Manifesting Breath: Empirical Evidence for the Integration of Shape-changing Biofeedback-based Artefacts within Digital Mental Health Interventions

Alexz Farrall
University of Bath
Bath, UK
af874@bath.ac.uk

Jordan Taylor
University of Bath
Bath, UK
jt2006@bath.ac.uk

Ben Ainsworth
University of Bath
Bath, UK
ba548@bath.ac.uk

Jason Alexander
University of Bath
Bath, UK
jma73@bath.ac.uk

ABSTRACT

Digital interventions are often used to support people with mental health conditions, but low engagement frequently reduces their effectiveness. We investigate the use of a Physical Artefact for Well-being Support (PAWS) to improve engagement and effectiveness of an audio-only guided well-being intervention. Through our handheld shape-changing biofeedback-based PAWS, users can synchronously feel their breath via kinaesthetic haptic feedback. By evaluating our device in a randomised-controlled experimental paradigm (N=58), we demonstrate significant reductions in physiological and subjective (self-reported) anxiety compared to an audio-only control. Our findings conclude that synchronous interactions with one‘s own physiological data via the PAWS, improves engagement and effectiveness of an intervention.

CCS CONCEPTS

• **Human-centered computing** → **Empirical studies in HCI**; **Haptic devices**; • **Hardware** → *Emerging interfaces*; • **Applied computing** → *Consumer health.*

KEYWORDS

Physicalization, Physical Artefact for Well-being Support (PAWS), Biofeedback, Shape-Change, Mental Health, Mental Well-being, Breath, Psychological Accessibility, Engagement

ACM Reference Format:
Alexz Farrall, Jordan Taylor, Ben Ainsworth, and Jason Alexander. 2023. Manifesting Breath: Empirical Evidence for the Integration of Shape-changing Biofeedback-based Artefacts within Digital Mental Health Interventions. In *Proceedings of the 2023 CHI Conference on Human Factors in Computing Systems (CHI '23), April 23–28, 2023, Hamburg, Germany*. ACM, New York, NY, USA, 14 pages. https://doi.org/10.1145/3544548.3581188

CHI '23, April 23–28, 2023, Hamburg, Germany

ACM ISBN 978-1-4503-9421-5/23/04...$15.00
https://doi.org/10.1145/3544548.3581188

1 INTRODUCTION

Tangible technologies have the potential to provide the next revolutionary step in mental health support. Uptake of digital interventions within clinical settings has led to individuals with reduced mental well-being frequently signposted to low-intensity applications [68]. Despite the accessibility and versatility of digital stimulation technologies, their compatibility with common transdiagnostic mental health symptoms [47, 95] may yield insight into difficulties with e-mental health adoption. Therefore, our approach aims to enhance the delivery of a Digital Mental Health Intervention (DMHI) by incorporating a Physical Artefact for Well-being Support (PAWS) (see Fig 1).

Digital interfaces proliferate everyday interactions within modern society, yet there is speculation surrounding their reliability for delivering mental health support [20]. Technologies that utilise DMHIs commonly report barriers of poor interactivity, avoidance, practical implementation, and task difficulty [19, 72], with a 3.9% 15-day average retention [12]. Regardless of the ease of access, if users do not experience DMHI benefits, they will not engage in future use. Further, there are often correlations between digital misuse and transdiagnostic symptoms, among whom often experience desensitisation to DMHI delivery mechanisms [24, 91]. Although incorporating engagement strategies within DMHIs has been shown to elevate the effectiveness of digital tools [43, 68], services struggle to recruit and retain mental health sufferers.

Thus, we explore how the emotional and psychological significance of touch [58] can improve the engagement and effectiveness of DMHIs. Specifically, we focus on the dynamic information representation effects of shape-changing technologies [5], which can broaden communication and affective responses via variations in size, oscillation frequency, or curvature [40]. By utilising biofeedback to manipulate artefacts, implicit real-time tailored feedback can improve the effectiveness of experiential therapeutic strategies. Similar to digital-biofeedback systems [60, 114, 125], we predict that physical interactions that are enhanced using physicalized physiological information will broaden self-awareness and facilitate greater self-regulation to an extent that is beyond current digital modalities. To explore how an increased bodily perception improves the effect of DMHIs, we follow a somaesthetic design approach [58] to create a handheld shape-changing synchronous

Figure 1: Our constructed shape-changing biofeedback-based pneumatic PAWS inflates and deflates in relation to captured inhalation and exhalation bio-signals.

biofeedback-based pneumatic sphere. Through our deformable kinaesthetic physicalization, users can manifest their breath by translating pulmonary activity into synchronous pneumatic actuation to enable real-time physiological interactions.

By creating advanced experiential learning opportunities, our aim for these intervention delivery enhancements is to provide alternative solutions to populations struggling with existing DMHI strategies, reduction in the stigma surrounding seeking support, and expedite psychotherapeutic treatments. Therefore this research conducts an intervention and self-worry-induced Randomised Control Trial (RCT) to examine the acceptability and feasibility of PAWS-integrated DMHIs, and contributes the following:

- The design and construction of a handheld shape-changing biofeedback-based sphere that enables real-time physical interactions with internal physiological information.
- Empirical evidence of the feasibility and acceptability of a physically augmented DMHI.

2 BACKGROUND

A multitude of reviews highlight the technology-enabled mental health design space, from synthesizations surrounding implementations for affective health [96], behavioural [35], mindfulness [104, 109], psychosocial [45], and emotional regulation [105, 116] technologies, to their employed engagement strategies [6, 55, 111]. Whilst emerging DMHI proliferate commercial and clinical forethought due to their physical accessibility, researchers have sought to go beyond digital technologies [16, 119].

By incorporating emotional regulation strategies: situation selection, situation modification, attentional deployment, cognitive change, and response modulation; technologies aim to apply didactic and experiential mechanisms to provide offline, prevention or remediation and on-the-spot, intermediation, embodied skills training [105]. These mechanisms are synonymous with techniques from evidence-based clinical frameworks, such as Mindfulness-Based Therapy (MBT), Cognitive Behavioural Therapy (CBT), and Acceptance and Commitment Therapy (ACT). Despite these frameworks which all commonly inaugurate users with effective breathing exercises, over 70% of users fail to complete practices, and more than 50% disengage before completing half of all treatment modules [59, 127].

Repetitive negative thinking is one example of a common transdiagnostic mental health symptom that is directly associated with poor interoceptive processing [91]. This interoceptive deficit leads to over-regulation or inattentiveness to an emotional state, and is defined as the inability to accurately sense and respond to internal sensations. Moreover, attempts to improve emotional regulation are often met with emotional learning difficulties that obstruct accurate self-regulation [105]. Therefore, prolonged exposure to reduced mental well-being causes neurological change [118] impeding both physical (attendance and adherence to sessions) and psychological (motivation, intention, commitment, and belief during sessions) engagement [9].

Biofeedback can provide real-time tailored information for learning and/or practising techniques through operant conditioning designed to overcome self-awareness difficulties [105]. Typically; graphical, illustrative, artistic, and ambient screen-based representations are the strategies most employed that allow the user to visualise their physiological state as part of meaningful gameplay. Interactions thereby consist of influencing information through self-adaption, with users preferring visualizations that relieve their cognitive load and processes [107]. Shape-changing physicalizations can then broaden information delivery and nudge users (sub-) consciously toward physiological states via direct bodily changes [53, 105]. In this manner, respondent conditioning may be additionally applied to embodied skills training to improve emotional regulation.

2.1 Physical Artefacts for Well-being Support

We introduce PAWS as a new classification consisting of tangible [51], haptic [82], and data physicalization [53] technologies which specifically focus on improving mental well-being through elevated physical and psychological engagement. They are devices, objects, and tangible constructs that can be physically felt and manipulated to improve interactions and information significance [29].

By personifying an object as the interaction medium, users can meaningfully engage with mundane or emotionally demanding tasks [8, 42, 97]. In this regard, self-regulation PAWS, as a self-help measure, are means to empower users and facilitate autonomy [11, 74, 102]. If external stimuli are not personalised within prolonged attention-based tasks, users may be unable to attune and engage with the intended activity [73, 74]. For this reason, Thieme et al. [110] believed users who physically held physiological representations would be able to carefully and quickly observe and connect with internal sensations. By incorporating biofeedback techniques into a system that aids regulation, greater self-control can be exhibited through greater self-awareness [31, 100]. Moreover, through pairing the biofeedback techniques with shape-changing interfaces, PAWS can support perceptual skills, such as focused attention or embodied awareness, that may compensate for interoceptive deficits [53].

These representations are often portrayed via breath-based physicalizations, which apply techniques linked to supporting mental functionality [127]. The psycho-physiological changes facilitated through regulated breath are fundamental to mental health techniques and are the most frequently adopted DMHI strategy. Mindful [128], diaphragmatic [39], and autogenic [71] breathing are examples of bio-integrative techniques for improving sustained attention [79]. These techniques represent initial conscious pulmonary control developmental practices that facilitate peri- and-post emotional regulation outcomes. Psychological engagement within a practice can therefore influence the effectiveness of the session and subsequently their protective benefits (e.g. prevention of anxious thoughts) [10, 121].

Current work within this space commonly relies on pneumatic actuation, such as a wearable corset [58], mouse pad [124], picture frame [63], sofa [106], and wall-mounted display [123]. However, due to the actuation difficulties of shape-changing technologies [5, 53], systems are typically anchored to a location, thus restricting interactions. For example, within a table-mounted semicircular airbag called 'Breath with Touch' [124], a user's palm is fixed to the device to feel kinaesthetic feedback. As a result, this reduces the potential for 'felt experiences' (squeezing, patting, stroking, hugging) that are used to convey and elicit emotions [22, 27]. Despite limited user performance and outcomes based on conformations to the system's operational needs [56, 69], dynamic touch-based stimulation received greater satisfaction significance compared to a digital control. Similarly, whilst wearable shape-changing biofeedback systems may offer an alternative hands-free experience, they have been known to elicit discomfort and unnatural sensations [58, 75, 86]. Therefore, to integrate both the passive (users follows object) and active (object influences user) self-regulation benefits [57] of shape-changing biofeedback systems, we create a novel device that enables mid-air (travelling, rotating, grabbing) [65] and touch-based (bimanual power grip, bimanual precision grip, uimanual power grip) [98] interactions in the form of a handheld shape-changing synchronous biofeedback-based pneumatic sphere.

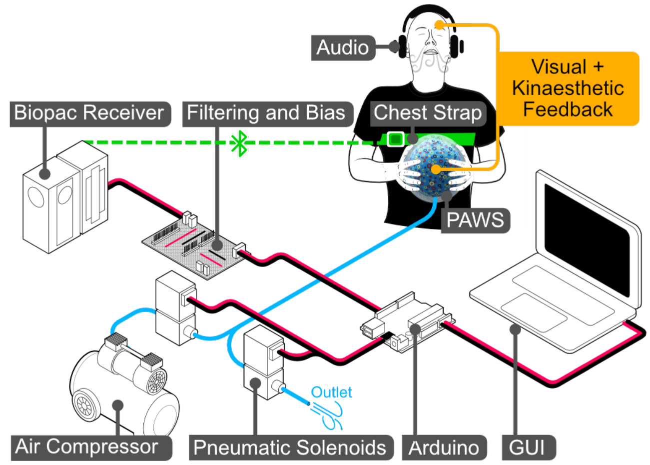

Figure 2: Operational diagram of key components to drive the PAWS in Fig 1. *Please note components are portrayed as abstract representations.*

3 SYSTEM

The constructed PAWS in Fig 1 was designed to enhance sensations of breath through the physicalization of physiological data. In this manner, as a user breathes, the handheld device synchronously expands and contracts in relation to inhalations and exhalations. Interactions, posture, and positioning can then be customised by the user to ensure the system is comfortably situated within a breathing experience. Thus, the user can tailor a full range of motions and interactions to their needs and/or desires. Construction involved bio-sensors, pneumatic actuation, and a shape-changing PAWS. Fig 2 depicts the apparatus overview and Table 1 its operational parameters.

