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A user-centered design approach for crafting personalized guided meditation

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ABSTRACT

Interest in technology supporting meditation continues to grow commercially and academically. Commonly, these approaches look at how audio-visual feedback based on physiological indicators can help induce a state of meditation. Haptic feedback is now seen as a promising alternative to audio-visual stimuli for meditation. However, as yet, little work has investigated how to personalize haptic feedback or how to combine it with other feedback modalities, notably audio-visual stimuli. In collaboration with a cognitive neuroscience laboratory, we investigated interactions between users and a haptic meditation device through three design research studies. Preparatory evaluations with 20 participants showed a preference for digital over analog interfaces for parameterization of the haptic meditation device. Based on these preliminary results, we developed a digital interface based on three scenarios of use. Extensive evaluations with 29 participants revealed high usability and aesthetic scores while highlighting different perceived user experience qualities. 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 multimodal interfaces for meditation which allow for parameterization of haptic feedback parameters, as well as a variety of options for the parameterization approach.

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 [1]. By adopting an alert and relaxed body posture in a calm, quiet environment [2], a distinctive state of clarity and concentration is induced [3]. 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 [1]. In her work, Shauna Shapiro characterizes Mindfulness as the awareness that arises from intentionally paying attention in an open, kind, and discerning way, along with the status of three fundamental pillars: the intention, the attention, and the attitude (IAA Model) [4]. Indeed, practicing meditation regularly has been shown to have significant benefits to physical and mental wellbeing [5,6]. However, it has been shown that the effects of meditation improve over time as the expertise of the meditator increases [7]. In this context, 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% [8]. Academic publications have followed an exponential development over the last decades, with more than 1100 academic papers published in 2015 [9].

Technological supports for meditation range from mobile applications, such as Headspace [10], to wearable devices, like Muse [11], and temple installations, such as the Ming Shan Digital Experience [12]. These can help attract people to the practice of meditation, and facilitate the effectiveness of the experience itself [13]. Guided meditation in particular is useful in getting people started with the practice [1] thanks to the instructions and steps it provides [2].

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 [14,15]. 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 [16,17], and little work addresses how to counter

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

this. In addition, without using biomarkers, few address 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 multimodal (haptic, audio and visual) system to support meditation developed by Metaphysiks [18], 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 [19]. During a short 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 (see Fig. 1). 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 human–computer interaction [20,21]. 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 [16,22,23], whilst others use biomarkers such as heart rate [24], brain activity [25] or skin conductivity [13]. Analyses of such approaches indicate benefits including deepening the meditative state [13,16] and making practitioners aware of mindwandering during meditation [26].

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 [27]. 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 [13,27]. 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 [28].

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 [14,15]. 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 [27]. However, some approaches that combine haptic feedback with other modes, have been shown to have the potential to distract the meditator [16,17]. Therefore, suggestions have been made for future work to limit the feedback modes to two [29]. 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 [30]. 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 the parameterization of a haptic feedback device for meditation should ideally be designed following a human-centered design approach. This took place over 3 studies; the first compared levels of control and the interaction media, the second compared the user experience of the three digital user interface scenarios, and the third evaluated a more developed – multimodal – final proposition, that includes sound and the haptic device.

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. [31]) and analog (e.g. [32]) 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 [16], 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 digital 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 multilevel 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 [33], the experience-based condition uses touch-reactive fluid graphics to set the parameters. The aim was to promote a more hedonic experience of the interface in which we intended for more interesting, and less typical interactions to promote engagement [34]. Furthermore, we intended to evaluate potential consequences of the parameterization procedure on the subsequent meditation in a subjective and objective way.

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 Fig. 2.

3.1. Participants

A diverse and well balanced (50% female) sample of 20 participants from the general population took part in this study. Eight were meditation novices and 12 were meditation practitioners (M = 17.9 min of meditation per week, SD = 26.1). Ages ranged broadly between 21 to 60 years (M = 37.55, SD = 13.22).

3.2. Procedure

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 (Fig. 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 50 CHF 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 parameterization tasks on the prototype, which took between two and five minutes, followed by a 10 min multimodal guided meditation combining voice over and haptics. The 10 min 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 parameterization application based on the Short User Experience Questionnaire (UEQ) [35] 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). In addition, electrodermal activity (EDA) was assessed throughout the three phases of each session (baseline, parameterization, meditation) and the time used for parameterization was measured. EDA is considered a reliable indicator of sympathetic arousal and has often been linked to affective states in psychophysiological research [36,37]. Therefore this physiological (objective) indicator was

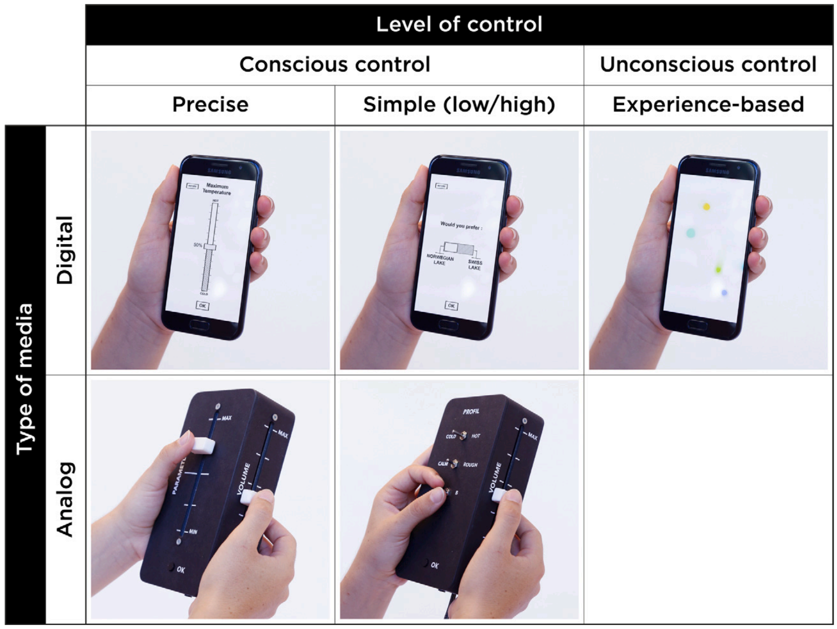

Fig. 2. The five prototype conditions.

