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Adapting haptic feedback for guided meditation

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Abstract

Technology supporting meditation is a multimillion-dollar market that continues to grow. There is also strong academic interest to understand and improve the impact technology can have for the user experience of practitioners. However, little work investigates how to modulate haptic feedback to accommodate individual requirements without using biomarkers. In collaboration with a cognitive neuroscience laboratory, we investigated interactions between users and a haptic meditation device through two design research studies. Preliminary evaluations with 20 participants showed a preference for digital over analog interfaces for parametrization of the haptic meditation device. The final study with 21 participants found that the hedonic and pragmatic preferences depend on both the experience of a user and their age. The work gives new insights into designing interfaces for haptic meditation which allow for parametrization of haptic feedback parameters, as well as a variety of options for the parameterization approach.

CCS Concepts

• ***Human-centered computing*** → ***Interaction devices; Interaction design;*** *Systems and tools for interaction design;* • ***Hardware*** → *Emerging interfaces;*

1. Introduction

Meditation is a practice in which individuals train their attention and awareness through various techniques in order to enter a specific emotional and mental state [GNSW04]. By adopting an alert and relaxed body posture in a calm, quiet environment [KZH09], a distinctive state of clarity and concentration is induced [WS06]. Notably, the effects of meditation improve over time as practitioners become more accustomed to its techniques [LW07]. Originally practiced in many religious traditions, secular forms of meditation, namely the Mindfulness-Based Stress Reduction program developed by Jon Kabat-Zinn in 1979, have become increasingly popular over the last 50 years [GNSW04]. Indeed, practicing meditation regularly has been shown to have significant benefits to physical and mental wellbeing [BR03, FMC06]. Thanks to this, there is a growing interest in using technology to facilitate meditation. Mindfulness meditation devices have reached a multi-million-dollar market with an annual growth of 8.5% [Kim18]. Academic publications have also followed an exponential development over the last decades, with more than 1100 academic papers published in 2015 [vDvVV*18].

Technological supports for meditation range from mobile applications, such as Headspace (https://headspace.com), to wearable devices, like Muse (https://choosemuse.com), and temple installations, such as the Ming Shan Digital Experience https://digital-experience.mingshan.ch. These can help attract people to the practice of meditation, and facilitate the effectiveness of the experience itself [HCR*21]. Guided meditation in particular is useful in getting people started with the practice [GNSW04] thanks to the instructions and steps it provides [KZH09].

Many technological supports give practitioners audio-visual feedback in real time, often based on physiological parameters such as breathing, to help them achieve a state of meditation. Recently, other work has looked at using haptic cues to facilitate meditation, as it is considered well-adapted to a practice which focuses on bodily sensations [BS15, FBCH20]. These typically work by monitoring, matching and then regulating the breathing rate of the user. Nonetheless, haptic feedback can cause distraction when combined with other modes such as light and sound feedback [VR13, DW11], and little work addresses how to counter this. In addition, without using biomarkers, few addresses how to adapt haptic feedback to fit the individual needs of practitioners.

Here we report on an investigation into interactions, performed by the meditator, to modulate the haptic parameters of a multi-modal (haptic, audio and visual) system to support meditation developed by Metaphysiks (https://metaphysiks.ch), a start-up spin-off from the Laboratory of Cognitive Neuroscience (LNCO) at the École polytechnique fédérale de Lausanne. The device, designed for wellness centers and public use, uses a technology called MetaTouch: a hydraulic system allowing precise thermal and pressure display on an inflatable silicone cell [IMA*23]. During a short,

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Figure 1: *Using a smartphone to set the parameters of the haptic meditation device. (Image © EPFL+ECAL Lab/Calypso Mahieu)*

guided meditation session based on breathing control and mindfulness, feedback is given through changes in pressure, temperature and rhythm of inflatable cells under the surface of the device, placed under the feet of the practitioner. Within the framework set by the collaboration, we evaluated how different interaction modes influence the experience of users (UX) and whether this has an influence on the quality of meditation.

This collaboration between cognitive neuroscientists, engineers, and design researchers gives new insights into the design of interfaces for haptic meditation devices and how these should allow adaptation to a range of personal and evolving factors.