3.1 Bio-signal Acquisition

For bio-signal recovery, we utilised a Biopac dual wireless respiration and electrocardiogram (ECG) BioNomadix transmitter[1]. This transmitter was placed over the sternum via a flexible chest strap. As thoracic expansion and contractions lengthened or shortened the chest strap, voltage output increased or decreased. Compared to other breath-based acquisition techniques [28], we adopted a chest strap for factors such as non-invasiveness, sensitivity to change, wirelessness, and real-time data transmission [103, 113].

3.2 Pneumatic actuation

To convert bio-signals into an interactive physicalization, a pneumatic system was utilised as the means of controlling the shape-changing PAWS. Biopac bio-signals were filtered through a custom voltage divider bias circuit and processed by an Arduino. The Arduino then applied dynamic time series smoothing to the real-time

[1]https://www.biopac.com/product/bionomadix-rsp-with-ecg-amplifier/

Initialisation size ∅*	16.5 cm	Force	0 - 6.9 N
PAWS size ∅*	15 - 18 cm	Exerted pressure (male)†	0 - 478 pa
Input pressure	0.6 bar	Exerted pressure (female)†	0 - 523 pa
Inflation/Deflation rate ∅*	0 - 6.2 mm/s	Internal Pressure	0.5 - 12.7 PSI

Table 1: Minimum and maximum PAWS operational breathing cycle parameters. †In relation to average surface area of hands [1]. *∅ = **diameter**

data and mapped positive, negative, and neutral respiration data changes to three states: (1) breathing in when $x_2 > x_1 + \gamma$, (2) breathing out when $x_2 < x_1 - \gamma$, and (3) holding breath when $(x_1 - \gamma) \leq x_2 \leq (x_1 + \gamma)$, where x_2 is a new smoothed bio-signal value, x_1 is the previous value, and γ is a system sensitivity variable. Upon each state, pneumatic solenoids are either activated or deactivated to: transitioning air from an 8l silenced air compressor[2] into the object, vent air from the object, or shut off circulation. A pressure regulator and a PSE530 pressure sensor[3] were incorporated for safe operation and monitoring. All apparatus components (except for the shape-changing PAWS) were located in a separate room from the user to ensure zero noise pollution and connected via long (3m) pneumatic tubing. Through our method, real-time feedback with no observable delay between breathing cycles was achieved.

3.3 Shape-changing PAWS

We designed our PAWS to align with the natural mechanism of breathing (i.e. the lungs) and the positive valence affects of geometrical circular shapes [40]. To minimise the activation of other cognitive or behavioural mechanisms [110], a spherical shape of no discernible characteristics was the basis of our design.

Akin to the alveolus (a balloon-shaped air sac) our shape-changing PAWS consists of two layers; a latex interior surrounded by a cotton exterior. During inhalation air is released into the object, causing the interior to expand, increasing the object's volume. Due to the physical restriction of the outer layer during expansion, pressure increases causing a reduction in airflow. This rise in air viscosity reduces the deflation rate, thus simulating fully inflated lungs. Similar to muscles relaxing during exhalation, the air is then released back into the compressor's surroundings, reducing the size and volume of the object. To provide elasticity similar to a muscle capillary, the PAWS' exterior was cotton threaded with an overlocked stitch enabling gradual deceleration towards full inflation [25, 41]. As the object's rigidity increases with size, so does the pliability and susceptibility to finger indentations. Further, we designed our PAWS to ensure an authentic representation of maximum changes (3cm) in human thoracic expansion [90]. An overview of the operational parameters in this description is depicted in Table 1.

4 METHODOLOGY

The goal of this study is to explore the acceptability and feasibility of a physically augmented DMHI. Within our work we follow existing definitions and define; *Acceptability* as the extent to which participants receiving the intervention consider it appropriate [101] and, *Feasibility* as the extent to which the intervention effects the outcome [92]. Therefore we conduct a Randomised Control Trial (RCT) exploring the influence of a physically augmented DMHI (i.e. audio + PAWS) in relation to an audio-only DMHI. We segment our study into four phases: baseline, intervention, reintervention, and worry induction.

4.1 Participants

Fifty-eight participants (46(F), 12(M); Age: 25(18-24), 22(25-34), 7(35-44), 2(45-54), 2(54+)) were randomly assigned into equal condition groups; experimental Group A = PAWS+audio, and control Group B = audio-only. To ensure comparative outcomes with potential future users, only those with minimal meditation experience were recruited. A pre-sign-up survey that included a general mindfulness practice frequency and excludable health condition requirements was used [3, 4]. If participants were over 18, had not undergone any formal intervention, and self-rated lower than a 5 on a 1 (I have never heard of mindfulness) to 6 (I regularly practice mindfulness) scale, they were included in the study. Within the survey, mindfulness was defined to participants as the practice of any technique that aims to facilitate sustained attention to one's internal thoughts in a non-judgmental manner [23, 62].

4.2 Measures

4.2.1 Self-report. To evaluate changes in a mental state between each phase, Visual Analogue Scales (VAS[1][2][3][4]) of 'anxious', 'nervous', 'worried') were utilised via likert scales rated from 0 (Not at all) to 100 (Extremely) [3, 49]. Alongside a six-item State-Trait Anxiety Inventory (STAI[1][2][4]) [112] and a Short Warwick-Edinburgh Mental Wellbeing Scale (SWEMWBS[1][4]) [78], VAS were implemented as validated measures to assess emotional states as unobtrusively as possible [14, 36, 64]. The FLOW State Questionnaire (PPL-FSQ[2]) absorption factor (0.708 McDonald's ω) [76], Intrinsic Motivation Inventory (IMI[2]) value factor (0.947 McDonald's ω) [46], Toronto Mindfulness Scale (TMS[2]) [67], and a Single Ease Question (SEQ[2]) related to task difficulty of sustained focus on breath [99] were used to explore perceived psychological engagement.

4.2.2 Physiological. Heart rate, in particular Heart Rate Variability (HRV[1][2][3][4]), was paired with respiration bio-signal recovery due to known correlations with psychopathological conditions [93] and psychological state [30, 115]. Typically Galvanic Skin Response (GSR) is a frequently adopted biomarker of stress detection, however

[2]https://hyundaipowerequipment.co.uk/hyundai-8-litre-air-compressor-4cfm-118psi-silenced-oil-free-direct-drive-0-75hp-hy5508
[3]https://docs.rs-online.com/4307/0900766b813dc232.pdf

Measure taken at: [1] = Baseline, [2] = Intervention, [3] = Reintervention, [4] = Worry Induction within our work we avoided touch-based restrictions to facilitate maximum sensory stimulation. To capture the electrical activity of the heart, three electrodes were placed near the Right Arm (RA), Left Arm (LA), and Left Leg (LL). HRV's Root Mean Square of the Successive Differences (RMSSD) index was then extrapolated by Biopacs AcqKnowledge software to correlate potential changes with emotional regulation and anxiety [126, 127].

4.2.3 System. Internal PAWS pressure[1][2][3] was captured during operation to explore how user-applied force changed in relation to system-applied force (volumetric changes) [108]. In this manner, the alignment of external to internal signals (i.e. biofeedback synchronicity) can further support acceptability insights [80].

4.3 Procedure

Phase One: Baseline. Self-report measures of VAS, SWEMWBS and STAI were first completed by participants. ECG sensors were then attached to the skin and connected to the BioNomadix transmitter. The respiration strap was placed over the clothes upon the sternum, before again being connected to the transmitter. Participants were instructed to then sit and watch a 5-minute light-hearted physical comedy show (Mr Bean) while their physiological data was being captured. Unbeknownst to Group A, the PAWS was operating in a separate room to also capture baseline values of internal PAWS pressure. The video was then taken away and both groups informed of the need to focus on their breathing within the next task. Both the benefits of the activity and the presence of audio guidance were conveyed to the participants. Group A was then handed the PAWS and instructed on its use. Neither group were given the opportunity to practice the exercise.

Phase Two: Intervention. Once the participants were ready to continue, they were left alone in a sound-isolated room to experience their conditional 10-minute intervention; experimental Group A consisting of PAWS+Audio, and control Group B audio-only. Physiological and PAWS pressure readings were captured during this time after which both groups completed self-report measures (VAS, STAI, PPL-FSQ, SEQ Ease of Task, TMS, and IMI). The audio was provided by Medito, a not-for-profit mindfulness app, and consisted of an evidence-based guided mindful breathing exercise that combined ambient music with trained practitioner instructional cues of maintaining focused attention of breath, allowing thoughts, and remaining in the present moment. All practices were validated by a scientific advisory board.

Phase Three: Reintervention. To ensure the intermediary self-report measures did not influence the mental state of the participant prior to Phase Four, participants re-experienced their conditional interventions for another 5 minutes. Again, physiological and PAWS pressure readings were captured during this time, however, only VAS self-report measures were completed.

Phase Four: Worry Induction. To measure the effect of the intervention, participants were subject to a worry induction task. To ensure comparative effectiveness across the conditions, both groups continued to wear the headphones with neither group having access to the PAWS. Consistent with existing studies [3, 49], a worry induction task is an effective 5-6 minute technique to elicit anxiety. Participants were instructed to deliberately bring their attention to a personal, non-depressogenic worry. After leaving the participant alone for 6 minutes, they were asked to rate their worry from 0 (Not at all) to 100 (Extremely) on how catastrophic it would be, how likely it was to occur, and how well they would cope with it. Self-report measures of VAS, STAI, and WEMWBS were again completed.

Debrief. Participants were given the opportunity to engage in a two-minute re-centring mindfulness meditation for de-stressing. Semi-structured interviews were then conducted to reflect upon experiences and to ensure all participants were safe. Finally, both groups were made aware of the other condition with control Group B being shown the PAWS to elicit further information.

5 RESULTS

We used repeated measures ANOVA to compare the effects of variants within groups and across conditions, and independent t-tests to compare the individual variants across conditions. HRV was used as a biomarker to support effectiveness and engagement measures and validated via a multilevel linear regression model. All tests for significance were made at the α = 0.05 level. The error bars in the graphs show a 95% confidence interval. An overview of results is depicted in Table 2. VAS, STAI, WEMWBS, re-centring attendance, and RMSSD were used to outline the feasibility, and PPL-FSQ, Ease of Task, TMS, IMI, and internal pressure KDE were used to outline acceptability.

Effectiveness. In our experimental condition intervention (MD = -44.72, SED = 13.2, t= -3.28, p< .001***) and worry induction (MD= -77.1, SED= 18.2, t= -4.25, p< .001***) VAS self-report anxiety ratings were shown to be significantly lower in Group A than Group B (Fig 3) resulting in an overall increased effect. Greater change was reported between the baseline-to-intervention phase (MD= -23.4, SED= 11.3, t= -2.07, p= .043*) and a lesser change between the reintervention-to-anxiety phase (MD= -41.0, SED= 17.5, t= -2.34, p= .023*) verifying the significant effect of the intervention. Baseline (MD= -21.4, SED= 17.9, t= -1.19, p< .237) and variant intervention to reintervention differences were not significant, thus both groups began on equal terms with self-report measures not altering mental states between phases.

