Inhaling and Exhaling: How Technologies Can Perceptually Extend our Breath Awareness

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ABSTRACT

Attending to breath is a self-awareness practice that exists within many contemplative and reflective traditions and is recognized for its benefits to well-being. Our current technological landscape embraces a large body of systems that utilize breath data in order to foster self-awareness. This paper seeks to deepen our understanding of the design space of systems that perceptually extend breath awareness. Our contribution is twofold: (1) our analysis reveals how the underlying theoretical frameworks shape the system design and its evaluation, and (2) how system design features support perceptual extension of breath awareness. We review and critically analyze 31 breath-based interactive systems. We identify 4 theoretical frameworks and 3 design strategies for interactive systems that perceptually extend breath awareness. We reflect upon this design space from both a theoretical and system design perspective, and propose future design directions for developing systems that "listen to" breath and perceptually extend it.

Author Keywords

Breath, Perceptually Extending, Mindfulness-based Design, Soma Design, Breathing Regulation, Breathing Synchronization

CCS Concepts

•**Human-centered computing** → **Interaction design theory, concepts and paradigms;**

INTRODUCTION

An increasing affinity towards digital technologies, from the systems that connect us to each other, to the systems that augment our homes and workplaces, to wearable technologies, made all aspects of our lives to some extent governed by technology. Such context gave rise to our current economy that captures our attention and feeds off our ability to surrender our attention to outwards [16], to experiences that **take** our breath away, interfaces that make us **loose** breath during exercises, or artifacts that **make us hold** our breath in anticipation and excitement. Yet, breath – felt but also an intangible aspect of the inner body (comprised of feelings, thoughts, and sensations), acts as a fine thread between our subjective experience and digital technologies that mediate our experiences. By accessing the inner body we become aware of invisible processes that shape our experience and that are essential to well-being [23]. In moments of upset, a balance can be achieved by directing our attention to take a deep breath and turn our gaze inwards to our inner body, a process often followed by a sigh of relief.

This act of *becoming aware* [19] of our experience in which we **regain attention** and direct it inwards to breath as an interface to listening to inner, subjective body [54] immediately changes the quality of the experience. In the long term, the act of paying attention to the inner body (as in various meditation practices) leads to feeling of balance, well-being and self-discovery [56]. Directing attention inwards requires our awareness to learn to recognize the cues and immediacy for when to shift gaze inwards, be that noticing fast escaping breaths or the feelings of being overwhelmed. Yet, not everyone can easily become aware of their inner body or sustain that awareness. While the quantified-self movement [48] provides means to gather insights about how our objective, measured bodies are doing (e.g., *is my breathing too fast for someone my age?*), this information may become disembodied and turn into yet another distraction. In our technology-saturated lives, technology often demands that we turn our attention outwards, to the external measures and objectified bodies. How then could technology instead help us sustain our attention inwards so that we don't lose our ability to discover the richness of our inner-self by attending to breath?

While the complexity of the present technological landscape may introduce challenges to how and where we pay attention, if utilized rather than ignored, these complexities open a rich design space for the exploration of how to guide one's attention inwards, and noticing of our inner body. With a rise in the number of systems that employ breathing in the interaction and that are embedded in various contexts of use, Patibanda et al. [60] proposed a taxonomy of breath-based interaction in games context. Beyond game design, we are interested in an overall understanding of different means and approaches that these systems employ to extend breath so that it becomes more perceptually available to our attention. Moreover, we are interested in interactive systems that "listen" to breath (capture breathing data of objective body) and establish immediacy of

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interaction [29] to elicit breath and body awareness. Höök defines this interaction as "the immediate and synchronized feedback rhymes with the rhythms and flows of the body in such a way that the interactive system is perceived more like an extension of the body than as a separate entity or communication counterpart" [29, p.106]. To that end and towards our long term endeavor, we are interested in perceptually extending breath through an artifact that becomes part of our body schema, "a system of sensory-motor capabilities that function, usually without awareness or the necessity of perceptual monitoring" [30, p.556]. According to 4E (embodied, embedded, extended and enacted) cognition theories we can extend our body schema through action-perception coupling [53, 88]. For instance, a person with vision impairments can incorporate their cane into their body schema because they use it to interact with the world. Here, our overarching question is: how can we utilize features of digital technologies that employ breath in such a way that features of the technology may be perceived as an extension of our body schema for knowing (and regulating) ourselves through breath-based interaction and by eliciting breath-awareness? To answer this question we perform a scoping review of the interactive systems that employ breath in interaction.

Objectives and Research Questions

In this review, we systematically analyzed publications of breath-based interactive systems. From the analyzed publications we extracted: 1. theoretical frameworks on which the research motivation and system design were based; and 2. system characteristics, including characteristics of collecting and perceptually extending breath data, attention-interaction modalities, and system features. The motivation for tackling theoretical frameworks of the systems comes from an observation that different frameworks have different value systems, resulting in different features that are privileged and others absent. By comparing these different epistemologies of research and design practice and the values they emphasize, we can gain a deeper understanding of the historical and present context of technological systems that we are designing for. Each framework embeds ideological assumptions and biases. By explicitly stating them and bringing awareness to this larger landscape of theoretical frameworks, their values and epistemological background, we can critically assess how we as designers choose to honor and engage with these different traditions **through more conscious design practice.** To assess the current state of the research in the interactive systems that perceptually extend breath, this scoping literature/system review will address two research questions:

RQ1: What is the theoretical framing, aim and motivation of the systems that perceptually extend breath?

RQ2: How is breath perceptually extended and what are the characteristics of the breath-based interactive systems that extend our breath awareness?

METHOD: SCOPING REVIEW PROTOCOL

We undertook a scoping review protocol [4, 40]. The characteristics of a scoping review protocol are: it is an explorative process encompassing broad research questions, inclusion/exclusion can be developed post hoc, and synthesis is more qualitative and typically not quantitative [5]. Following the scoping guidelines, we undertook these steps:

1. Identified the research questions;
2. Identified relevant articles describing the systems;
3. Selected systems based on the selection criteria;
4. Coded and charted the data;
5. Collated, summarized, and reported results.

Identifying Relevant Studies

We performed an extensive search of the literature with a particular focus on HCI and interactive system design, using the ACM Digital Library, Design and Applied Arts Index (DAAI), IEEE Xplore (IEEE/IET Electronic Library) and Google Scholar. We used keywords related to breath, respiration, biofeedback, and interactive systems.

