Personalising TaHaMi: Tangible Haptic Mindfulness Interface for Novice Meditators

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While most HCI research on mindfulness meditation focused on audio and visual feedback to support attention regulation, haptic interfaces have been less explored. We present the design, and exploration with 19 novice meditators of a novel haptic interface integrating vibration and soft haptic. The study also engages users in the personalisation of their haptic patterns. Findings highlighted key experiential qualities of the two modalities and their potential to support or hinder mindfulness states. In particular, the result supports novice meditators' phenomenological experience of mindfulness, facilitates grounding through deep breathing and promotes subtle, non-gamified interaction. We conclude with four design implications for haptics-based mindfulness technologies.

Mindfulness meditation, Novices, Haptic patterns, Vibrotactile, Soft haptic, Personalisation, Tangible

1. INTRODUCTION

There has been growing HCI interest in mindfulness technologies as part of the third-wave HCI agenda towards a richer understanding of felt-life experiences and affective interaction (Daudén Roquet and Sas, 2021; Foo et al., 2020). Such work explored neurofeedback through the tracking of mindfulness states, and real-time feedback on them. Mindfulness meditation has been defined as non-judgmental, present-moment centred awareness, through which arising thoughts, feelings, or sensations are acknowledged and accepted, but without reacting to them (Bishop et al., 2004). Recent HCI research on mindful meditation highlighted its physical and emotional experiences associated with each stage of grounding, becoming mindful, being mindful, and mind-wandering, respectively (Daudén Roquet and Sas, 2020).

Most HCI research on static mindfulness technologies has explored focused attention meditation involving concentration on specific stimuli, such as objects, i.e., candlelight, or body sensations, such as breathing, heart rate. Previous work explored various interfaces, particularly audio (Sas and Chopra, 2015), visual (Mosher, 2022), or audio-visual ones (Silvestre-López and Ferrando, 2017) for mapping meditation states to audio or visual representations, i.e., high-pitch sound, agitated sea mapped to less mindful states, and low-pitch sound, calm sea mapped to mindful states.

In contrast to audio-visual modalities, haptic interfaces have been less explored, which is surprising given recent findings on the role of bodily sensations during meditation (Daudén Roquet and Sas, 2020), which may be better leveraged through haptic modalities such as vibration or thermal. While more ambiguous than visual neurofeedback, thermal is also experienced more like coming from the body, so more embodied and less likely to lead to self-judgment when people become aware of their mind wandering (Daudén Roquet and Sas, 2021).

Despite previous findings on the potential of haptic bio-feedback to support self-regulation, for instance, of affective states such as stress (Umair et al., 2019, 2021), the exploration of haptics for mindfulness training has focused mostly on thermal and vibration actuators (Kim et al., 2021, Choi and Ishii, 2020, Hao et al., 2017, Miri et al., 2020). In contrast, other actuating technologies, such as soft haptics, have been less explored. However, they do offer new opportunities to support mindfulness meditation through their affordances for gentle stimulation, such as a feeling of light touch or elation.

To address this gap, we report the design of a novel haptic interface for mindful meditation and its exploration through an in-lab study with 19 novice meditators. We focused on three research questions: (i) how can we design tangibles as situated technologies within the structured practice of mindfulness meditation, (ii) what is the feasibility of vibration motors and pneumatic soft actuators for subtle haptic support during mindfulness meditation, (iii) how novice meditators may personalise, and experience such tangible interfaces.

Our contributions include the design rationale for TaHaMi, a novel haptic mindfulness interface (Figure 1), the introduction of a 1D vibrotactile array with overlapping, temporally asymmetric actuation to support richer qualities of perceived movement on skin, and four design implications for tangible mindfulness technologies.

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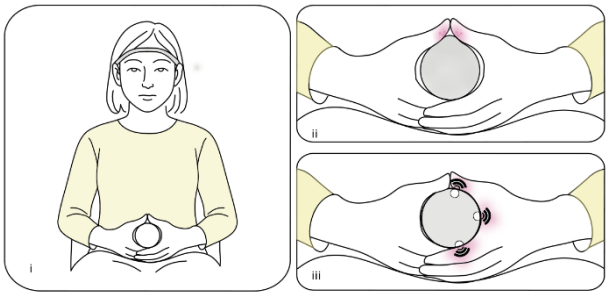

***Figure 1**: TaHaMi prototype handheld in cosmic mudra during mindful meditation. (i) not actuated (ii) soft pressure through pouch inflation for representing mindfulness state (iii) downward vibration pattern from thumb to palm to support grounding and attention back to the present moment during mind wandering state*.

2. RELATED WORK

Most mindfulness technologies capture brain activity and provide real-time feedback on mindfulness states, such as being mindful or mind wandering. Common neurofeedback interfaces include visual (Daudén Roquet et al., 2023) or aural feedback (Cochrane et al., 2018, 2021; Sas and Chopra, 2015), with less work exploring haptic modalities (Daudén Roquet and Sas, 2021). In addition to such neurofeedback for attention regulation to support present moment awareness, mindfulness technologies have also focused on guided meditation (Yoon et al., 2021), or ancient meditation techniques such as Ming Shan (Gao et al., 2022; Henchoz et al., 2021). Another strand of work has focused on complementary support for the regulation of emotional states (Umair et al., 2019, 2021; Wang et al., 2022) or bodily states such as breathing (Foo et al., 2020; Malaver Turbay et al., 2022) by leveraging also shape-changing displays (Farral et al., 2026)**.**

