

Puffer: Breathing Regulation Through Sequential Soft Robotics

Daksh Kapoor

School of Literature, Media, and Communications
Georgia Institute of Technology
Atlanta, Georgia, USA
dkapoor30@gatech.edu

Mingqi Wang

School of Industrial Design
Georgia Institute of Technology
Atlanta, Georgia, USA
mwang766@gatech.edu

Sophanit Sebh

School of Industrial Design
Georgia Institute of Technology
Atlanta, Georgia, USA
ssebh3@gatech.edu

Yueyi Zhu

School of Industrial Design
Georgia Institute of Technology
Atlanta, Georgia, USA
yzhu824@gatech.edu

Abstract

Breathing is a natural, continuous process, yet stress often disrupts our awareness of it, leading to shallow and irregular patterns. To address this, we introduce *Puffer*, a social robot that guides users' breathing through soft, sequential tactile cues. While prior soft robotic systems support breath regulation, *Puffer* is distinct in its use of silicone pores that inflate and deflate in a traveling sequential wave synchronized to the user's physiological state. Designed for shared spaces, it prioritizes touch over vision or sound, and re-frames breathing regulation as an embodied interaction with a soft and socially situated artifact. We present the robot's hardware and interaction design, highlight how its adaptive and sequential haptics differ from existing pneumatic devices, and discuss deployment scenarios that show how *Puffer* can foster social and touch-based awareness of breathing.

CCS Concepts

• **Human-centered computing** → *Haptic devices; Ubiquitous computing*; • **Hardware** → **Emerging technologies**;

Keywords

Sequential Tactile Feedback, Adaptive Breathing, Breathing Regulation, Social Robotics

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1 Introduction

Cross-national surveys indicate that close to one-third of young adults live with ongoing psychological distress [4]. For many Gen Z



Figure 1: User interacting with *Puffer* by placing their finger on the pulse sensor while hugging.

and Millennial individuals, this distress is intensified by an "always-on," digitally overloaded lifestyle that often disrupts even the simplest physiological acts such as mindful breathing. Compromised breathing patterns, especially rapid and shallow respiration, are tightly coupled with acute stress, and are empirically linked to diminished mood and poor mental health outcomes [2, 3].

Controlled and rhythmic breathing is a proven intervention for stress relief, offering measurable improvements in physiological arousal and overall mental health across diverse contexts [2, 7]. To increase accessibility, studies have explored a range of modalities, from audio and visual cues [15] to multisensory and VR technologies [9]. Recent research points to tactile feedback as particularly effective for embodied, less distracting breath guidance [10, 11], since other interactions can demand heightened sensory focus and hinder relaxation. However, existing tactile and pneumatic devices largely provide static expansion-contraction cues or pre-scripted synchronized patterns, and typically lack an adaptive, closed-loop control system that responds to users' live breathing or physiological state [5, 20]. Moreover, these systems are generally framed as personal devices rather than as socially situated artifacts that can support shared awareness or collective breathing rituals. To address these limitations, we introduce *Puffer*, an interactive soft robotic system designed as an adaptive and closed-loop tactile breath guidance device that functions as a social robot. Unlike prior devices, *Puffer* renders breathing as a traveling tangible wave that moves



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Figure 2: Close up images of pore inflation/deflation.

sequentially along the user's forearms while hugging the robot. The timing of this wave is adapted from the user's heart rate, enabling *Puffer* to tune the speed of the tactile trajectory to the user's current physiological state and gradually guide them toward slower and more regular breathing cycles. We position this mechanism within a shared social robot that is deployed in publicly accessible spaces.

2 Related Works/Literature

2.1 Tangible Guided Breathing

Interactive systems increasingly use tactile and pneumatic cues to support paced breathing and stress reduction. Prior work explores vibrotactile pacing [16], wearable or body-adjacent pneumatic actuation [5, 6], airflow-based peripheral guidance [8], and rhythm-modulated soft surfaces for relaxation [14]. Meta-analytic evidence also demonstrates that deliberate breath control can reliably reduce stress, anxiety, and depressive symptoms [3], reinforcing the value of technologies that scaffold slower and intentional breathing. These systems demonstrate that tactile feedback can regulate breathing in subtle ways and are often calibrated to a user's baseline breathing rate. However, most devices operate at a single point of contact such as the wrist, hand, or chest. They provide rhythmic cues through uniform motion or localized vibration, rather than through spatial patterns that travel across the body. None explore breathing guidance delivered through a large, body-contact form that distributes tactile cues across the arms or torso.