Overall, SWEMWBS reductions of well-being were found to be more significant in Group B between variants (MD= 2.83, SED= 0.570, t= 4.94, p< .001***) and across conditions (MD= 2.31, SED= 0.967, t= 2.39, p= .020*) (Fig 4a). Worry severity reported no significant differences across groups (MD= -0.016, SED= 0.030, t= -0.528, p= .6) with control Group B significantly opting to engage with an additional re-centring activity (MD= -0.276, SED= 0.114, t= -2.428, p= .018*). Experimental Group A reported no significant changes between pre- and post-study SWEMWBS results (MD= -0.207, SED= .573, t= -0.361, p= 1.00) indicating condition A to be more protective against self-induced worries.

STAI measures reported significant change for both groups within variants (Group A: baseline to intervention MD= 2.793, SED= .677, t= 4.13, p< .001***, and intervention to anxiety MD= -7.24, SED= .677, t= -10.7, p< .001***; Group B: baseline to intervention MD= 3.24, SED= .677, t= 4.79, p< .001***, and intervention to anxiety

MD = Mean Difference
SED = Standard Error Difference

MD= -8.856, SED= .677, t= -12.027, p< .001***) and no significance between conditions (Fig 4b).

Psychological Engagement. Engagement was delineated through the active absorption of the task alongside mindfulness, motivation, and ease of task measures. PPL-FSQ absorption (MD= 4.207, SED= 1.491, t= 2.82, p= .007**) (Fig 4c) and ease of task scores (MD= -2.90, SED= 0.34, t= -8.52, p< .001***) (Fig 4d) were significantly higher for experimental Group A, with TMS (Fig 4e) and IMI (Fig 4f) measures showing no significance across conditions. TMS and IMI measures showed similarities with literature: high levels of curiosity, decentering, and value [46, 67]; emphasising overall intervention affect. However, effectiveness measures differed between conditions, indicating mindfulness and motivation measures whilst high, may not have been germane to specific types of effective interventions.

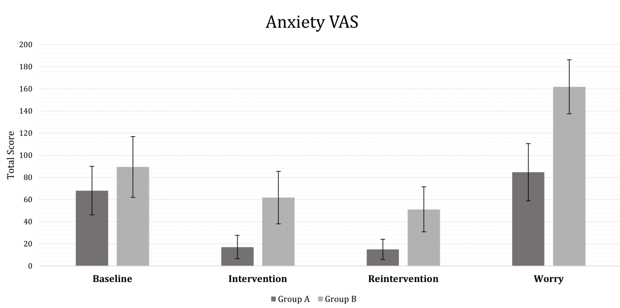

Figure 3: The sum of three self-report anxiety Visual Analogue Scales (VAS) [('anxious', 'nervous', 'worried') rated 0 (Not at all) to 100 (Extremely)] measured after each phase of the study.

RMSSD. ECG recordings were cleaned through artefact removal and manual data labelling corrections. RMSSD was extrapolated every 120 seconds with an applied moving average across time intervals. Changes in RMSSD were then calculated by negating each participant's values against their original baseline score (Fig 5). We formulate a one-tailed t-test to see if belonging to Group A has a positive effect on the ΔRMSSD values independent of time step. More formally, we assume the linear relationship through Equation 1. We formalise the null hypothesis as $\beta_A = 0$, and the alternative as $\beta_A > 0$. We report the following statistics at a 95% confidence interval: $\beta_A = 5.495,\ \text{CI} = [3.085, 8.812],\ t = 4.080,\ p < .001^{***}$. Since we have a significant p-value, we reject the null hypothesis and accept that being in Group A has a positive effect on ΔRMSSD independent of time step, attributing greater overall PAWS influence on psychological state. This improved state highlights reductions in fatigue, distractions, or ruminations across all study phases [9]. Within the intervention, our control Group B did not initially show improvements within RMSSD indicating difficulties of sustained attention [9]. Conversely, our experimental Group A saw significant physiological improvement after 6 minutes $\beta_A = 9.20,\ \text{CI} = [-1.0150, 19.4083],\ t = 1.78,\ p < .038^{*}$ than their digital-only counterparts, attributing greater self-regulatory efforts [126, 127] whilst using the PAWS. Across time intervals of worry induction, no significance was found $\beta_A = 6.67,\ \text{CI} = [-3.5438, 16.8790],\ t = 1.29,\ p < .099$, however observable differences highlight emphasise physiological retention benefits.

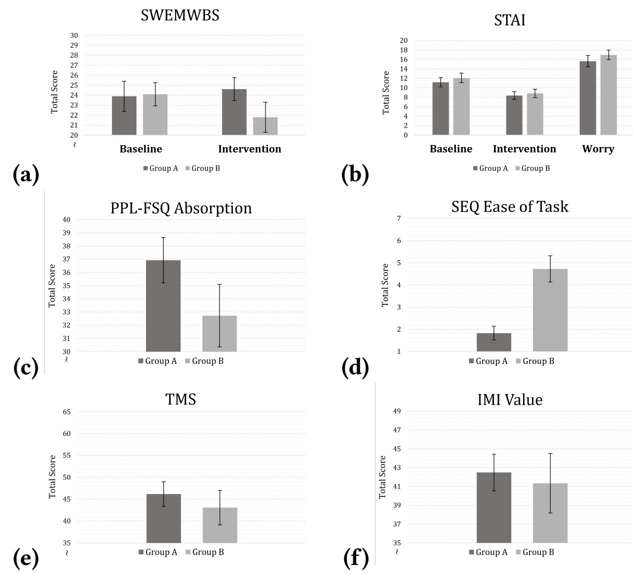

Figure 4: Descriptive plots of the experimental Group A and control Group B.

$$\Delta\text{RMSSD}_{ij} = \beta_0 + \beta_A g_i + \beta_j + e_{ij} \tag{1}$$

Equation 1. Modelling the Delta RMSSD values as a linear sum of an intercept, the group, and time. Where i is an index for the participant, j is an index for the time step, g_i is 1 if the i-th participant belongs to group A, 0 otherwise, e_{ij} is the residual error term for the i-th participant at the j-th time step, and β_0, β_A, and β_j are the coefficients of the intercept, the effect on ΔRMSSD if the participant belonged to group A, and the effect on ΔRMSSD at the j-th time step respectively.

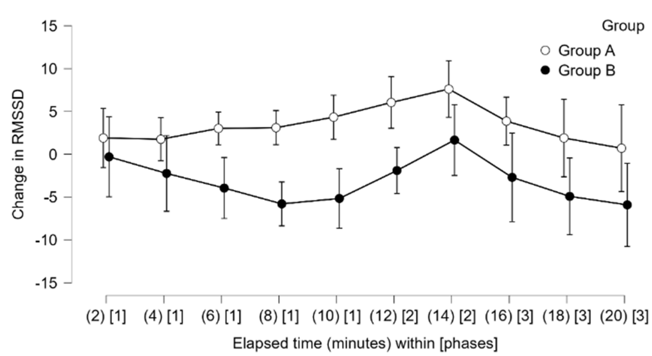

Figure 5: Elapsed time of average ΔRMSSD across all group participants from baseline to: intervention [1], reintervention [2], and worry induction [3] study phases.

Variable	Group	Baseline	Intervention	Reintervention	Worry Induction
VAS	A	68.0 (60.2)	17.0 (29.0)***	14.9 (25.3)***	84.6 (71.3)***
	B	89.4 (75.3)	61.7 (65.1)	51.1 (55.7)	161.8 (66.9)
SWEMWBS	A	23.9 (4.13)	-	-	24.1 (3.16)*
	B	24.6 (3.20)	-	-	21.8 (4.14)
STAI	A	11.2 (2.67)	8.38 (2.27)	-	15.6 (3.29)
	B	12.1 (2.78)	8.83 (2.42)	-	17.0 (2.77)
PPL-FSQ	A	-	36.9 (4.73)***	-	-
	B	-	32.7 (6.49)	-	-
Easy of Task	A	-	1.83 (0.848)***	-	-
	B	-	4.72 (1.62)	-	-
TMS	A	-	46.1 (7.71)	-	-
	B	-	43.1 (10.8)	-	-
IMI	A	-	42.5 (5.34)	-	-
	B	-	41.4 (8.69)	-	-
Re-centering	A	-	-	-	0.138 (0.351)***
	B	-	-	-	0.414 (0.501)
Worry Severity	A	-	-	-	0.610 (0.134)
	B	-	-	-	0.626 (0.090)

Table 2: Summary of results; Mean (Standard Deviation); *significant at $p < .05$; **significant at $p < .01$; ***significant at $p < .001$

Object Interaction. Alignment of external to internal signals can enhance the efficiency of interoceptive processing [80]. Kernel Density Estimate (KDE) [117] (a smooth interpolation of the histogram) of internal PAWS pressure was generated as a means to explore the interactions of a user during shape-changing biofeedback operation. Fig 6 gives insight into observable force differences and details KDE measures of the mean, minimum and maximum PAWS' internal pressure, where measures were calculated across phases, experimental participants, and breathing states (in, out, and hold). *Mean:* Minor noticeable differences were observed within the intervention whilst breathing in, holding breath, and breathing out compared to baseline measures. Small variations outline the presence of hands (i.e. user-applied weight slightly decreased inflation rate during intake and slightly increased inflation rate during output), where during average operation, participants were receptive to system movements via minimal contention. *Min:* Minor noticeable differences were observed whilst breathing in and breathing out. These variations portray deeper breaths which yield lower volumes of air than baseline measures. *Max:* Higher levels of noticeable differences were observed, indicating reactions to volumetric changes (i.e. change in state). Due to minor variations in *min* and *mean*, discrepancies within *max* indicate that only between the transition of breathing states did the likelihood of asynchronous interactions increase. Therefore KDE findings highlight average biofeedback synchronicity that facilities deeper breathing and the potential for re-synchronous interaction during periods of unfocused attention [80].

5.1 Thematic Analysis

To better understand our participants' experiences with the PAWS, we analysed their qualitative feedback using inductive thematic analysis from a critical-realist perspective [18]. Embedded quotes were grammatically modified via *"[ ]"*, to be consistent with the flow of writing.

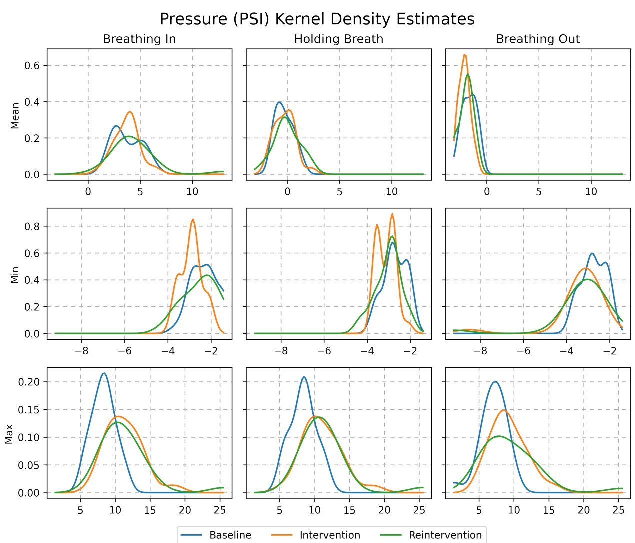

Figure 6: Pressure Kernel Density Estimates (KDEs) by Breath. The x-axis represents the pound-force per square inch (PSI) within the PAWS and the y-axis the estimate of the Probability Density Function (PDF) [117].