Since meditation is a bodily practice (Daudén Roquet and Sas, 2020), previous work has also highlighted the value of embodied metaphors for representing mindfulness states (Antle et al., 2018; Daudén Roquet and Sas, 2021). For instance, scholars explored haptic-based embodied metaphors of mindfulness states (Daudén Roquet and Sas, 2021; Cho et al., 2024; Ezer et al., 2024), through thermal feedback (Daudén Roquet and Sas, 2021; Ezer et al., 2024) or midair vibrations (Cho et al., 2024). However, real-time haptic neurofeedback has been limited. An example is WarmMind (Daudén Roquet and Sas, 2021) which consists of an adjustable necklace attached to a vertical string with four actuators providing different thermal patterns aligned with each meditation state, i.e., mindfulness state – radiating warmth as a static pattern through all actuators pulsating together, and mind wandering – random patterns of warmth movement. Their findings also suggest that the latter random pattern, while reflecting the movement of random thoughts, provides little support for bodily awareness and hinders attention regulation. Ezer et al. (2024) also leveraged thermal upward and downward patterns on the belly and shoulders to support interoception during meditation, while Cho et al.'s (2024) exploration of thermal neurofeedback showed participants' rich experience of warmth during meditation, albeit increased cognitive effort to align with haptic pattern (Cho et al., 2024). Explorative user studies of these design exemplars indicated their value of haptic patterns for mindful meditation, and in particular interoceptive interaction or inward focus supported by such actuation (Daudén Roquet and Sas, 2021; Ezer et al., 2024).

To conclude, while previous work indicated the potential of thermal and midair vibrations as subtle interactions for mindfulness meditation, they also highlight some limitations, which the less explored soft haptics could potentially address. Our work aims to address this opportunity gap by extending existing research on haptic neurofeedback. Thus, our novel prototype integrates both vibrations, for grounding during mind wandering states, and soft pressure, for representing mindful states.

3. DESIGNING TAHAMI: A SOMAESTHETIC EXPLORATION

Similar to Daudén Roquet and Sas (2021), we employed a somaesthetic approach to the design of the TaHaMi prototype with a focus on the actuators, their materiality, and experiential qualities (Höök et al., 2016). The subtle vibrations and soft pressure have been less explored for mindfulness meditation, so experiencing first-hand their qualities was essential. Our design rationale draws from stages of mindfulness meditation, and their embodied experiential qualities (Daudén Roquet and Sas, 2020; Daudén Roquet and Sas, 2021), such as vertical and horizontal movement patterns conveyed through vibrations (Kim et al., 2021), or thermal actuators (Daudén Roquet and Sas, 2021; Ezer et al., 2024; Dublin et al., 2026).

To address some of the identified challenges of previously explored haptic patterns, we followed Daudén Roquet and Sas (2021) suggestion to support, rather than represent a mind-wandering state; through a vertical downward movement, associated with the bodily experience of grounding (Daudén Roquet and Sas, 2020). *Grounding* is a common initial stage of meditation consisting of taking three deep breaths while sitting in the correct posture, in order to bring attention to the present moment (Kabat-Zinn, 2013). Daudén Roquet and Sas, (2020) also indicated the radiating light or bodiless sensations associated with being mindful, which may be represented through materials of light and air. These are qualities that soft haptics may be uniquely positioned to support. Thus, grounded in previous work, our design rationale informed the following requirements: subtle, tactile

neurofeedback which limits self- judgements; maps mindful states to vertical upward movement through soft haptics, and mind wandering state to downward movement to support grounding.

3.1 Hands Posture: Cosmic Mudra

We also explored a tangible prototype which can be handheld during mindful meditation. To leverage the sitting meditation, and its specific posture, we looked at the relevant hand gesture, and in particular the so-called *cosmic mudra* (Fig. 2), its mechanoreceptors and how they can be best recruited. This posture consists of both hands in the meditator's lap, palms facing up, with one hand holding the other, fingers extending, while thumbs touch lightly in an oval form (Bien and Didonna, 2009; Ghori and Chung, 2007; Kabat-Zinn, 2016).

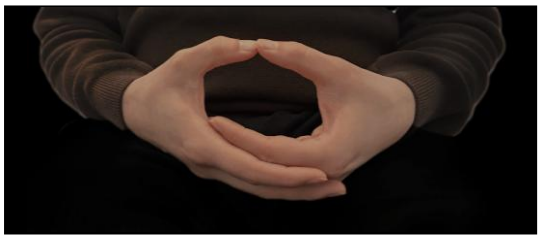

Figure 2: *Cosmic mudra*

3.2 Cosmic Mudra: Mechanoreceptors

Unlike other hand postures in meditation, such as palms resting on knees, the *cosmic mudra* provides less explored opportunities for tangible mindfulness interfaces, given that they are designed to seamlessly fit the posture, while leveraging the digital affordances. To further explore the suitability of *cosmic mudra*, we looked at the skin mechanoreceptors in the palms, that a tangible held prototype held by both hands could stimulate. For this, we have drawn from sensory physiology research on the most common mechanoreceptors present in palms and fingers, namely Meissner corpuscles and Merkel disks, both with a rapid response to stimuli, as well as a narrow and shallow location beneath the skin (Johansson and Vallbo, 1979). Meissner corpuscles sense skin deformation and react quickly when stimulated by light touch, or low frequency vibrations, i.e., 1-300Hz, while Merkel disks, highly dense in the fingertips' ridges, are stimulated by pressure (Culbertson er al., 2018; Johansson and Vallbo, 1979, 1983; Johnson, 2001; Schaack et al., 2019).

