Exploring Singing Breath: Physiological Insights and Directions for Breath-Aware Augmentation in Mixed Reality Design

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Abstract

This paper investigates singing breath, the distinctive respiratory pattern that occurs while singing a melody, as a structured and expressive form of breathing that can support breath-aware interaction. First, we conduct a user study to collect the breath dataset from 16 amateur singers using a custom wearable breath band. Next, we analyze and evaluate the multi-site respiratory data across four conditions (rest, deep, pitch, and song breath). The initial results show that pitch tasks elicit stronger ribcage expansion while song tasks naturally encourage abdominal engagement. Building on these insights, we design a Mixed Reality (MR) system that visualizes real-time breath using particle-based feedback to enhance somatic awareness. We position singing breath as an engaging and embodied alternative to conventional breathing training and propose directions for breath-aware augmentation that combine biosensing, MR, and affective self-regulation.

CCS Concepts

• **General and reference** → **Design**; **Measurement**; • **Human-centered computing** → *User studies.*

Keywords

singing breath, mixed reality, embodied interaction, biofeedback system, mindful singing

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1 Introduction

Breath is a powerful medium for emotion regulation, attention control, and self-awareness. While extensive research has demonstrated that both *focused breathing* and *slow-paced breathing* can reduce negative affect and support emotional regulation [1, 4, 8], these techniques often pose engagement challenges, especially for beginners. In mindfulness training, sustaining focus on breath-centered practice can be challenging due to the abstract, repetitive nature of traditional breathing exercises.

In contrast to paced breathing methods, *singing breath* offers a more active, structured, and expressive form of breath control. Existing guided breathing systems—typically relying on auditory pacing or ambient cues such as ocean waves—rarely incorporate singing or musical phrasing. Yet singing naturally integrates active inhalation with prolonged exhalation, shaped by rhythm, melody, and timing. These features make it a uniquely embodied and inherently engaging breathing form. Notably, supporting long phrases in song often recruits abdominal and diaphragm engagement (i.e., lower-body breath), aligning with the principles of diaphragmatic breathing in conventional training. Respiratory cycle analysis—specifically inhalation and exhalation timing—is widely used in stress and emotion research to control for Heart Rate Variability (HRV) [5]. Prior studies have revealed that *structured singing interventions improve physiological health measures in individuals with respiratory conditions* [3] and *musical structure determines heart rate variability* in singers [14]. Furthermore, recent research indicates that *slow breathing patterns can induce respiratory–cardiac coherence and parasympathetic regulation* [12]. This suggests that singing breath, when intentionally designed, may produce resonant effects beyond basic paced breathing, opening new possibilities for affective regulation and embodied awareness. Despite this potential, little research has explored *singing breath*—the structured breath patterns shaped by musical phrasing—as a modality for guided, interactive breathing systems.

In terms of system interaction, prior works on breath training have shown that real-time feedback on breath, pitch, and muscle activation can support singing control and improve somatic awareness [6, 7]. Similarly, recent developments in Mixed Reality (MR)-based mindfulness systems, such as Ural et al. [13] and Potts et al. [9], illustrate how immersive and sensor-driven breathing

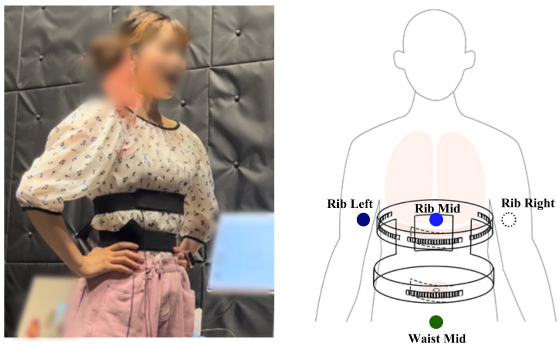

Figure 1: Sensor positions (right) correspond to color-coded channels in signal plots (Figure 2)

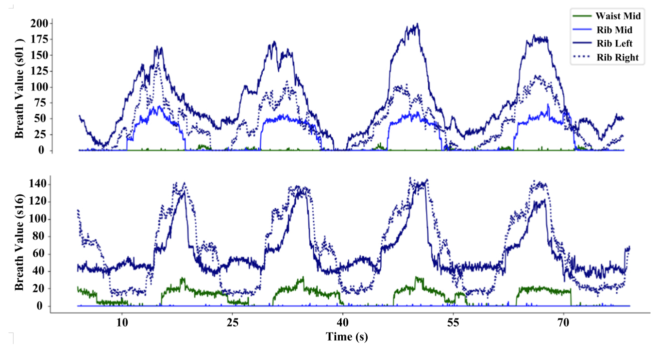

Figure 2: Breathing signals from participant samples (s01, s16) during deep breathing. The top shows chest-dominant breathing with ribcage expansion; the bottom shows abdominal-dominant breathing with stronger waist movement. The breath data reveals distinct activation patterns of thoracic vs. diaphragmatic breathing.