2.2 Soft Robotic Interfaces for Affective and Interoceptive Engagement

Soft robotic and shape-changing interfaces have been used to support affective expression, attention, and interoceptive awareness. Texture-changing robotic skins convey emotional states [12], while soft inflatable surfaces modulate attention or support breathing depth through slow rhythmic expansion [1, 18]. Other systems explore soft actuation as a calming tactile stimulus around the neck and upper chest [13, 14]. Yet these systems typically rely on global inflation or localized haptics, and do not implement sequential, directional pneumatic patterns. They also engage limited body areas and are not framed as social robots that support recurring sensory rituals involving hugging or full-body contact.

2.3 Research Gap and Contribution

Across guided breathing and soft robotic affective interfaces, prior work rarely considers spatially sequenced tactile patterns that move across the body, nor does it explore multi-site contact through hugging a soft social robot. Existing systems offer rhythmic motion or localized haptics, but not directional, wave-like actuation across the arms and torso. Additionally, these devices are framed as tools rather than ritual-driven social companions. *Puffer* addresses this gap by using a soft, inflatable robot with sequential pore actuation and multi-body placement to guide users' breathing through embodied, ritualized touch.

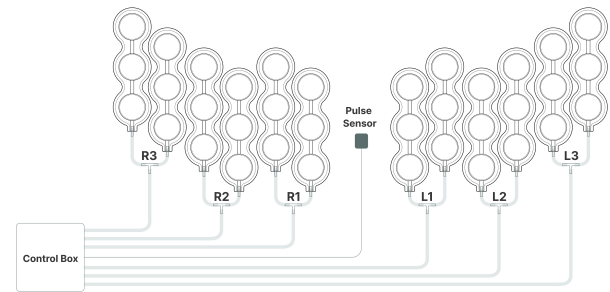


Figure 3: Visualization of the how the silicone slabs, sensor, and the control box are integrated.

3 Design

Puffer's design centers on soft and tangible silicone-based slabs animated by air pumps that generate rhythmic, traveling haptic patterns across the skin. When users rest their arms around the robot and place a finger on the heart-rate sensor, located in between where the arms meet, the system reads their beats per minute (BPM) and adapts its pumping speed accordingly to guide slower and more mindful breathing. The silicone slabs contain "pores" that sequentially inflate and deflate along the arm path, creating a directional wave that users can feel moving across their skin as they inhale and exhale.

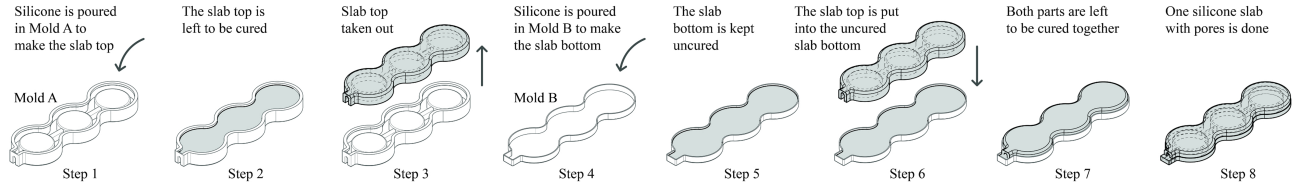


Figure 4: Step by Step fabrication of the silicone slabs.

