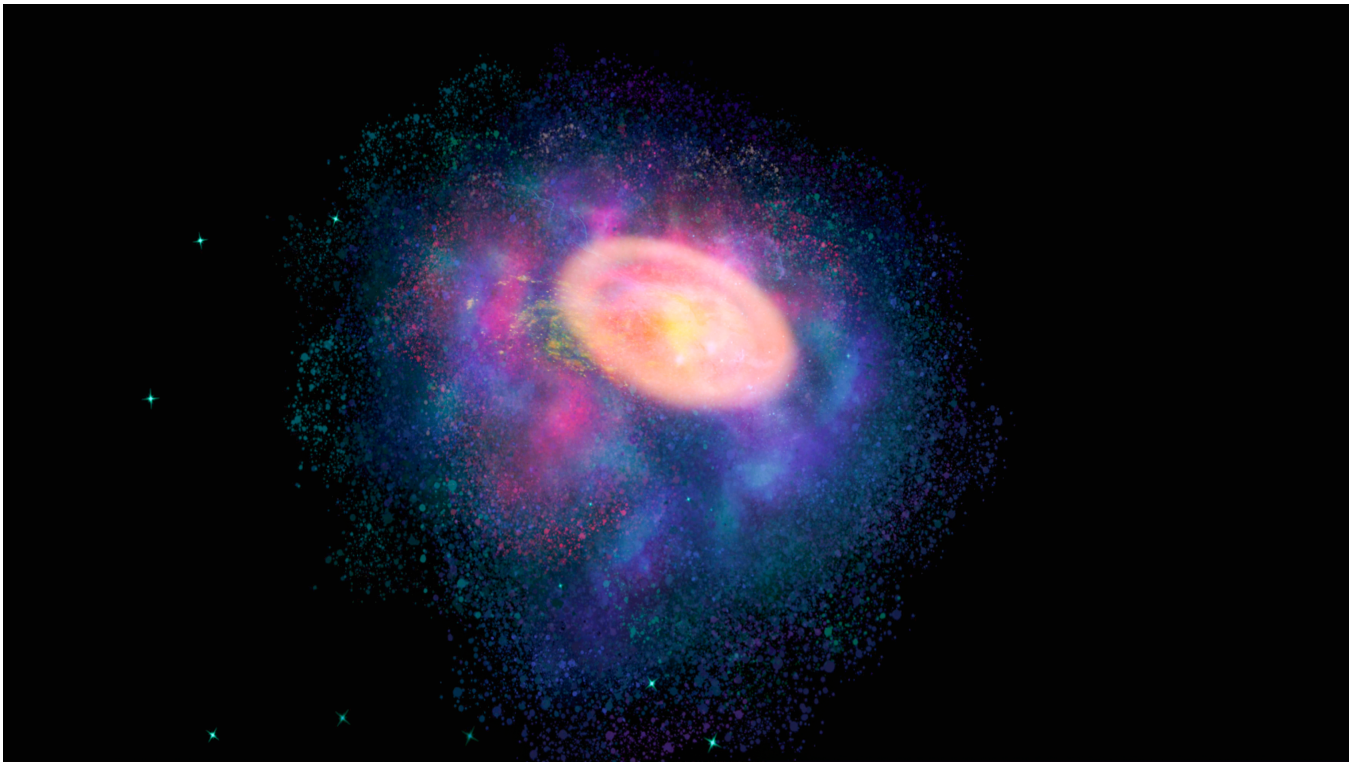

Figure 1: Snapshot from Unity of environmental response activated by initial diaphragm expansion, particles start lighting up to encourage the user to reach the following stage. Fractal dimensions are set at D=1.78.

Abstract

RESPIRA is a science-based art project that provides immersive training and practice of diaphragmatic breathing as a powerful tool supporting mental health first aid. Through a belt-mounted abdominal sensor, we provide real-time feedback through a fractal-based visualization. Fractal dimensions are calculated to provide users with an interactive, responsive environment designed with patterns generated by engaging and restorative ranges (D=1.3-1.7). By integrating art, science, and technology, RESPIRA aims to explore the potential of digital environments in spreading knowledge for daily mental health, providing powerful support for psychologically challenging conditions, such as panic attacks, and anxiety management.

CCS Concepts

• **Human-centered computing** → **Virtual reality**; **Visualization theory, concepts and paradigms**; • **Applied computing** → **Media arts**.

Keywords

Fractal dimensions, responsive digital environments, diaphragmatic breathing, anxiety management, interactive training, Virtual Reality.