Drawing from previous findings on the importance of the subtleness of real-time feedback for mindfulness meditation (Daudén Roquet and Sas, 2021; Sas and Chopra, 2015), and the specific qualities of Meissner corpuscles and Merkel disks, namely immediate response to localised subtle haptic stimuli, we decided to focus on stimulating these mechanoreceptors through a handheld tangible interface for mindfulness meditation. This shape also fits well within the *cosmic mudra* by snugly filling in the space between the palms and the thumbs. To stimulate the Meissner corpuscles, we focus on low frequency vibrations generated through small vibration motors placed on the sphere, to stimulate a downward movement from the top to the bottom of the thumb in order to support one to become grounded during mind wandering. To stimulate the Merkel disks, we focus on soft pressure generated by a small haptic pouch located on the top of the sphere in order to gently raise the top of the thumbs by a small vertical raise (<1 cm) in order to represent when the meditator reached mindfulness state.

3.3 TaHaMi Prototype

Our tangible prototype consists of a 3D printed handheld sphere integrating three 310–103 EMR vibration motors, and a pneumatic actuator (soft pouch) (Figure 3), all controlled by an Arduino Mega unit with four 4-channel motor driver shields (Fig. 4).

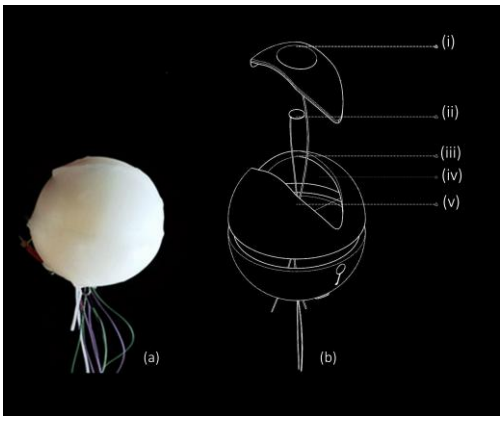

Figure 3: *(a) TaHaMi prototype, (b) the layout of the TaHaMi prototype including: (i) soft haptic pouch, (ii) vibration motors, (iii) pipe, (iv) interior filling material, and (v) exterior cover.*

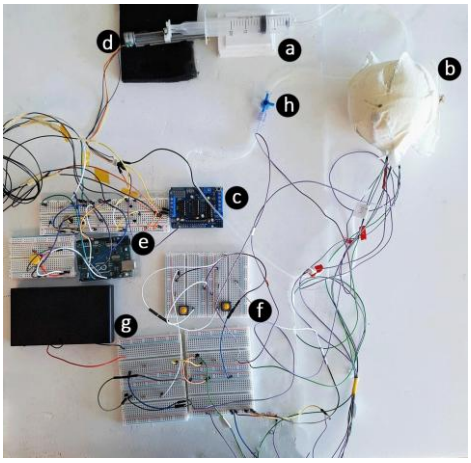

Figure 4**:** *Controller of TaHaMi: (a) syringe (20 ml), (b) TaHaMi, (c) L293D motor driver shield, (d) step angle stepper motor screw, (e) Arduino Uno, (f) control buttons, (g) 8 AA batteries, (h) air connector*

The sphere was cast in 3D printed moulds, using silicon Eco Flex, which has excellent elasticity. This allows for a customizable form and the integration of a soft pouch into the prototype's body. We experimented and compared different sizes of the sphere with diameters ranging from 7.5 to 10 cm, to explore how comfortably it can be held in *cosmic mudra.* This exploration was useful, as the size of the sphere together with the size of one's hands impact on how snug the hold is, which matters in order to perceive the vibrations. Thus, we decided to settle for two sizes: 7.5 to 9 cm, as they provided the best fit for small and large hand sizes. The user can compare the two different sizes of the prototype and determine which one suits their hand position.

To the vibration motors, we added 33-ohm resistors for gentle vibrations, and to control the pneumatic actuator's speed and pressure, we used a syringe operated by a stepper motor. This feature enables us to regulate inflation and deflation simply by pressing two buttons on the board. The small size of vibration motors and their limited range of vibration intensity ensured that their actuation was with limited noise. In addition, we also mounted them in stitched pockets on the silicon sphere. To limit the noise of the syringe actuating the soft pouch, we secured it on a noise absorbing foam surface (Fig 4 d).

To capture brain activity or electroencephalogram (EEG) during the meditation, we used Muse, a commercial wearable headband with electroencephalogram sensors (EEG). Muse app also provides real time forest soundscape-based neurofeedback on meditation states, namely rainfall for mind wandering state, and birdsong for mindfulness state.

3.4 Vibrotactile Patterns for Grounding During Mind Wandering

To design vibrotactile patterns resembling continuous downward movement (Daudén Roquet and Sas, 2021) within cosmic mudra, we have drawn from two research directions on perceived vibrotactile patterns travelling in space across vibration motors (Israr and Poupyrev, 2011; Kim et al., 2009) and asymmetric individual vibrations (Culbertson et al., 2017).

Previous work has shown how multiple vibration motors can be actuated by controlling their intensity and timing (Israr and Poupyrev, 2011): sequentially and partly overlapped actuation of two consecutive motors, to support users' perception of travelling vibrotactile waves. We explored such patterns, and our experience was that the feeling of grounding from the downward movement was limited. Then, we looked at asymmetric vibrations whose waveform amplitude is not symmetric across positive and negative phases but differs in the onset and offset, i.e., duration, rate of change (Culbertson et al., 2017). This asymmetry stimulates Meissner corpuscles, impacting users' perception of the temporal force profile of vibration on the skin, and interpretation of having a direction-like quality (Culbertson et al., 2017). This work, however, is limited to an individual vibration motor, and the direction-quality is more like push and pull rather than spatially perceived, i.e., up or down.