2. Related Work

Technologies that support mindfulness and meditation are of increasing interest in HCI [DRS20b, THHS19]. Propositions range from mobile applications to wearable devices, as well as larger and more immersive installations that aim to help practitioners achieve and maintain the desired meditative state. Many approaches give creative feedback to meditators in real time based on various physiological parameters. Some focus on mapping breath onto soundscapes or other audiovisual feedback [VR13, PTF*18, RGFH17], whilst others use biomarkers such as heart rate [vRLH*16], brain activity [SI15] or skin conductivity [HCR*21]. Analyses of such approaches indicate benefits including deepening the meditative state [HCR*21, VR13] and making practitioners aware of mind-wandering during meditation [BWK17].

Yet despite the immediate benefit of a technology that responds directly to biomarkers, there are concerns that the practitioner could become over-reliant on it, and would miss the opportunity to train themselves to become aware of mind wandering [DRS20a]. Nonetheless, adapting feedback to individual differences is important, as an individual's familiarity with meditation, their familiarity with using devices to support meditation, as well as personal preferences, can all affect their experience with technology-supported meditation [HCR*21, DRS20a]. Therefore, alternative ways for individuals to adapt the feedback they receive should be found, although the interaction and meditation phases should be separated to allow the focus of mind during meditation [HASSNR17].

Whilst the examples already mentioned are based around audio and visual feedback, other work suggests the relevance of haptic feedback for meditation, a practice in which bodily sensations are highly important [BS15, FBCH20]. This is supported by the outcomes of exploratory workshops with meditation practitioners, in which the lived experience of distinct meditation stages was described by participants as relating to parts of the body and physical sensations [DRS20a]. However, some approaches that combine haptic feedback with other modes, have been shown to have the potential to distract the meditator [VR13, DW11]. Therefore, suggestions have been made for future work to limit the feedback modes to two [Sar06]. Indeed, in an evaluation of the multimodal, haptic installation Soma Mat, which combines just audio and heat feedback, participants reported an increased awareness of body changes and breathing [SJM*16]. Nonetheless, work that combines the benefits of haptic feedback with interactions to allow for individual differences is limited.

Therefore, the scope of this project was to investigate how a meditator could set the parameters of a haptic feedback device for meditation. This took place over 2 studies; the first compared levels of control and the interaction media, the second evaluated a more developed final proposition.

3. Study 1: Level of control, interaction type and exploration

There are many ways in which the device supporting meditation could be parameterized with regard to pressure, temperature and rhythm. Indeed, a literature review and analysis of other meditation technology products led to various questions which were addressed in this first study. Firstly, existing products use both digital (e.g. [SNSMHA*17]) and analog (e.g. [TGM*17]) controllers. We hypothesized that in this context, the former has the advantage of flexibility, whilst the latter might integrate better into the haptic multimodal experience. Therefore, our first research question was whether users prefer digital or analog interaction for parameterization. Secondly, as the perceived level of control is considered critical to a self-regulation experience [VR13], two further research questions were developed. One was whether users prefer gradual adjustment options or binary high/low settings. The other was whether users prefer explicit, conscious parameterization (understanding the setting they have chosen) or a more experience-based, unconscious parameterization (ludic interaction with a digi-

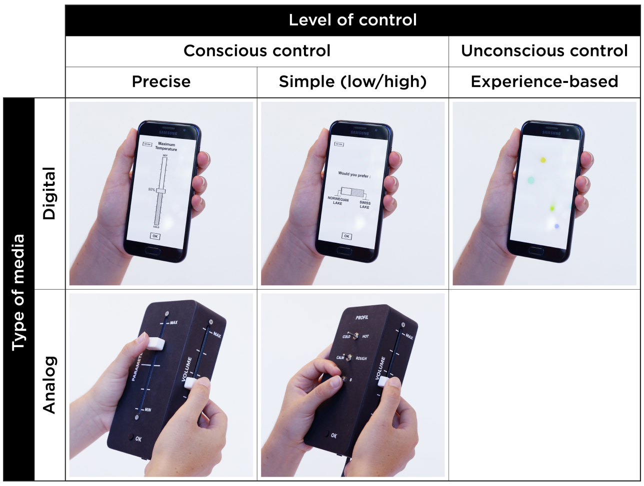

Figure 2: *The five prototype conditions.*

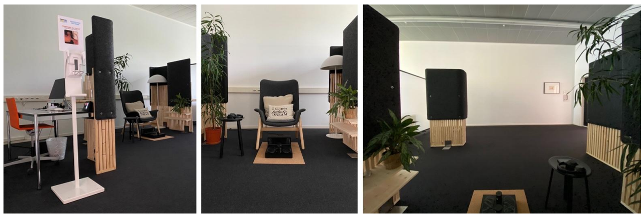

Figure 3: *Different views of the user evaluation room.*

tal interface without directly indicating the different parameters that are to be adjusted).