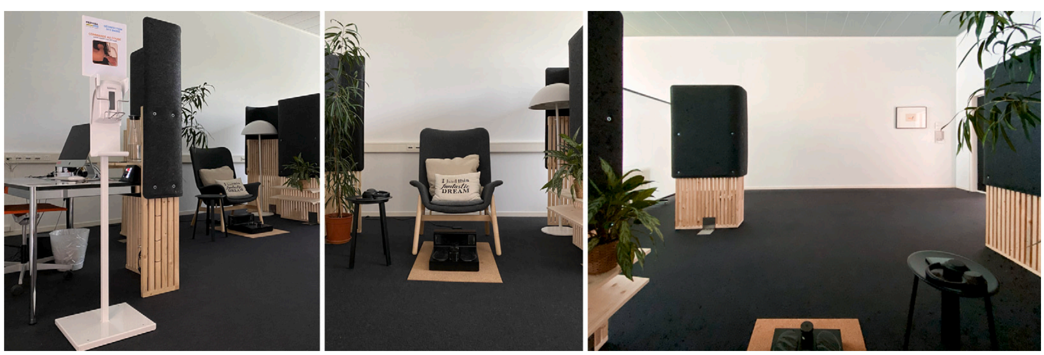

Fig. 3. Different views of the user evaluation room.

used in this study as proxy for meditative calmness (as opposed to arousal).

Data was analyzed comparing all five prototypes using a one-factorial ANOVA.

3.3. Results

Comparison of UX evaluations are presented in Fig. 4. The analysis of the **UEQ overall score** indicates a significant effect comparing the five prototypes ($F(2.3, 43.6) = 3.7$, $p = .03, \eta_p^2 = .16$). Sidak-corrected post-hoc analyses revealed one significant single comparison (comparing *Experience-based Digital* with *Simple Digital*, $p = .01$). Visual inspection of the mean values indicates that evaluations of *Experience-based Digital* and *Precise Analog* have obtained lower UX ratings compared to the other prototypes.

The analysis of measures of **Pragmatic Quality** revealed a significant effect ($F(2.0, 38.4) = 10.8$, $p < .001, \eta_p^2 = .36$) with sidak-corrected post-hoc comparisons (c.f. Fig. 5 for descriptives) revealing significant effects for the comparisons between *Experience-based Digital* with all the other prototypes but *Precise Analog* (p-values ranging between .001 and .48).

Interestingly, measures of **Hedonic Quality** did not differ significantly between the different prototypes ($F(2.9, 54.1) = 1.15$, $p = .34$, $\eta_p^2 = .06$).

Data analysis regarding the subjective evaluation of the **Configuration Procedure** revealed a significant effect ($F(4, 76) = 9.56$, $p < .001$, $\eta_p^2 = .34$). Pairwise comparisons (c.f. Fig. 6 for descriptives) with Sidak correction indicated lower ratings for *Experience-based Digital* compared to *Simple Digital* ($p = .01$), *Precise Digital* ($p = .001$) and *Simple Analog* ($p = .001$). All the other comparisons were not significant, the difference between *Precise Digital* and *Precise Analog* does, however, almost reach significance level ($p = .06$). This provides us some preliminary clues that a digital interaction modality might be particularly suitable to control a haptic device in a multimodal meditation context.

Participants' subjective evaluations of their **Meditation Experience** did not show significant effects between the different prototypes ($F(2.50, 47.48) = 2.10$, $p = .12, \eta_p^2 = .10$), neither did EDA data show significant differences between the five prototypes ($F < 1$).

In addition to these measures, **the Time participants needed to parametrize the meditation tool** was measured. Analysis of this data revealed a significant effect ($F(2.85, 54.05) = 15.84$, $p < .001, \eta_p^2 = .46$), with *Precise Analog* ($M = 278, SD = 123$), *Precise Digital* ($M = 278$, $SD = 89$), *Experience-base Digital* ($M = 252, SD = 102$) and *Simple Analog* ($M = 191, SD = 62$) requiring more time for the setup procedure compared to *Simple Digital* ($M = 109, SD = 44$). All Sidak-corrected post-hoc comparisons of *Simple Digital* with the other four prototypes were significant (p <.001) while all the other comparisons did not reach significance level.