Study Selection

In the first stage of the scoping review, we identified 52 peer-reviewed articles and dissertations that were published before June 2019. The inclusion criteria was that the articles were: written in English, contained sufficient and clear detail describing the system, focus on designing **interactive** systems/artifacts for breath awareness or regulation or breath-based interaction, and that the systems described collect user's breathing data and employ it in interaction design. In the second stage, we excluded 21 systems that either 1) do not collect user's breathing data, or 2) collect user's breathing data but do not employ it in interaction design. Finally, we proceeded to analyze 31 systems that satisfied the inclusion criteria.

Coding and Charting the Data

The resulting 31 articles are coded following both an inductive and deductive coding approach in nVivo 12 qualitative data analysis software [68]. Deductive categories included a pre-set coding scheme that yielded 14 codes divided into the following categories: 1. meta data: full reference, the system's name, technology used (features); 2. theoretical framework: framework and the system's aim; 3. input: respiratory sensor type, respiratory parameters; 4. interaction: mapping of breath, content in direct relation to breath (mapped to breath or cues for breath to follow), interaction-attention paradigms; 5. output: onset time, stimulus rate, response salience; 6. interactive strategies: strategies addressing how breath is perceptually extended or accommodated through design of a system. Simultaneously to coding in nVivo12, all data was charted in a concept matrix (see `http://metacreation.net/members/mirjana-prpa/breath-based-interactive-systems/`). The inductive codes emerged in parallel with the process of deductive coding. The coding scheme was discussed by the authors. The first author coded 80% of the articles, while the second author reviewed the codes and coded the rest.

Collating, Summarizing and Reporting Data

We utilized two analysis mechanisms within *nVivo 12* for each of the publications. First, the analysis of each system's background work and references enabled us to gain insights into identifying four theoretical frameworks and grouping them under the 1st meta-category – *the Theoretical Framework*. Second, the iterative process of analyzing all groups of individual codes yielded the 2nd meta-category – *How breath is perceptually extending in Interactive Systems* – encompassing three design strategies:

1. Design approaches to perceptually extending breath;
2. Modalities in guiding attention to breath;
3. Design features of the systems: breath parameters.

THEORETICAL FRAMING OF ATTENDING TO BREATH

In reviewing the 31 systems, we observed similarities in what these systems aimed to achieve and how they were informed by the theoretical framing of the systems. By analyzing background work and references in these articles, we identified four categories of theoretical frameworks (TF): 1. breathing regulation – *TF1-regulation* (14 systems), 2. mindfulness – *TF2-mindfulness* (8 systems), 3. soma design and somaesthetics – *TF3-soma* (3 systems*), and 4. social connection through breath – *TF4-social* (6 systems*) [1]. We examine each of these theoretical frameworks below in order to answer RQ1: What is the theoretical framing and its values, and how those translate into the aim, and motivation of the systems that perceptually extend breath?

TF1-regulation: Systems for Breathing Regulation

In the medical literature, *breathing* is defined in physiological terms as an involuntary function of the autonomic nervous system that can be voluntarily controlled through activation of the somatic nervous system. This literature demonstrates the benefits of voluntary regulation of breathing: engaging in slow, deep breathing triggers a physiological response that the *TF1-regulation* framework builds upon. We identified the two most dominating paradigms within this framework: the first paradigm is that reducing the breathing rate to 6 breaths per minute leads to improved cardiovascular health [46, 62, 90] and alleviated stress [14, 31, 89]. The second paradigm is that by slowing breathing rate below the resting rate of 12-16 breaths per minute the physiological indicators of stress can be down-regulated [14, 76].

Regarding HCI and systems for breathing regulation, the same paradigms are present. While regulation of breathing rate through technology use implies regulation of physiology in the first place, it also leads to a change of experiential qualities associated with the elicited states (stress-relief, anxiety reduction, etc.). However, the emphasis of the systems for breathing regulation is on the objective, quantifiable outcomes of the interaction with the system. The knowledge in the field is created by evaluating the system's capacity to induce a change in breathing rate, which then elicits changes to the physiology, leading to improved health outcomes. However, we find that experiential considerations are rarely ever discussed regarding the systems for breathing regulation and not commonly embraced as a valid knowledge that guides the design of these systems.

Analysis: We identified 14 systems that we grouped under the *TF1-regulation* framework. All systems promise to improve health in the user interacting with the system. Eleven out of fourteen systems are built to decrease the breathing rate of the user. One system trains users in pursed-lip breathing [61], a particular technique for deep breathing with positive health outcomes, and the other two systems help a user sustain the awareness of the workings of their lungs [1, 8] in order to improve their lung capacity. Overall, the main motivation for systems in this framework is to combat stress (10 research papers justify building a system for breathing regulation to decrease stress-related health consequences), or to provide a relaxing experience (2 systems [21, 87]).

TF2-mindfulness: Mindfulness of Breath and Self-regulation of Attention

The relationship between breath and attention has a long history within Eastern traditions of developing insight through a deliberate attending to the inner body. Attending to the inner body by listening and noticing breath as a primary object of attention has been practiced as Focused-Attention Meditation (FAM) [41, 85]. The purpose of attending to breath in FAM is to stabilize one's attention and *tame the busy mind* while developing an awareness of sensations that arise with each breath. The inner body becomes the site of research [82] and a source of first-person knowledge. Often, FAM is then followed by the practice of *open monitoring* [41] of sensations, thoughts, and any feelings that occur at the moment as well as the sensations originating outside of the body, in the immediate environment. By engaging with these two practices, one is learning "through the experience of self" [82] and a first-person knowledge gathering that emphasizes the values of subjectivity in discovering about the inner self and self in relation to the world. Also, this knowledge is grounded in the person's capacities for developing sustained attention and reaching the state of mindfulness defined as "the clear and single-minded awareness of what actually happens to us and in us, at the successive moments of perception" [83, p.5].

While the understanding of mindfulness in the East relates to a comprehension of the greater body of Buddhist philosophy, which is taught and practiced as a way of alleviating personal suffering [84], mindfulness meditation in the West has also included a path that acknowledged a secular perspective that defined mindfulness as "a form of mental training to reduce cognitive vulnerability to reactive modes of mind that might otherwise heighten stress and emotional distress or that may otherwise perpetuate psychopathology" [9, p.231]. This particular interest in mindfulness meditation practice as mental training for combating physical and psychological illnesses arose in the early '80s through the work of John Kabat-Zinn on *Mindfulness Based Stress Reduction* programs (MBSR) [33], that contextualized mindfulness practices within clinical interventions and management of stress and chronic pain [9]. MBSR guided breath-meditation supports a practitioner in a mental training of sustaining attention on the breath through noticing bodily sensations as they arise with each breath moment-to-moment [45].