To address these questions, we developed 3 scenarios, which were differentiated by the level of control (precision and complexity) of their interactions. In the precise condition, participants were given a multi-level scale to determine the strength of each parameter. This allowed precise changes, with a more technical, pragmatic expression. In the simple condition, each parameter was split into two extreme values instead of a scale. This allowed for simpler changes but less nuance. Inspired by applications such as Pause (https://ustwo.com/work/pause), the experience-based condition uses touch-reactive fluid graphics to set the parameters. The aim was to promote a more hedonic interaction with the interface.

A digital and analog prototype was made for the first two scenarios. The experience-based prototype was unrealizable with an analog version, so existed only as a digital application. The five prototypes are summarized in Figure 2.

3.1. Participants

20 participants from the general population took part in this study. 8 were meditation practitioners and 12 were novices. Ages ranged between 21 to 60 years old ($M = 37.55, SD = 13.22$).

3.2. Protocol

Following a controlled (Latin-square) repeated measures design, each participant evaluated all five prototypes (participants evaluated one prototype per day). After arrival, participants were guided into a room with a calm ambiance and dim light (Figure 3). A facilitator explained to them the purpose of the study, the measures that were recorded (physiological data, questionnaire data), and asked them to read and sign the information and consent forms. They were also offered the opportunity to request a 50CHF cash reward, which they would receive as compensation at the end of the last session. They were then installed in an armchair with their bare feet in contact with the haptic device. The facilitator placed the disposable electrodes (Biopac EL507, using a Biopac SS57LA lead set) on the index and middle finger of the non-dominant hand of participants, which were then connected to the Biopac MP36 recorder. Next to the chair was a coffee table, where the prototype (Android smartphone (SAMSUNG Galaxy A3) or analog controller) to control the haptic device and the earphones (SONY WH-1000XM3) for the instructions, audiobook and guided meditation were placed.

When the experiment was about to start, the facilitator withdrew behind the partition wall to check the physiological measurements and the instruments. Neither they, nor the technology, were visible for the participants. No assistance was given to the participants. During each session, participants first listened for five minutes to an audiobook (a passage without "action" from the fictional story Sherlock Holmes) for baseline measures of the physiological indicators. Then, they completed the parametrization tasks on the prototype, which took between two and five minutes, followed by a 10-minute multimodal guided meditation combining voice over and haptics. The 10-minute session was chosen as it gives enough time to enter a meditative state whilst being short enough for the practicalities of the study.

After this, participants rated their user experience of the parametrization application based on the Short User Experience Questionnaire (UEQ) [SHT14] and evaluated the quality of their meditation session based on two items ("how pleasant was your meditation experience today?" and "how deep was your meditation today?" on a Likert scale ranging from 1 (very unpleasant/shallow) to 7 (very pleasant/deep). These questions were chosen based on previous work and consultation with a user experience psychologist. In addition, electrodermal activity (EDA) was assessed throughout the three phases of each session (baseline, parametrization, meditation) and the time used for parameterization was measured.

In a first step, data was analyzed comparing the four prototypes in the conscious control conditions (i.e., digital vs. analog and precise vs. simple) using a two-factorial repeated-measures ANCOVA with age as covariate. In a second step, all five prototypes were compared in a one-factorial ANCOVA (using age as covariate).

3.3. Findings

Comparison of UX evaluations (overall UEQ measure) between the four conscious control conditions indicated no significant main effect of type of media ($F < 1$) and level of control ($F < 1$). However, the interaction of the two factors reached a significant level,