5.1.1 Theme 1: Tangibility of Breath: Throughout object interactions, the most prevalent theme amongst participants was the tangibility of externalised physiological data (*"I am physically able to feel my breath."*$_{P12}$; *"It provides me something real and something I can just hold. Like, I can just feel it."*$_{P1}$). By *"hold[ing] [their] breath and feel[ing] it in another way"*$_{P1}$ participants were able to draw on *"additional feedback in [their] hands"*$_{P37}$ and *"fingertips"*$_{P17}$ to heighten awareness of breath (*"When I feel the ball, I have a more clear understanding of my own breathing"*$_{P33}$; *"You can actually like* *tell what your breathing is like"*$_{P21}$). Such physical interactions with physiological manifestations evoked elevated levels of curiosity (*"It's just fun to sort of see what your breath is doing"*$_{P14}$*; "You're just like focusing on it and you're really interested"*$_{P13}$) and pleasure (*"It's good to focus. It's good to focus. It's very good"*$_{P41}$*; "I like that, I really like that"*$_{P20}$*; "Lovely, really enjoyed that"*$_{P17}$).

Through the object's innate spatial presence and tangible properties, participants felt interactions with a physical device *"that does not disappear"*$_{P1}$ provided greater assurance compared to visual and thought-based exercises. Instead of auditory cues that focus on bodily sensations (i.e. *"nose or throat"*$_{P40}$), the object facilitated an *"instant"*$_{P40}$ awareness that enabled participants to *"immediately bring [their] attention back to the breath"*$_{P40}$.

5.1.2 Theme 2: Susceptibility of Breath: The access to an abundance of sensory information provided a *"more powerful"*$_{P12}$ and *"active"*$_{P37}$ experience, beyond *"just sitting [there] with [your] hands in [your] lap and just consciously thinking"*$_{P12}$. The intuitivity of a device that changes shape in relation to *"real time"*$_{P12}$ internal data lowered the mental difficulty of the task (*"I don't have more energy to think about anything or lose my mind. I just feel this ball."*$_{P5}$*; "I find it quite hard to like, stay focused, actually, like intensely... whereas I think [the object] helped a bit more"*$_{P37}$). This *"complemented the experience"*$_{P1}$ and allowed participants to "*improve concentration, because it let [them] focus on something more concrete rather than just sitting with [their] own thoughts*"$_{P16}$. Hence, the object created an environment that facilitated *"easier"*$_{P25}$ focus of *"thoughts on the breath"*$_{P25}$ and *"refocus"*$_{P25}$ wandering thoughts.

Conjointly with elevated feelings of awareness and focus, an enhanced sense of control was identified. Participants noticed they were able to more effectively control *"the pace of [their] breath"*$_{P24}$ via *"the pace of [the] ball"*$_{P24}$. Through physically *"holding"*$_{P43}$ their breath, participants felt a *"quantifiable"*$_{P43}$ context to their breathing, which enabled a *"measure in tangible terms"*$_{P43}$ that could *"help [them] in regulating and maintaining... healthy inhalation and exhalation strateg[ies]"*$_{P43}$. Further, this tangible awareness aided participants in noticing when they were not in control. For instance, participants recalled feeling *"[their] breathing [was] getting a bit out of control"*$_{P12}$ due to feelings of *"shallowness"*$_{P12}$ of breath reflected within the object, triggering conscious self-regulation of their unrelaxed inner-self.

5.1.3 Theme 3: Representability of Breath: The uniqueness of interactions with a manifested inner-self led participants to associate the object with relative metaphorical references. Elicitation centred around: intimate sensations (*"Like going to sleep with someone next to you, with their breath going up and down... in particular, actually, of my children when they were young"*$_{P38}$*; "When I was a kid...and I was upset, my mom's breathing... because it was so slow, would calm me down. Yeah. So [the object is] kind of similar"*$_{P20}$), living *"creatures"*$_{P19}$ (*"Like a little animal or something"*$_{P23}$*; "Like a pet...when a cat or something sit[s] on you"*$_{P36}$), environmental experiences (*"It reminded me of when I went scuba diving... like everything sort of like quiet. But you're just only thinking... like, just breathe and you'll be okay... you're like a bit removed from everything around you"*$_{P49}$), and abstract references (*"a little ball of light"*$_{P46}$). In summary, establishing relative associations created stronger bonds between object and user, leading participants to feel the device was *"something [they] wanted to look after"*$_{P23}$ and something *"[they wanted] to be nice to"*$_{P47}$. In some instances, participants felt such emotional attachment that when they needed to relinquish the device between the study phases, they felt a sense of loss or sadness.

Interestingly, participant feelings extended beyond associations of physiological data and transcended into levels of trust and reliability (*"it helped remind you that's what you were doing, or help remind me that's what I was doing"*$_{P37}$). By *"giv[ing] [them] a spot to stand on"*$_{P37}$, participants could entrust themselves to the device and use it to *"ground"*$_{P44}$ them. Through increased task confidence of *"feel[ing] what you're supposed to be doing"*$_{P14}$ participants experienced sensations where, as *"[they] went deep into the breathing, [the object] was no longer required"*$_{P14}$.

6 DISCUSSION

The main aim of this study was to explore the acceptability and feasibility of a shape-changing biofeedback-based artefact within a DMHI. In line with our hypothesis, results showed advantageous evidence of physiological and subjective (self-reported) anxiety when compared to our digital control. Our experimental sample self-reported a 75% average anxiety reduction within our augmented intervention and were 56% more protected against worry-induced thoughts. Compared to our control, we saw a 27.6% reduction difference (41.4%-13.8%) in the experimental group who engaged with an optional re-centring activity and no decreases in mental well-being. Within our study, formations in human-object relations, multisensory integration, and positive participant responses indicate a willingness for PAWS-integrated DMHIs. We attribute our elevated levels of effect to three key findings: (1) Ease of Task, (2) Organic Self, and (3) Superior Guidance.

Ease of Task. Our results characterise significant improvements in absorption during the guided breathing practice and a 61% reduction in difficulty. By creating a tangible 'touchable' device that supports intangible behavioural and psychological components, our experimental sample attained higher levels of mental well-being compared to our digital control. We believe this to be the result of reductions in cognitive task load, which illustrates a relationship between psychological availability and information processing [33, 107, 124]. Information overload can cause stress and dissatisfaction [15] and, in turn, psychological disengagement forms, creating the opportunity for rumination and worry [15]. These repetitive negative thinking patterns can occur during acts of sustained attention, and can vary between individuals [91]. As detailed within Bishara's (2021) work [15], not everyone can easily mentally attune to bodily sensations. Interoceptive deficits increase task difficulty and inhibit beneficial outcomes [19, 91]. Even so, the tailored multi-modal information provided by the PAWS enabled our experimental participants to perceive the task to be 2.58x easier, thereby reducing the mental effort needed to follow their breath. Through providing our experimental sample with an intuitive affordance, those that may have originally struggled with DMHIs had an opportunity to attain greater intervention outcomes [91, 120].

Organic Self. An unexpected finding within our work was the affective (emotional) engagement that participants applied to the artefact, specifically the effect of known correlations between positive emotions and better self-regulation [120]. During our study participants transitioned from an initially *"weird"*$_{P36}$ and *"alien"*$_{P25}$ novel object interaction mentality to strong feelings of bodily representation. Similar to Karpashevich et al's [58] breath-based pneumatic postphenomenological interpretations, the participant's felt experiences could be categorised into three relationships: (1) *'monster'*, discordance with the object (2) '*twisted mirror*', recognition of conscious control, and (3) *'organic self'*, the blurring of boundaries between object and self. Despite initial reactions of discordance, our sample rapidly transitioned through the states to attain an 'organic self'. Corroborations of minor pressure variations between baseline and intervention KDE measures emphasise physical biofeedback synchronicity, where discordance would have inferred contention with kinaesthetic feedback [80]. In this manner, our KDE data portrays additional evidence to our thematic findings and suggest participants engaged in the task though merging with the object's bio-reflective movements. Therefore, multisensory integration [21, 34] may have enabled participants to experience the object as part of their bodies and, as a result, were more attentive to their manifested breath.

Superior Guidance. Within the intervention, our experimental group achieved greater physiological activation, indicating additional self-regulation efforts and reduced mind-wandering during PAWS operation [17, 127]. As an individual exerts self-regulatory efforts, HRV is found to increase [126, 127]. In these situations, the prefrontal cortex inhibits the sympathoexcitatory subcortical circuits that support the effort needed for emotional regulation [17]. To engage with higher-level behavioural intervention tasks, this process must be practised through repeated cycles of focusing and noticing [67]. Whilst our sample reported no significant differences in self-report mindfulness, indicating equally perceived intervention performance, our RMSSD findings infer greater self-regulation within our experimental sample. We again attribute these differences to the additional multisensory channels that facilitate consistent, tangible, quantifiable, kinaesthetic feedback. Specifically the elevated ability to regulate real-time physiological activities through a closed-loop mechanism. By offering physical cues as a means of operant conditioning, greater guidance may overcome the mixed results or no-effect results of screen-based and auditory biofeedback systems [60, 70, 125].

6.0.1 Implications. Although much literature has explored the mixed effectiveness of DMHIs [43, 68], we provide evidence for a system that seeks to go beyond current clinical means. Our research gives rise to an effective and engaging alternative to populations who are unlikely to be compatible with conventional interventions, such as children, the elderly, individuals with neurodiversity, individuals with deafness and/or blindness, and those with severe mental health symptoms [15, 32, 44, 48]. Whilst practical and physical implementation for every user is unlikely and unnecessary, our work details advantageous opportunities for supporting auditory and/or visual emotion regulation strategies.

Accordingly, the present study raises the possibility of a method that improves psychological accessibility and enables greater peri- and post-intervention outcomes. Through our PAWS, significant reductions in physiological and subjective (self-reported) anxiety were identified. Although physiological significance was not maintained during the self-worry-induction phase, our experimental sample needed less support after self-induced worries, self-reported less anxiety, and saw no reduction in their mental well-being compared to our digital control. Thus indicating greater experimental intermediation and prevention emotional regulation benefits.

Though existing mediums have been utilised for breath-based representation [57, 58, 63, 88, 106, 122], we designed our PAWS to be spherical to maximise interactions but do not suggest spheres to be the only pathway to implementation. Although one physical shape-changing biofeedback-based artefact design was explored, non-significant findings have been reported with alternative pneumatic artefact designs [70]. Due to the mechanisms of deliberate touch reflecting elevated attentiveness [54, 87], we infer a preference for hand-held mid-air interaction-based systems for improving embodied skills. Through autonomous and effective touch inciting psychological engagement, a greater intent to self-improve is attainable [54, 87]. Similar to existing non-pneumatic artefacts [7, 8, 11, 42, 74, 110], tangible mediums free of position and orientation constraints can facilitate greater intrinsic motivation [98].

Finding alternative strategies for improving engagement is therefore key to changing the future of mental health support. Current mental health services either experience huge waiting lists or are hidden behind paywalls [81]. Despite DMHIs being an attempt to circumvent in-person treatments, long-term engagement is poor, with physical support becoming more favourable in modern services [37, 85]. We propose PAWS as a means to provide more potent psychotherapeutic mental health solutions for services and clients. By implementing PAWS within pathways, a second tier of more effective remote support may reduce the saturation of services and the economic costs of accelerated mental health needs [52].

6.1 Limitations and Future work

Our work represents one of the first empirical studies to explore the effects of a shape-changing biofeedback handheld artefact. Although we define our PAWS as an effective means of greater anxiety reduction, much work is needed to ascertain its effects within a diagnosed population. Albeit our results infer strong alignment with the difficulties of populations suffering from interoceptive deficits, our major limitation is knowing if, and how, our results translate to a clinical application. Hence, future work should aim to iteratively co-create and evaluate new shape-changing biofeedback emotion regulation strategies. This may yield more critical qualitative findings, as, within our work, only one participant elicited negative feedback concerning physical limitations. In particular, PAWS operation lacked a sufficient deflation and inflation rate to represent rapid oscillations of breath. This meant occurrences of sharp inhalations and exhalations did not have enough dynamic airflow to accurately replicate full pulmonary activity. Despite this feature being superfluous to slow breathing, dynamic representation is necessary for future applications to enable other DMHI techniques or self-exploratory exercises.

