Viscereality: A Bio-responsive VR System for Breath-Based Interactions and Coupled Oscillator Dynamics to Augment Altered States of Consciousness

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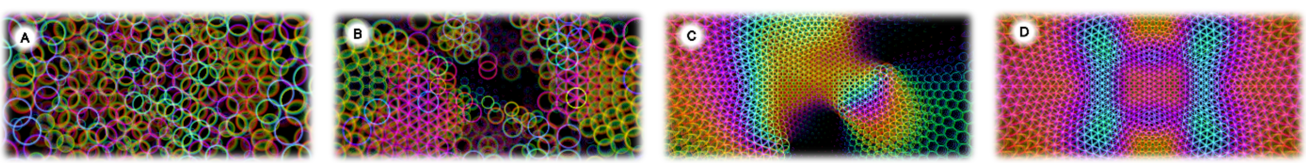

Figure 1: Evolution of particle patterns in the Viscereality system during breath-driven dynamic coupling. Shown are four snapshots spanning a typical 2–3 second breathing phase: (A) initial disorder, (B) early clustering, (C) emergent symmetry, and (D) full geometric coherence.

Abstract

We introduce a bioresponsive virtual reality system that maps users' breathing patterns to dynamic, spatialized visual feedback. The system implements Gestalt principles, such as good figure, similarity, and symmetry, within a 3D particle-based environment to enhance the embodiment of interoceptive and exteroceptive space, aiming to blur the subjective boundary between bodily self and the external virtual space. Moreover, the system incorporates coupling kernels

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within a dynamic system composed of Kuramoto oscillators, enabling the emergence of geometric visual symmetries during breath retention phases. This architecture provides an experimental framework for investigating how visual–respiratory coupling of space can influence perceived bodily boundaries and peripersonal space, as well as for testing how such coupling affects positively valenced aspects of subjective experience, drawing on principles from the Symmetry Theory of Valence. A short video summary of the system is available at: https://osf.io/4enfg.

CCS Concepts

• **Human-centered computing → Virtual reality**; *Information visualization*; *HCI theory, concepts and models.*

Keywords

altered states of consciousness, bioresponsive systems, breath-based interaction, symmetry theory of valence, interoceptive-exteroceptive substitution, visual-respiratory coupling

1 Introduction

1.1 Bio-responsive Interfaces and Interoceptive Signal Integration

Breathing is not only fundamental to sustaining life but also plays an active role in the subjective experience of our emotional states. People hold their breath in anticipation, release their breath as a sign of relief, and hyperventilate when they are anxious. And an Emerging body research from the field of mind-body interactions supports the view that interoceptive signals, such as cardiac rhythms and breathing patterns, shape how we construct conscious experience via the dynamic integration internal and external sensory states [7, 12, 16, 23, 26]. These principles are increasingly being applied in human-computer interaction to influence conscious experience through the modulation of interoceptive signals [19, 37]. Our aim was to explore how embedding such signals into bio-responsive interfaces could expand the experiential state-space [4] and facilitate access to non-ordinary states of consciousness—states often characterized by a loosening of self–world boundaries and akin to those induced by breathwork or meditation.

Specifically, our design sought to dissolve the boundary between interoception and exteroception by coupling internal bodily rhythms with external sensory feedback, fostering a unified field of embedded and embodied awareness within virtual reality. We briefly review prior work on breath-based interfaces and their somatosensory mapping in HCI, and introduce how a theoretical framework from consciousness research with a broad explanatory scope was adapted into a tangible, aesthetics-driven design principle for augmenting breathwork-induced experiences in virtual reality.

1.2 Contemporary VR Breathing Applications and Somatosensory Design Mapping

Breath-based interactive systems have proliferated across HCI and VR research, leveraging respiratory patterns as input for applications spanning meditation aids [22, 34, 40], therapeutic training [46], art installations [25, 42], and gaming [41, 45]. Most existing interfaces utilize representations that mimic human lung mechanics, mapping respiratory activity directly onto virtual representations through expanding and contracting visual elements, vertical movements, and fade sequences congruent with breath [32].