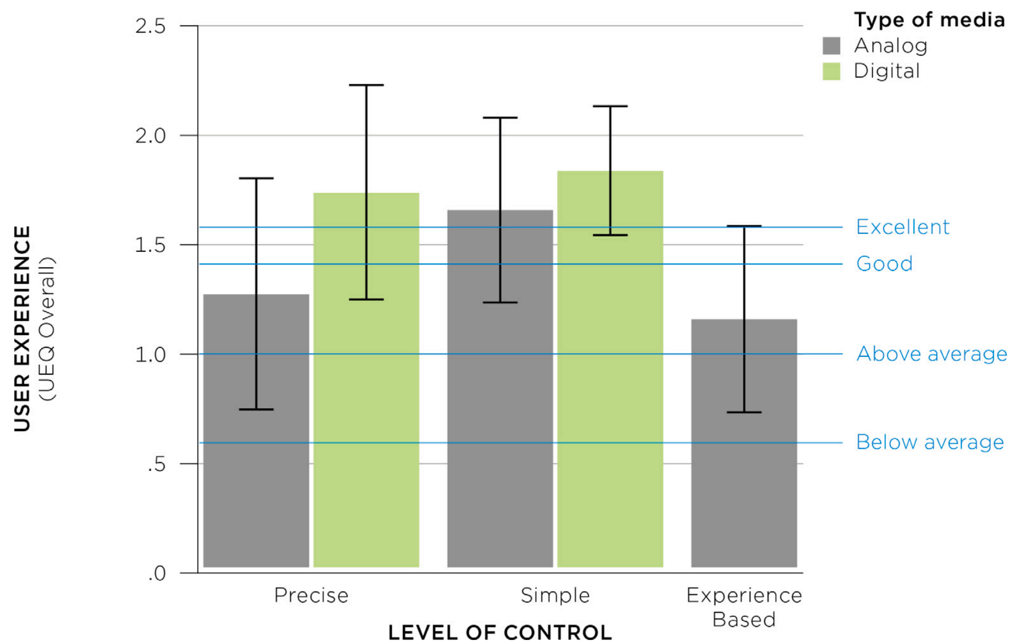

Fig. 4. UEQ Overall as a function of type of media and level of control (error bars indicate 95% CI).

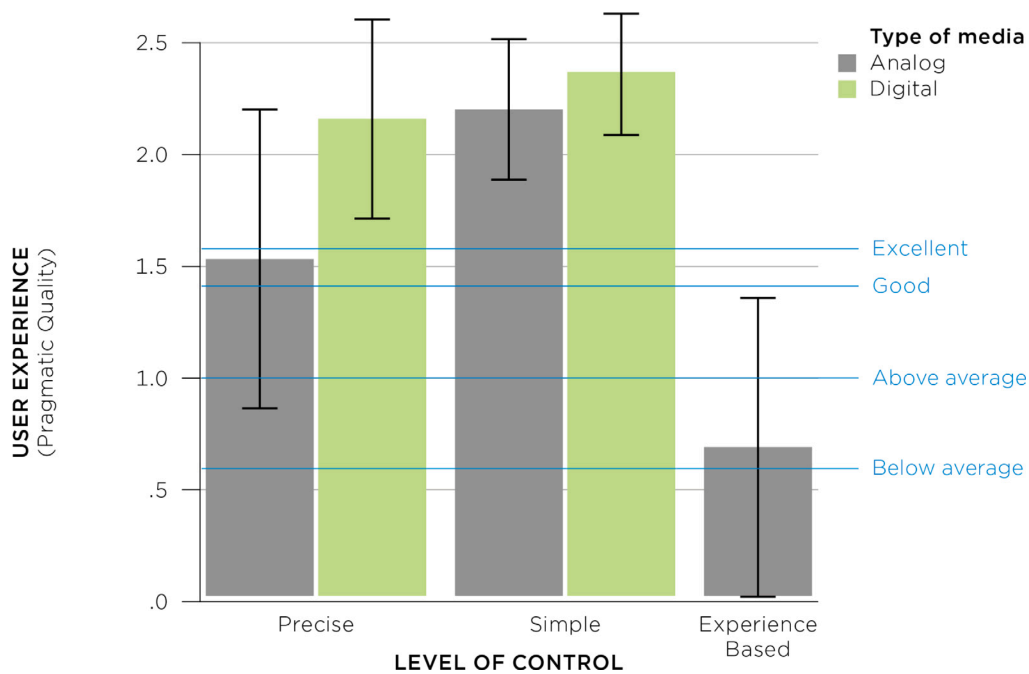

Fig. 5. UEQ Pragmatic quality as a function of type of media and level of control (error bars indicate 95% CI).

3.4. Discussion

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, 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

Based on the results of the first study, 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 were denoted *Define*, *Explore* and *Compose* (Fig. 7).

Our task was to create a digital user interface that seamlessly balance aesthetics with performance. This required meticulous selection and layout of graphical elements to prevent them from diverting users from their primary goal: enhancing the personalization of their meditative experience. Indeed, previous studies have shown that graphical elements can influence users' attention [38,39].

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 two options proposed.

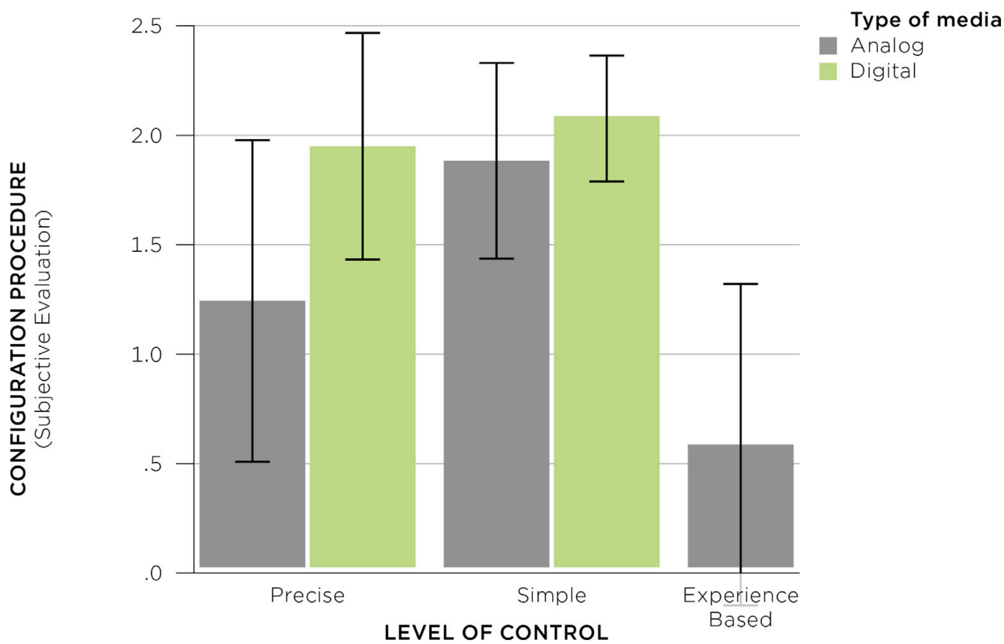

Fig. 6. Subjective evaluation of the configuration procedure as a function of type of media and level of control (error bars indicate 95% CI).