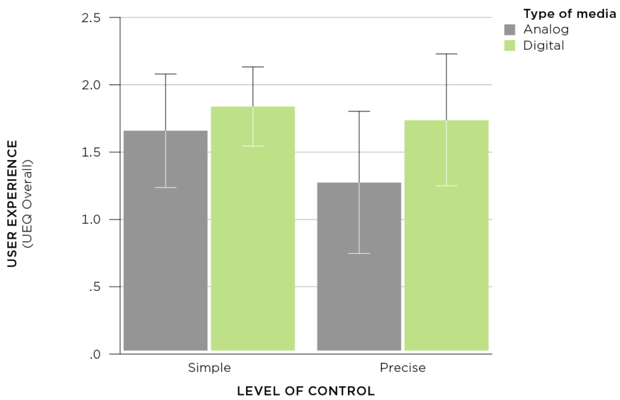

Figure 4: *UEQ Overall as a function of type of media and level of control (error bars indicate 95% CI).*

$F(1,18) = 4.76, p = .043, \eta_p^2 = .21$). Figure 4 illustrates this interaction effect, which indicates that especially in the precise condition, the digital interface led to higher UX ratings.

Similarly, in terms of subjective meditation experience, a 3-factorial GLM comparison (with Precise/Simple and Digital/Analog, and meditators/non-meditators as a third factor) revealed a significant main effect ($F(1,18) = 5.39, p < 05, \eta_p^2 = .23$) of Digital interaction media over Analog. Other results showed the potential of all scenarios for different situations and users. For example, expert participants valued the playfulness of the experience scenario, rating it as "excellent", (above 1.55 according to the benchmark [SHT14]) with a mean of 2.03, ($SD = .67$) for the hedonic aspect of the UEQ, the only prototype to do so. In terms of meditation quality for novices however, the simple and precise scenarios were preferred. Additionally, the time taken to configure the device was significantly faster with the digital version of simple scenario compared to the other prototypes ($F(2.9, 52.6) = 15.0, p < .001, \eta_p^2 = .45$), with an average of 108.99 seconds ($SD = 43.97$).

3.4. Conclusion

These results led us to conclude that we should continue with the design of a digital interface. Due to the variation in results for level of control and experience, depending on the experience of meditators, we decided to maintain multiple scenarios for parameterization. Therefore, in addition to being able to adjust the haptic feedback, meditators could also choose the way in which to do so. Creating a digital interface, instead of an analog one, also facilitated this flexibility.

4. Interface Design

We designed a three-scenario smartphone application to control the pressure and rhythm, as well as the temperature of the feedback given by the haptic device. These two parameters could be independently controlled to allow for a greater degree of personalization. The three scenarios are Define (Introduction), Explore and Compose (Figure 5). Users can choose their preferred scenario to set up the haptic device based on their preference or expertise.

Figure 5: *The Define, Explore and Compose scenarios.*

Define (Introduction) is the most pragmatic scenario, communicating simplicity and efficiency. In three successive stages, a switch allows the user to compare and make a choice between the two options proposed. The two options represent the two extremes of a particular parameter such as cold and hot. This scenario is also used for on-boarding users who are new to the application as it introduces all of the parameters one by one and was the fastest set up scenario in our preliminary tests (scenario 2).

Explore allows users to set up the experience by moving a cursor on a surface where two pairs of parameters – related to movement (calm/rough) and temperature (hot/cold) – are represented on two orthogonal axes. The user is therefore able to directly interact with the device according to actions they can clearly understand. This

Figure 6: *The eight haptic profiles.*

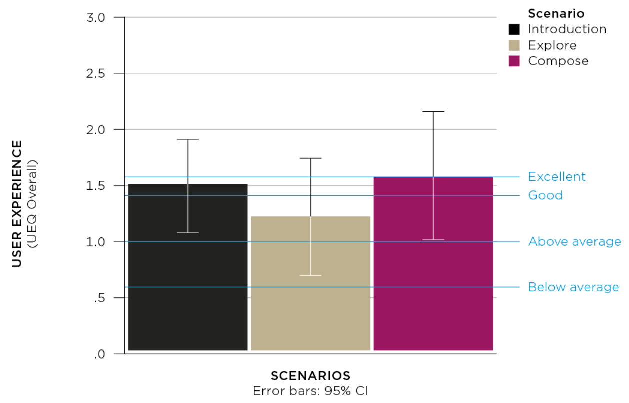

Figure 7: *UEQ Overall scores for all prototypes.*

fine-tuning gives users the possibility to indicate their preferences with precision.

Compose, the most hedonic scenario, allows users to compose their own personalised haptic pattern. This is based on the idea that different people will have different preferences for hot/cold or rough/smooth sensations. In a playful representation, they place a succession of sensations of their choice, defining their order and duration.