For the latter, we need not just the perception of how a single vibration changes over time, but also how two or more vibration motors, at different locations, change over time. In this way, we can explore if having more than one vibration motor can support the perception of continual tactile motion between them on the skin. To generate asymmetric vibration for the perception of the continuous, downward movement, we needed at least two vibrator motors and a maximum of three since the area to be stimulated is limited (from the top of the thumb to the bottom of the palm). Thus, we explored three motors placed in a linear spatial pattern across the top of the sphere. Most of our exploration involved the vibration pattern, both in terms of vibration intensity and temporal actuation of all three. We explored and narrowed down the vibration intensity, ranging from 30 PWM (22Hz) as the lowest perceivable vibration, to 70 PWM (118Hz) (Johnson, 2001) as the highest value which can be noticed but is not alarming.

Regarding timing, actuation pattern length ranged from 1500 to 2900 ms, with each motor lasting no more than 200 to 600 ms, since we noticed that durations exceeding 1000 ms can be disruptive. To ensure gentle and smooth vibrotactile sensation, we used coin vibration motors with linear signal and explored the generation of sinusoids wavy patterns. Through a first-person experience of different configurations, we found the right balance between the periods of vibration (around 125 ms) and specific intensity, which declines gradually (2 PWM). Each vibration pattern included three motors actuated as follows: the first one vibrates at 34 PWM intensity for 350 ms, the second one starts at 33 PWM intensity for 1000ms, and the third ones subsequently vibrates at 33 PWM intensity for 1400 ms.

3.5. Soft Pouch Pressure for Representing Mindfulness States

To support gentle awareness of mindfulness states, we leveraged the associated bodily feeling of upward movement, light and air (Daudén Roquet and Sas, 2019). For this, we used a shape-changing pneumatic pouch whose inflation gently lifts, by no more than 1 cm, both thumbs resting on top of the tangible sphere. After actuation, the soft pneumatic actuator deflates gently to its initial state. We explored the form factor of the pouch, the force and speed of actuation. For this, we considered different sizes and shapes of pouch, also made of moulded silicon pouch, to be inserted at the top of the sphere, to ensure that they are large enough to lift the

thumbs so is just noticeable and small enough that they can be filled up with air in the moment, and their volume do not push to thumbs too high to shift the cosmic mudra. We explored circular and oval shapes of these pouches, and agreed on the oval one of about 2 cm length, 1 cm wide (Figure 3), which, when inflated, took the shape of a tiny dome or half sphere under the touching tips of the thumbs.

We also explored different force intensities as the speed of the stepper motors from the pneumatic syringe inflating the pouch. We decided on different speeds, and the most suitable range: 7000 RPMs (revolutions per minute) to 25000 RPMs, and pouch inflation volume range: 1.57ml to 3ml.

4. EXPLORATORY USER STUDY

Our study aims to explore novice meditators' experience with the TaHaMi prototype. We recruited through university mailing lists and flyers posted on campus a convenience sample of 19 participants with no experience of mindfulness meditation (7 females and 12 males, average age of 35). The study consisted of four parts: (i) introduction to the study including mindfulness meditation and a 3 min meditation to practice, (ii) presentation of the TaHaMi prototype and participants' personalisation of both forms of haptic feedback, (iii) sitting meditation for 10 minutes in total using both haptic, and sound neurofeedback in counterbalanced order: 5 minutes with the TaHaMi prototype, and 5 minutes with Muse soundscape, with 5 min break in between in line with previous research (Yamaya et al., 2021). The study concluded with (iv) semi-structured interviews.

To leverage the potential of user-led personalisation for self-regulation (Umair et al., 2021) we also supported participants to select the values of main parameters for both vibration motors: intensity and duration within the range of 30 PWM (22Hz) as the lowest perceivable vibration to 70 PWM (118Hz) (Johnson, 2001), and the duration of the vibration pattern. The latter includes selection of the duration of the first vibration motor: 200ms, 500ms, 800ms, and 1000ms, and for soft pressure actuator, selection of inflation speed (7000 – 25000 RPMs) and volume: 1.57ml, 2.2ml, 3ml. During personalisation, participants were encouraged to select the values that they still perceive, but do not distract their attention.

For the 5-minute mindfulness meditation, participants were instructed to focus on meditation, and if they perceived vibrations while using the tangible prototype, to take three deep breaths. The Muse app's sound feedback was delivered to participants through headphones, while the vibration pattern and soft haptic feedback were provided through TaHaMi. For the haptic feedback, we employed the Wizard of Oz using the Muse headband feedback. Only the researcher listened through headphone to the Muse soundscape reflecting participant's meditation states, in order to manually delivered in real time, the corresponding vibration and soft haptic feedback. This approach was previously used in HCI research on mindfulness neurofeedback in sound and haptic modalities (Daudén Roquet and Sas, 2021).

The semi-structured interviews explored participants' personalisation of vibrations and soft pressure, and their experience with the prototype, perception of vibration and soft pressure feedback, including their qualities and timing, and how the prototype impacted users' recognition of mindfulness and mind-wandering states.

The interviews lasted 30 minutes, were audio recorded, fully transcribed and coded using a hybrid approach. Deductive codes included those on the value of personalisation of actuators' parameters such as intensity (Umair et al., 2021), meditation states such as mind wandering and mindfulness (Daudén Roquet and Sas, 2020, Kabat-Zinn, 2013), and self-judgement as main aspect of mindfulness (Guluzade and Sas, 2026, Kabat-Zinn, 2013), types of haptic actuators: vibration, soft pressure (Kim et al., 2021; Farrall et al., 2023), as well as experiential qualities particularly those of ambiguity (Hook, 2008) and subtleness (Daudén Roquet and Sas, 2020, Höök, 2008). Within these broader deductive codes, inductive ones informed from the interview data included preferences for the personalisation parameters, perceived benefits and limitations of each haptic feedback, how the actuators supported or hindered mindful meditation, and their specific experiential qualities.