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.

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 users are therefore able to directly interact with the device according to actions they can clearly understand. This fine-tuning gives users the possibility to indicate their preferences with precision.

Compose, the most hedonic scenario, allows users to compose their own personalized 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 parameterization, regardless of the chosen scenario, all users are assigned one of eight "haptic profiles" (Fig. 8) 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 min of meditation, the session is over.

5. Study 2: Interface evaluation

Once we had designed our prototype, we carried out a study to evaluate participants' experience when interacting with it. We aimed to compare the scenarios (*Define*, *Explore*, *Compose*) as neutrally as possible. Indeed, studies show that contextual factors can influence the way a product is evaluated [40,41], as can the addition of haptic feedback to audio-visual media [42]. We therefore chose to conduct this study online, limiting the interaction to the digital prototype, without asking participants to meditate.

A high-fidelity digital prototype including an introduction and 3 scenarios was coded. It included all necessary features to control the haptic meditation device parameters (pressure, temperature, rhythm).

5.1. Participants

29 participants were recruited from the general population. Ages ranged between 19 to 49 years old ($M = 29, SD = 7.9$). Twenty-one were meditation practitioners and reported a mean meditation frequency of 35 min per week ($SD = 60.3$), 8 were novices reporting 0 min.

5.2. Procedure

The study was conducted online via a video-conference session in which a facilitator was present. Participants took part individually in a single-session of around 40 min and they received 20 CHF as compensation for their participation.

At the beginning of the session, the facilitator explained the aims of the study and the measures that would be recorded (questionnaire data). Participants were asked to be in a quiet and peaceful place, and to prevent any form of distraction (e.g. turn off their phones, close all other windows on their computer, etc.). We recommended that they imagine themselves in a wellness center where they were trying out a device designed to promote meditation and relaxation.

Regarding technical requirements, participants needed a device with sound output in addition to screen sharing capability, as sound is crucial for the digital prototype. The experiment started upon acceptance of the information and consent forms. Once the experiment was

Fig. 7. The *Define*, *Explore* and *Compose* scenarios.

underway, the facilitator switched off their video sharing to minimize distraction.

After completing the introduction on the prototype, participants interacted in a repeated measures design with the three interactive scenarios during a single session. Participants were asked to explore the different possibilities offered by the three scenarios independently. These scenarios were presented in a randomized order, following a Latin-square design.

As in the first study, participants were asked to complete a series of questionnaires specific to the configuration of the application after each scenario. Participants' user experience was measured with the short version of the UEQ (see 3, Study 1). At the end of the experiment, we asked the participants to evaluate the aesthetics of the prototype using the Visual Aesthetics of Websites Inventory (VisAWI) [43].

We calculated a mixed ANOVA with scenarios as repeated measures factor (3 levels: *Define*, *Explore*, *Compose*) and expertise as between subjects factor (Experts ($N = 21$) and Novices ($N = 8$)).

5.3. Results

User Experience based on the UEQ (User Experience Questionnaire) indicated positive evaluations for all three scenarios and the introductory path. Compared with the benchmarks published with the UEQ instrument [44], all scenarios obtained excellent scores. The analysis of the UEQ overall score indicated no effect between scenarios ($F < 1$). Expertise of participants did not show an effect ($F(1, 27) = 1.0$, $p = .33, \eta_p^2 = .04$), and no interaction with scenario was found: $F(2, 54) = 1.2$, $p = .37, \eta_p^2 = .04$.

Statistical analysis of the pragmatic quality revealed a significant effect between scenarios ($F(1.8; 47.2) = 5.08$; $p = .01, \eta_p^2 = .16$). Results are presented in Fig. 9. The pairwise comparisons with Sidak correction indicated that *Compose* and *Define* were significantly different ($p = .04$). All scenarios obtained high scores, ranging from Excellent (*Introduction*, *Define*, *Explore*) to Good (*Compose*) compared with the benchmarks. The

Fig. 8. The eight haptic profiles.

main effect of experience ($F < 1$) as well as the interaction of experience and scenario did not reach significance level ($F(1, 27) = 3.47$, $p = .07, \eta_p^2 = .11$).

Similarly, statistical analysis of the hedonic quality revealed a significant difference between scenarios ($F(2; 54) = 4.05$; $p = .02, \eta_p^2 = .13$). Results are presented in Fig. 10. The pairwise comparisons with Sidak correction indicated no significant differences even though the comparison between *Compose* and *Explore* is almost significant ($p = .056$). Compared with the benchmarks, scenarios obtained scores ranging from Excellent (*Compose*) to Good (*Introduction*, *Define*) to Above Average (*Explore*). The main effect of experience ($F < 1$) as well as the interaction of experience and scenario did not reach significance level ($F(2, 54) = 2.4$, $p = .01, \eta_p^2 = .08$).

Regarding the aesthetic measures (VisAWI Score), the global evaluation of the prototype revealed high ratings for all four dimensions (simplicity, diversity, colorfulness, craftsmanship) compared with the benchmarks published with the VisAWI questionnaire. However, the main effect of scenarios did not reach significance level ($F(2, 54) = 2.25$, $p = .12, \eta_p^2 = .08$), as for the interaction ($F(2, 54) = 1.15$, $p = .32, \eta_p^2 = .04$) and for the expertise ($F < 1$).

5.4. Discussion

This second study contributed to the development of our tool and confirmed that the different approaches formulated through our three scenarios can satisfy the needs of humans with different levels of previous meditation experience. This observation was expressed by the hedonic and pragmatic quality ratings, which revealed marked preferences for the *Define* scenario, which we hypothesized to be the most pragmatic, and the *Compose* scenario, which we hypothesized to be the most hedonic. These variations offered flexibility in parameterizing haptic feedback, while providing a tailored experience, despite the degree of expertise. In fact, overall, we did not observe any statistical difference in appreciation between experts and novices.