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1 INTRODUCTION

RESPIRA is a scientifically grounded art project deployed within Virtual Reality (VR) in support of mental health, particularly for anxiety management and high-stress conditions. Drawing on fractal theory and calculations, RESPIRA is designed according to fractal dimension ranges proven to be beneficial for both psychological and visual comfort needs (Figure 1).

RESPIRA in Italian means "breathe". The goal of this prototype relies on transmitting to the user the necessary knowledge and practice to perform diaphragmatic (belly) breathing. Diaphragmatic breathing is vital both physiologically, aiding in oxygen exchange, and psychologically, helping manage anxiety [Tomich et al. 2007]. This technique serves as a powerful self-help tool during sudden panic attacks and other anxious situations, enhancing physiological health and mitigating the psychological impacts of anxiety, making it an essential strategy for managing acute anxiety and its associated symptoms[Tomich et al. 2007]. This project highlights the societal value of integrating art, science, and technology in view of providing more tools for mental health support. It demonstrates how art can effectively address daily life challenges. Through this science-based art practice, we aim at spreading knowledge about diaphragmatic breathing as an immediate self-performed first aid for mental health and its beneficial effects for anxiety and panic attacks.

2 DIGITAL ENVIRONMENTS FOR ANXIETY MANAGEMENT

Virtual Reality (VR) has been vastly employed to support anxiety management by providing exposure-based interventions[Maples-Keller et al. 2017]. This approach includes delivering exposure therapy, providing psycho-education, and offering relaxation therapy to individuals suffering from anxiety[Ioannou et al. 2020; Mohammad and Ahmad 2019]. Additionally, VR interventions have incorporated elements such as psychological storytelling in games, personalized mindfulness coaching, and digital therapeutics to enhance the therapeutic experience[Baghaei et al. 2020; Hudlicka 2013]. Recent research has integrated neuron and bio-feedback methods within VR applications to improve relaxation, such as meditation and mindfulness, making these practices more enjoyable, measurable, and personalized[Gromala et al. 2015; Wang et al. 2022]. More specifically, VR has been utilized to enhance mindful practices through guiding breathing rhythms using sensory feedback like vibration, sound, and lighting to enhance effectiveness [Miner et al. 2024; Sato et al. 2015]. Integrated with biofeedback, VR can make breathing patterns more visual and perceptible to help users to voluntarily adjust their breathing rhythm and achieve relaxation[Ban et al. 2018; Zhang et al. 2023]. Diaphragmatic breathing is an essential strategy for managing anxiety and its symptoms. Despite its potential, diaphragmatic breathing remains under-explored within VR settings.

3 FRACTAL DIMENSIONS AND RESTORATIVE EFFECTS

The innovation of integrating fractal dimensions within built environments has drawn much attention for its potential to enhance visual engagement [Abboushi et al. 2019; Sun and Firestone 2021; Wu and Chen 2020] and for the restorative benefits coming from visualizing certain fractal patterns [Taylor et al. 2005; Zueva 2015]. Fractals have been used to describe self-similar patterns that repeat at different scales[Barnsley 2014; Mandelbrot and Mandelbrot 1982]. Fractal dimensions quantify the spatial visual complexity of fractal patterns. Defined by a D value ranging from 1 to 2, fractal analysis reveals the degree to which a fractal fills space [Abboushi et al. 2019; Feder 2013; Mandelbrot and Mandelbrot 1982]. This characteristic has been found to have a strong connection with human visual cognition and psychological states[Forsythe et al. 2011; Sun and Firestone 2021; Wu and Chen 2020]. Studies have shown that fractal patterns within the D range of 1.3-1.7 are visually comfortable and restorative [Abboushi et al. 2019; Forsythe et al. 2011; Taylor et al. 2005]. Within this range, D= 1.3-1.5 is rated as the most aesthetically pleasing [Forsythe et al. 2011], while those with D= 1.4-1.6 lower physiological stress markers such as heart rate and skin conductance [Taylor et al. 2005]. Furthermore, fractals in the D=1.5-1.7 range peak in visual interest, promoting cognitive performance and mental clarity[Abboushi et al. 2019].