We employed qualitative content analysis to report descriptive topic summaries from participants' answers (Rigby and Iacovides, 2026). The first author read and coded all interview transcripts using Atlas.ti 8 software. Most of descriptive codes were initially generated and iteratively extended with inductive codes through ongoing conversations with the second author. The following section presents the outcomes organised under main summary topics (Nowell et al., 2017) as key areas targeted by interview questions and present in participants' accounts: personalisation of haptic patterns, user overall experience of each haptic modality, and its specific experiential qualities. The study received institutional ethics approval. All participants provided written informed consent prior to the study and were informed that they could withdraw at any time without providing a reason.

5. FINDINGS

Study findings are organised under the two types of haptic feedback and users' experience of them, both positive and problematic, preceded by personalisation preferences.

5.1 Personalisation of Haptic Patterns

Findings indicate different preferences for the personalisation of vibrotactile and soft pressure parameters. Regarding vibration intensity and its provided range of 34 to 66 PWM, about half of participants selected low intensity 34-49 PWM (average 43), and the rest selected higher intensity 49-66 PWM (average 57). Their descriptions of perceived vibrations also contrast, with the former group describing their low-intensity vibrations as "*fairly subtle, so not very intensely*" (P19), while the latter group described their vibrations of higher intensity as "*strong*" (P3) or "*firm*" (P1). With respect to the personalisation of vibration duration (1200-3000 ms), findings indicate that almost two-thirds selected longer durations 2400-2900 ms, while the rest selected shorter durations 1200-2265 ms.

In terms of preference for the soft pressure feedback, such as inflation speed (7000- 30000 RPMs) and inflation volume (1.57ml- 3ml), about half of the participants selected a lower speed (7000-10000 RPMs), average 8500 RPMs, and the rest selected a higher speed of inflation (10000-30000 RPMs), average 20000 RPMs. Most participants mentioned that the inflation speed was suitable. In terms of inflation volume, most participants selected 2.2ml, which they described as "*comfortable*". Study outcomes also indicate that these preferences matter not only for how people may like each feedback to be delivered, but also on their perceived support or hindrance during mindfulness meditation.

5.2 User Experience of Vibrotactile Feedback

Participants reported mixed user experience in relation to vibrotactile patterns. The positive experience was reported by about half, with respect to notifying them during mind wandering and for prompting grounding. Essential here appears to be the perceived subtleness of these notifications. Indeed, most participants who appreciated vibrotactile feedback are among those who personalised their vibrations as low intensity.

Subtle Notifications of Mind Wandering: Grounding

An important outcome is that most participants acknowledged vibrations' value for interrupting mind wandering: "w*hen I could feel it, it sort of reminded me that I needed to sort of be less distracted and sort of just try and breathe*" (P16). As this quote indicates, vibrations support both the awareness of having been in mind wandering, as well as the bringing attention back to the present moment. For this, participants noted that vibrations also prompted to ground themselves through three deep breaths: "*It's reminding me that I'm meditating. It reminded me to refocus even when subconsciously I would grab on to a thought; it would be like the perfect subtle [prompt to] bring you back to your conscious sort of thinking*" (P18).

Another important finding is that positive feedback about vibrotactile patterns appears to relate to their lower intensity and duration. All participants who personalised vibrations as lower intensity found that level to be appropriate during mind wandering. "*I quite liked it because it wasn't too strong or too soft*" (P8) and that despite being low intensity "*it was enough for me to perceive the vibration*" (P18). In addition, several participants perceived vibrations as useful: "*like a gentle nudge almost, to sort of start focusing on the meditation again*" (P19). With respect to vibration duration, findings suggest limited impact on participants' experience, with even longer durations being "*good enough, like, not too much"* (P3), although "*if it had been longer, I would have been annoyed by it*" (P8).

Intense Vibrations: Continuing Mind Wandering & Self-Judgmental Attitude

An interesting outcome is that several participants appeared to have overestimated vibration intensity in the personalisation stage, although they thought they selected a lower intensity value, which during meditation was stronger than expected: "*I thought it was perfect when we did it [personalisation part]. But then in the meditation phase, I think it was stronger than what I expected […] in the meditation everything feels like doubled. You know, like vibration was much stronger*" (P11). While most participants appreciated the value of gentle vibrations for interrupting mind wandering, a few noted the negative impact of vibrotactile feedback. Interestingly, some participants noted familiar use of vibrations for notification, and their potential interruptive quality: "*I think any or any form of vibration because mobile phones ring when there's a notification, so it's like my brain automatically ooh There's a notification*" (P9).

In particular, vibrations personalised to high intensity appeared to lead to more mind wandering: "*it made me think so much that I am not in a mindful state, so I had to think that now […] my mind is wandering. Like I started thinking. […] So that's why it became worse and worse over time*'' (P11). As this illustrative quote indicates, a problematic perception of vibrations not only stops users from mind wandering, but may extend mind wandering and follow-up vibrations may contribute to a negative reinforcement loop hindering present moment awareness. Findings also indicate that, for a few participants, vibrations may also lead to self-judgement attitude when users perceive them as indication of failure to maintain mindfulness state: "*It's kind of like a negative comment, right? Uh, your mind is wandering now and now is wondering again*" (P6), "*it was upsetting. Sometimes it was like I'm already mind wandering, and the vibration makes me wander even more*" (P3).