Evaluation of the aesthetics and configuration procedure also revealed high scores in comparison with the state of the art, which could suggest that our digital interface would be easy to learn and use, as it complies with best practices in the creation of digital tools.

Therefore, we decided to maintain each of our three scenarios and carry out a final in situ evaluation, in a context linked to wellbeing, meditation and relaxation, using the haptic device to accompany the various phases, including the meditation phase.

6. Study 3: Multimodal evaluation

The third and final study of this design research project was a multimodal evaluation combining the audio-visual media and haptic feedback. We invited participants to test our prototype, interacting with the three scenarios we tested in study 2 in a real-life meditation session, using the haptic device. The idea here was to evaluate a global experience, including a meditative part, as we did in the first study.

6.1. Participants

Twenty-one participants (16 identified as female, 5 as male) were recruited from the general population: their ages ranged from 20 to 67 years, ($M = 42.62, SD = 13.46$). Most of the participants meditated regularly, with a reported monthly mean meditation frequency of 8.8 ($SD = 11.6$) sessions, 0 being the minimum and 30 the maximum.

6.2. Procedure

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 3 were identical with the ones described in study 1.

Data was analyzed using analysis of covariances (ANCOVA), with meditation expertise and age entered as covariates. Age was considered because previous research has shown differences between younger and older participants when evaluating interfaces [45,46]. In this context, age can be considered a proxy for proficiency in technology use. Various studies have shown that there may be age-related differences in appreciation and performance when using digital media (e.g. button sizes [47,48]), but also similar preferences between generations (e.g. text layout [49]). To better illustrate significant interaction effects of participants' age, two equal groups were created (10 participants were under 40, and 11 were older). This is purely a measure to illustrate the interaction effects — the statistical analysis is based on the continuous data. Meditation expertise was considered as it showed important effects in previous research addressing questions of technology-enhanced guided meditation [13].

7. Results

User Experience based on the UEQ (User Experience Questionnaire) indicated positive evaluations for all three interfaces (c.f. 11). Compared with the benchmarks published with the UEQ instrument [35], all scenarios obtained high scores (cf. Fig. 11) ranging from Above Average (for the *Explore* scenario) to Good (*Define*) to Excellent (*Compose*). Statistical comparison of the UEQ-evaluations of the different scenarios showed a significant effect of scenario, $F(1.5, 26.3) = 11.28$, $p < .001$, $\eta_p^2 = .39$, 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 expertise did not show a significant main effect, $F(1, 18) = 1.23$, $p = .28, \eta_p^2 = .06$. While the main effect of age was not significant ($F < 1$), the interaction of age and scenario reached significance level, $F(1.5, 26.3) = 9.66$, $p = .002, \eta_p^2 = .35$. Fig. 12 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., *Define* and *Compose*). The interaction of meditation practice and scenario as well as the three-way interaction did not reach significance level (*all* $F < 1$). The analysis of the two subdimensions of the UEQ (i.e., pragmatic and hedonic quality)

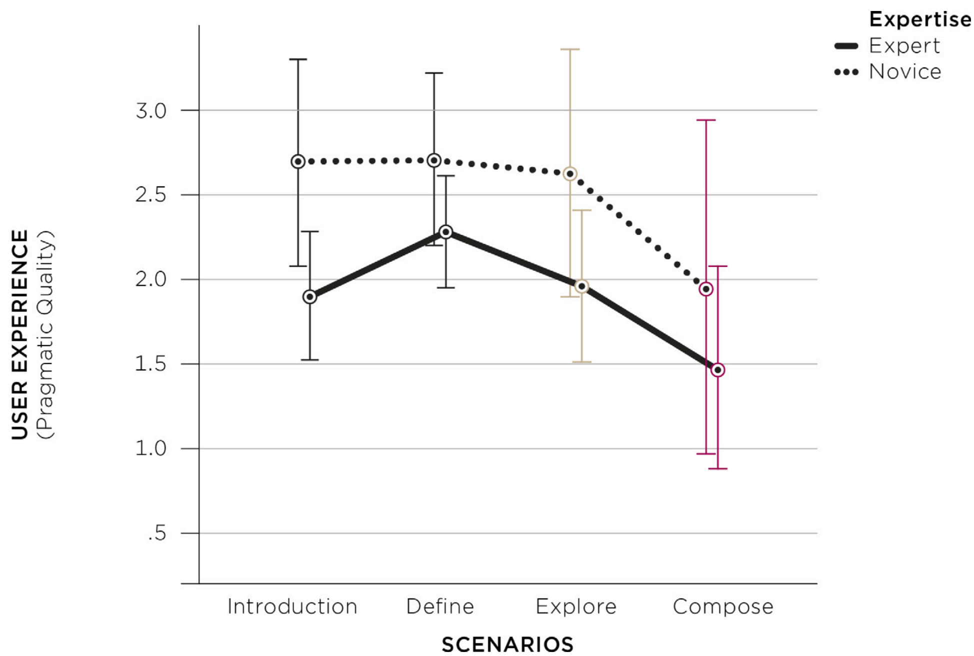

Fig. 9. UEQ Pragmatic Quality scores as a function of prototype and expertise. Error bars indicate 95% CI (between comparisons).