A widely adopted strategy involves externalizing breath through direct somatosensory mapping—where lung volume expansion animates a virtual avatar's rising chest [11, 27] or controls a jellyfish's pulsation [14]. This approach has also been termed as exteroceptive-interoceptive sensory substitution [17, 44], where internal bodily signals are made externally perceivable. Unlike simple biofeedback, which presents real-time physiological data to help users learn to consciously regulate their bodily functions, interoceptive–exteroceptive sensory substitution maps internal sensations into immersive exteroceptive forms such as dynamic visuals and spatial audio that feel like an extension of the body into the surrounding environment, aiming to increase awareness of bodily state. However, these implementations typically position users as third-person observers of their breath, viewing external objects contract and expand in response to respiration, whereas our system creates a first-person experience in which the user inhabits and embodies the expansion and contraction of space itself.

Moving beyond self-embodiment, some applications explore environmental manipulation. Flowborne demonstrates this shift by using diaphragmatic breathing—measured via VR controller—to guide movement through virtual seascapes, requiring optimal breathing rates for navigation [5, 34]. While this approach focuses on breathing optimization for goal achievement, it suggests possibilities for more fundamental environmental coupling.

Our approach extends this concept toward first-person interoceptive-exteroceptive substitution, where users experience the immersive environment as an extension of their respiratory rhythm. This embodiment of the external environment leverages metaphoric mapping where spatial expansion corresponds to inhalation depth. Inspired by research showing larger quantity perception following inhalation [3], we hypothesize that lung volume expansion can be mapped to environmental spaciousness through embodied metaphoric associations. This design is intended to map increases in lung volume during inhalation to the perceived expansion of the surrounding virtual space, creating an intuitive user interface that links bodily changes to an externally mapped process. This mapping is intended to extend the body schema, the system of multimodal sensory–motor functions that enables control of the position of body parts in space [15], to encompass the surrounding virtual space, thereby blurring the boundaries between interoception and exteroception.

1.3 Translating Symmetry Theory of Valence into a Tangible VR Interface

Current research on consciousness often uses a two-dimensional model based on *arousal* (the degree of wakefulness) and *awareness* (the amount of information available for cognitive processing) [13]. However, conscious experience is complex and includes many subjective qualities that this model cannot fully describe. Recognizing these limitations, the non-ordinary states paradigm views consciousness as a dynamic spectrum influenced by neurobiological and contextual factors. Instead of seeing consciousness as simply normal versus altered, this approach highlights the wide range of similarities and differences across human experiences—from meditation [9] and breathwork [2, 18, 24] to psychedelic and mystical states [10, 48].

Proponents of this view argue that consciousness does not have a fixed baseline but should instead be conceptualized as existing within a multidimensional state space—a mathematical and conceptual framework that represents all potentially accessible conscious states across phenomenological, neural, cognitive, and behavioral dimensions. Within this state space, certain regions may be associated with more positive or negative subjective experiences, raising questions about what properties determine the valence of different conscious states.

To investigate this question, we draw inspiration from the Symmetry Theory of Valence [20, 31, 36]—a conceptually ambitious but empirically underexplored framework proposing that symmetrical neural patterns correlate with positive subjective experiences. This theory provides a potential organizing principle for navigating the conscious state space toward more pleasant regions. By utilizing breathwork as an established method for inducing altered states [2, 18, 24], we sought to augment these experiences through visual dynamics that translate this theoretical framework into practice using coupling kernels: mathematical functions that define how connected, oscillating particles in our VR system influence one another.