Haptic Patterns and Temporal Aspects

We also explored the vibrotactile pattern with findings indicating that most participants feel the vibration pattern: "*it is a little bit wavy like the wave. So, it's moved in my hand like*" (P2). Several participants described it during the interview by gesturing a downward motion. Most participants perceived the vibrotactile feedback as a pattern rather than three distinct vibrations: "*feels like it's more like a line connecting the three dots*" (P4).

Regarding temporality, outcomes indicate that almost half of participants confirmed being in mind wandering at the moment when they received the vibrotactile feedback: "*I can say for the vibration it was exact when I get my mind wander*" (P13). Although we deliberately limited the frequency of vibrations through a temporal gap between consecutive vibrations of at least 10 seconds, some participants perceived this gap as still large: "*I'd already be sort of working on refocusing and as I'm entering this state of refocusing, I get another vibration*" (P18). The same participant added: "*I knew my mind was wandering, and I was trying to fix it. And closer to when I was already fixing it*, *managing to sort of get focused again, then the vibration would come. And in that case, the second one, it was a bit more distracting*" (P18). This is an important outcome, as the ability to bring back attention to the present moment is the key skill that mindfulness meditation aims to develop. So future work should explore how to protect its development, by tailoring the vibration frequency to users' needs.

5.3 User Experience of Soft Pressure Feedback

With respect to the soft pressure feedback provided as small upwards inflation under the tips of the thumbs to represent mindfulness states, findings indicate a largely positive experience. This relates to the recognition of a mindfulness state, indication of progress, and possible risk of attachment to it.

Upward Inflating Pouch: Recognition of Mindfulness State

Findings indicate the soft pressure actuated by the upward-inflating pouch supported participants to identify mindfulness states as they arise, and thus to access their experiential quality: "*I realised when I would get the feedback as in, what thoughts would lead to the feedback, but I would probably not have recognised that as me being mindful without the feedback*" (P8). This is an important outcome, confirming that the recognition of mindfulness states is not trivial, and the value of neurofeedback on these states for novice meditators. Such learning could further support later recognition of a mindfulness state, even in the absence of soft pressure feedback, which users may no longer need as practice develops.

Subtle Progress Markers: Self-Efficacy

Findings suggest that soft pressure provided markers of progress by representing haptically when a mindfulness state was reached. Most participants saw this as valuable and needed confirmation. Participants also mentioned how the soft pressure feedback helped them become more confident in how they meditate: "*I think it centres me a little bit because I see it as a recognition of my effort of trying to meditate, so it's like, hey, you're doing well*".

Such perceived confirmation may foster self-efficacy in mindfulness, as confidence in the ability to meditate and even motivation: "*it helped me be confident that I'm doing good, […] it was motivating to hold my attention*" (P3). The value of novice meditators' self-efficacy has been previously acknowledged (Birdee et al., 2020; Hunt et al., 2025). While this external confirmation can be valuable for novice meditators, it also poses potential challenge of attachment to the outcome of mindfulness state. Findings indicate few such possible concerns like in this quote: "*it was telling me that, yes, you're doing good, and that positive affirmation is very important*" (P3).

The subtleness quality of the inflating pouch was important in this respect. Indeed, several participants mentioned overestimating inflation speed in the personalisation part of the study. And while they did select a slower speed, in the meditation session, they would have liked an even slower one: "*maybe it could have been slower. So, you recognise the process because I guess it was quite fast in the sense that. It would go up, and then you would sort of realise, oh, it's up not, oh, it's going up. You know what I mean? So maybe it could be more gradual*" (P18). The preference for inflation volume did not appear to impact users' experience during mindfulness meditation, which is not surprising since its range was already constrained by the size of the pouch.

5.4 Experiential Qualities of Vibrotactile Pattern vs Inflating Pouch

Both our haptic interactions leverage the body through the image schemata as sensory-motor patterns of interacting with the world, such as force (Lakoff and Johnson, 2008) in the form of downward movement as a metaphor for grounding, and upward movement for mindfulness. The former prompts three deep breaths, a common grounding task at the start of the meditation (Kabat-Zinn, 2013). We also asked participants to compare the qualities of the two forms of haptic feedback, with findings indicating that, compared to the vibrotactile pattern, the inflating pouch was experienced as subtler: "*it felt more natural. It felt more subtle and I think it helped"* (P15). Other participants extended this by describing the inflation pouch as calmer: "*it was a different feeling. It was calmer"* (P19), and more natural compared to vibrations: "*I think soft, it was*

not mechanical, mechanical was vibration" (P12) especially high intensity ones which "*can be a little bit irritating*" (P19) and "*distracting*" (P15).

Study outcomes also indicate the surprising support that the inflating pouch appeared to provide for deep breathing: "*it feels like breathing*" (P1). The soft rising and descending of the air pouch were perceived by some as breathing in and out: "*soft. It's like breathing […] go up. Like when you breathe, your lungs go up […] down […] the movement is similar to my body, I can feel this inside my body […] Go inside my body [...] that was good*" (P2). This quote illustrates an internal focus towards bodily sensation of breathing, usually facilitated by the grounding stage of mindfulness meditation. In fact, some participants even referred to this: "*I remember your instructions at the beginning: take some deep breaths*" (P16). This participant further added, "*it was easy to have like a reminder without focusing on it*" (P16) which suggests a passive support for breathing which does not require focused attention.

Other participants further detailed the inflating pouch value in this respect, when used for slow breath entrainment: *"helped me focus on the meditation because it was kind of like synchronising with my breathing*" (P4). A similar view was described by participant P3: "*I was trying to match it with my breathing*" (P3), and P1, who experienced the aliveness quality of the inflating pouch: "*I kind of felt it, and felt like breathing, something that's alive that's breathing with me*" (P1).