Analysis: We observed the influence of Kabat-Zinn's mindfulness framing in the HCI literature: out of eight *TF2-mindfulness* articles we reviewed, six articles cite Kabat-Zinn. Our findings are congruent to the findings of Terzimehić et al. [81] who analyzed mindfulness research in HCI and similarly found that the majority of the articles on HCI and mindfulness cite MBSR and Kabat-Zinn. As a motivation for designing the *TF2-mindfulness* system, six articles mention stress reduction as the main motivation, while the other two discuss overall improvements in cognition and well-being. Further, we

[1]* two systems belong to 2 theoretical categories: TF3-soma and TF4-social, and TF3-soma and TF2-mindfulness

observed that all *TF2-mindfulness* articles we reviewed focus on mental training of attention by supporting a sustained breath awareness, either by supporting breath-based meditation (2 systems [64,71]) or some aspects of it, such as sustained breath and bodily awareness. However, while all eight articles focus on breath awareness, only four articles [65, 69, 72, 92] discuss bodily aspects of such practice. Bodily sensations discussed are either referring to the sensation of air passing through nostrils [72], or to how the medium can contribute to body awareness, in particular how *immersiveness* [65] and *tangibility* [69] of the medium used to support breath awareness can elicit bodily sensations. Finally, while in the reviewed articles the motivation behind using the technology is in the quantifiable outcome of the improvement of health and well-being, the emphasis is not on regulating physiology (breathing) but on augmenting the experiential process of "attending to self in order to act upon the self" [82, p.53] where the interactive system (technology) can augment some of the processes of attending to the self.

TF3-soma: Soma-esthetics, Experience and Design — Appreciation of Felt Experience of Breath

Somatics is concerned with the first-person experience and knowledge of felt and tacit bodily processes, out of which regulation happens [32]. Interest in somatics arose in the early 20th century, through work of practitioners who focused on the implications of paying attention to the body and body awareness for healing. Very early on, through the work of Elsa Gindler on how to pay attention by focusing on the bodily experience of breathing and the qualities of breath earned this practice a title of "Western meditation" [32]. While breath has been a central element in early somatics, today this field encompasses a variety of practices (e.g., Alexander, Feldenkrais) that support and guide a person in listening to quiet processes in our bodies (soma), sensing muscles, nerves, and attuning the senses in "the selective use of awareness to isolate the unlearned function and, by association, to learn it – that is, make it part of the conscious functioning of the sensory-motor system" (Thomas Hanna in [32, p.352]). The focus is on the soma as inseparable from movement, cognition, perception and social contexts [73] out of which *somaesthetic* [73] qualities emerge in eliciting first-person knowledge through the whole bodily experience.

In HCI, the field of *soma design* [29] builds upon the ideas of *somaesthetics* and somatics. The design practice in this field focuses on the artifacts that can guide, aid and *extend aesthetic sensibility* [29] of our bodies. The goal is to extend beyond merely instrumental use of the technology for achieving particular states or outcomes and with a goal of providing means to learn how to pay attention, and appreciate first-person somaesthetic experience that emerges in the process of attending to our body. In the context of soma design, breathing can be seen as a bodily process that provides a gentle stimulus and helps redirect the attention to the perception of bodily sensations that arise with each breath. Breath is, in a sense, a portal to the first-person experience of a whole body. Schiphorst sees the breath as "an access point to contacting and sharing state data between bodies" [70, p.178]. While HCI and design fields offer means to augment breath and guide user's attention to it through biofeedback and mirroring one's states, Höök [29] argues that this is not sufficient, and that the process must encompass "learning about and changing yourself" [29, p.83]. Any guidance from a system must: facilitate the process of sense-making and body-awareness through subtle guidance, make space for reflection, provide means for articulating experience and establish an intimate correspondence between a system and the bodily sensations [29]. A system is seen as an extension of the body; therefore the emphasis is on the implicit interaction, immediacy of the response and the synchronization between the perceiver (a user) and what is being perceived (augmented breath).

Analysis: Consistent with soma design theory, three soma design systems in our review are built to elicit and then cultivate body and breath awareness through interaction design. Ståhl et al. [79] designed *Breathing Light* to "support a meditative bodily introspection subtly guiding participants to turn their gaze inwards, to their own bodies" [79, p.305]. Similarly, Aslan et al. [6] built a plush toy that mirrors the user's breathing. While the first two are single user, the third system by Schiphorst [70] expands the number of participants, allowing one or more to become aware of their breath through shared interaction and intimacy. The motivation for these systems is supporting self-discovery and curiosity for attending to breath first, then to the body as a whole. The role of breath in soma design then is one of a "portal": the attention is guided to breath from where it spans to particular nuances of the experience as supported by the system features.

TF4-social: Systems for Shared Communication, Emotion and Human Connection via Breath

As humans, we are a social species, significantly affected by other people around us, and continuously seeking human connection, which is crucial for supporting our physical and mental health [11]. Merleau-Ponty [47] proposed the notion of *intercorporeality* - the process through which we develop intersubjectivity by aligning the state of our body with others. Intercorporeality highlights that our body exists within and is influenced by the social context. In turn, any social interaction is always embodied: "the experience of being embodied is never a private affair, but is always mediated by our continual interactions with other human and nonhuman bodies" [93, p.5]. While the role of gestures and body language in augmenting the verbal communication has a long research history and is easily observable in our day to day interactions [22], our body may have an additional, less salient role in social interactions. For instance, by synchronizing our movement with others it reduces self-other dichotomy and fosters mutual understanding, connection and social relationships [39, 44, 67]. While movement synchronization is the most studied in psychological literature, the physiological dimensions, including breathing, of our bodily co-presence also synchronize [15, 52, 57]. Due to the interdependence of controlled movement and breathing, breathing synchronization often occurs in collective activities such as singing in a choir, synchronous swimming, couple dancing, rowing, yoga, etc. Breathing synchronization is essential in an intimate mother-infant relationship [86] and can facilitate relationships requiring trust and empathy such as psychotherapy [37, 75]. Therefore supporting breathing synchrony could promote the shared experience of an intimate connection between people. Moreover, as breathing rhythm is indicative of emotion [28, 66] and as it can be observed or heard during an interaction, it can be used to communicate one's affective state to others [18].