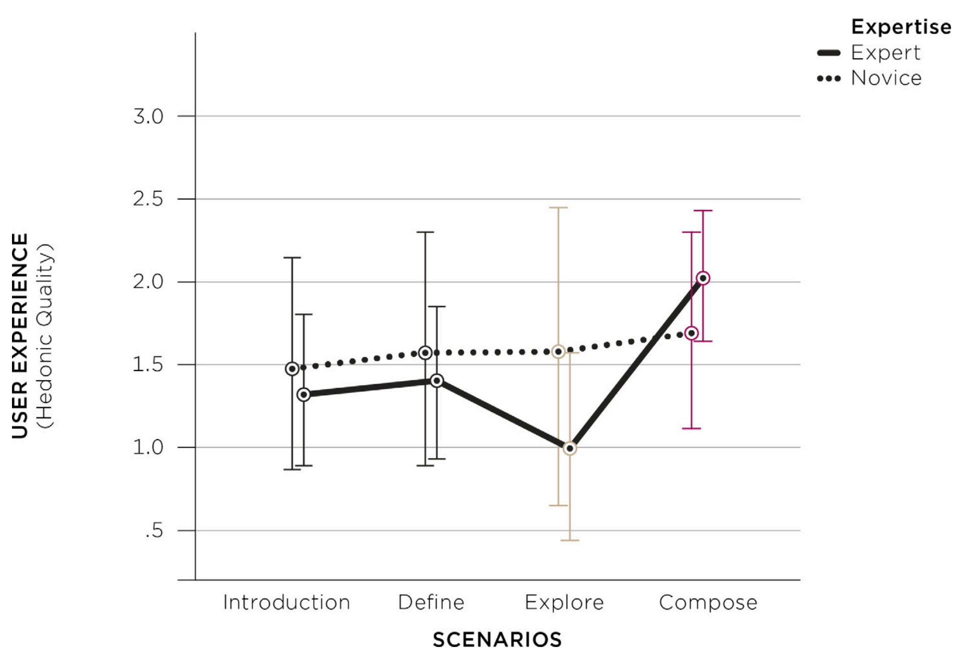

Fig. 10. UEQ Hedonic Quality scores as a function of prototype and expertise. Error bars indicate 95% CI (between comparisons).

did show a similar effect pattern and are therefore not reported in detail here.

Regarding participants' subjective evaluation of the configuration procedure, a significant main effect of the interface on the configuration ratings was observed ($F(2,36) = 4.95,\ p = .01, \eta_p^2 = .22$), with highest ratings for *Define* ($M = 5.9, SD = 0.94$), followed by *Explore* ($M = 5.8, SD = 1.1$) and *Compose* ($M = 5.7, SD = 1.6$). Sidak-corrected post-hoc tests however did not reveal any significant comparison. Participants' expertise and age did not show significant effects (all $F < 1$).

With regard to subjective perception of the meditation, data analysis revealed a significant effect of the scenario, $F(2,36) = 5.15,\ p = .01$, $\eta_p^2 = .22$. 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 *Define* and *Compose* ($p = .03$). While age and meditation expertise showed no noteworthy influences on meditation experience (*all* $F < 1$), there was a significant interaction between age and scenario, $F(2,36) = 5.19$, $p = .01, \eta_p^2 = .22$, with young participants reporting lower values

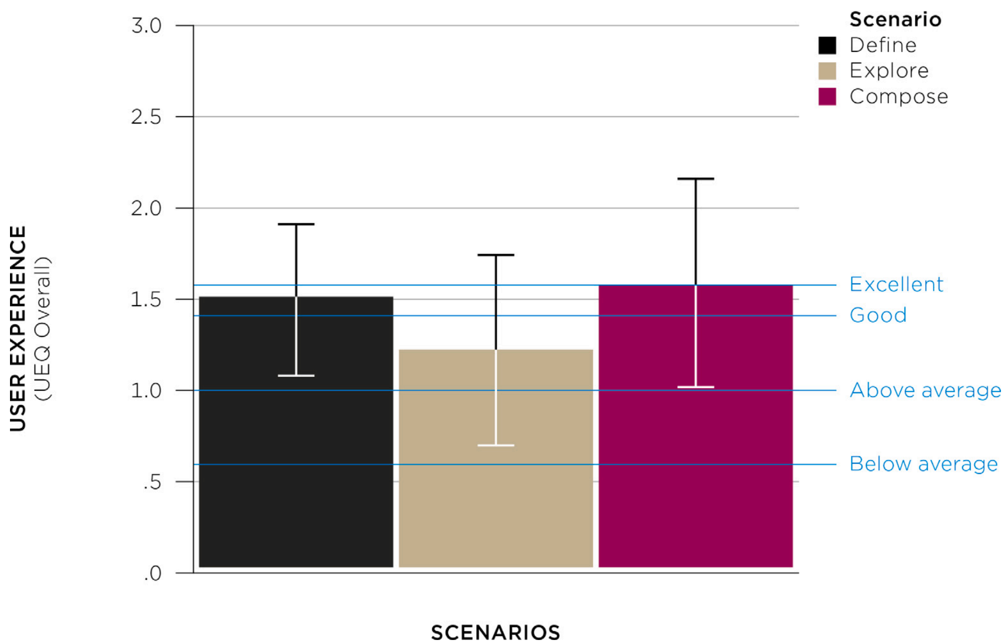

Fig. 11. UEQ Overall scores for all prototypes (error bars indicate 95% CI).