Having completed the parametrization, regardless of the chosen scenario, all users are assigned one of eight "haptic profiles" (Figure 6) which corresponds to a different combination of parameters. We matched each haptic profile to a water body such as a lake or a sea, as the cyclical variations in pressure, temperature and rhythm of the pixels of the device can simulate the feeling of waves underfoot. For example, a Swiss Lake would be gentle and cool, whilst the Mediterranean Sea would be warmer and rougher. The aim here was twofold. Firstly, to let the user quickly understand the meaning of the profiles with something relatable. Secondly, to give recurrent users something easy to remember for future use.

With their haptic profile defined, the user begins the guided meditation session. At this point no further interactions are required from the user, and no further visual feedback is given. The session starts with a human voice to foster concentration on awareness of body and mind, through attention to different body parts and breathing. After a few minutes of immersion, ambient sounds contextualize the session. The voice then asks users to imagine themselves with their feet on the edge of the lake or sea defined in their haptic profile. For one minute, users will feel warm waves under their feet, which can vary in intensity depending on the haptic profile. This is followed by another minute of cold waves, and so on until the end of the session. During this alternation, users are asked to focus on the perceived sensations and to explore the feeling in their body and in their mind. After 10 minutes of meditation, the session is over.

5. Study 2: Interface evaluation

5.1. Participants

21 participants were recruited from the general population: their ages ranged from 20 years old to 67 years old, ($M = 42.62, SD = 13.46$). Participants reported a mean monthly meditation frequency of 8.81, 0 being the minimum and 30 the maximum.

5.2. Protocol

Participants interacted in a repeated measures design with three interactive scenarios over three separate sessions on different days. The Define (or Introduction) scenario was always presented in the first session as it was considered important for the general understanding of the parameterization process. The two other scenarios were presented in a randomized order. The procedure, measures and instruments of study 2 were identical with the ones described in study 1.

Data was analyzed using analysis of covariances (ANCOVA), with age entered as covariate. To better illustrate significant interaction effects of participants' age, two equal groups were created (persons under and over 40). This is purely a measure to illustrate the interaction effects - the statistical analysis is based on the continuous data.

6. Findings

User Experience based on the UEQ (User Experience Questionnaire) indicated positive evaluations for all three interfaces. Compared with the benchmarks published with the UEQ instrument [SHT14], all scenarios obtained high scores (cf. Figure 7) ranging from above average (for the Explore prototype) to good (Introduction) to excellent (Compose). Statistical comparison of the UEQ-evaluations of the different prototypes showed a significant effect of prototype, $F(1.5, 26.3) = 11.28, p < .001, \eta_p^2 = .39$, when controlling for age as covariate. Holm-corrected post-hoc comparisons however did not reveal significant differences in UEQ-evaluations between the three versions of the application. Meditation practice did not show a significant main effect, $F(1, 18) = 1.23, p =$

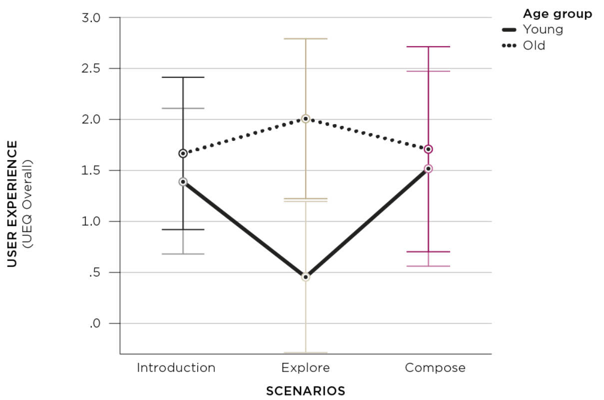

Figure 8: *UEQ Overall scores as a function of prototype and age (error bars indicate 95% CI).*

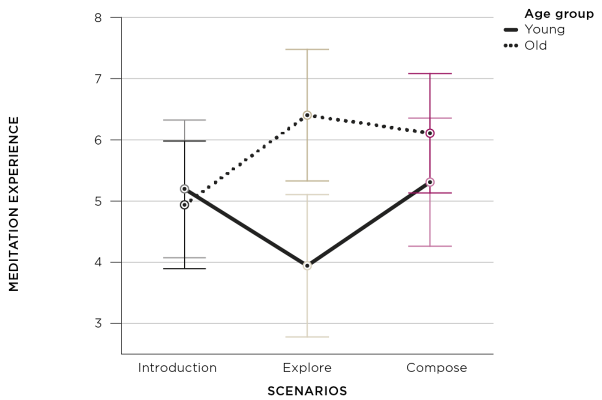

Figure 9: *Subjective evaluation of meditation experience as a function of prototype and age (error bars indicate 95% CI).*