Digital technology can allow us to extend our intercorporeal relationships with others over distance [35]. Allowing for communication of physiological signals in social HCI could support social interactions and connect users [13]. Social bio-responsive systems allow for the access to the usually mostly hidden and private physiological dimension of one's existence. Making this private information available for another user allows for an intimate connection to emerge. The majority of physiological communication systems in HCI focus on heart-rate [27], which, unlike breathing, is much harder to consciously control, and thus it has more limited potential for interaction. Making one's physiological data, such as breathing, available to others, can first provide them the insight into one's inner state, supporting affective communication. Second, it facilitates the ability of one user to adapt to the state of the other by synchronizing their breathing. Finally, by adapting the state of the body to the other and mirroring their internal state, it can support empathy, the feeling of connection, and 'togetherness'. While the first user adapts to the second user, the second user adapts to the first. Such dynamic creates a feedback loop that guides both users to a converging state and encourages each user to attend to other's and their own breath, inner body, and their relationship with each other. As Höök argued: "Mirroring ourselves in others is an important part of learning about the self" [29, p.114]. Thus these shared systems can extend the perception of breath and self via the social interaction.

Analysis: We identified six systems that fit the *TF4-social* framework. Three [24,36,80] have the goal of supporting affective communication over distance that consequently can support the feeling of connection, empathy, and intimacy, while the other three systems were designed for co-present interaction to elicit or enhance the feeling of connection [20, 70] or to also augment and support existing yoga practice [49]. Most of the systems are designed for two users, except for *Exhale* [70] which allows multi-user interaction. While only three systems were explicitly designed to encourage breathing synchronization by providing biofeedback not only to breathing but also to the level of synchrony [20, 49, 70], designers of the other systems also discussed that their users would naturally adapt their breathing to each other. Thus, in all systems attending to breath allows the user to adapt it to the breathing of the other and to feel more connected with them. While neither of the reviewed papers discuss it explicitly, based on our analysis we propose that all of the systems rely on the notion of *intercorporeality of human interaction* as a mechanism for achieving the discussed effects of affect communication, connection, and empathy.

Discussion of Theoretical Frameworks

Theoretical Frameworks share similar motivations but differ in how they contribute to design knowledge We identified four theoretical frameworks and analyzed them (Table 1). We found that overall these theoretical frameworks share the same motivation that is self-improvement, either of the user's overall health or supporting well-being through mindfulness (*TF2-mindfulness*), body-based practices (*TF3-soma*) or with the "help" of others (*TF4-social*). We also found that while similar in motivation these frameworks differ in the epistemological commitments they draw from. Bardzell defines epistemology as "a theory of knowledge, including to whom, by what means, and under what circumstances knowledge is produced." [7, p.677]. Epistemological commitments in different frameworks provide a lens for understanding the aim and the values emphasized through the interaction design, as well as methods used to produce knowledge. While there is a variety of specific system's aims discussed regarding their development, we observe that in their core, these systems share similarities in what and how the systems are evaluated, and what is valued as contributing to design knowledge. This led us to dig deeper into our analysis to understand the background and related work cited in the papers describing each of the systems to fully grasp epistemological commitments each design is built upon and contributing to.

While most of the studies involving the systems from *TF1-regulation* focus on breathing regulation and measuring breath as 3rd person – quantifiable and measurable data, other frameworks tend to expand the scope in how the knowledge is constructed to include first-person experiences of the users. In that sense, *TF1-regulation* is limiting its scope on breathing regulation as a mechanical act of matching the amplitude or the frequency to the optimum values that then result in regulation of physiological measures. Therefore, the design knowledge in this framework is limited to the system's capacities to elicit **change in the physiology** of the user. However, while the aim behind regulating breathing in most of the systems is to combat stress by decreasing breathing rate (change in the user's physiology), decreasing breathing rate below resting rate can sometimes trigger unexpected experiential qualities, such as heighten stress in participants who lack previous exposure to slow breathing [2, 58]. Learning how to pay attention to breath and how to slow breathing is a skill acquired over diligent practice, similar to the one in breath-based focused attention meditation. While systems for breathing regulation focus mainly on regulating breath and decreasing breathing rate, the health benefit associated with breathing regulation might be linked to other contributing factors and experiential qualities that within *TF1-regulation* are rarely discussed. Yackle et al. [95] identified neurons that link breathing, relaxation, attention, excitement, and anxiety and mapped neural mechanisms that are potentially shared in both, mindfulness practices of focused-attention meditation and in medical approaches for regulating/decreasing breathing rate.

Therefore, there is more to the history of self-regulation through attending to the inner body than what is commonly reported in contemporary medical literature on breathing regulation. Johnson [32] outlined the history of medical breath regulation that stemmed from a variety of contexts of use and was based of the works of the pioneers in "Western meditation" [32] who acknowledged the importance of not only "mechanical" regulating breathing but the experience of noticing the quality of breath, the pauses between inhales and exhales, and heightened awareness of thoughts and emotions

Theoretical Framework	Motivation	Evaluation	Values	Most Frequent Words
TF1-regulation	health improvement	physiology	**change** is physiological state	rate, respiration, stress
TF2-mindfulness	health improvement, self-improvement	state of mindfulness, physiology	**practice** of attending to self, state of mindfulness	mindfulness, meditation, experience
TF3-soma	extending aesthetic sensibility of body	quality of experience of movement, body-based practices	**experience** of attending to one's body	body, interaction, design
TF4-social	social connection and communication	emotions, breathing synchronization	**experience** of connection, emotion, intimacy between self and other	biofeedback, communication, emotion

Table 1. Comparison of Four Theoretical Frameworks found in 31 breath-based interactive systems

that arise with each breath. Charlotte Seller even voiced concerns about blindly engaging in breathing regulation that can lead to a disconnect from the world and happenings in it [32]. *TF1-regulation* systems are designed as an intervention, and thus there is a question whether the achieved breathing regulation would be transferable outside of the use of the system. A lack of longitudinal studies in this area opens a space for the understanding of the long-term effects of interacting with these systems and answering the question of whether users remain dependent on the technology to regulate their breath. In that sense, *TF2-mindfulness* and *TF3-soma* frameworks are more encompassing than *TF1-regulation*. They embrace **the experience of self-regulation** that arises from an awareness of breath and practice of attending to the inner body: noticing the quality of the experience and sensations in the body that arise with breath without the necessity to alter it. Furthermore, systems in the fourth framework – *TF4-social* expand beyond attending to self to encompass meaning-making processes of attending to self through someone else's representation, expanding the experience from noticing experiential qualities of attending to the inner body through the augmented lens of shared emotion, connection, intimacy, and empathy.