In our implementation, these kernels synchronize the particles exclusively during the stillness of the breath retention phase—the pause after inhalation or exhalation. This process propagates fluid changes across particle attributes such as motion, color, and texture, producing coherent, symmetrical patterns that stand in marked contrast to the preceding chaotic dynamics. While these formations may resemble the geometric properties of psychedelic hallucinations [6], this quality emerges naturally from the use of full-spectrum RGB color mapping and symmetrical geometries rather than from any intention to prime participants with a "*psychedelic*" aesthetic. These symmetrical configurations are intended to be aesthetically pleasing, giving retention phases an additional sensory quality that promotes engagement and makes them more pleasurable to inhabit. Because sphere size changes do not occur during retention and thus do not provide the same ongoing visual reinforcement as during inhalation or exhalation, the system instead uses an increase in coherence across particle motion, color, and oscillatory phase as a form of biofeedback. This coherence serves both as a perceptual marker of breath retention and as an intrinsic incentive to prolong it. Although this is not the primary aim of traditional meditation, it aligns with the objectives of contemplative breathing practices such as pranayama, box breathing, and resonance breathing, where deliberate emphasis on breath retention is central. By making these phases more engaging, the system may act as an adjunct psychosomatic modality for facilitating specific breathing patterns and enhancing awareness of these often-overlooked moments in the respiratory cycle, with potential applications in both contemplative and clinical contexts.

2 Design and Implementation

2.1 System Overview and Design Principles

We introduce Viscereality, a bioresponsive virtual reality system that translates the Symmetry Theory of Valence into a tangible interface for augmenting breathwork experiences. The system incorporates: (1) controller-based breath detection enabling respiratory biofeedback \cite{blum2020, rockstroh2021}; (2) a 3D particle environment implementing Gestalt principles to unify internal and external awareness through dynamic, spatialized visual feedback; and (3) coupling kernels within a Kuramoto oscillator system, derived from the Symmetry Theory of Valence, that generate geometric visual coherence during breath retention phases.

This results in a dual-layered design: conscious breath control modulates the environment's dynamics, while periods of breath retention trigger emergent aesthetic coherence. The system provides an experimental platform to investigate how visual symmetry influences positive valence in altered states, enabling controlled comparisons between conditions with and without dynamic visual coherence.

Crucially, our design decouples the user's conscious task from the aesthetic manipulation. While participants focus on expanding and contracting a sphere through their breath, visual symmetry is subtly introduced during breath holds in a manner intended to elude conscious awareness. This approach allows us to treat emergent coherence as an independent variable and to rigorously assess its psychological effects—relative to a control condition lacking such coherence—in future studies.

2.2 Visual-Respiratory Coupling and Particle Depth Dynamics

Our system integrates two principal biofeedback mechanisms to shape breathing patterns in VR: (1) adaptive sphere radius control and (2) coupled oscillator dynamics. Together, these establish a breath-responsive environment intended to foster specific respiratory rhythms, preserving user comfort while augmenting breathwork.

2.2.1 Hardware Considerations. The prototype was developed in Unity for standalone use on the Meta Quest 3, with compatibility for the Quest 2, using integrated six-degree-of-freedom tracking. It operates entirely on the headset hardware without a tethered PC. The visual system is optimized for mobile VR through lightweight shaders. CPU-optimized processing handles compute tasks, leaving the GPU fully dedicated to rendering and reserving capacity for potential compute shader use to refine particle control. Communication between CPU and GPU is implemented via the custom data module of Unity's Shuriken particle system. A data-oriented programming approach using the Unity Job System for batched parallel CPU processing maintains a stable 72 Hz frame rate, reducing motion sickness risk.

2.2.2 Breath Detection. Our system adopts its breath detection method from the VR application *Flowborne* [5, 34], using the VR controller's built-in positional tracking to infer respiratory displacement without extra sensors. During an initial calibration, the user places the controller near their lower abdomen to establish a tracking axis. The algorithm processes positional changes along this axis to classify the user's respiratory state as inhale, exhale, pause, or bad tracking. To ensure reliability, movement variance monitoring filters out non-respiratory motions. This classification drives the system's visual changes. The system functions equally well when seated or lying down; while posture does not affect tracking accuracy, lying down can make diaphragmatic breathing easier.