$.28, \eta_p^2 = .06$. While the main effect of age was not significant ($F < 1$), the interaction of age and prototype reached significance level, $F(1.5, 26.3) = 9.66, p = .002, \eta_p^2 = .35$. Figure 8 illustrates this interaction (based on a median split of age for illustration purposes), indicating that UEQ evaluations of younger participants were lower for the Explore scenario compared to older participants while age did not show an effect in the other two scenarios (i.e., Introduction and Compose). The interaction of meditation practice and scenario as well as the three-way interaction did not reach significance level ($Fs < 1$).

In terms of configuration, there was no significant main effect of the interface on the configuration ratings, $F(2, 30) = 1.31, p > .05, \eta_p^2 = .08$, but the perception of the configuration was significantly influenced by the interaction between the interface and the participants' experience, $F(4, 30) = 2.92, p < .05, \eta_p^2 = .28$. Thus, the Exploration interface was rated as most appropriate, easy, useful, and fun, by both participant groups with high meditation experience ($M = 5.72, SE = .47$) and those with medium experience ($M = 6.20, SE = .45$), whilst it was rated lowest by inexperienced participants ($M = 5.85, SE = .44$). These participants rated the Composition interface the highest ($M = 6.35, SE = .53$) whilst it was rated lowest by the participants in the medium experience group ($M = 4.89, SE = .54$). However, post-hoc analysis revealed that none of the mean values differ significantly (all $p > .05$). Neither participants' age, $F(1, 15) = 1.05, p > .05, \eta_p^2 = .06$, nor participants' experience, $F(2, 15) = 1.04, p > .05, \eta_p^2 = .12$, significantly influence the configuration ratings. In addition, no other interaction effects reached significance level (i.e., interface x participants' age, $F(4, 30) = .41, p > .05, \eta_p^2 = .03$; interface x participants' age x experience, $F(4, 30) = 1.77, p > .05, \eta_p^2 = .19$).

With regard to subjective perception of the meditation, data analysis revealed a significant effect of the scenario, $F(2, 36) = 5.15, p = .011, \eta_p^2 = .22$. Participants rated their meditation as being deeper and more pleasant with the Compose interface ($M = 5.61, SE = .24$), compared to Explore ($M = 5.10, SE = .26$), and Introduction ($M = 4.86, SE = .24$), with Holm-corrected post-hoc tests revealing a significant difference between Introduction and

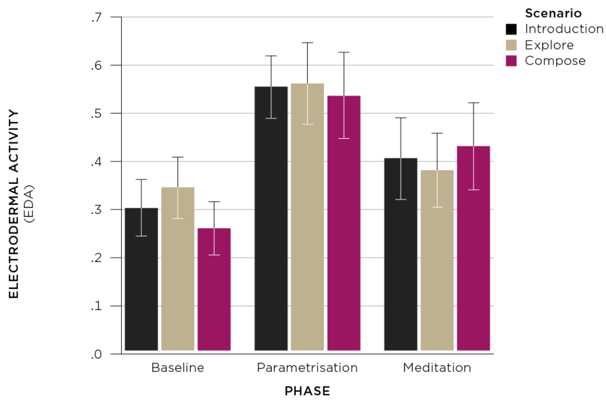

Figure 10: *EDA as a function of Prototype and Phase of the study (error bars indicate 95% CI).*

Compose ($p = .03$). While age, meditation practice, and the interaction scenario showed no noteworthy influences on meditation experience (both $Fs < 1$), there was a significant interaction between age and prototype, $F(2, 36) = 5.19, p = .010, \eta_p^2 = .22$, with young participants reporting lower values for the explore prototype compared to older participants (see Figure 9 for an illustration of the interaction effect based on a median split of age).