The premise of *TF1-regulation* framework is that a lower respiratory rate contributes to stress reduction from a physiological aspect; however, subjective experience may not change in the users. Many authors [25, 43, 58, 94] reported that lower respiratory rate does not equal to more relaxed subjective feeling, which is contrary to the expectations from a system for stress reduction. Similarly to *TF1-regulation*, the majority of *TF2-mindfulness* focused on achieving a goal of reducing stress, however as Kabat-Zinn explained, Mindfulness-Based-Stress Reduction program was never just about stress reduction, instead "the emphasis was always on awareness of the present moment and acceptance of things as they are, however, they are in actuality, rather than a preoccupation with attaining a particular desired outcome at some future time, no matter how desirable it might be" [34, p.17]. Cherishing the aesthetics of attending to the breath and inner body is accomplished through sustained practice. While gathering experiential qualities of a sustained practice supported by an interactive system may not lead to immediate and measurable health outcomes as in, for example, *TF1-regulation* framework, this type of data still adds valuable insights to design knowledge about how to design systems for breath-awareness.

PERCEPTUALLY EXTENDING BREATH IN INTERACTIVE SYSTEMS: BREATH, ATTENTION, DESIGN FEATURES

In this section we present the results addressing RQ2: How is breath perceptually extended and what are the characteristics of the breath-based interactive systems that extend our breath awareness?

Perceptually Extending Breath

The aim of the reviewed systems is to capture and perceptually extend breath through different perceptual modalities to make breath more perceptually accessible to our attention. Here we focus on the technologies in direct contact with users' bodies, that capture and extend breath through different modalities.

Sensing Breath: We observed a variety of ways how breathing can be captured by systems that vary in the degree of obtrusiveness to the user's body. The least obtrusive approach is using radar technology that senses the movement of the user's belly from a distance [74, 79]. The rest of the systems require sensors to be either held as with spirometer (measures the air flow) [8] and thermistor (measures the temperature change of the inhaled /exhaled air) [77], or placed on the body. Twenty-three of the systems reviewed captured user's breath by placing a belt either around user's chest (e.g., [25, 26]) or their belly (e.g., [50, 64]). One system used a vest with breathing and balance sensors to measure breathing data [17]. Three systems use a microphone either in a smartphone headset [1], attached to a user throat [63] or in a Virtual Reality (VR) Head Mounted Display (HMD) [61] and one integrates Inertial measurement unit [12] in a wearable pendant [24].

Perceptual Modalities: Once captured, breath was "translated" to 3 perceptual modalities: *seeing* (visual), *listening* (audio), and *feeling* (kinesthetic) (Figure 1). The majority (18 out of 31) of the systems target only **one perceptual modality**: 9 systems focused on translating breath to visual cues through mobile applications [1, 59, 94], desktop applications [8, 50, 51], HMD VR [78, 87] and as a physical, spatial installation [49]; 5 systems translated breath to audio for mobile applications [10, 26, 94], desktop application [63], and as a spatial installation [92]; 3 systems employed kinesthetic cues to breath through a mobile application [10], and everyday objects such as sofa cushion [80], and stuffed animal toy [6]. Systems that targeted **two perceptual modalities** focused on combining seeing and listening together through HMD VR [17, 20, 61, 65, 72], desktop applications [64, 71, 77], and a spatial installation [79]. Perceptual extending breath to visual

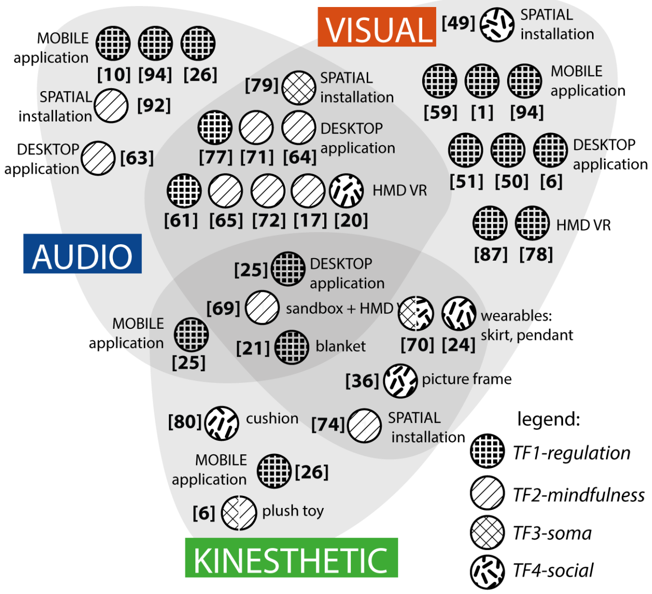

Figure 1. Perceptual Modalities: System references are in [#]

and kinesthetic representations of breath are combined in the systems for shared communication as in wearables [24, 70] and everyday object: picture frame that expands at the pace of the other person's respiratory rate [36]. *Breathing room* [74] translates the breathing data to tangible and visible movements in the walls of a spatial installation in which the participant is seated. Only one mobile application combines listening and feeling [10]. Finally, only 3 systems target **three perceptual modalities**: one desktop application [25], one everyday object: blanket [21], and one mixed-reality system [69].

Guiding Attention to Breath Through Interaction

Here we present different ways how the system guides the user's attention to breath (Figures 2: a. and b.). We observed three main attention directing modalities in the interaction loop between the system and the user. **Self-System-Self** modality is initiated by sensing the user's breath and sending it to the System, where the attention is directed from Self to the System. The system responds to the breath and the user's attention is directed from the System to the Self. This kind of directedness (Self-System-Self) characterizes any of the biofeedback loop systems in which the system senses the user (some physiology parameter) and based on that provides a feedback to the user. The second modality is initiated from the system to self and then from self to the system: **System-Self-System**. The systems that utilize this modality are in majority from the category of systems for breathing regulation through pacing (see Figure 2). These systems bring attention to breath by first providing a cue, in most cases a pacing stimulus that the user pays attention to. By attending to the cue and matching their breathing to the frequency of the pacing cue, the user's attention is brought to the breath. While the first two modalities explain the directedness of interaction and attention between a system and one user, **Self-System - Other - System-Self** is a modality that captures breathing of two or more people, and utilizes it in interaction between them mediated trough a system. In 3 systems this modality included a direct Self-System interaction for all [20, 70] or for one of two users [49]. As can be seen in the Figure 2 or evident from modality naming, the more complex modalities have the other modalities embedded in them.