tasks can enhance self-awareness and emotional grounding. These findings support the idea that biofeedback on singing breath in an MR environment may serve as a meaningful entry point for embodied interaction. Building on these insights, we propose singing breath as an expressive, embodied, and engaging alternative to conventional guided breathing, particularly when combined with wearable bio-sensing and MR interaction.

To explore the potential of singing breath, we conducted an initial study with 16 participants under four conditions—rest, deep breathing, pitch, and song. Our initial analysis revealed distinct respiratory strategies: pitch-based tasks encouraged thoracic expansion, while singing naturally recruited more abdominal engagement. These insights informed the development of our MR system, which provides real-time biofeedback on breath patterns through particle-based visualization, supporting both sensing and expressive interaction. Our goal is to enhance somatic awareness, emotional regulation, and user engagement through this embodied and musical approach.

Our contributions include: (1) a novel approach that leverages singing as an expressive and engaging modality for mindful breath training; (2) a multi-condition breath dataset (N=16) demonstrating how different singing tasks engage distinct respiratory strategies; and (3) an MR system integrating bio-sensing to visualize singing breath in real time, expanding the design space for breath-aware interaction.

2 Methods

We adopted an iterative design process—combining physiological data collection, user study, and early-stage system prototyping—to examine how different breath tasks engage the respiratory system and inform the design of somatic feedback. The following sections detail our methods.

2.1 Breath Data Collection

Setup: To capture singing breath patterns, we designed a customized breath band inspired by prior work [7]. Considering the diaphragm's importance in both singing and mindfulness breathing, we positioned RP thin-film bend pressure sensors to focus on key areas of diaphragmatic movement in Figure 1. The band includes four sensors placed at the lower abdomen, center back waist, and left and right mid-rib regions. The sensors are embedded in a flexible, adjustable nylon band with stretchable Velcro, allowing for repositioning to accommodate individual body shapes.

We collected the breath data using an Arduino-compatible M5Stick C-Plus ESP32 board[2], streaming data via serial communication. For real-time data acquisition, we implemented a Python script using `pySerial` to receive, timestamp, and store the breath data sampling at 100Hz (waist and rib data) locally as CSV files. The setup is to record breath across four conditions—rest breath, deep breath, pitch breath, and song breath—for initial analysis and system design.

Participants & Recruitment: We recruited 16 participants (6 female, 10 male; age range: 21–33, *Mean* = 25.7) from two local academic institutions. All participants were amateur singers with basic vocal knowledge and prior singing experience, such as karaoke or casual vocal training. Participants were compensated with a 1000 yen gift card per hour for their time. The study was approved by the institutional review board (IRB) of the host institutions. All data collected during the study were anonymized and only used with participants' explicit consent.

2.2 Study Design

1) Welcome & Familiarization: Before data collection, participants were informed of their rights and the purpose of the study, and signed a consent form. A short questionnaire collected demographic information and singing background. Participants were then introduced to the breath sensor and completed a 5-minute familiarization session to get used to the device.

2) Breathing Tasks: Participants performed four breathing tasks in a counterbalanced order to mitigate order effects and fatigue bias, with each condition lasting 2 minutes:

- **Rest Breath**: Participants stood and breathed spontaneously.
- **Deep Breath**: Participants followed a 4-2-4 breathing pattern (inhale for 4s, hold for 2s, exhale for 4s), a rhythm shown to be easy to follow [11].