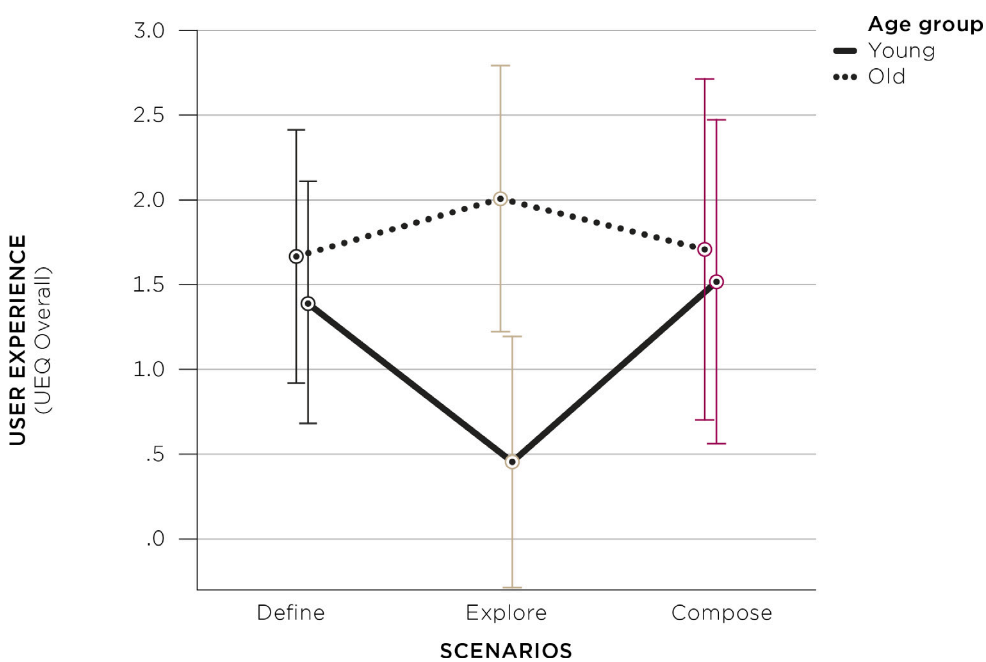

Fig. 12. UEQ Overall scores as a function of prototype and age (error bars indicate 95% CI).

for the *Explore* scenario compared to older participants (see Fig. 13 for an illustration of the interaction effect based on a median split of age).

Analysis of Electrodermal Activity (EDA) (c.f. Fig. 14) indicated different levels of physiological activation between baseline, parameterization and meditation phase ($F(2,76) = 39.6$, $p < .001, \eta_p^2 = .68$) but no main or interaction effect of scenario and meditation expertise ($all\ F < 1$). 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 parameterization phase. This result pattern was expected. During the baseline phase, participants remain seated quietly, following a controlled activity (listening to a calm audiobook). Then, they completed parameterization tasks, which increase physiological arousal due to active engagement and reflection, resulting in increased EDA levels. In the meditation phase, guided meditation was expected to lower psychophysiological arousal, as indicated by the EDA data.

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

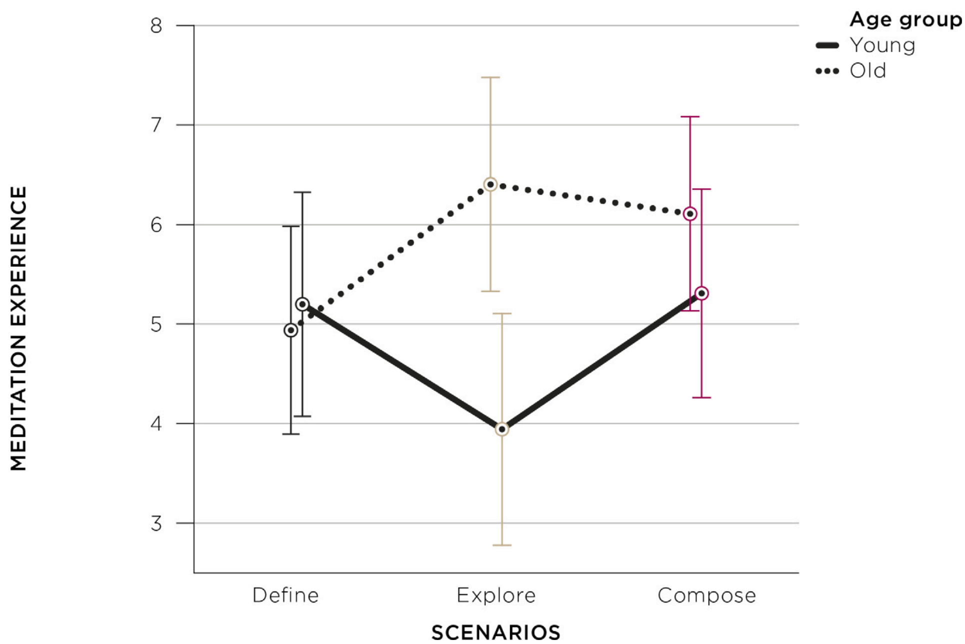

Fig. 13. Subjective evaluation of meditation experience as a function of scenario and age (error bars indicate 95% CI).

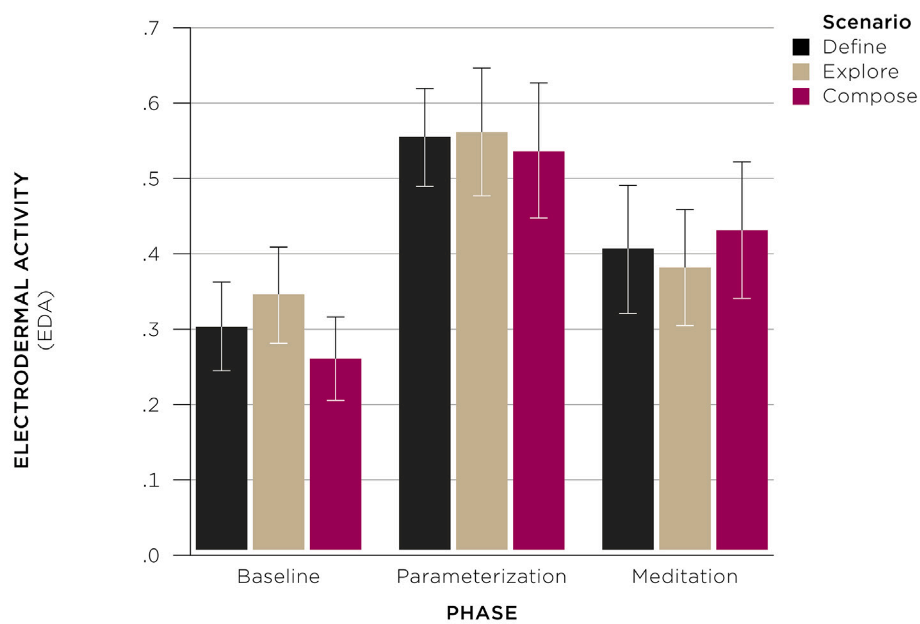

Fig. 14. EDA as a function of scenario and phase of the study (error bars indicate 95% CI).