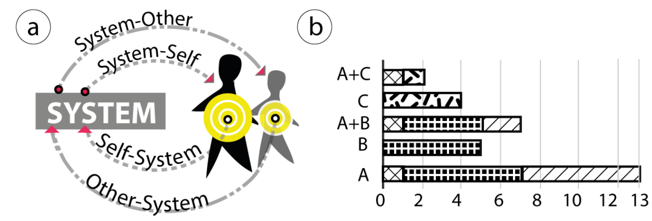

Figure 2. Interaction directedness that guide attention: a. All identified interaction-attention modalities; b. Count of systems by framework and the modality: A – Self-System-Self; B – System-Self-System; A+B – Self-System-Self + System-Self-System; C – Self-System-Other-System-Self; A+C – Self-System-Self + Self-System-Other-System-Self.

Design Features of the Systems

Here we present the features of the system design that contribute to closing the loop between the user and the system.

Breath Parameters: Once captured, breathing data is used in 5 different ways that determine the interaction between the user and the system (Figure 3.a). Most of the systems (27) extract **respiratory rate** and use that data in interaction design. Respiratory rate is a respiratory frequency defined as a count of breaths within a time period usually counted as breaths per minute (bpm). Examples include systems that use respiratory rate to determine: the timing of system's response (e.g. if breathing rate is above the threshold rate, the system provides cues to breath (as in e.g. [25, 51]), or complexity of presented cues as seen in the mobile application that introduces white noise and decreases the audio track complexity when respiratory rate exceeds 6 bpm [26] or increases the complexity of the virtual environment as the respiratory rate increases [65]. **Respiratory amplitude** is another, more nuanced parameter used in 15 systems; it is the "depth" of a breath (shallow breathing = low amplitude, deep breathing = high amplitude) that controls, for example, vertical movement in the virtual environment (going up with an inhale, going down with an exhale) [65, 87]. Exhalation duration is used in two systems: Schiphorst's system utilized exhale to provide a connection between the users by translating breathing into haptic sensations elicited by the fan under the user's garments (skirts) [70], while Patibanda's system measured exhalation time and the rest time between two successive exhales [61]. **Lung capacity** (tidal volume) is measured in two systems. Abushakra and Faezipour's system quantifies lung capacity [1] while in *Deep* [87]' virtual environment unsatisfactory lung capacity changes game mechanics by applying the force of gravity. Finally, three systems are measuring and representing **synchronization of respiration** between multiple participants: in *Exopranayama* [49] an "Om" sign is projected on the tent when the sync is established, in *Exhale* [70]'s wearable system lights lit up , while in *JeL* [20] virtual environment a coral-like structure starts growing.

Mapping Breath Parameters: In our analysis, we observed two distinct mapping approaches to how breath parameters are utilized and mapped to interactive elements to bring attention to the breath (Figure 3.b). *Direct* mapping utilizes breath

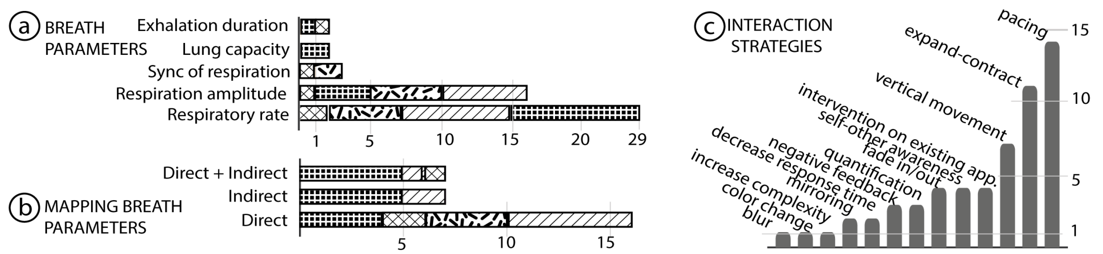

Figure 3. Frequency of different design features of the systems across 31 papers we analyzed. For color-coding across different TFs see Figure 1.

parameters (in most cases, respiratory amplitude) to provide an immediate response from the system. Examples of this type of mapping include systems that capture user's breath and move the user along a sine wave that matches the amplitude of user's breath [65] or present an element that expands with inhaling and contracts with an exhale [94]. Another example of direct mapping is Patibanda et al.'s *Life Tree* in which the user blows the tree leaves towards the tree as they exhale and the interaction is bound to the duration of an exhale [61]. In *Indirect* mapping, the system performs one or more operations on breathing data parameters before it is mapped to interactive elements. *BrightBeat* utilizes indirect mapping by "listening" to respiratory rate, and should respiratory rate exceed the previously set threshold (current respiratory rate > 12 bpm) the system changes screen brightness and sound volume to bring user's attention to the breath.

Seven systems utilize both approaches to mapping: direct and indirect mapping. *Deep* [87] is an underwater fantasy world that utilizes respiratory rate, amplitude and lung capacity in interaction. While the user's respiratory amplitude moves the virtual character through the environment on a vertical axis (inhale-move up; exhale - down), lung capacity is captured, and if it is less than 50%, gravity is applied to the character (indirect mapping). Therefore, attending to breath by slow and deep breathing make the user progress in the game. All three interpersonal synchronization systems [20, 49, 70] use some form of combined direct and indirect mapping by providing direct feedback of individual breathing along with feedback of synchrony. Interestingly, in all of them synchronization is mapped to an increasing object's luminescence.