We also recognise the feasibility limitations within this research. Whilst we explore if the PAWS could feasibly affect intervention outcomes within a RCT paradigm, a true feasibility study should explore the suitability of the innovation for everyday use within a real-world setting, including justification of sample size based on achieving estimates [89, 92]. To achieve this, a more practical and portable PAWS is needed within a longitudinal study that more deeply explores usability and outcomes. This should also include investigations into alternative actuation mechanisms, such as a mechanical design that mitigates the need for a localised compressor. Although our set-up confined noise or latency effects to imperceptible levels, the apparatus could not be used within a field environment. Additionally, to explore optimum bio-signal acquisition for DMHI integration and user adoption, alternate techniques should be incorporated into future design processes; accelerometers [94], microphones [38], wearable sensors [28], and thoracic electrical bioimpedance [83] would all show capabilities in breath acquisition.

Finally, to effectively explore the capabilities and psychological mechanisms of PAWS we determine a range of embodied skills training is needed, beyond our inexperienced general population sample. In particular, while existing evidence and theory suggest that improved interoception is a likely mechanism by which benefits are conferred, specific cognitive studies that explore the impact of the intervention on interoception are needed. Under these circumstances, further research is required to explore how stakeholders perceive PAWS for supporting the engagement of higher-level behavioural tasks. This includes comparing the effective and engagement differences between modalities and building upon existing work [2, 124] to examine the implications of visual (e.g. smartphones, virtual reality (VR), augmented reality (AR)) and haptic (e.g. shape-change, vibration, ultrasonic) biofeedback technologies (e.g. HRV and/or respiration) on embodied skills development. As well as the potential of additional textures [50], shapes [40], and materials [26] which have been known to influence the mental well-being of an individual or the incorporation of electrochemical biosensing [61, 66, 77], olfactory outputs [13], and living media surfaces [84] to provide better diagnostic and delivery techniques.

7 CONCLUSION

We designed and constructed a handheld shape-changing biofeedback-based sphere that enabled real-time physical interactions with internal physiological information. By integrating this Physical Artefact for Well-being Support (PAWS) within a Digital Mental Health Intervention (DMHI) audio-only breathing activity, greater physiological and subjective (self-reported) anxiety reductions were attained within our sample. Through kinaesthetic feedback, felt experiences facilitated improvements in our experimental group's psychological engagement.

These results are worthy of consideration for the use of integrated PAWS within DMHIs. Digital technologies are devoid of touch-based stimulation and, whilst effective, struggle to retain a large majority of individuals suffering from reduced mental well-being. Within our findings, PAWS provided a greater opportunity to improve the effectiveness and engagement with a DMHI. Accordingly, much work is needed to explore the long-term benefits of these technologies, specifically in populations at higher risk of mental health disorders.

ACKNOWLEDGMENTS

This project has received funding from the European Research Council (ERC) under the European Union's Horizon 2020 research and innovation programme and the Engineering and Physical Sciences Research Council (EPSRC).

REFERENCES

[1] Pawan Agarwal and Sashikant Sahu. 2010. Determination of hand and palm area as a ratio of body surface area in Indian population. *Indian Journal of Plastic Surgery : Official Publication of the Association of Plastic Surgeons of India* 43, 1 (jan 2010), 49. https://doi.org/10.4103/0970-0358.63962

[2] Mahmoud Mohamed Hussien Ahmed, Chaklam Silpasuwanchai, Kavous Salehzadeh Niksirat, and Xiangshi Ren. 2017. Understanding the role of human senses in interactive meditation. In *Conference on Human Factors in Computing Systems - Proceedings*, Vol. 2017-May. Association for Computing Machinery, 4960–4965. https://doi.org/10.1145/3025453.3026000

[3] B. Ainsworth, H. Bolderston, and M. Garner. 2017. Testing the differential effects of acceptance and attention-based psychological interventions on intrusive thoughts and worry. *Behaviour Research and Therapy* 91 (apr 2017), 72–77. https://doi.org/10.1016/J.BRAT.2017.01.012

[4] Ben Ainsworth, Jemma E. Marshall, Daniel Meron, David S. Baldwin, Paul Chadwick, Marcus R. Munafò, and Matthew Garner. 2015. Evaluating psychological interventions in a novel experimental human model of anxiety. *Journal of Psychiatric Research* 63 (apr 2015), 117–122. https://doi.org/10.1016/J.JPSYCHIRES.2015.02.001

[5] Jason Alexander, Anne Roudaut, Jürgen Steimle, Kasper Hornbæk, Miguel Bruns Alonso, Sean Follmer, and Timothy Merritt. 2018. Grand challenges in Shape-changing interface research. *Conference on Human Factors in Computing Systems - Proceedings* 2018-April (apr 2018). https://doi.org/10.1145/3173574.3173873

[6] Mona Alhasani, Dinesh Mulchandani, Oladapo Oyebode, and Rita Orji. 2020. A systematic review of persuasive strategies in stress management apps. In *CEUR Workshop Proceedings*, Vol. 2662.

[7] Miguel Bruns Alonso, David V. Keyson, and Caroline C.M. Hummels. 2008. Squeeze, rock, and roll; Can tangible interaction with affective products support stress reduction?. In *TEI'08 - Second International Conference on Tangible and Embedded Interaction - Conference Proceedings*. ACM Press, New York, New York, USA, 105–108. https://doi.org/10.1145/1347390.1347413

[8] Madeline Balaam, Geraldine Fitzpatrick, Judith Good, and Rosemary Luckin. 2010. Exploring affective technologies for the classroom with the subtle stone. In *Conference on Human Factors in Computing Systems - Proceedings*, Vol. 3. ACM Press, New York, New York, USA, 1623–1632. https://doi.org/10.1145/1753326.1753568

[9] Moitree Banerjee, Kate Cavanagh, and Clara Strauss. 2018. Barriers to Mindfulness: a Path Analytic Model Exploring the Role of Rumination and Worry in Predicting Psychological and Physical Engagement in an Online Mindfulness-Based Intervention. *Mindfulness* 9, 3 (jun 2018), 980–992. https://doi.org/10.1007/s12671-017-0837-4

[10] Jonathan B. Banks and Matthew S. Welhaf. 2022. Individual differences in dimensions of mind wandering: the mediating role of emotional valence and intentionality. *Psychological Research* 86 (7 2022), 1495–1517. Issue 5. https://doi.org/10.1007/S00426-021-01579-2/FIGURES/9

[11] Matthew Barker and Janet Van Der Linden. 2017. Sprite catcher: A handheld self reflection and mindfulness tool for mental healthcare. In *TEI 2017 - Proceedings of the 11th International Conference on Tangible, Embedded, and Embodied Interaction*. Association for Computing Machinery, Inc, New York, NY, USA, 419–425. https://doi.org/10.1145/3024969.3025068

[12] Amit Baumel, Frederick Muench, Stav Edan, and John M. Kane. 2019. Objective User Engagement With Mental Health Apps: Systematic Search and Panel-Based Usage Analysis. *Journal of medical Internet research* 21 (9 2019). Issue 9. https://doi.org/10.2196/14567

[13] Phoebe R. Bentley, Jessica C. Fisher, Martin Dallimer, Robert D. Fish, Gail E. Austen, Katherine N. Irvine, and Zoe G. Davies. 2022. Nature, smells, and human wellbeing. *Ambio* (2022). https://doi.org/10.1007/S13280-022-01760-W

[14] Johan M. Berghmans, Marten J. Poley, Jan van der Ende, Frank Weber, Marc Van de Velde, Peter Adriaenssens, Dirk Himpe, Frank C. Verhulst, and Elisabeth Utens. 2017. A Visual Analog Scale to assess anxiety in children during anesthesia induction (VAS-I): Results supporting its validity in a sample of day care surgery patients. *Paediatric anaesthesia* 27, 9 (sep 2017), 955–961. https://doi.org/10.1111/PAN.13206

[15] Saied Bishara and Michael William Dunn. 2021. Psychological availability, mindfulness, and cognitive load in college students with and without learning disabilities. *http://www.editorialmanager.com/cogentedu* 8, 1 (2021). https://doi.org/10.1080/2331186X.2021.1929038

[16] Ann Blandford. 2019. HCI for health and wellbeing: Challenges and opportunities. *International Journal of Human-Computer Studies* 131 (nov 2019), 41–51.