3.1 Structure

We explored several fabrication methods before choosing silicone casting, which allowed us to create a lightweight and soft structure with thin, durable pore surfaces. Silicone was selected for its flexibility and gentle tactile quality, making the object comfortable to hold while still enabling users to feel each pore expand and contract in sequence. Each slab contains three circular pores sized to balance sensitivity with a form large enough for users to embrace and perceive the movement of the wave across their arms. As shown in Figure 4, each slab is made using a two-part mold. One side shapes the circular pores, and the other forms the base, creating sealed hollow cavities that inflate and deflate. The thickness of the pores were refined to maintain both clear tactile feedback and structural durability. The pillow format was chosen for its inviting softness and generous size, which allows users to wrap their arms around the surface so the silicone pores can make full contact with the skin and convey the sensation of a traveling breath wave. Tubing and Velcro connect the completed slabs to the pillow.

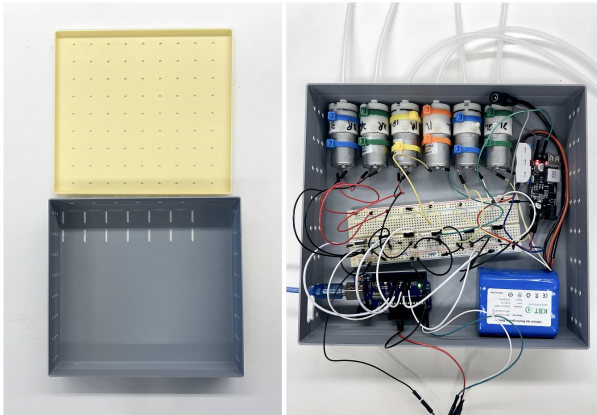


Figure 5: Top view of the control box. Left: Empty open box. Right: All electronic components situated in the box.

3.2 Electronics

Puffer uses six Adafruit 5V DC air pumps to drive a total of 12 inflatable slabs of silicone-based pore structures. Each pump supplies air to a pair of slabs via tubing and a Y-connector, yielding three slab-pairs (6 total slabs) on the left and three pairs (6 total slabs) on the right (Figure 3). As seen in Figure 1, a pulse sensor

mounted near the end of the robot, where users rest their hand, captures a photoplethysmography (PPG) signal from which we derive heart beats and estimate beats per minute (BPM). The sensor stream is continuously sampled and the BPM is updated once per second using a moving average over the most recent few seconds to smooth transient peaks. This smoothed BPM value is then mapped to the timing of the pumps' inflation and deflation cycles. Both the air pumps and pulse sensor are controlled using an Arduino Uno and powered by an external battery. For compactness and visual clarity, the air pumps, battery, Arduino Uno, and remaining electronics are integrated into a single 3D-printed control box (Figure 5). We labeled the pumps R1–R3 on the right arm and L1–L3 on the left arm such that each numbered pair (R1/L1, R2/L2, R3/L3) inflates and deflates in synchrony to create matching sensations on both sides of the body. The pairs are triggered sequentially from the center outward with a BPM-dependent delay between them, producing a traveling wave of pressure along the arms that users experience as a “breath” moving across the skin. Higher BPM values shorten the overall cycle and pair-to-pair delay, while lower BPM values lengthen them, nudging users toward slower, more regular breathing.

As shown in Figure 6, `delayBetween` defines the temporal offset between pumps, so a full ‘inhalation’ wave lasts $3 \times \text{delayBetween}$ milliseconds (3 pumps each side), and the exhalation wave uses the same duration. The `delayBetween`, calculated using BPM, allows *Puffer* to provide personalized and adaptive tactile guidance based on each user's current physiological state. When no valid pulse signal is present, the controller keeps all pumps off, preventing unintended motion and ensuring that actuation only occurs in response to a detected user. Prior work on slow-paced breathing and HRV biofeedback suggests that respiration rates around 6 breaths per minute enhance mediated heart rate variability and support stress reduction [17, 19]. Inspired by this work, *Puffer* uses delays that produce relatively long inhalation–exhalation cycles (3–6 s per phase, 6–12 s per full breath), nudging users toward slower, more regular breathing. The exact mapping from smoothed heart rate (BPM) to `delayBetween` values was chosen empirically to balance constraints such as: cycles slow enough to resemble recommended slow-breathing ranges and a noticeable sequential wave across the three pumps. As such, these values should be viewed as an interaction design heuristic rather than a clinical protocol; refining this mapping is an avenue for future work.