Representations of Breath: In our analysis, we are interested in the interactive elements breath parameters are mapped to. We observed that all elements belong to one of four categories: nature inspired, human inspired, everyday objects and abstractions. *Nature inspired* elements are mostly visual and take form of: a jelly fish [20, 72, 78], puffer fish [77], sea/ocean [65, 69], sun [72], light [79], wind [61, 69], tree/leaves [61], and sound of water/ocean waves [21, 94]. *Human inspired* elements are: a virtual avatar [71], a human silhouette [64], animation of lungs [1], a breathing sound [63], and a tactile sensations on the skin when a breath passed from one person to other [70]. *Everyday objects* mapped to breath consist of: expanding and contracting picture frame [36], cushions [80], plush toy [6], and wearable skirt [70] and a pendant [24]. *Abstract* elements consist of quantified breathing performance [1, 50], a horizontal bar across the screen [51], expanding/contracting circle [64, 87, 94], tactile sensations - vibration [10, 21], white noise [26] and gong chimes [10].

Interaction Strategies

Representation-related strategies: In *Figure 3.c* we present 13 identified strategies implemented in 31 reviewed systems that aim to guide attention to breath. *Pacing* is used in 14 systems that utilize System-Self and Self-System-Other-System-Self interaction - attention modalities (see above). The user is presented with representation of a breath that either moves on a vertical axis collecting points in the game [77] or expands/contracts at a certain rate [94]. Rate is either *fixed* (e.g.6 bpm) or *adaptive*: the system initially matches the user's breathing rate and slowly introduces changes in the response to gradually reach user's target breathing rate. In systems with two or more users, the system is pacing at the rate of the other person (e.g., [20, 24, 36, 80]) making for a rich design space for further exploration how these rates change and influence each other. *Expand-contract* is applied to breath representations such as: circles [64, 87, 94], animation of lungs [1] puffer fish [77], jelly fish [72] and in inflatable everyday objects (cushions [80], picture frame [36]). *Vertical movement* is observed in a horizontal bar placed on the screen [51], moving a user in virtual environments and games, both screen based [8, 77, 78, 87] and HMD [20, 65, 72], and everyday objects/installations [21, 49]. *Fade in/out* is used for audio [94], light [79], and haptic representations of breath [24].

Attention-related strategies: While the majority of the systems (24/31) are built to be in the focus of attention of a user, five systems are built on top of existing applications, with the aim to provide a seamless distribution of attention between the primary task and breathing. These applications include screen-based horizontal bar [51] and add-on in system tray -*BreathTray* [50] that reminds the computer users to focus on their breath when respiratory rate reaches a threshold during their work. Some strategies are disruptive and obscure the primary activity, such as an audio application for music listening that introduces white noise and reduces track complexity incrementally as the respiratory rate deviates from 6 bpm [26].

Self-Other strategies: *Mirroring self in other* relates to a strategy used in systems with 2 or more users. In these systems, the user is discovering and sense-making of their breath by relating to the other person's breathing data. This allows for users to align their breathing that can allow alignment of inner bodies, thus supporting empathy and feeling of connection. An interesting use of this strategy was implemented in a single-user VR narrative-based game developed to promote empathy for refugees [38]. There, the participant holds their breath similarly to the protagonist of the story to progress to the positive ending, thus synchronizing their breath with the character, participant can embody their state and develop empathy. Some systems are explicitly designed to support breathing synchrony by providing positive reinforcement when participants sync to encourage them to achieve the alignment of inner bodies and connection, while other systems only provide the information about the other user's breathing (and don't have an explicit goal of synchrony). While participants tend to sync in both strategies, providing positive reinforcement makes the interaction more goal-oriented. Providing positive reinforcement also seems to be more inducive compared to the spontaneous synchronization that occurs when breathing information is just simply communicated between people.

HOW DESIGN STRATEGIES EMPHASIZE THE VALUES OF THEORETICAL FRAMEWORKS

So far, we have identified 4 theoretical frameworks and 13 strategies used to support breath-awareness in the systems built upon those frameworks (see Figure 3.c). Here we discuss how different strategies are used to support different experiential qualities of interaction and elicit breath-awareness in those 4 previously identified theoretical frameworks. We recognize the difference in experiential qualities that arise from interacting with the systems built upon different theoretical frameworks. These qualities are: **immediacy** in *TF1-regulation*, **sustained observation through practice** in *TF2-mindfulness*, gentle **sensory engagement** in *TF3-soma*, and **extending self through the other** in *TF3-social*.

Supporting Immediacy of Interaction Through Representations of The Breathing Mechanics in *TF1-regulation*: The main goal of the systems in *TF1-regulation* is to perceptually extend breath so that the participant regulate their breathing by interacting with the system. The emphasis is on a physiology regulation and efficacy of slowing breathing to an optimal respiratory rate. Such goals value immediacy of interaction over aesthetic or experiential consideration of the design. To that end, we observed that representational strategies used in the design of *TF1-regulation* systems contributed to a sense-making of incoming breathing cues at large by mimicking the mechanics of human lungs in the majority of the systems within this framework. We report strategies such as: expanding and contracting, vertical movement and fade in/out applied to representations of breath. All of these movements are found in the immediacy of mechanics of the human lungs that expand on each inhale and contract with an exhale, moving the chest and the whole body up (on a vertical axis) and along the hyperbola (fade in/out). This is congruent with the concept of *metaphoric mapping* based on previously learned everyday image-schemas [42] such as lung mechanics or concepts such as "increase is up" (vertical movement on the inhale). The second mapping used is *isomorphic mapping* [42] based off one-to-one literal mapping of a breathing data (input) to the breath representations and mirroring the state of user's breath (e.g., the character follows the dynamic of the user's breathing). Both require little to no conscious effort for understanding more abstract concepts, and for this reason, these two mappings of interactions are considered to be "intuitive" [42] and may be one of the main reasons for the choice of compatible strategies that support immediacy as interaction quality within this framework.

Sustained Observation Through Practice *TF2-mindfulness*: The *TF2-mindfulness* systems also build upon the strategies that support immediacy (as described above) by utilizing the dynamics of breathing mechanics for vertical movement [17, 65], or by guiding the user's attention to expanding and contracting elements representing their breath [64]. However, the emphasis of the *TF2-mindfulness* system design is on eliciting breath awareness by supporting the practice of attending to self. While two systems directly focus on supporting breath-based focused-attention meditation practice [64, 71] the rest of the systems in this framework support focused practice of attending to breath by creating an immersive experience around the user. The goal of such approach is to elicit curiosity and engage one in continuous process of **sustained observing** and listening to breath representations and therefore attending to their breath. For example, in Sonic Cradle [91, 92], an immersive interactive sonification of breathing cycles, uses the strategy of *increasing complexity over time* by triggering a new sound on the exhale. Similarly, *decreasing complexity* of breath representations is used in the *Meditation Chamber*, an HMD VR depicting a jellyfish that fades to black as the user progresses in attuning to their breath [72]. To this end, we observed that in *TF2-mindfulness* there is a design consideration of the threshold of breath representation enough to support curiosity and exploration such as in Pisa et al.'s system [63] that amplifies user's breathing sounds only when the user is hyperventilating but minimized once the breath-awareness is elicited and practice established.