The restorative benefits of fractal patterns extend beyond merely visual comfort and visual pleasantness. Ulrich's stress-reduction framework [Ulrich 1981; Ulrich and Biophilia 1993] and Kaplan's Attention Restoration Theory [Kaplan 1995] use fractal patterns as portals for a detailed understanding of human visual perception, brain load, and psychological well-being, positing that the visual complexity of fractal patterns is restorative for the brain, boosting mental recovery and attention [Kaplan 1995]. Marks-Tarlow [Marks-Tarlow 2010, 2013] further explores the restorative potential of fractals, suggesting that their recursive, self-similar nature of patterns mirrors human cognitive processes and can be used therapeutically to promote mental well-being. Her work also highlights the use of fractals in psychotherapy for effective emotional healing during and after therapy sessions [Marks-Tarlow 2010, 2013]. Furthermore, the application of fractal dimensions within VR environments is limited, with current research predominantly using fractal geometry to generate specific scenes in VR[Van Almkerk and Huisman 2018]. Few studies have quantified fractal geometry using fractal dimension as a measurable indicator for visual comfort and restorative visual effects in VR scenarios[Della-Bosca et al. 2017].

The restorative range of fractal dimensions and their positive effects on cognitive performance demonstrate significant potential for use in immersive environments specifically tailored for mental health support. Comprehensively, there is a lot of potential for integrating diaphragmatic breathing as an anxiety management tool, as opposed to its more common application in enhancing breathing awareness and delivering interactive feedback for meditation or relaxation.

4 RELATED WORK

The application of fractal dimension in artistic practice primarily focuses on the generation of patterns and aesthetic evaluation. In the realm of artwork, fractal dimensions are predominantly used in generative art and pattern design and play a crucial role in the aesthetic evaluation of artworks, particularly paintings. [Chen and Zhang