Smoothed BPM	delayBetween	Inhale/Exhale
>110	2000ms	6000ms
Between 110 and 100	1700ms	5100ms
Between 100 and 80	1600ms	4800ms
Between 80 and 65	1300ms	3900ms
Between 65 and 50	1200ms	3600ms
<50	1000ms	3000ms

Figure 6: Pump delay calculation using BPM.

4 Interaction Scenario

In designing *Puffer*, the goal is to support calming, self-regulatory interactions that help users notice and gradually slow their breathing during moments of acute stress. The primary interaction involves a user approaching the robot, wrapping their forearms around its soft body, and placing a finger on the embedded pulse-rate sensor. As *Puffer* detects the user's heart rate and begins to generate sequential tactile patterns along the arms, the user is invited to close their eyes and attune their inhalation and exhalation to the traveling waves of pores. The envisioned context for these interactions is everyday high-stress situations faced by young adults, particularly early-stage college students. Typical scenarios include waiting outside an exam room, preparing for a job interview, or decompressing after an overwhelming day of classes. In these moments, *Puffer* could be situated in shared campus spaces—such as hallways near lecture halls, student lounges, or library nooks—much like a couch or bench that is always available for brief, grounding breaks. Beyond individual regulation, the interaction is designed to have a social dimension. Multiple students can observe how *Puffer*'s movements change as different people connect with it, noticing variations in pumping tempo and sequential patterns that reflect different heart rates and breathing states. Over time, this shared use can cultivate a form of social awareness around stress and breath: users can compare their own experience with that of peers, or even invite a friend or classmate to “breathe with” the robot together. Similar deployments could be imagined in staff rooms or clinic waiting areas, where teachers or health professionals might use *Puffer* as a quiet, tangible reminder to pause and regulate their own breathing during demanding workdays.

5 Discussion

Integrating a breathing regulation robot in a social context holds a potential to shift social norms and culture. Such contexts could signal that mindful breathing and stress regulation are valued, which can lead to shaping campus norms around rest and self-care. Situating *Puffer* in public, high-traffic spaces such as university corridors, libraries, and student lounges transforms it from an individual relaxation aid into a quiet campaign for breathing awareness. Over time, this form of ambient advocacy has the potential to normalize short “breathing breaks” alongside familiar norms like taking a coffee break, subtly reshaping local cultures of rest and self-care. We hope that this design can also be framed as a companion object

to which people return to across the day, building a light, ongoing relationship rather than a purely instrumental tool.

6 Limitation and Future Work

The current prototype has notable limitations in design and sensory qualities. Visually, *Puffer* looks clinical, and exposed tubing may unintentionally increase anxiety, opposing its calming intent. Future versions should explore soft textile covers thin enough to preserve tactile feedback while concealing plumbing by extending the pore slabs. The pumps also create mechanical noise that can disrupt the calming atmosphere. Embedding pumps deeper in the pillow can reduce this, but sound-proof housing and synchronized ambient audio could further mask the noise.

The interaction design constrains the use of *Puffer* to hugging the pillow which can limit future deployment. Because the pore slabs are flexible, future designs could adapt them as arm wraps or surfaces on chairs, tables, or counters to support varied postures. Altering the sequential pattern to allow sensing of individual pores instead of grouped sets could also enhance breath pacing while maintaining synchronized inflation. The heart rate to breath timing mapping currently uses heuristics; collaborating with clinicians to validate and refine this would improve robustness and utility.

7 Conclusion

This paper introduced *Puffer*, a social robot that uses sequential waves of silicone pores and live physiological sensing to guide users' breathing. Its contribution lies in combining adaptive, closed-loop haptic feedback with a socially situated form factor to create shared, touch-based breathing rituals for young adults, particularly college students. We outlined how users could interact with *Puffer*, described contexts in which it could be deployed, and highlighted how it differs from existing pneumatic breathing devices. Looking ahead, *Puffer* could be extended through integration with other biofeedback modalities to further support everyday stress management and mindful breathing.

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