Sensory Engagement in *TF3-soma*: Our interest in making breath perceptually accessible by extending it through systems that utilize breathing is based on an understanding of the act of perceiving as "about one's personal relationship to the incoming information" [32, p.195]. Ståhl et al. [79, p.307] used light "to achieve an intimate correspondence between the perception of the breathing and the light, so that the light is perceived as an extension of the body, creating a deepened experience for each breath". The breath representations, in the form of light and temperature from the light, serve as a gentle guide and support to the user's experience of extending their body. That is, the *TF3-soma* framework engages in bodily-based knowing and experiential, kinesthetic qualities that emerge from guiding attention to the breath and the body. To that end, the strategies that support kinesthetic experience are translating breathing data into perceptible sensations on the body. In Schiphorst's installation *Exhale* [70] a breath is shared between the participants as a perceptible breeze on the participant's skin. One possibility that we noticed is that the majority of the systems utilize breathing data from the sensors placed on the body. Núñez-Pacheco and Loke demonstrated how the use of "body-centric artifacts" such as a vibrating glove could guide the participant's attention to their bodies and develop aesthetic sensibility [55]. We ask then, can breathing sensors placed on the body serve as "body-centric artifacts" to guide the participant's attention and the unfolding of aesthetic appreciation of body and breath awareness?

Extending Self through the Other in *TF4-social*: The notion of personal relationship to incoming information contributes to experiential qualities in *TF4-social* framework too. In interacting with the representations of breath of the Other (person), the notion of who the Other is changes the experiential qualities of interaction. Knowing that a virtual character, such as a jellyfish [20], or a tangible object, such as picture frame [36] are not simply entities responding to or pacing one's breathing, but are an embodiment of breathing of another person, often a significant other or a family member, can fundamentally change the experience. While the mechanic of the interaction may be the same, when looking at a pulsating cushion, controlled by an algorithm guiding you to slow down your breathing to achieve a state of calm, when the participant is aware that the pillow is embodying inhales and exhales of someone we are intimately, or emotionally involved with changes the meaning we assign to such experiences. The experiential quality of our relationship with the other person will contribute to the phenomenological experience of the interaction, creating an intercoporeal relationship letting us learn about ourselves through mirroring in the *other* [29].

TAKEAWAYS: EXTENDING BREATH THROUGH DESIGN

1. **Conscious Design Practice Acknowledges The Importance of Deliberate Theoretical Frameworks** – Theoretical frameworks not only impact how the system is designed, but they also guide design knowledge production in the field by framing how and what questions are asked. Theoretical frameworks have established evaluation methods that are often implied and rarely discussed. However, the value that design knowledge contributes stems directly from what is both valued and evaluated within design practice, as well as the recognition of how theoretical frameworks shape our design processes.

We have reflected on the value of considering the long history of reflective, social, scientific, and philosophical traditions that frame our design processes. Explicitly acknowledging the epistemological commitments present in our theoretical histories allows us to uncover more nuanced approaches to designing in context, and to recognize our methodological processes. In our analysis, it was often hard to distinguish designs between TF2 and TF3 (mindfulness and soma-aesthetics). This ambiguity could be solved by explicitly acknowledging the TF and opening a discourse about their associated evaluation methods as a future work. We hope that by embracing a discourse regarding TFs and their impact on design processes we can increase our sensitivity to values and evaluation approaches, and increase the quality of our design strategies.

2. **Inherent Values of Theoretical Frameworks Can Determine The Scope of Evaluated Experiential Range** – We showed how TFs and their epistemological commitments frame design processes and system designs. While there is no optimal way to design these systems, there are common strategies shared by the systems analyzed, as presented in this paper. While we unveiled some of the common relationships between the TFs and the design strategies, the relationship between the presented designs and the experiential qualities they elicit is often unclear and requires further investigation. To that end, we recognize that by bringing more explicit critique and reflection into possible TF interconnections and their experiential accounts, our designs can incorporate a greater experiential dynamic range in a given system including the physiological, attentional, somatic, and social aspects. As in the case of designing for mindfulness, Akama et al. [3] discuss the importance of acknowledging the experiential complexity of mindfulness in both design and evaluation. Extending this argument, we encourage the designers of breath-based systems to go beyond the quantitative evaluations of physiological states (e.g., TF1) and incorporate evaluations that recognize the complexity of subjective experiences of extended breath awareness.

Our research unveiled a complexity of cues and interaction within our human attentional capacities. How can we leverage our capacity for directing and re-directing our attentional resources that can access and share knowledge between ourselves and others? There is so much we still do not understand about the transformative potential of extended breath. How can we more fully explore extending the experience of breathing through an artifact and incorporate body schemas with the interaction? And if we do extend ourselves through the artifact - what does it mean to be extended - for the person extending and for others perceiving the extension?

Limitations of The Scoping Review

While conducting this review we faced limitations in our analysis process. (1) *Theoretical Frameworks are not always obvious or clearly stated*: To identify the theoretical frameworks, we analyzed references and previous work; (2) *Lack of a first-person experience with the systems*: For majority of the systems we did not have a first-person experience (except [20, 64, 70, 74, 91]). Instead, we relied on the information provided in the articles that describe those systems. While all articles provided some description of its system design, a majority of the articles focused more on testing the hypothesis regarding the system, and less on describing the nuances of the system or experiential consideration; (3) *Imbalance in the number of analyzed systems through different theoretical frameworks*: We notice that some TF have more system implementations than others (14 systems in *TF1-regulation* vs 3 systems in *TF3-soma*) which may have influenced the identified characteristics to a certain degree.

CONCLUSION

We critically analyzed 31 breath-based interactive systems and unveiled four theoretical frameworks that shape design goals and decisions through their differing epistemological commitments. Our goal was to deepen the understanding of design approaches employed to perceptually extend breath awareness. To that end, we discussed three design features of these systems that help users in guiding and sustaining attention to their breathing, and how these features support the theoretical frameworks underlying the motivation of the systems. We conclude the paper with two takeaway points regarding design of systems that perceptually extend breath.

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