https://doi.org/10.1016/J.IJHCS.2019.06.007
[17] Roberta Bortolla, Marco Galli, Gea Elena Spada, and Cesare Maffei. 2022. Mindfulness Effects on Mind Wandering and Autonomic Balance. *Applied Psychophysiology Biofeedback* 47, 1 (mar 2022), 53–64. https://doi.org/10.1007/S10484-021-09527-X/TABLES/4
[18] Virginia Braun and Victoria Clarke. 2006. Using thematic analysis in psychology. *Qualitative Research in Psychology* 3, 2 (2006), 77–101. https://doi.org/10.1191/1478088706QP063OA
[19] Brian E. Bunnell, Lynne S. Nemeth, Leslie A. Lenert, Nikolaos Kazantzis, Esther Deblinger, Kristen A. Higgins, and Kenneth J. Ruggiero. 2021. Barriers Associated with the Implementation of Homework in Youth Mental Health Treatment and Potential Mobile Health Solutions. *Cognitive Therapy and Research* 45 (4 2021), 272–286. Issue 2. https://doi.org/10.1007/S10608-020-10090-8/TABLES/8
[20] Peter André Busch and Stephen McCarthy. 2021. Antecedents and consequences of problematic smartphone use: A systematic literature review of an emerging research area. *Computers in Human Behavior* 114 (1 2021), 106414. https://doi.org/10.1016/J.CHB.2020.106414
[21] Gemma A. Calvert and Thomas Thesen. 2004. Multisensory integration: methodological approaches and emerging principles in the human brain. *Journal of physiology, Paris* 98, 1-3 (jan 2004), 191–205. https://doi.org/10.1016/J.JPHYSPARIS.2004.03.018
[22] Doga Cavdir and Ge Wang. 2022. Designing felt experiences with movement-based, wearable musical instruments: From inclusive practices toward participatory design. *Wearable Technologies* 3 (2022), e19. https://doi.org/10.1017/WTC.2022.15
[23] Alberto Chiesa and Peter Malinowski. 2011. Mindfulness-based approaches: are they all the same? *Journal of Clinical Psychology* 67, 4 (apr 2011), 404–424. https://doi.org/10.1002/JCLP.20776
[24] Anna Ciaunica, Luke McEllin, Julian Kiverstein, Vittorio Gallese, Jakob Hohwy, and Mateusz Woźniak. 2022. Zoomed out: digital media use and depersonalization experiences during the COVID-19 lockdown. *Scientific reports* 12 (12 2022). Issue 1. https://doi.org/10.1038/S41598-022-07657-8
[25] Caroline Cohen, Timothée Mouterde, David Quéré, and Christophe Clanet. 2015. Capillary muscle. *Proceedings of the National Academy of Sciences of the United States of America* 112 (5 2015), 6301–6306. Issue 20. https://doi.org/10.1073/PNAS.1419315112/ASSET/F7801E46-EAB5-4C65-9733-C9793DBB27B9/ASSETS/GRAPHIC/PNAS.1419315112FIG06.JPEG
[26] G. Crippa, Valentina Rognoli, and Marinella Levi. 2012. Materials and emotions: A study on the relations between materials and emotions in industrial products. *8th International Conference on Design and Emotion: Out of Control - Proceedings* (01 2012).
[27] Heather Culbertson, Cara M. Nunez, Ali Israr, Frances Lau, Freddy Abnousi, and Allison M. Okamura. 2018. A social haptic device to create continuous lateral motion using sequential normal indentation. *IEEE Haptics Symposium, HAPTICS* 2018-March (5 2018), 32–39. https://doi.org/10.1109/HAPTICS.2018.8357149
[28] Taisa Daiana da Costa, Maria de Fatima Fernandes Vara, Camila Santos Cristino, Tyene Zoraski Zanella, Guilherme Nunes Nogueira Neto, and Percy Nohama. 2019. Breathing Monitoring and Pattern Recognition with Wearable Sensors. *Wearable Devices - the Big Wave of Innovation* (6 2019). https://doi.org/10.5772/INTECHOPEN.85460
[29] Claudia Daudén Roquet, Nikki Theofanopoulou, Jaimie L. Freeman, Jessica Schleider, James J. Gross, Katie Davis, Ellen Townsend, and Petr Slovak. 2022. Exploring Situated & Embodied Support for Youth’s Mental Health: Design Opportunities for Interactive Tangible Device. *Conference on Human Factors in Computing Systems - Proceedings* (apr 2022). https://doi.org/10.1145/3491102.3502135
[30] Jason Davies, Pamela Ugwudike, Hayley Young, Chloe Hurrell, and Peter Raynor. 2021. A Pragmatic Study of the Impact of a Brief Mindfulness Intervention on Prisoners and Staff in a Category B Prison and Men Subject to Community-Based Probation Supervision. *International Journal of Offender Therapy and Comparative Criminology* 65 (1 2021), 136. Issue 1. https://doi.org/10.1177/0306624X20944664
[31] Holger Schna Delbach, Ainojie Irune, David Kirk, Kevin Glover, and Patrick Brundell. 2012. ExoBuilding: Physiologically Driven Adaptive Architecture. *ACM Transactions on Computer-Human Interaction (TOCHI)* 19, 4 (dec 2012). https://doi.org/10.1145/2395131.2395132
[32] Darren Dunning, S. Ahmed, L. Foulkes, C. Griffin, K. Griffiths, J. T. Leung, J. Parker, Blanca Piera Pi-Sunyer, A. Sakhardande, M. Bennett, C. Haag, Jesus Montero-Marin, D. Packman, Maris Vainre, P. Watson, Willem Kuyken, J. Mark G. Williams, Obioha C. Ukoumunne, Sarah Jayne Blakemore, and Tim Dalgleish. 2022. The impact of mindfulness training in early adolescence on affective executive control, and on later mental health during the COVID-19 pandemic: a randomised controlled trial. *Evidence-Based Mental Health* 25, 3 (aug 2022), 110–116. https://doi.org/10.1136/EBMENTAL-2022-300460
[33] Okolo Efe Stanley. 2021. Information Overload: Causes, Symptoms, Consequences and Solutions. *Asian Journal of Information Science and Technology* 11, 2 (nov 2021), 1–6. https://doi.org/10.51983/AJIST-2021.11.2.2887
[34] Henrik H. Ehrsson. 2020. Multisensory processes in body ownership. *Multisensory Perception: From Laboratory to Clinic* (jan 2020), 179–200. https://doi.org/10.1016/B978-0-12-812492-5.00008-5
[35] Daniel A. Epstein, Clara Caldeira, Mayara Costa Figueiredo, Xi Lu, Lucas M. Silva, Lucretia Williams, Jong Ho Lee, Qingyang Li, Simran Ahuja, Qiuer Chen, Payam Dowlatyari, Craig Hilby, Sazeda Sultana, Elizabeth V. Eikey, and Yunan Chen. 2020. Mapping and Taking Stock of the Personal Informatics Literature. *Proceedings of the ACM on Interactive, Mobile, Wearable and Ubiquitous Technologies* 4, 4 (dec 2020), 126. https://doi.org/10.1145/3432231
[36] E. Facco, G. Zanette, L. Favero, C. Bacci, S. Sivolella, F. Cavallin, and G. Manani. 2011. Toward the Validation of Visual Analogue Scale for Anxiety. *Anesthesia Progress* 58, 1 (2011), 8. https://doi.org/10.2344/0003-3006-58.1.8
[37] Christopher G. Fairburn and Vikram Patel. 2017. The impact of digital technology on psychological treatments and their dissemination. *Behaviour Research and Therapy* 88 (jan 2017), 19. https://doi.org/10.1016/J.BRAT.2016.08.012
[38] Yu Fang, Zhongwei Jiang, and Haibin Wang. 2018. A Novel Sleep Respiratory Rate Detection Method for Obstructive Sleep Apnea Based on Characteristic Moment Waveform. *Journal of Healthcare Engineering* 2018 (2018). https://doi.org/10.1155/2018/1902176
[39] Corinna Anna Faust-Christmann, Bertram Taetz, Gregor Zolynski, Tobias Zimmermann, and Gabriele Bleser. 2019. A Biofeedback App to Instruct Abdominal Breathing (Breathing-Mentor): Pilot Experiment. *JMIR mHealth and uHealth* 7 (2019). Issue 9. https://doi.org/10.2196/13703
[40] Feng Feng, Dan Bennett, Zhi jun Fan, and Oussama Metatla. 2022. It’s Touching: Understanding Touch-Affect Association in Shape-Change with Kinematic Features. *CHI Conference on Human Factors in Computing Systems* (4 2022), 1–18. https://doi.org/10.1145/3491102.3502003
[41] Barnhardt Natural Fibers. 2022. Properties of Cotton | Cotton Fiber Properties | Cotton Manufacturing. https://barnhardtcotton.net/technology/cotton-properties/
[42] Carolina Fuentes, Iyubanit Rodríguez, and Valeria Herskovic. 2015. EmoBall: A study on a tangible interface to self-report emotional information considering digital competences. In *Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics)*, Vol. 9456. Springer Verlag, 189–200. https://doi.org/10.1007/978-3-319-26508-7_19
[43] Daniel Z.Q. Gan, Lauren McGillivray, Jin Han, Helen Christensen, and Michelle Torok. 2021. Effect of Engagement With Digital Interventions on Mental Health Outcomes: A Systematic Review and Meta-Analysis. *Frontiers in digital health* 3 (nov 2021). https://doi.org/10.3389/FDGTH.2021.764079
[44] Paul J. Geiger, Ian A. Boggero, C. Alex Brake, Carolina A. Caldera, Hannah L. Combs, Jessica R. Peters, and Ruth A. Baer. 2016. Mindfulness-Based Interventions for Older Adults: A Review of the Effects on Physical and Emotional Well-being. *Mindfulness* 7, 2 (apr 2016), 296–307. https://doi.org/10.1007/S12671-015-0444-1
[45] Moojan Ghafurian, Jesse Hoey, and Kerstin Dautenhahn. 2021. Social Robots for the Care of Persons with Dementia. *ACM Transactions on Human-Robot Interaction (THRI)* 10, 4 (sep 2021), 41. https://doi.org/10.1145/3469653
[46] Ángel Luis González Olivares, Óscar Navarro, Francisco Javier Sánchez-Verdejo, and Álvaro Muelas. 2020. Psychological Well-Being and Intrinsic Motivation: Relationship in Students Who Begin University Studies at the School of Education in Ciudad Real. *Frontiers in Psychology* 11 (sep 2020), 2054. https://doi.org/10.3389/FPSYG.2020.02054/BIBTEX
[47] Katherine A. Grisanzio, Andrea N. Goldstein-Piekarski, Michelle Yuyun Wang, Abdullah P.Rashed Ahmed, Zoe Samara, and Leanne M. Williams. 2018. Transdiagnostic Symptom Clusters and Associations With Brain, Behavior, and Daily Function in Mood, Anxiety, and Trauma Disorders. *JAMA psychiatry* 75 (2 2018), 201–209. Issue 2. https://doi.org/10.1001/JAMAPSYCHIATRY.2017.3951
[48] Areum Han. 2022. Mindfulness-Based Interventions for Older Adults with Dementia or Mild Cognitive Impairment: A Meta-Analysis. *Clinical gerontologist* 45, 4 (2022), 763–776. https://doi.org/10.1080/07317115.2021.1995561
[49] Colette R. Hirsch, Sarra Hayes, and Andrew Mathews. 2009. Looking on the Bright Side: Accessing Benign Meanings Reduces Worry. *Journal of Abnormal Psychology* 118, 1 (2009), 44–54. https://doi.org/10.1037/A0013473
[50] Marina Iosifyan and Olga Korolkova. 2019. Emotions associated with different textures during touch. *Consciousness and Cognition* 71 (may 2019), 79–85. https://doi.org/10.1016/J.CONCOG.2019.03.012
[51] Hiroshi Ishii. 2008. Tangible Bits: Beyond Pixels. *Proceedings of the 2nd international conference on Tangible and embedded interaction - TEI ’08* (2008). https://doi.org/10.1145/1347390
[52] Spencer L. James and et al. 2018. Global, regional, and national incidence, prevalence, and years lived with disability for 354 Diseases and Injuries for 195 countries and territories, 1990-2017: A systematic analysis for the Global Burden of Disease Study 2017. *The Lancet* 392, 10159 (nov 2018), 1789–1858. https://doi.org/10.1016/S0140-6736(18)32279-7/ATTACHMENT/DB6E3413-74DC-43AE-B7CC-CA155C28589E/MMC2.PDF

[53] Yvonne Jansen, Pierre Dragicevic, Petra Isenberg, Jason Alexander, Abhijit Karnik, Johan Kildal, Sriram Subramanian, and Kasper Hornbæk. 2015. Opportunities and challenges for data physicalization. In *Conference on Human Factors in Computing Systems - Proceedings*, Vol. 2015-April. Association for Computing Machinery, New York, NY, USA, 3227–3236. https://doi.org/10.1145/2702123.2702180

[54] H. Johansen-Berg and D. M. Lloyd. 2000. The physiology and psychology of selective attention to touch. *Frontiers in bioscience : a journal and virtual library* 5 (2000). https://doi.org/10.2741/A558

[55] Daniel Johnson, Sebastian Deterding, Kerri Ann Kuhn, Aleksandra Staneva, Stoyan Stoyanov, and Leanne Hides. 2016. Gamification for health and wellbeing: A systematic review of the literature. , 89–106 pages. https://doi.org/10.1016/j.invent.2016.10.002

[56] Will Johnson. 2020. The posture of meditation : a practical manual for meditators of all traditions. (2020), 161.