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).

8. 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 solely analog interfaces [32]. This suggests that exploring distinct and innovative analogue device designs, rather than adhering to the conventional digital controller approach, could be a compelling direction. In fact, the resemblance between our analogue designs and familiar digital devices (e.g. smartphones) may have led to unfavorable comparisons, potentially placing analogue devices at a disadvantage. Therefore future studies could repeat this comparison in

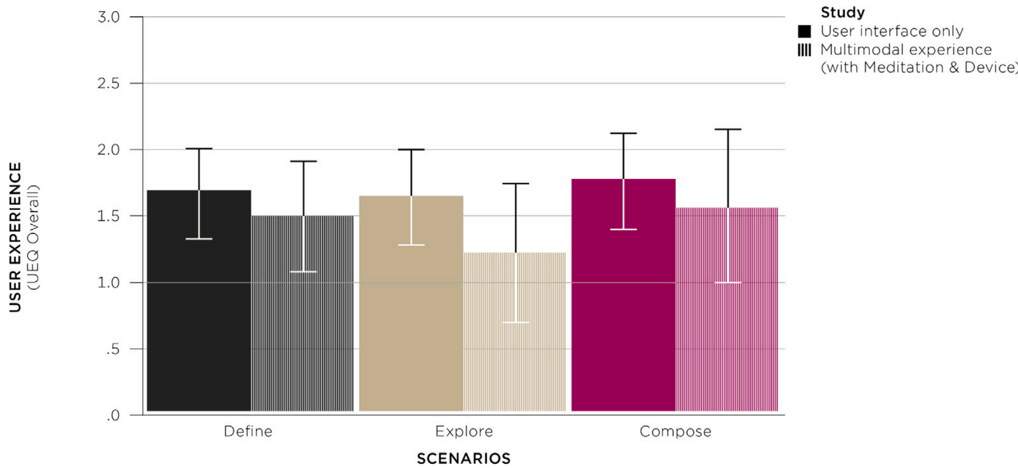

Fig. 15. Studies 2 (user interface only) and 3 (multimodal experience, with meditation and device) UEQ overall scores (error bars indicate 95% CI).

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 meditation expertise, as cited by existing work [13,27]. 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 third study, comparisons of the different parameterization scenarios showed that the evaluation of their pragmatic and hedonic values, did depend on the user's experience of meditation.

Our second study confirmed the idea that different scenarios were needed to address an audience ranging from experts to novices in meditation practice. In fact, although the three scenarios obtained similar ratings for the overall user experience (UEQ Score), the results from the hedonic and pragmatic dimensions indicated that the scenarios met their criteria differently.

These results were reinforced by the evaluation of aesthetics, which also highlights the good quality of our prototype (VisAWI Score). The dimensions of this questionnaire also showed a well-balanced distribution of values, which led us to suppose that the prototype was perceived as pleasantly varied, but coherent. This observation was all the more interesting given that previous research showed that aesthetics can influence the user experience [50].

In our second study, we were also confronted with the fact that the degree of expertise can play a role in the perception of our tool, and in the user experience. Although trends were discernible, the measures' differences between scenarios were not statistically significant, unlike in the third study.

In our third 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 expertise 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 [51].

In the third 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 [28]. Finally, the haptic feedback was given in a cyclical fashion which has been suggested by other works as a support for meditation practice [27].

The third study also revealed that a multimodal device can influence the perceived user experience of a digital user interface. Indeed, we compared the overall UEQ score and observed that all scenarios tended to be rated slightly lower when used simultaneously with a multimodal device (cf. Fig. 15), compared with using the user interface alone. Also, this comparison is not statistically significant and should be treated with caution. The panel of participants, the methodology and the context varied between the two studies. Nevertheless, this trend opens up interesting prospects for research into the accuracy of feedback in relation to the intentions when defining the parameters.

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. For example, instead of just the name "Swiss Lake" for a series of parameters, a longer qualitative description of an Alpine scene could be given. This suggests an interesting direction of investigation for future projects working with haptic feedback for meditation.

9. 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 such as breathing rate and heart rate. 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, placed under the feet of meditators, were investigated. Findings from the first study showed that users preferred a digital interface over an analog interface in this context. A secondary study revealed that scenarios of use based on different approaches can lead to a consistent overall user experience evaluation. However, hedonic and pragmatic qualities of this user experience differed depending on the user's level of experience with meditation. Tertiary evaluations highlighted that hedonic and pragmatic preferences depend on both the experience of a user and their age. Formulating different design hypotheses that addressed the research question of how to design the process to parametrize the device was challenging. The data obtained of users actually interacting with the different design options allowed us to test our design hypotheses empirically and make informed decisions about the future development of the interface. The work can inform the design of interfaces for multimodal haptic meditation devices in the future and highlights the importance of adaptability to a range of personal parameters such as age and meditation expertise. Finally, the approaches used in this project can provide inspiration for future interdisciplinary collaborations between engineers and designers.

CRediT authorship contribution statement

Romain Collaud: Writing – review & editing, Writing – original draft, Visualization, Project administration, Investigation, Conceptualization. **Yoann Douillet:** Writing – review & editing, Writing – original draft, Visualization, Software, Methodology, Investigation, Conceptualization. **Emily Groves:** Writing – review & editing, Writing – original draft. **Andreas Sonderegger:** Writing – review & editing, Validation, Methodology, Formal analysis, Data curation, Conceptualization. **Cédric Duchêne:** Software, Resources. **Nicolas Henchoz:** Writing – review & editing, Supervision, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Data availability

Data will be made available on request.

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