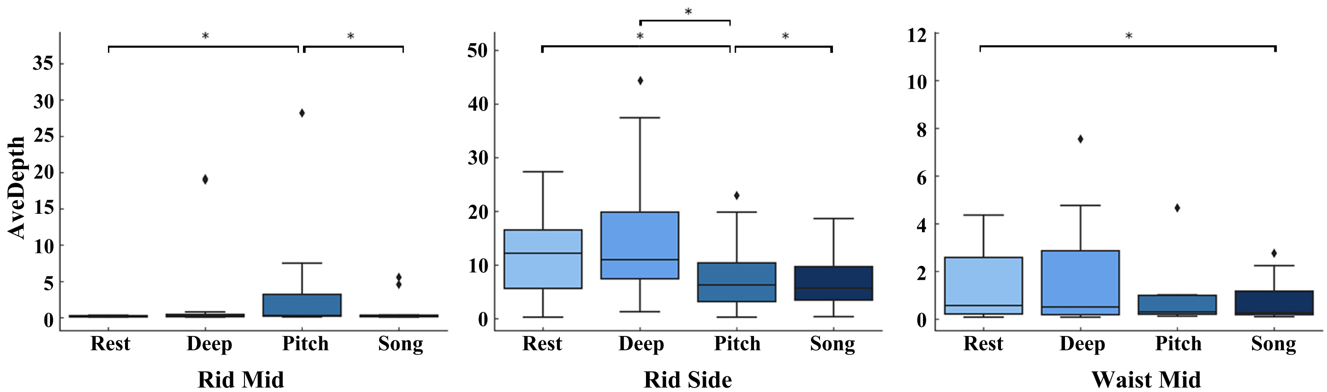

Figure 3: Boxplots showing the distribution of average breath depth across four conditions (AvgDepth). Asterisks (*) denote significant differences ($p < 0.05$).

- **Pitch Breath**: Participants vocalized a pitch scale (e.g., G3–G4 in scientific pitch) with 80 BPM piano accompaniment, sustaining each pitch for 2s.
- **Song Breath**: Participants sang "Happy Birthday" in G major, following 80 BPM piano backing (phrasing 4s).

3) Exit Interview: After completing the tasks, participants were asked to reflect on their experience with each breathing condition and the feedback system. The semi-structured interview included questions about perceived bodily awareness, ease of control, and emotional engagement during the tasks.

2.3 Initial Analysis and Insights

Processing and Feature Extraction: All breathing tasks were performed in a stable standing posture, with slow and rhythmically controlled motion. The band remained firmly fixed with minimal artifacts. We applied a lightweight four-step pipeline: (1) segmenting 120 seconds of data via labeled timestamps, (2) smoothing with a Savitzky–Golay filter (window size 51, order 3), (3) detecting inhalation/exhalation phases using peak–valley analysis, and (4) extracting respiratory features. Following prior work [5, 10, 12], we focused on signals from four sensor channels (waist and ribs) per condition (rest, deep, pitch, song). Left and right ribcage data were averaged into a composite *ribside* index. Key features include:

- **BR (Breath Rate)**: Number of breath cycles per minute. Lower BPM indicates a more relaxed or controlled breathing pace.
- **AvgDepth (Average Depth)**: Mean amplitude of breath cycles, calculated from peak-to-valley differences. Higher depth indicates deeper or more forceful breathing.
- **CVDepth (Coefficient of Variation)**: Standard deviation of breath depth divided by the mean. Lower CV indicates more consistent patterns.
- **IER (Inhale/Exhale Ratio)**: Ratio of inhalation to exhalation duration. Values below 1 reflect slower exhalation.

Initial Results and Insights: Our initial data revealed individual differences in breathing patterns during the deep breath task, with some participants relying more on chest expansion than abdominal movement, suggesting the difficulty of uniformly eliciting diaphragmatic breathing (see examples in Figure 2).

To further investigate the breathing features varied across the four task conditions, we performed the Friedman test, resulting in significant differences in AveDepth, particularly in the ribside with a significant effect (χ^2 = 10.5, $p < .05$). We next conducted post hoc pairwise Wilcoxon signed-rank tests showed that AvgDepth in the Pitch condition was significantly greater than in Rest, Deep, and Song, while Song had the lowest AvgDepth overall. Additionally, we found that AveDepth in the waist region was significantly greater than in Rest (p=0.0356). In contrast, although Deep breathing encourages intentional deep inhalation, it did not result in stronger rib expansion, indicating that passive deep breathing and active vocal control involve different respiratory strategies. The Song condition involved the shallowest breathing, likely due to rhythm- and lyric-imposed constraints, which limited inhalation time and required prolonged, regulated exhalation. Other features such as BR, CVDepth, and IER did not differ significantly between conditions, suggesting that while breathing depth varied with task demands, temporal rhythm and regularity were relatively stable. In sum, our results reveal distinct respiratory patterns across tasks. The Song condition showed significantly greater abdominal expansion (waistmid AvgDepth) than Rest, indicating enhanced diaphragmatic involvement likely driven by prolonged lyrical exhalation, even without explicit instruction. In contrast, Pitch tasks elicited greater thoracic expansion (ribside AvgDepth) with minimal abdominal engagement, reflecting a more chest-dominant, upper-body breath control strategy. These findings suggest that while Pitch tasks support precise vocal modulation, Song tasks may naturally foster more holistic, lower-body breathing aligned with diaphragmatic or mindfulness-based practices.