[57] Annkatrin Jung, Miquel Alfaras, and Pavel Karpashevich. 2021. Exploring awareness of breathing through deep touch pressure. In *Conference on Human Factors in Computing Systems - Proceedings*, Vol. 15. Association for Computing Machinery. https://doi.org/10.1145/3411764.3445533

[58] Pavel Karpashevich, Pedro Sanches, Rachael Garrett, Yoav Luft, Kelsey Cotton, Vasiliki Tsaknaki, and Kristina Höök. 2022. Touching Our Breathing through Shape-Change: Monster, Organic Other, or Twisted Mirror. *ACM Transactions on Computer-Human Interaction (TOCHI)* 29 (2 2022). Issue 3. https://doi.org/10.1145/3490498

[59] E. Karyotaki, A. Kleiboer, F. Smit, D. T. Turner, A. M. Pastor, G. Andersson, T. Berger, C. Botella, J. M. Breton, P. Carlbring, H. Christensen, E. De Graaf, K. Griffiths, T. Donker, L. Farrer, M. J.H. Huibers, J. Lenndin, A. Mackinnon, B. Meyer, S. Moritz, H. Riper, V. Spek, K. Vernmark, and P. Cuijpers. 2015. Predictors of treatment dropout in self-guided web-based interventions for depression: an 'individual patient data' meta-analysis. *Psychological medicine* 45, 13 (oct 2015), 2717–2726. https://doi.org/10.1017/S0033291715000665

[60] Lauren Kennedy and Sarah Henrickson Parker. 2019. Biofeedback as a stress management tool: a systematic review. *Cognition, Technology and Work* 21 (5 2019), 161–190. Issue 2. https://doi.org/10.1007/s10111-018-0487-x

[61] Kamyar Khoshnevisan, Elham Honarvarfard, Farzad Torabi, Hassan Maleki, Hadi Baharifar, Farnoush Faridbod, Bagher Larijani, and Mohammad Reza Khorramizadeh. 2020. Electrochemical detection of serotonin: A new approach. *Clinica chimica acta; international journal of clinical chemistry* 501 (feb 2020), 112–119. https://doi.org/10.1016/J.CCA.2019.10.028

[62] Bassam Khoury, Bärbel Knäuper, Francesco Pagnini, Natalie Trent, Alberto Chiesa, and Kimberly Carrière. 2017. Embodied Mindfulness. *Mindfulness* 8, 5 (oct 2017), 1160–1171. https://doi.org/10.1007/S12671-017-0700-7/TABLES/1

[63] Jina Kim, Young Woo Park, and Tek Jin Nam. 2015. BreathingFrame: An inflatable frame for remote breath signal sharing. In *TEI 2015 - Proceedings of the 9th International Conference on Tangible, Embedded, and Embodied Interaction*. ACM, New York, NY, USA, 109–112. https://doi.org/10.1145/2677199.2680606

[64] Christoph H. Kindler, Christoph Harms, Felix Amsler, Thomas Ihde-Scholl, and Daniel Scheidegger. 2000. The visual analog scale allows effective measurement of preoperative anxiety and detection of patients' anesthetic concerns. *Anesthesia and Analgesia* 90, 3 (2000), 706–712. https://doi.org/10.1097/00000539-200003000-00036

[65] Panayiotis Koutsabasis and Panagiotis Vogiatzidakis. 2019. Empirical Research in Mid-Air Interaction: A Systematic Review. *https://doi.org/10.1080/10447318.2019.1572352* 35, 18 (nov 2019), 1747–1768. https://doi.org/10.1080/10447318.2019.1572352

[66] Sophie Lakard, Ileana Alexandra Pavel, and Boris Lakard. 2021. Electrochemical Biosensing of Dopamine Neurotransmitter: A Review. *Biosensors* 11, 6 (jun 2021). https://doi.org/10.3390/BIOS11060179

[67] Mark A. Lau, Scott R. Bishop, Zindel V. Segal, Tom Buis, Nicole D. Anderson, Linda Carlson, Shauna Shapiro, James Carmody, Susan Abbey, and Gerald Devins. 2006. The Toronto Mindfulness Scale: development and validation. *Journal of clinical psychology* 62, 12 (dec 2006), 1445–1467. https://doi.org/10.1002/JCLP.20326

[68] Susanna Lehtimaki, Jana Martic, Brian Wahl, Katherine T. Foster, and Nina Schwalbe. 2021. Evidence on Digital Mental Health Interventions for Adolescents and Young People: Systematic Overview. *JMIR Ment Health 2021;8(4):e25847 https://mental.jmir.org/2021/4/e25847* 8 (4 2021), e25847. Issue 4. https://doi.org/10.2196/25847

[69] M. H. Liao and C. G. Drury. 2000. Posture, discomfort and performance in a VDT task. *Ergonomics* 43 (3 2000), 345–359. Issue 3. https://doi.org/10.1080/001401300184459

[70] Brenna Lin, Christopher Prickett, and Steven Woltering. 2021. Feasibility of using a biofeedback device in mindfulness training - a pilot randomized controlled trial. *Pilot and feasibility studies* 7, 1 (dec 2021). https://doi.org/10.1186/S40814-021-00807-1

[71] I. Mei Lin, San Yu Wang, Sheng Yu Fan, Erik Peper, Sui Pi Chen, and Ching Yu Huang. 2020. A Single Session of Heart Rate Variability Biofeedback Produced Greater Increases in Heart Rate Variability Than Autogenic Training. *Applied psychophysiology and biofeedback* 45 (12 2020), 343–350. Issue 4. https://doi.org/10.1007/S10484-020-09483-Y

[72] Jake Linardon and Matthew Fuller-Tyszkiewicz. 2020. Attrition and adherence in smartphone-delivered interventions for mental health problems: A systematic and meta-analytic review. *Journal of consulting and clinical psychology* 88 (1 2020), 1–13. Issue 1. https://doi.org/10.1037/CCP0000459

[73] Anna Macaranas, Alissa N. Antle, and Bernhard E. Riecke. 2015. What is Intuitive Interaction? Balancing Users' Performance and Satisfaction with Natural User Interfaces. *Interacting with Computers* 27, 3 (may 2015), 357–370. https://doi.org/10.1093/IWC/IWV003

[74] Miroslav Macik, Katerina Prazakova, Anna Kutikova, Zdenek Mikovec, Jindrich Adolf, Jan Havlik, and Ivana Jilekova. 2017. Breathing friend: Tackling stress through portable tangible breathing artifact. In *Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics)*, Vol. 10516 LNCS. Springer Verlag, 106–115. https://doi.org/10.1007/978-3-319-68059-0_6

[75] Diana MacLean, Asta Roseway, and Mary Czerwinski. 2013. MoodWings: A wearable biofeedback device for real-time stress intervention. In *ACM International Conference Proceeding Series*. ACM Press, New York, New York, USA, 1–8. https://doi.org/10.1145/2504335.2504406

[76] Tímea Magyaródi, Henriett Nagy, Péter Soltész, Tamás Mózes, and A. Oláh. 2013. Psychometric properties of a newly established flow state questionnaire. *undefined* (2013).

[77] Kuldeep Mahato, Buddhadev Purohit, Keshav Bhardwaj, Amit Jaiswal, and Pranjal Chandra. 2019. Novel electrochemical biosensor for serotonin detection based on gold nanorattles decorated reduced graphene oxide in biological fluids and in vitro model. *Biosensors & bioelectronics* 142 (oct 2019). https://doi.org/10.1016/J.BIOS.2019.111502

[78] Hendramoorthy Maheswaran, Scott Weich, John Powell, and Sarah Stewart-Brown. 2012. Evaluating the responsiveness of the Warwick Edinburgh Mental Well-Being Scale (WEMWBS): Group and individual level analysis. *Health and Quality of Life Outcomes* 10, 1 (dec 2012), 1–8. https://doi.org/10.1186/1477-7525-10-156/TABLES/3

[79] Peter Malinowski. 2013. Neural mechanisms of attentional control in mindfulness meditation. *Frontiers in neuroscience* 7 (2013). Issue 7 FEB. https://doi.org/10.3389/FNINS.2013.00008

[80] Amanda C. Marshall, Antje Gentsch-Ebrahimzadeh, and Simone Schütz-Bosbach. 2022. From the inside out: Interoceptive feedback facilitates the integration of visceral signals for efficient sensory processing. *NeuroImage* 251 (may 2022). https://doi.org/10.1016/J.NEUROIMAGE.2022.119011

[81] F. Matcham, L. Rayner, J. Hutton, A. Monk, C. Steel, and M. Hotopf. 2014. Self-help interventions for symptoms of depression, anxiety and psychological distress in patients with physical illnesses: A systematic review and meta-analysis. *Clinical Psychology Review* 34, 2 (mar 2014), 141–157. https://doi.org/10.1016/J.CPR.2014.01.005

[82] Troy McDaniel and Sethuraman Panchanathan. 2019. Therapeutic haptics for mental health and wellbeing. , 149-181 pages. https://doi.org/10.1007/978-3-030-34230-2_6

[83] Qing Long Meng, Yan Sun, Hui Jing He, Hao Wang, and Guang Liang Shan. 2021. Non-invasive thoracic electrical bioimpedance technique-derived hemodynamic reference ranges in Chinese Han adults. *Chinese Medical Journal* 134, 20 (oct 2021), 2515. https://doi.org/10.1097/CM9.0000000000001465

[84] Timothy Merritt, Foad Hamidi, Mirela Alistar, and Marta DeMenezes. 2020. Living media interfaces: a multi-perspective analysis of biological materials for interaction. *https://doi.org/10.1080/14626268.2019.1707231* 31, 1 (jan 2020), 1–21. https://doi.org/10.1080/14626268.2019.1707231

[85] David C. Mohr, Pim Cuijpers, and Kenneth Lehman. 2011. Supportive Accountability: A Model for Providing Human Support to Enhance Adherence to eHealth Interventions. *J Med Internet Res 2011;13(1):e30 https://www.jmir.org/2011/1/e30* 13, 1 (mar 2011), e1602. https://doi.org/10.2196/JMIR.1602

[86] Stuart Moran, Nils Jäger, Holger Schnädelbach, and Kevin Glover. 2016. ExoPranayama: a biofeedback-driven actuated environment for supporting yoga breathing practices. *Personal and Ubiquitous Computing* 20, 2 (apr 2016), 261–275. https://doi.org/10.1007/s00779-016-0910-3

[87] Matthias M. Müller and Claire Marie Giabbiconi. 2008. Attention in sense of touch. *Human Haptic Perception: Basics and Applications* (2008), 199–206. https://doi.org/10.1007/978-3-7643-7612-3_15/COVER

[88] Kristin Neidlinger, Khiet P. Truong, Caty Telfair, Loe Feijs, Edwin Dertien, and Vanessa Evers. 2017. AWElectric: That gave me goosebumps, did you feel it too?. In *TEI 2017 - Proceedings of the 11th International Conference on Tangible, Embedded, and Embodied Interaction*. Association for Computing Machinery, Inc, 315–324. https://doi.org/10.1145/3024969.3025004

[89] NICE. 2020. Recommendations | Behaviour change: digital and mobile health interventions | Guidance | NICE. https://www.nice.org.uk/guidance/ng183/chapter/Recommendations

[90] Bryson Padasdao, Ehsaneh Shahhaidar, and Olga Boric-Lubecke. 2013. Measuring chest circumference change during respiration with an electromagnetic biosensor. *Proceedings of the Annual International Conference of the*

IEEE Engineering in Medicine and Biology Society, EMBS (2013), 1936–1939. https://doi.org/10.1109/EMBC.2013.6609906

[91] Heekyeong Park, Stella M. Sanchez, Rayus Kuplicki, Aki Tsuchiyagaito, Sahib S. Khalsa, Martin P. Paulus, and Salvador M. Guinjoan. 2022. Attenuated interoceptive processing in individuals with major depressive disorder and high repetitive negative thinking. *Journal of Psychiatric Research* 156 (dec 2022), 237–244. https://doi.org/10.1016/J.JPSYCHIRES.2022.10.020

[92] Nicole Pearson, Patti Jean Naylor, Maureen C. Ashe, Maria Fernandez, Sze Lin Yoong, and Luke Wolfenden. 2020. Guidance for conducting feasibility and pilot studies for implementation trials. *Pilot and Feasibility Studies* 6, 1 (dec 2020). https://doi.org/10.1186/S40814-020-00634-W