Analysis of Electrodermal Activity (EDA) data as indicator for physiological arousal (c.f. Figure 10) indicated a significant effect of phase ($F(2, 76) = 39.6, p < .001, \eta_p^2 = .68$) but no main or interaction effect of prototype and weekly practice ($Fs < 1$). Post-hoc comparisons indicated significant differences (all $p < .002$) between the three phases, with lowest electrodermal activity for the baseline measure, followed by the meditation phase and the parametrization phase. All were within typical ranges.

Qualitative comments collected from participants are reported here with the frequency across the three sessions in brackets. Many comments were positive with the following words being used repeatedly: “pleasant” (8), “nice” (8), “relaxing” (5), “peaceful” (3) and “soothing” (3). Some gave recommendations for making the session longer to induce a deeper meditative state (6), and others suggested giving more contextual information to understand the scenario (4). There was some variation in opinion regarding the voice of the guided meditation. 7 positive comments were made stating that “the voice is soothing and non-intrusive” and “helpful in relaxing”, but equally, 6 other comments criticized the voice for its tone (1) and content (5).

7. Discussion

This project explored how to adapt haptic feedback for meditation. We looked at strategies to dissociate interaction and meditation to avoid distraction, as well as how to take into account the individual needs of practitioners without using biofeedback.

Our preliminary work indicated that in our context, digital controllers were preferred in a direct comparison with analog ones. We can speculate that this was due to the fact that participants are more accustomed to seeing unfamiliar digital interfaces than unfamiliar analog ones. It could also have been perceived as more adaptable and flexible, allowing for more hedonic interfaces. Nonetheless, care must be taken to avoid other distractions of using smartphones as controllers (from unassociated notifications for example). In addition, other successful projects have used analog interfaces [TGM*17], and our participants were relatively young, therefore future studies could repeat this comparison in different contexts, and gather further qualitative data to understand preferences.

The results of the first study also led to the conclusion that the parameters of feedback have to be adjusted for individuals with different meditative experience, as cited by existing work [HCR*21, DRS20a]. However, on top of this, we also showed that the way in which the parameters are adjusted, must also be adaptable depending on expertise and context. Indeed, in our second study, comparisons of the different parametrization scenarios showed that the evaluation of their pragmatic and hedonic values, did depend on the user’s experience of meditation.

In our second study, we also found that age affects evaluations of pragmatism and hedonism in the interface, something that we have not seen in other works. Participants over 40 liked the medium-level of control of the Explore scenario significantly more than those under 40, who found the more complex, gamified Compose scenario more attractive. These findings suggest that future work should consider taking into account both an individual’s meditation experience and age in the interactions.

Qualitative remarks collected from participants also highlighted varying opinions, with mixed reactions about the voice for the guided meditation. This suggests another aspect of the multimodal meditative experience which could be adapted in the future for different users. Another direction could be to develop the voice to synchronize with the haptic feedback, as demonstrated in immersive storytelling audio-haptic experiences [SRF*22].

In the second study, all the scenarios proposed were evaluated highly in terms of user experience of the interaction, as well as the perception of meditation. This could be due to several factors in the design that were informed by previous projects. Firstly, the personalization of the haptic profile could have enhanced the experience. In addition, the interactions to set the parameters all occurred before meditation, reducing the chance of distraction during the session [HASSNR17]. Finally, the haptic feedback was given in a cyclical fashion which has been suggested by other works as a support for meditation practice [DRS20a].

Comments from the participants did not mention a specific value in the haptic profiles, which we contextualized as lakes and seas in order to help users understand and recognize them. Nonetheless, several participants mentioned that there could have been further contextualization to help match the haptic sensations to a state of mind. This suggests an interesting direction of investigation for future projects working with haptic feedback for meditation.

8. Conclusion

Meditation is a practice that can have significant benefits to physical and mental wellbeing. As such, there is growing academic and commercial interest in using technology to facilitate meditation. Approaches that provide haptic feedback are suggested as having particular relevance for supporting meditators, because of the importance of bodily sensations to the practice. However, little work investigates how best to modulate this feedback to fit the range of needs required by different individuals without the use of biomarkers. In this paper we reported on a collaboration between design researchers and a cognitive neuroscience laboratory, in which interactions between users and a haptic meditation device were investigated in two studies. Findings from the first study showed that users preferred a digital over an analog interface in this context. Secondary evaluations highlighted that hedonic and pragmatic preferences depend on both the experience of a user and their age. The work can inform the design of interfaces for haptic meditation devices in the future and highlights the importance of adaptability to a range of personal and evolving parameters.

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