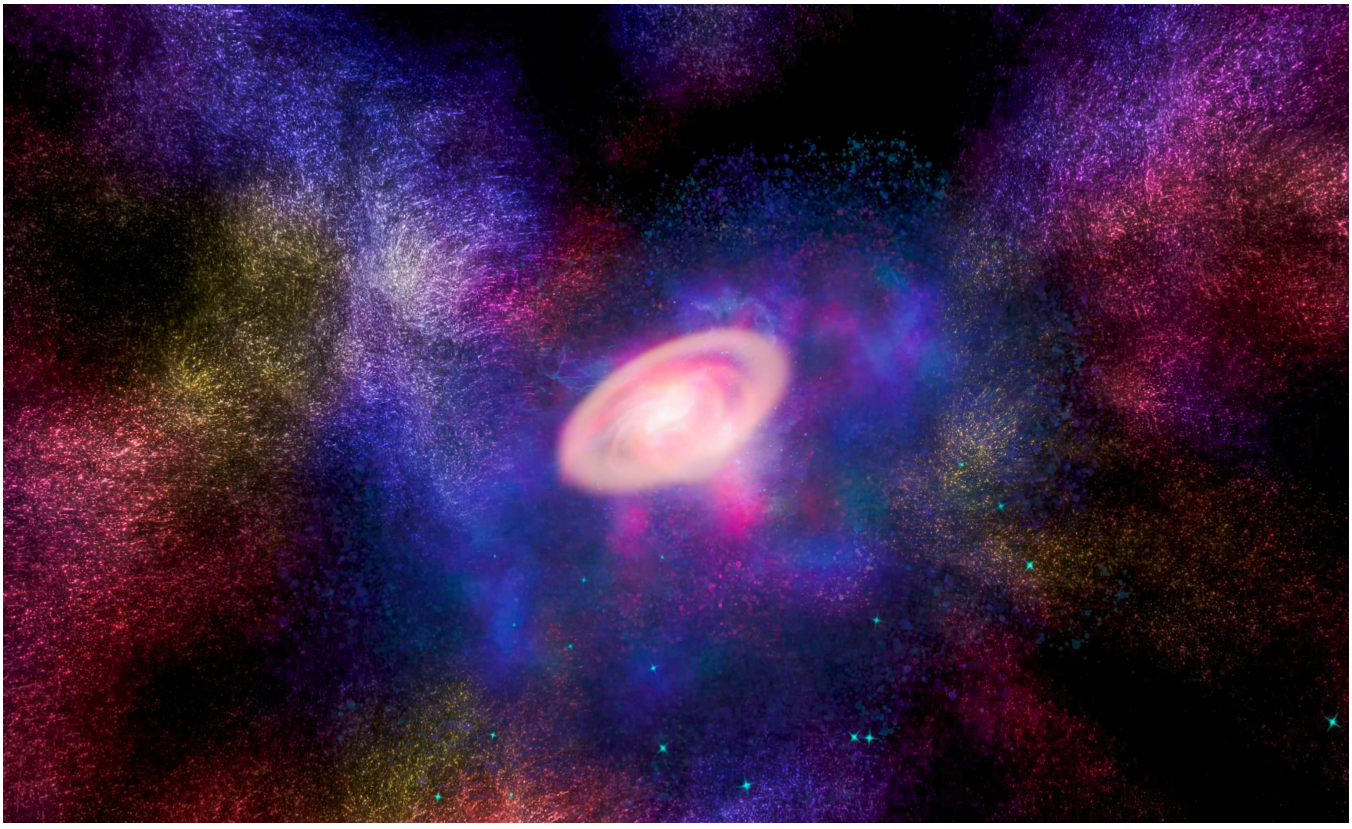

Figure 2: Snapshot from Unity of the environmental response to correct performance of diaphragmatic breathing with full expansion of the diaphragm (Stage 3). Fractal dimensions set at D=1.5 through Otsu authomatic threshold.

2023] have combined fractal dimension with Chaoshan Drawnwork to design and digitalize patterns for traditional crafts. The fractal patterns were created using UF6, a fractal art software, enabling the seamless integration of fractal designs with traditional Chaoshan drawnwork motifs. In addition, fractal dimensions serve as an aesthetic feature in generating and evaluating artworks created by computer-based algorithms [Wu 2018]. They are also used to assess artistic elements such as color distribution in Impressionist art [Fukumoto et al. 2004]. These studies highlight an emerging field known as computational aesthetic evaluation [Galanter 2012]. In research related to VR, fractal dimensions are utilized to generate specific VR scenes [Fukumoto et al. 2004], and help quantify the level of complexity within these scenes to enhance user experiences. This demonstrates how fractal analysis can be an invaluable tool in the early stages of testing for experience and interaction design [Della-Bosca et al. 2017].

5 RESPIRA

RESPIRA is a VR interactive experience that advances diaphragmatic breathing techniques by providing clearer instructions, more precise feedback, and an enhanced visual experience designed according to fractal dimensions (Figure 2). This system delivers oral instructions both at the start and throughout each breathing stage, ensuring users are guided effectively. The core functionality of RESPIRA involves diaphragmatic breathing, which emphasizes engaging the diaphragm fully during inhalation. The breathing system, equipped with an elastic belt named Elastech, allows users to wear it around the belly at the level of the navel and transform the belly breathing behavior into numerical data, which is collected through the expansion of the belt and has periodic changes in magnitude. The system includes four different stages in the breathing process (Figure 3).

1. Stage 0 aims to collect users' unique breathing data thresholds and apply them to mapping systems in later stages. In this initial stage, users perform normal breathing to establish a baseline before engaging in diaphragmatic breathing, highlighting the distinction between normal and diaphragmatic (belly) breathing.
2. Stage 1 introduces initial engagement and visual feedback through controls such as background stars, ring colors, and audio instructions. At this stage, the VR environment presents a ring orbiting around the central pattern. The average interval is mapped to colors: a 1-second interval displays a cyan color (Figure 4), while a 3-second interval shows orange (Figure 5). When the magnitude of received data exceeds more than 2% of the maximum threshold measured during the previous customization process, the system moves to the next stage. D value is set highest to 1.95.

3. Stage 2 enhances feedback with additional controls, including activation, colors, size, position, and particle emission rates of outer smoke (Figure 1). The system will advance to the next stage if the magnitude of received data exceeds the maximum by more than 4% for 3 times. However, if the data falls below 2% of the maximum consecutively 4 times, the system reverts to the previous stage. D value in Stage 2 slightly decreases, as a positive feedback, to 1.78 (since Stage 2 is relatively easy to achieve).

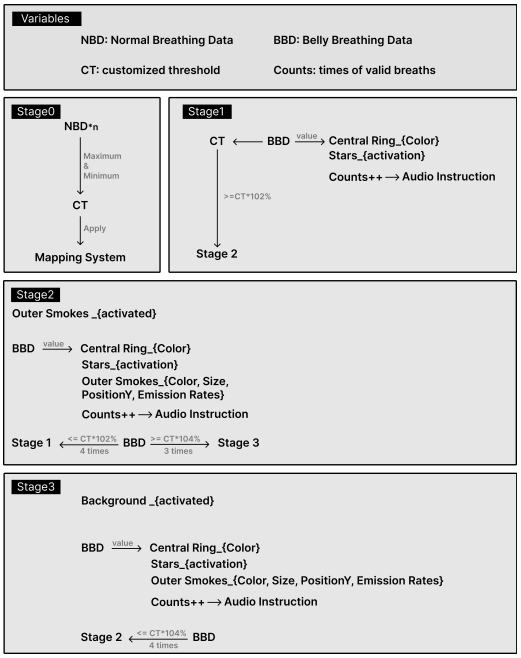

Figure 3: Data mapping, interpretation, and processing algorithm of the 4 stages.