[93] Nicola Petrocchi and Simone Cheli. 2019. The social brain and heart rate variability: Implications for psychotherapy. *Psychology and psychotherapy* 92 (6 2019), 208–223. Issue 2. https://doi.org/10.1111/PAPT.12224

[94] D. H. Phan, S. Bonnet, R. Guillemaud, E. Castelli, and N. Y.Pham Thi. 2008. Estimation of respiratory waveform and heart rate using an accelerometer. *Proceedings of the 30th Annual International Conference of the IEEE Engineering in Medicine and Biology Society, EMBS'08 - "Personalized Healthcare through Technology"* (2008), 4916–4919. https://doi.org/10.1109/IEMBS.2008.4650316

[95] Nathan Sakiris and David Berle. 2019. A systematic review and meta-analysis of the Unified Protocol as a transdiagnostic emotion regulation based intervention. *Clinical psychology review* 72 (aug 2019). https://doi.org/10.1016/J.CPR.2019.101751

[96] Pedro Sanches, Axel Janson, Pavel Karpashevich, Camille Nadal, Chengcheng Qu, Claudia Daudén Roquet, Muhammad Umair, Charles Windlin, Gavin Doherty, Kristina Höök, and Corina Sas. 2019. HCI and Affective Health Taking stock of a decade of studies and charting future research directions. In *Conference on Human Factors in Computing Systems - Proceedings*. Association for Computing Machinery, 17. https://doi.org/10.1145/3290605.3300475

[97] Federico Sarzotti. 2018. Self-monitoring of emotions and mood using a tangible approach. *Computers* 7, 1 (jan 2018), 7. https://doi.org/10.3390/computers7010007

[98] Kadek Ananta Satriadi, Jim Smiley, Barrett Ens, Maxime Cordeil, Tobias Czauderna, Benjamin Lee, Ying Yang, Tim Dwyer, and Bernhard Jenny. 2022. Tangible Globes for Data Visualisation in Augmented Reality. *Conference on Human Factors in Computing Systems - Proceedings* (apr 2022). https://doi.org/10.1145/3491102.3517715

[99] Jeff Sauro and Joseph S. Dumas. 2009. Comparison of three one-question, post-task usability questionnaires. *Conference on Human Factors in Computing Systems - Proceedings* (2009), 1599–1608. https://doi.org/10.1145/1518701.1518946

[100] Mark S. Schwartz and Frank Andrasik. 2016. BiofeedBack: A Practicioner's guide. (2016).

[101] Mandeep Sekhon, Martin Cartwright, and Jill J. Francis. 2017. Acceptability of healthcare interventions: an overview of reviews and development of a theoretical framework. *BMC health services research* 17, 1 (jan 2017). https://doi.org/10.1186/S12913-017-2031-8

[102] Jinsil Hwaryoung Seo, Annie Sungkajun, Tiffany Sanchez, and Jinkyo Suh. 2015. Touchology: Peripheral interactive plant design for well-being. *Interaction Design and Architecture(s)* 27, 1 (apr 2015), 175–187. https://doi.org/10.1145/2702613.2732883

[103] Ameneh Shamekhi and Timothy Bickmore. 2018. Breathe deep: A breath-sensitive interactive meditation coach. *ACM International Conference Proceeding Series* (may 2018), 108–117. https://doi.org/10.1145/3240925.3240940

[104] Jacek Sliwinski, Mary Katsikitis, and Christian Martyn Jones. 2017. A Review of Interactive Technologies as Support Tools for the Cultivation of Mindfulness. *Mindfulness* 8, 5 (oct 2017), 1150–1159. https://doi.org/10.1007/S12671-017-0698-X/TABLES/2

[105] Petr Slovak, James J Gross, Katherine Isbister, Uc Santa Cruz, Alissa N Antle, Nikki Theofanopoulou, and Claudia Daudén Roquet. 2022. Designing for emotion regulation interventions: an agenda for HCI theory and research. *ACM Transactions on Computer-Human Interaction* (mar 2022). https://doi.org/10.48550/arxiv.2204.00118 arXiv:2204.00118

[106] Xiaotian Sun and Kiyoshi Tomimatsu. 2017. Breath is to be perceived - breathing signal sharing involved in remote emotional communication. In *Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics)*, Vol. 10291 LNCS. Springer, Cham, 472–481. https://doi.org/10.1007/978-3-319-58697-7_35

[107] Zhida Sun, Nan Cao, and Xiaojuan Ma. 2017. Attention, comprehension, execution: Effects of different designs of biofeedback display. In *Conference on Human Factors in Computing Systems - Proceedings*, Vol. Part F127655. Association for Computing Machinery, New York, NY, USA, 2132–2139. https://doi.org/10.1145/3027063.3053082

[108] Faisal Taher, Jason Alexander, John Hardy, and Eduardo Velloso. 2014. An empirical characterization of touch-gesture input-force on mobile devices. *ITS 2014 - Proceedings of the 2014 ACM International Conference on Interactive Tabletops and Surfaces* (11 2014), 195–204. https://doi.org/10.1145/2669485.2669515

[109] Nađa Terzimehić, Renate Häuslschmid, Heinrich Hussmann, and M. C. Schraefel. 2019. A review & Analysis of mindfulness research in HCI framing current lines of research and future opportunities. In *Conference on Human Factors in Computing Systems - Proceedings*. Association for Computing Machinery, New York, NY, USA, 1–13. https://doi.org/10.1145/3290605.3300687

[110] Anja Thieme, Jayne Wallace, Paula Johnson, John McCarthy, Siân Lindley, Peter Wright, Patrick Olivier, and Thomas D. Meyer. 2013. Design to promote mindfulness practice and sense of self for vulnerable women in secure hospital services. In *Conference on Human Factors in Computing Systems - Proceedings*. 2647–2656. https://doi.org/10.1145/2470654.2481366

[111] Kelly J Thomas Craig, Laura C Morgan, Ching-Hua Chen, Susan Michie, Nicole Fusco, Jane L Snowdon, Elisabeth Scheufele, Thomas Gagliardi, and Stewart Sill. 2020. Systematic review of context-aware digital behavior change interventions to improve health. *Translational behavioral medicine* (2020). https://doi.org/10.1093/tbm/ibaa099

[112] Audrey Tluczek, Jeffrey B. Henriques, and Roger L. Brown. 2009. Support for the reliability and validity of a six-item state anxiety scale derived from the State-Trait Anxiety Inventory. *Journal of nursing measurement* 17, 1 (2009), 19–28. https://doi.org/10.1891/1061-3749.17.1.19

[113] Vasiliki Tsaknaki, Pavel Karpashevich, Kelsey Cotton, and Pedro Sanches. 2021. "Feeling the Sensor Feeling you": A Soma Design Exploration on Sensing Non-habitual Breathing; "Feeling the Sensor Feeling you": A Soma Design Exploration on Sensing Non-habitual Breathing. *Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems* (2021). https://doi.org/10.1145/3411764

[114] Muhammad Umair. 2021. Design and Evaluation of Biofeedback Interfaces for Awareness and Regulation of Affect. https://doi.org/10.1145/3197391.3205436

[115] Ken Umetani, Donald H. Singer, Rollin McCraty, and Mike Atkinson. 1998. Twenty-Four Hour Time Domain Heart Rate Variability and Heart Rate: Relations to Age and Gender Over Nine Decades. *Journal of the American College of Cardiology* 31 (3 1998), 593–601. Issue 3. https://doi.org/10.1016/S0735-1097(97)00554-8

[116] Greg Wadley, Wally Smith, Peter Koval, and James J. Gross. 2020. Digital Emotion Regulation. *https://doi.org/10.1177/0963721420920592* 29, 4 (jun 2020), 412–418. https://doi.org/10.1177/0963721420920592

[117] Stanislaw Weglarczyk. 2018. Kernel density estimation and its application. *ITM Web of Conferences* 23 (01 2018), 00037. https://doi.org/10.1051/itmconf/20182300037

[118] Jessica A. Wojtalik, Shaun M. Eack, and Matthew J. Smith. 2018. Using cognitive neuroscience to improve mental health treatment: A comprehensive review. *Journal of the Society for Social Work and Research* 9, 2 (jun 2018), 223–260. https://doi.org/10.1086/697566/ASSET/IMAGES/LARGE/FG1.JPEG

[119] Kieran Woodward, Eiman Kanjo, David Brown, T. M. McGinnity, Becky Inkster, Donald J Macintyre, and Athanasios Tsanas. 2019. Beyond Mobile Apps: A Survey of Technologies for Mental Well-being. *arXiv* (may 2019). arXiv:1905.00288 http://arxiv.org/abs/1905.00288

[120] Kui Xie, Benjamin C. Heddy, and Barbara A. Greene. 2019. Affordances of using mobile technology to support experience-sampling method in examining college students' engagement. *Computers & Education* 128 (jan 2019), 183–198. https://doi.org/10.1016/J.COMPEDU.2018.09.020

[121] Mengran Xu, Christine Purdon, Paul Seli, and Daniel Smilek. 2017. Mindfulness and mind wandering: The protective effects of brief meditation in anxious individuals. *Consciousness and Cognition* 51 (5 2017), 157–165. https://doi.org/10.1016/J.CONCOG.2017.03.009

[122] Shunsuke Yanaka, Motoki Ishida, Takayuki Kosaka, Motofumi Hattori, and Hisashi Sato. 2013. Resolution of sleep deprivation problems using zzzoo pillows. In *ACM International Conference Proceeding Series*. ACM, New York, NY, USA. https://doi.org/10.1145/2466816.2466843

[123] Bin Yu, Nienke Bongers, Alissa Van Asseldonk, Jun Hu, Mathias Funk, and Loe Feijs. 2016. LivingSurface: Biofeedback through shape-changing display. In *TEI 2016 - Proceedings of the 10th Anniversary Conference on Tangible Embedded and Embodied Interaction*. Association for Computing Machinery, Inc, New York, NY, USA, 168–175. https://doi.org/10.1145/2839462.2839469

[124] Bin Yu, Loe Feijs, Mathias Funk, and Jun Hu. 2015. Breathe with touch: A tactile interface for breathing assistance system. *Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics)* 9298 (2015), 45–52. https://doi.org/10.1007/978-3-319-22698-9_4/FIGURES/7

[125] Bin Yu, Mathias Funk, Jun Hu, Qi Wang, and Loe Feijs. 2018. Biofeedback for Everyday Stress Management: A Systematic Review. *Frontiers in ICT* 5 (9 2018), 23. Issue SEP. https://doi.org/10.3389/fict.2018.00023

[126] Bin Yu, Jun Hu, Mathias Funk, and Loe Feijs. 2018. DeLight: biofeedback through ambient light for stress intervention and relaxation assistance. *Personal and Ubiquitous Computing* 22, 4 (aug 2018), 787–805. https://doi.org/10.1007/s00779-018-1141-6

[127] Andrea Zaccaro, Andrea Piarulli, Marco Laurino, Erika Garbella, Danilo Menicucci, Bruno Neri, and Angelo Gemignani. 2018. How Breath-Control Can Change Your Life: A Systematic Review on Psycho-Physiological Correlates of Slow Breathing. *Frontiers in Human Neuroscience* 12 (sep 2018), 353. https://doi.org/10.3389/FNHUM.2018.00353

[128] Bin Zhu, Anders Hedman, Shuo Feng, Haibo Li, and Walter Osika. 2017. Designing, Prototyping and Evaluating Digital Mindfulness Applications: A Case Study of Mindful Breathing for Stress Reduction. *Journal of medical Internet research* 19 (2017). Issue 6. https://doi.org/10.2196/JMIR.6955

Received 15 September 2022; revised 13 December 2022; accepted 13 January 2023