2.2.3 Adaptive Sphere Radius Control. The primary feedback loop maps the user's breathing state (inhale, exhale, or pause) to the radius of a surrounding sphere. To avoid claustrophobic effects, we set a minimum radius so the sphere never contracts too close to the user. Conversely, a maximum radius limits outward expansion at the point where further changes are no longer perceptible. This arrangement naturally moderates breathing, as any breath depth beyond these limits produces no additional feedback. To ensure smooth transitions, we use spring-based interpolation:

$$r_{\text{target}} = r_{\min} + (r_{\max} - r_{\min}) \times \text{breathProgress}, \tag{1}$$

where breathProgress is a normalized measure of inhalation/exhalation depth. This approach ensures that shifts in the sphere's radius do not appear abrupt or disorienting.

2.2.4 Particle Visualization and Depth Enhancement. In addition to modulating sphere size, we employ a minimalist, particle-based rendering strategy to reinforce breath feedback. Each point on the sphere's surface is rendered as a ring with a radial gradient, oriented toward the viewer. In low-coherence states, these rings overlap minimally and move somewhat independently; when coherence strengthens, they enlarge in unison and form a distinctive "flower of life" pattern—a hexagonal lattice of overlapping circles from which various shapes such as triangles, hexagons, and polygons emerge. This emergent geometry enhances visual symmetry and aesthetic complexity.

To enhance depth perception, we introduce short-lived tracers that follow the rings during expansion and contraction, generating cone-like motion trails that underscore the sphere's three-dimensionality. As particles move closer to or further from the viewer during sphere expansion and contraction, their tracers create temporal echoes that provide additional depth cues. The combination of our ring-shaped particle design with these motion trails produces a cone-like visual effect during depth movement, significantly enhancing the perception of three-dimensional motion. Subtle depth-wave animations prevent the environment from feeling static, thereby sustaining engagement and embodied presence. During initial testing, we found that purely spherical particle distributions without depth waves resulted in reduced engagement and embodiment.

2.3 Generating Geometric Aesthetics with Coupling Kernels

Whereas the sphere's radius expansion provides large-scale breathing feedback, coupling kernels in the Kuramoto oscillator network determine the fine-scale interactions that shape the sphere's surface texture. These kernels specify how oscillators influence one another based on their relative positions, thereby controlling which resonant modes emerge and whether the system transitions into coherent wave-like patterns or remains disordered. By enabling self-organizing dynamics, coupling kernels produce flowing, field-like visuals hypothesized to reflect high-valence states akin to those reported during meditative or psychedelic experiences. Figure 1 shows a representative, rapid transition from initial disorder to full geometric coherence following kernel activation. Adjusting kernel shapes or parameters highlights different spatial frequencies, potentially modeling processes such as connectome-specific harmonics observed in psychedelic-induced visual phenomena [20, 31]. Rather than converging on a static configuration, the system continuously evolves, embodying a dynamic, self-organizing transition intended to sustain user engagement throughout the breathwork session and provide a pleasant incentive for lengthening breath retention.

2.3.1 Sphere Design and Oscillator Distribution. To facilitate stable coupling, we represent the sphere as an icosphere obtained by recursively subdividing a regular icosahedron. Each triangular face splits into four smaller triangles, whose new vertices are projected onto a unit sphere. After four subdivisions, the mesh contains 2,562 vertices, a density sufficient to ensure smooth continuity and avoid noticeable edge effects. This number balances the density needed for rich dynamic behavior with the computational constraints of mobile VR hardware. Each non-original vertex position accommodates an oscillator connected to exactly six neighbors in a hexagonal arrangement, while oscillators at the original 12 icosahedron vertices maintain five neighbors each in a pentagonal pattern. This topological consistency creates ideal conditions for coupled dynamics.