6. DISCUSSION

This section revisits the three research questions. **RQ1 focused on how we can design tangibles as situated mindfulness technologies.**

For this, we reflect on our approach to designing TaHaMi: a novel tangible prototype integrating two haptic actuators to provide subtle, real-time support for mindfulness meditation to novice meditators. It extends the current space of mindfulness technologies focused on mostly distal sensory modalities through visual (Daudén Roquet et al., 2023) or aural feedback (Cochrane et al., 2018, 2021; Sas and Chopra, 2015), while the haptic modality remains limitedly explored (Kim et al., 2021) despite its potential for stronger hedonic and embodied qualities (Umair et al., 2021) for attention regulation (Daudén Roquet and Sas, 2021).

However, unlike visual or aural interfaces, tangibles raise additional questions on how they may become seamlessly situated within mindfulness meditation (Bien and Didonna, 2009; Kabat-Zin, 2013, 2016) as they are not only to be seen or listened to, but actively held. To design TaHaMi, we employed a somaesthetic approach (Höök et al., 2016) through first person experience of our initial prototypes, which previous research has also leveraged for mindfulness technologies (Daudén Roquet and Sas, 2021). We started by exploring hand postures in mindfulness meditation, and selected cosmic mudra because it lends itself to holding an object, especially a sphere-shaped, which may fill in the space between the two palms. Next, we looked at cosmic mudra's mechanoreceptors to identify a suitable combination of haptic actuators stimulating these mechanoreceptors. For the haptic interaction, we leveraged bodily experiences during meditation (Daudén Roquet and Sas, 2020), force image schemata (Lakoff and Johnson, 2008), and embodied metaphors (Daudén Roquet and Sas, 2021) for mind wandering and mindfulness: downward and upward movement. Our approach illustrates a novel way in which tangible mindfulness technologies can be designed.

RQ2 explores the feasibility of vibration motors and pneumatic soft actuators for mindfulness meditation. We extend previous work on comparative exploration of two actuator modalities, such as thermal and sound (Daudén Roquet and Sas, 2021) or haptic submodalities such as vibrations and thermal (Umair et al., 2021), to vibration and soft inflation. Our design exploration informed the complementary fit of two haptic actuators to support awareness of mindfulness states and refocus of attention to the present moment during mind wandering.

Both actuators were explored to support the perception of movement, experienced on the thumbs and palm, while holding the TaHaMi sphere in cosmic mudra hand posture. They required experimentation to identify the range of vibration intensity and duration, as well as inflation speed and amount. To design a vibrotactile pattern as a downward continual movement, we integrated both travelling and asymmetric vibrations. The former are vibrotactile patterns that support perception of travelling in space across vibration motors (Israr and Poupyrev, 2011; Kim et al., 2009). The latter are sole vibrations with asymmetric phase, which support perception of direction-like quality on the skin (Culbertson et al., 2017), and we leveraged them to better convey the lingering downward pull or feeling of weight, as the movement progresses to the final vibration motor.

Thus, we extended the concept of asymmetric vibrations from a single vibration source to what we call *1D vibrotactile array with overlapping, temporally asymmetric actuation*. This is a small 1D array of vibration motors, where each motor is independently controlled, and with partly overlapping actuation with its nearby motors in order to generate a continuous movement in space. Temporal asymmetry, such as our extended actuation for the second and third motor, can support richer motion qualities, like lingering downward movement.

RQ3 focused on how novice meditators may personalise tangible interfaces

Findings indicate that participants overestimated during personalisation the two parameters that mattered the most: the intensity of vibrotactile patterns and the speed of inflation. This is an interesting outcome. On the one hand, personalisation matters as it supports users' autonomy, and future adoption through the IKEA effect (Sas and Neustaedter, 2017).

Personalisation also addresses individual differences in haptic perception (Umair et al., 2021) and sensory thresholds (Ekman et a., 2021). On the other hand, the overestimated intensity of vibrations, and speed of inflations aligns with users' need for stimulation (Sheldon et al., 2001) that interactive interfaces have been traditionally designed to support (Hassenzahl, 2010). In contrast, mindfulness interfaces benefit from less stimulation (Sas and Chopra, 2015) which users are less familiar with.

Our study extends those on users' personalisation of haptic actuators, such as vibration intensity for stress regulation, which showed a preference for lower values (Umair et al., 2021). Our results indicate that for mindfulness meditation, about half of novice meditators selected high values from the provided range, and that most acknowledged such overestimation. However, unlike stress regulation which most people engage in often, mindfulness is a new practice for novices. Findings also show that participants appreciated vibrotactile patterns for their low intensity and ability to gently prompt users to breathe in order to bring their attention back to the present moment from mind wandering. They indicate the challenge that higher intensity vibrotactile patterns pose for a self-judgemental stance.

Participants also appreciated the pneumatic soft actuator's qualities of a subtler, more natural, and calmer experience, which supported the identification of mindfulness state and its lived experience. Inflating pouch also provided an indication of progress, which most participants appreciated, although for a few, it also indicated a possible risk of attachment to the mindfulness state. This is important, suggesting the value of soft actuator to provide a light calibration input, which previous research argued that novice meditators can benefit from (Abdoun et al., 2019; Nyklíček, 2020). Another key experiential quality of the pneumatic soft actuator was its aliveness, which not only prompted users to breathe deeply but also the slow breath entrainment with the gentle inflation and deflation of the pouch. This opens up novel design opportunities to integrate support for deep breathing in mindfulness technologies.

7. DESIGN IMPLICATIONS

Study outcome led to four implications for the design of tangible interfaces for mindfulness technologies to support novices' mindfulness phenomenology, non-judgemental attitude, deep breathing, and design for subtle, ephemeral, non-gamified interaction.