3 Concept Design and Development

Building on our preliminary analysis of singing-related breathing, we observed that the Song condition may naturally promote deeper abdominal engagement compared to resting, even without explicit instruction. This suggests the potential of singing as an implicit form of diaphragmatic breathing training, aligning well with the goals of mindful breath awareness. Motivated by these insights, we designed a system that integrates real-time biosensing with VR visual feedback to enhance users' awareness of their breathing patterns. Leveraging the Meta Quest 3 headset, the MR environment features a semi-transparent avatar representing the user, overlaid with spatialized, dynamic particle effects that visualize activity in key respiratory muscle groups. For example, particles animate around the chest and abdomen to reflect thoracic and diaphragmatic engagement in real time. These visuals are generated by a breath-aware augmentation module, which responds continuously to users' physiological signals streamed via a local network.

As illustrated in Figure 4, the system architecture consists of a wearable respiratory band (see Figure 1) that captures thoracic and abdominal signals, along with a heart rate sensor to monitor emotional and physiological states during different breathing tasks. A networked computer collects and synchronizes these biosignals, streams them to the headset, and stores them with system markers for offline analysis. This multimodal setup enables a multisensory and interactive experience that supports breath awareness, emotional regulation, and embodied self-reflection. The system is currently under active development, and screenshots of the MR interface are not yet available.

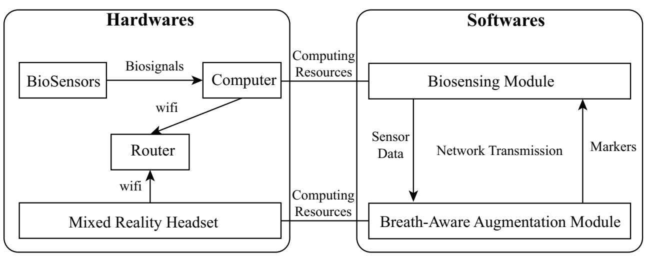

Figure 4: MR Breath-aware augmentation system overview.

4 Toward Breath-aware Design

Based on our initial findings, we envision two promising directions for extending the design of singing-driven breath modulation.

Alternative Breath Practices: First, we aim to explore how *singing breath*—especially during song tasks—can be intentionally guided to promote stronger diaphragmatic engagement, potentially matching or even exceeding the effectiveness of traditional paced breathing methods. While our current data suggest spontaneous abdominal participation during song tasks, future work could integrate real-time biofeedback to actively reinforce this tendency. Visual strategies, such as MR-based breath expansion overlays or rhythm-synchronized flow particles, may help direct users' attention toward lower-body movement. Alternatively, haptic feedback around the waist could be used to subtly cue and support abdominal breathing during vocalization.

Expressive Breath Practices: Second, we plan to investigate how singing-induced breathing differs from conventional breath training (e.g., rest or deep breathing) in terms of *physiological and affective outcomes*. Since singing tasks inherently involve vocal intention, rhythmic phrasing, and emotional engagement, their breath patterns may evoke distinct autonomic responses. We propose collecting a more comprehensive dataset that includes HRV and subjective affective measures across conditions. Our proposed exploration of HRV differences across singing vs. conventional breathing aligns with clinical findings that therapeutic singing yields measurable respiratory and psychological health advantages [3, 5, 12, 14]. This phase will focus on amateur singers to better understand how expressive breath practices might support emotional self-regulation in broader contexts.

Design Challenges: We also note challenges such as sensor placement consistency, inter-subject variation in breathing style, and potential latency in MR rendering, which may affect user perception. Additionally, the choice of musical material affects user engagement and breath dynamics. We currently use simple, well-known melodies to ensure low learning effort and support focus on breath awareness. In future work, we plan to explore a broader range of musical genres and structures to better understand how different styles influence respiratory patterns and user experience.

5 Conclusion

Our exploration of singing breath underscores its potential as both a functional and expressive form of respiration. Using a custom wearable with multi-site sensors, we collected a breath dataset (N=16) across multiple conditions. Initial results show that pitch singing tends to engage thoracic expansion, while song singing encourages deeper abdominal involvement. These patterns suggest that singing may serve as an intuitive gateway to embodied and emotionally aware breath practices. We envision future systems leveraging this potential through real-time biofeedback and Mixed Reality environments. Looking ahead, we aim to spark dialogue on how biosensing, vocal expression, and embodied interaction can converge to support well-being, self-regulation, and somatic design.

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