2.3.2 Kuramoto Oscillators and Local Coupling. To support complex dynamic behavior while maintaining perceptual coherence, we implemented a Kuramoto oscillator network—a well-established mathematical model for describing synchronization in complex systems [1, 8, 35, 47]. The near-uniform geodesic subdivision ensures that most vertices form locally hexagonal neighborhoods, minimizing spatial distortion and promoting stable local coupling. In our design, coupling strengths are mapped to the sphere's radius (linked to the user's inhalation/exhalation), causing coherence to peak at radius extremes and decline near the midpoint for rapid decoherence. Each oscillator follows the Kuramoto phase model:

$$\frac{d\theta_i}{dt} = \omega_i + \sum_j K_{ij}(r)\sin(\theta_j - \theta_i), \tag{2}$$

where θ_i is the i-th oscillator's phase, ω_i is its intrinsic frequency, and $K_{ij}(r)$ is a radius-dependent coupling strength.

2.3.3 Two-Tier Neighbor System. To manage local versus medium-range coupling efficiently, we adopt a two-tier neighbor approach. Each oscillator has either six (or five) immediate, first-tier neighbors and a second tier of 12 additional vertices. We define coupling piecewise:

$$K_{ij}(r) = \begin{cases} K_1(r), & \text{if } j \text{ is first-tier,} \\ K_2(r), & \text{if } j \text{ is second-tier.} \end{cases} \tag{3}$$

Both K_1 and K_2 are governed via Unity's AnimationCurve, mapping normalized radius values to spline-based functions. During inhalation (sphere expansion), local coupling $K_1(r)$ generally increases while $K_2(r)$ decreases, encouraging synchronized wavefronts.

2.3.4 Radius-Dependent Coupling Modulation. For precise control over coupling behavior throughout the breathing cycle, we implement radius-dependent coupling through animation curves:

$$K_n(r) = K_{n,\text{limits.x}} + (K_{n,\text{limits.y}} - K_{n,\text{limits.x}}) \cdot C_n(f(r)), \quad (4)$$

where $C_n(x)$ represents the evaluation of the nth coupling curve at position x, $K_{n,\text{limits}}$ defines the minimum and maximum coupling bounds, and $f(r) = \frac{r - r_{\min}}{r_{\max} - r_{\min}}$. At the extremes of inhalation and exhalation, coupling peaks, reinforcing coherent local synchronization. Near the midpoint, coupling diminishes to allow fast decoherence, reflecting conceptual work on coupling kernels and visually induced hallucinations. We update oscillators in parallel each frame using Unity's Job System with precomputed neighbor relationships for efficient mobile VR performance.

2.4 Particle Visualization System

Our implementation includes a versatile particle visualization framework. For the initial pilot study, we chose a minimalist particle design to focus on testing fundamental interaction hypotheses while maintaining clear visual feedback of system states. Each oscillator is represented by a view-aligned ring with a radial gradient texture, featuring a smooth outer edge for realistic 3D depth perception and a sharp inner edge to emphasize particle overlap effects. The particle size modulation directly corresponds to oscillator phase: during decoherent states, neighboring particles maintain minimal overlap due to phase differences; in coherent states, synchronized phase changes cause coordinated size variations; at peak coherence, maximum particle sizes combine to form a "flower of life" geometric pattern. This approach applies key Gestalt principles such as good figure, the tendency to perceive grouped elements as a unified form, similarity, the grouping of elements that share visual characteristics, and symmetry, the perception of balanced and evenly arranged repeating patterns as coherent forms. These principles provide consistent visual cues for depth and spatial coherence, ensuring that changes in particle size, motion, and arrangement are perceived as continuous transformations in three-dimensional space. The particle field incorporates structured noise to prevent static or overly predictable motion, creating an interplay between order and disorder. During breath retention phases, the coupling kernel aligns the oscillatory states of particles, synchronizing their motion, color, and size into coherent geometric patterns. These transitions from chaos to order are intended to be aesthetically pleasing, giving breath retention phases an additional aesthetic quality that promotes engagement and makes them pleasurable to inhabit, with the aim of encouraging their natural extension. An installable APK demo of the system is available at: https://osf.io/t25xp.