4. Stage 3 represents full diaphragmatic breathing and advanced feedback, with complex, visually appealing patterns emerging in the background (Figure 2). If the magnitude of received data falls below 4% of the maximum for consecutively 4 times, the system reverts to the previous stage. The D value in Stage 3, which decreases to around 1.5, reaches the most desirable range of low cognitive load and high visual interest, rewarding for the huge effort exerted in belly breath.

6 USER FEEDBACK

Overall, user feedback (Figure 7) shows increased awareness and engagement with breathing patterns. Positive comments and unexpected insights from users highlight the potential of RESPIRA in fostering synthesis, embodiment, and creativity, as well as learning and training. User feedback on the experience and evaluation of RESPIRA was gathered through a Likert-scale survey and brief interviews.

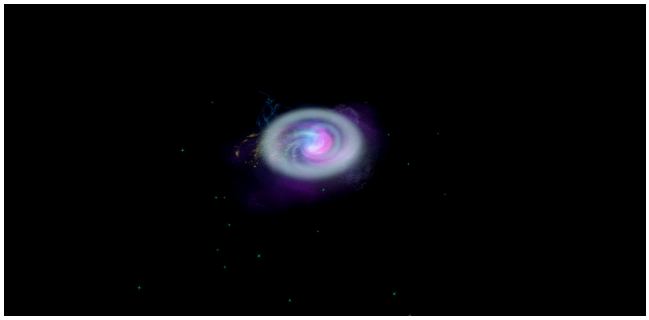

Figure 4: Stage 1 is set as the starting stage. Blue crown stands for faster breathing, to slow down and try perform diaphragmatic breathing color will need to switch to orange.

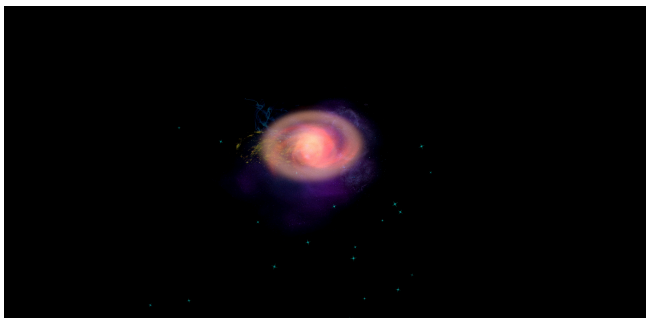

Figure 5: Stage 1, orange crown, breathing is slowing down, good track for switching to stage 2.

6.1 Awareness, engagement, and continuation intentions

A significant majority (64.71%) reported increased awareness of their breathing patterns and a better understanding of diaphragmatic breathing. The responsive virtual environment, characterized by elements such as nebulas and particles, was deemed visually comfortable by 88.24% of participants and visually appealing by 82.36%. The use of patterns within the virtual reality setting notably enhanced engagement with the breathing training for 76.47% of participants. Additionally, 70.58% of participants indicated a likelihood to continue using a similar system for practicing diaphragmatic breathing in the future. These results underscore the system's potential for ongoing use and its effectiveness in promoting better respiratory awareness and technique.

6.2 Co-creativity

After experiencing RESPIRA, we further conducted interviews asking about what you found most helpful, enjoyable, or other interesting feelings during the training session and what's the suggestion of this breathing system. We present here some comments that showcase a co-creative state for users and an immersive feeling.

"The designed elements are both abstract and imaginative, and I hope to co-create the scenes with my imagination, wondering 'Is there an eye in the middle?' 'Is that water below?' and I feel