Support Novices' Mindfulness Phenomenology

Findings indicate that novice meditators appreciated low intensity vibrotactile patterns as feedback on mind wandering, prompting grounding through deep breathing. The soft pressure inflation supported awareness of mindfulness states and as a subtle marker of progress, contributed to self-efficacy. It was also perceived as supporting slow breathing. These outcomes are important since meditation is a deceptively demanding practice requiring time and effort to learn to attend to, and regulate one's attention, whose tacit and internal characteristics make it difficult (Abdoun et al., 2019; Rowe et al., 2016; Nyklíček, 2020). Much research on the lived experience of mindfulness indicates that novice meditators can benefit from support to correctly identify their phenomenologically ambiguous meditation states (Abdoun et al., 2019).

Tangibles in particular, through their integration in the situatedness of meditation and its hand postures (mudras), open up novel design opportunities to support such awareness of the lived experiences of meditation states (Abdoun et al., 2019) and their phenomenology (Lutz et al., 2015).

Support Novices' Non-Judgmental Attitude

Study findings also showed that more intense patterns increased self-judgemental attitude, and the 10 seconds gap between patterns was perceived as small by some participants. Non-judgmental attitude is essential to mindfulness meditation, supporting the acceptance of each experience as it arises, without judgment or reactance (Bishop et al., 2004; Kabat-Zinn, 2013). The design of our haptic actuations for both vibrotactile and soft pressure feedback supported regulation of attention in mind wandering and awareness mindfulness state. In particular, downward movement of vibrations prompted grounding through three deep breaths, and inflating the pouch during mindfulness states supported their phenomenological recognition, which novices need (Abdoun et al., 2019; Nyklíček, 2020).

However, our findings also indicate potential for a self-judgmental attitude, particularly of intense vibrations delivered during mind wandering, and by attachment to the outcome (i.e., experience of mindfulness state) rather than the process of meditation. These indicate the need for sensitive design for subtle real-time feedback, which decreases over time as novice meditators

understand the felt experience of their meditation states, and gradually shift reliance from external to internal indicators of progress. Future work may explore how such support can evolve over time to limit users' dependency on it and increase their ability to self-regulate attention without external support.

Integrate Support for Deep Breathing within Mindfulness Technologies

Findings also indicate the value of deep breathing, both for grounding and the one prompted by the raising and falling of the soft pouch. Previous research suggested fewer bodily sensations when mindfulness is achieved, even when preceded by sensations of light and upwards movement (Daudén Roquet and Sas, 2020).

In our case however, deep breathing was already introduced as part of initial grounding, and also prompted by vibrotactile feedback. Moreover, the expressive quality of the pneumatic soft actuator to resemble breathing motion was particularly highlighted. Thus, we can draw from the growing HCI research on supporting deep breathing through vibrations (Hao et al., 2017; Miri et al., 2020), or even shape-changing interfaces (Farrall et al., 2023). We can also extend such work from wearables or hand-level actuation, to finger-level actuation where fine-grained control of actuators' intensity, speed, and timing is critical.

Design Subtle, Ephemeral, Non-Gamified Interaction

Together, our findings extend previous calls on the importance of limiting the risk of self-judgmental attitude entailed by real-time feedback on mindfulness training (Daudén Roquet and Sas, 2019; Guluzade and Sas, 2026). We extend such a call to tangibles for mindfulness meditation, through design guidelines for subtle, ephemeral, and non-gamified interaction. For this, we can explore design for just noticeable feedback: large enough to be noted, albeit in the background, without distracting attention from the meditation itself. Individual differences in haptic thresholds (Kawai and Tanaka, 2022) and people's preference for personalisation of haptic feedback (Umair et al., 2021) can also be accounted for. We thus suggest support for personalisation within low vibration intensity range, i.e., 35 PWM (22Hz), and inflation speed 10000 RPMs.

We also suggest designing for ephemeral interactions in the form of just-in-time, transient feedback on mindfulness states that remains unlogged and non-gamified in order to provide light calibration for awareness of one's progress during initial stages of mindfulness meditation, while prioritising internal memory of one's progress rather than external history of achievements.

8. Limitation and Future Work

We acknowledge the limitation of our small sample and qualitative findings, hence the need of careful generalisation, and of future work focusing on exploring the efficacy of TaHaMi for mindfulness meditation. Findings also indicate the challenge of personalising beyond low intensity vibration or low speed inflation, and its likelihood to increase self-judgemental attitude. This suggests that users can benefit from clearer personalisation guidance towards more subtle neurofeedback, and from the provision of a lower range of vibration intensity and inflation speed. While we aimed to provide low to medium values for these parameters, future work could focus exclusively on the lower range. Regarding the discomfort associated with self-judgemental stance, this may not be entirely prevented, as it is integral to novices' progress with mindfulness training. However, users may benefit from more detailed induction regarding self-judgmental stance and how to be used as opportunity to re-focus attention to the present moment rather than reactively engaging in further mind wandering. Future work can also explore wireless functionality and more ergonomic shape to support the exploration of TaHaMi in naturalistic settings.

9. Conclusion

We report the design of TaHaMi, a tangible interface integrating vibrotactile patterns and pneumatic soft inflation for mindfulness meditation. This was personalised and explored by 19 novice meditators with findings indicating the value of low intensity vibrations, and low inflation speed, of vibrotactile pattern perceived as a downward movement to prompt grounding through deep breaths, and of upward inflation movement to increase phenomenological recognition of awareness of mindfulness state. Our findings inform four design implications for tangible mindfulness meditation technologies to support novices' mindfulness phenomenology, non-judgmental attitude, deep breathing, and subtle, ephemeral, non-gamified interaction.

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