3 Discussion

In this paper, we introduced *Viscereality*, a bioresponsive system that maps respiratory biofeedback to immersive, dynamic visual displays. By linking users' breathing to a 3D particle environment, the system provides real-time sensory feedback that makes respiratory processes more salient, aiming to enhance interoceptive awareness and extend it to encompass the surrounding external space. The primary design intention is to blur the subjective boundary between the bodily self and the surrounding virtual space, although this intended effect remains to be empirically validated, for instance via peripersonal space paradigms [28, 39]. Its core innovation lies in enabling a dual-layered interaction. On one level, the system responds directly to the user's breathing, dynamically altering the virtual environment in ways intended to extend the body into surrounding space. On another level, it introduces geometric symmetrical coherence during breath retention phases, designed to enhance the aesthetic valence of the particle system. These two layers represent distinct aspects of functionality, with one focused on embodied respiratory coupling and the other on visual–aesthetic modulation, and each requires separate empirical validation.

The second layer reflects a secondary hypothesis that took shape during system development, informed by the Symmetry Theory of Valence [20, 36], which proposes that visual symmetry is associated with positive affect. This secondary hypothesis is operationalized through the implementation of coupling kernels that synchronize particle behavior during breath retention, thereby integrating it into the existing breathing-responsive framework. This hypothesis requires empirical validation, which could be pursued by comparing subjective effects in conditions with and without coupling kernels. Together, these elements establish Viscereality as a versatile platform for HCI-driven consciousness research, particularly for studies of altered states where subjective effect reports are, as demonstrated by [30], prone to influence from contextual factors. This is likely to be a challenge for virtual reality research as well, especially when meaningful control conditions are lacking.

4 Future Work

A key direction for future research is to empirically test whether the system blurs the boundaries between self and environment by assessing the potential of our VR application to expand peripersonal space (PPS) [21], which is the multisensory, body-centered representation of the space immediately surrounding the body that mediates interactions with the environment [29, 33, 38]. Based on embodied metaphoric mapping and prior findings linking inhalation to enhanced spatial perception, we specifically hypothesize that PPS will be measurably larger during inhalation than during exhalation. This prediction can be tested using established multisensory paradigms, similar to those in VR studies showing that immersive experiences can modulate PPS representation [21, 39], providing an objective complement to subjective reports and directly evaluating whether respiratory–visual coupling can dynamically reshape the body schema in a phase-dependent manner.

Another step is to empirically validate the system's effects through a pre-registered user study. This study will employ a standardized breathwork protocol, such as box breathing, to regulate the duration of breath retention phases. The primary hypothesis is that symmetrical, aesthetically engaging visuals—synchronized with these retention phases—can enhance the positively valenced dimensions of altered states of consciousness, as measured by validated instruments such as the 11-ASC questionnaire [43]. Figure 2 outlines our planned validation framework. Participants will undergo both a dynamic condition, in which visual coherence emerges during breath holds (https://www.youtube.com/watch?v=TBcWh4R4wck), and a static control condition with continuously disordered particle behavior (https://youtu.be/-r4e6XpME7U). This within-subject