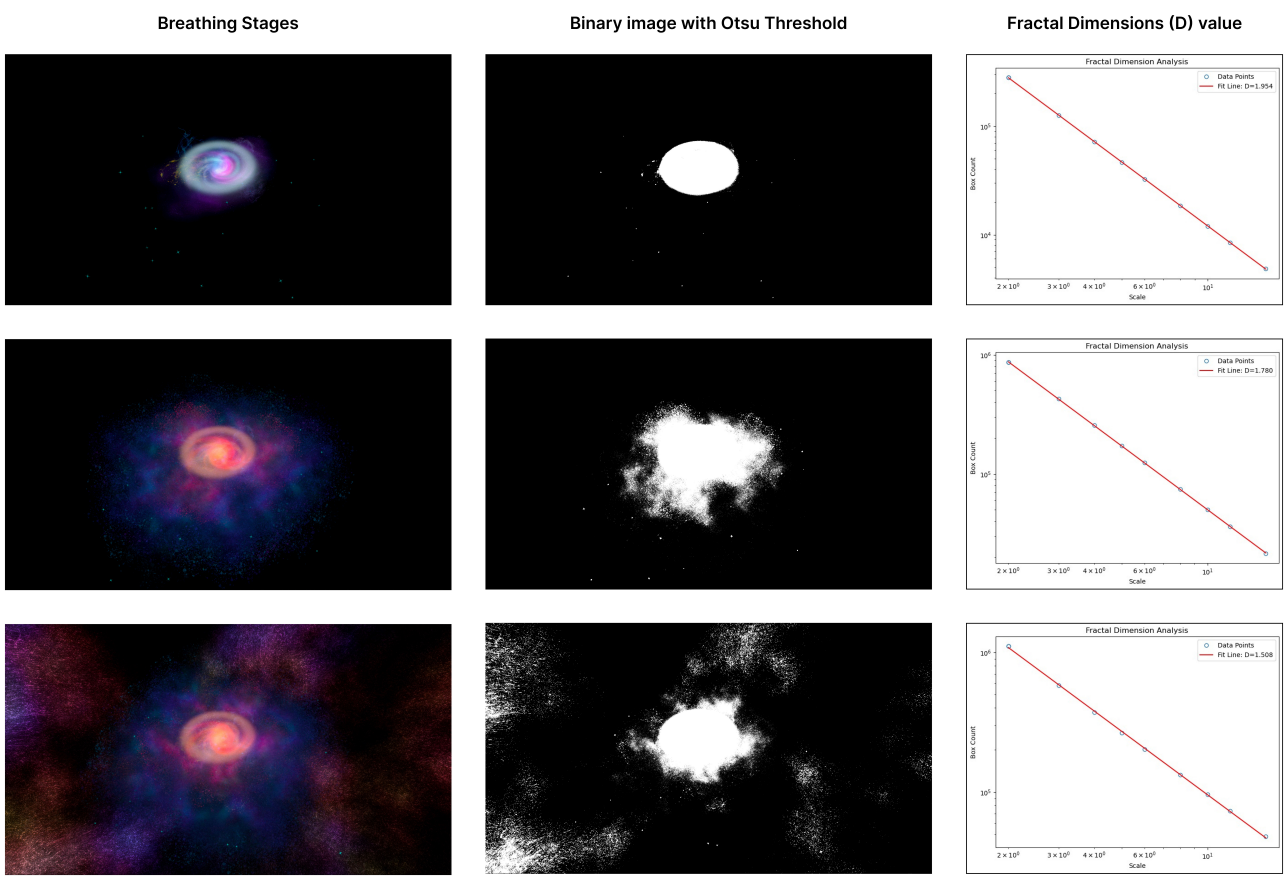

Figure 6: Fractal dimensions calculation through Otsu automatic threshold of the three main interactive stages.

immersed and safe in the co-created environment. " "It feels creative, full of vitality, with breathing closely related to environmental changes." "I hope to join and become embodied with the nebula during the process. When I feel that the nebula is changing dynamically with my breath, it gives a sense of co-existence."

7 CONCLUSION

This paper introduces RESPIRA, an interactive training providing users with learning and practice of diaphragmatic breathing for daily mental health support and mental health first aid. Through this, we explore the potential of scientific-based art to enhance psychological and physiological well-being. Drawing inspiration from fractals, a pervasive pattern in nature that has been scientifically proven to have restorative effect, we have employed fractal patterns and calculated fractal dimensions to not only promote art visualization but also to amplify its efficacy for anxiety management. The positive feedback from participants confirms that patterns in the virtual environment can enhance engagement during belly breathing training, and a fractal-based environment contributes to mental well-being by securing a visually comfortable and restorative immersive environment. Beyond providing mental health support and

Figure 7: Users wearing a VR headset (VIVE Focus 3) and Elastech, an elastic belt equipped with a motion sensor.

visual restoration, unexpected insights from users have unveiled RESPIRA's potential for synthesis, embodiment, and creative expression. These findings highlight the project's ability to positively

impact society by integrating innovative, science-based artistic approaches, thus challenging traditional boundaries between disciplines and redefining their roles in enhancing human health.

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