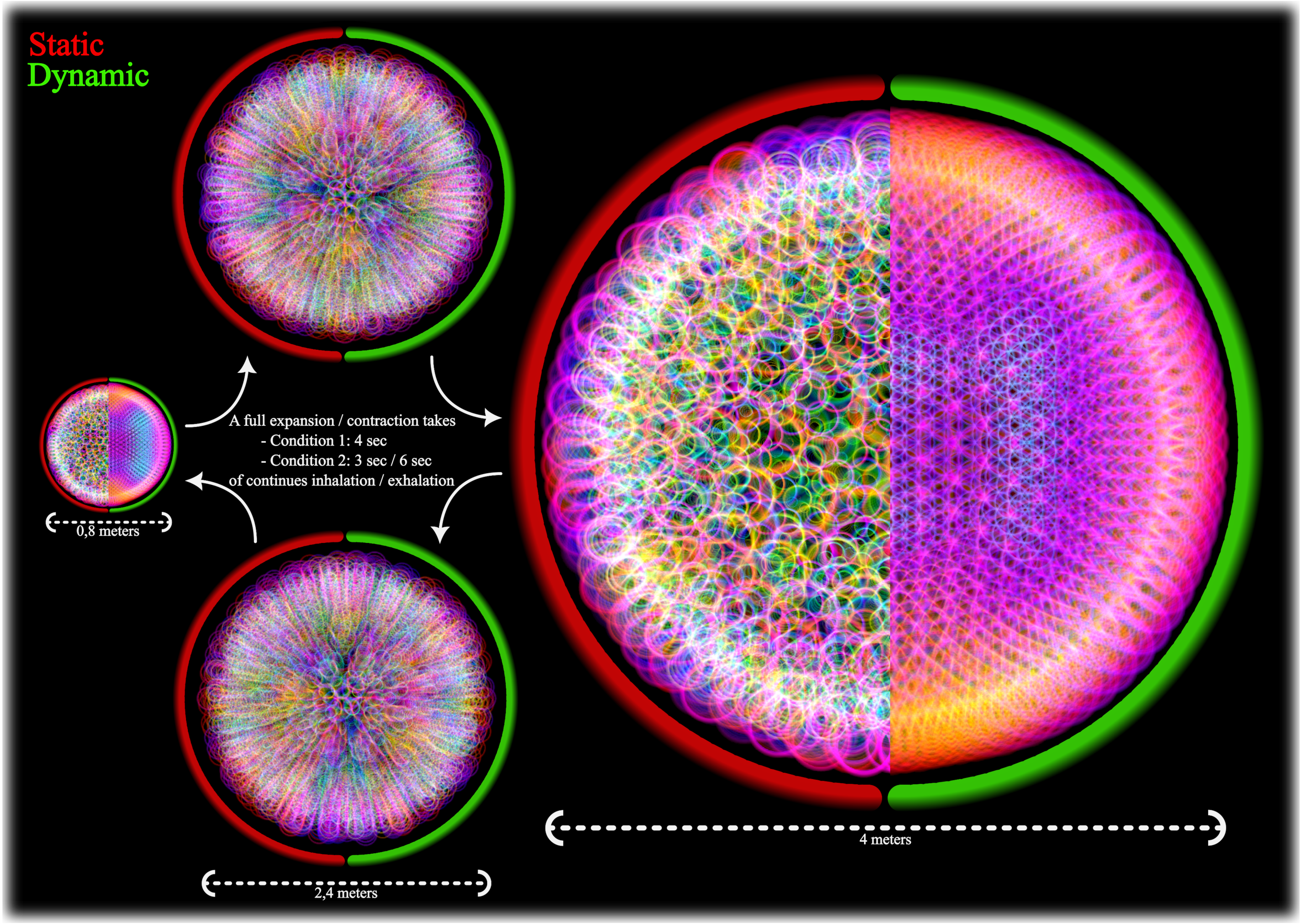

Figure 2: Comparison between static (red border) and dynamic (green border) coupling conditions across standardized breathing cycles. In the static condition, particle behavior remains disorganized throughout all phases of the breath. In the dynamic condition, the coupling kernel synchronizes motion, color, and scale during breath retention phases, producing coherent symmetrical patterns that contrast with the preceding chaotic dynamics. Scale indicators show the range from minimum (0.8 m) to maximum (4 m) sphere radius during typical breathing cycles.

design will enable rigorous comparison of the impact of dynamic visual symmetry on subjective experience.

5 Conclusion

We presented *Viscereality*, a bioresponsive VR system that integrates respiratory rhythms with dynamic visual feedback to explore the relationship between breath, symmetry, and altered states of consciousness. Grounded in the Symmetry Theory of Valence, the system enables controlled investigation of aesthetic coherence as a potential amplifier of positive affect. While empirical studies are forthcoming, the system provides a novel foundation for experimental research at the intersection of embodiment, aesthetics, and conscious experience.

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//dlobser.com/) contributed essential refinements to the project's geometry and particle textures, enhancing both visual quality and system performance. Scientific guidance and supervision was provided by Bigna Lenggenhager and Michael Gaebler, with institutional support from the ALIUS research network, the University of Konstanz and the Max Planck Institute for Human Cognitive and Brain Sciences.

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