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DOI
10.3390/mti8020009

Publication date
2024

Document Version
Final published version

Published in
Multimodal Technologies and Interaction

Multimodal Technologies and Interaction

MDPI

Article

Technology and Meditation: Exploring the Challenges and Benefits of a Physical Device to Support Meditation Routine

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Abstract: Existing studies of technology supporting meditation habit formation mainly focus on mobile applications which support users via reminders. A potentially more effective source of motivation could be contextual cues provided by meaningful objects in meaningful locations. This longitudinal mixed-methods 8-week study explored the effectiveness of such an object, Prana, in supporting forming meditation habits among seven novice meditators. First, the Meditation Intentions Questionnaire-24 and the Determinants of Meditation Practice Inventory-Revised were administered. The self-report habit index (SrHI) was administered before and after the study. Prana recorded meditation session times, while daily diaries captured subjective experiences. At the end of the study, the system usability scale, the ten-item personality inventory, and the brief self-control scale were completed, followed by individual semi-structured interviews. We expected to find an increase in meditation frequency and temporal consistency, but the results failed to confirm this. Participants meditated for between 16% and 84% of the study. The frequency decreased with time for four, decreased with subsequent increase for two, and remained stable for one of them. Daily meditation experiences were positive, and the perceived difficulty to start meditating was low. No relevant correlation was found between the perceived difficulty in starting to meditate and meditation experience overall; the latter was only weakly associated with the likelihood of meditating the next day. While meditation became more habitual for six participants, positive scores on SrHI were rare. Despite the inconclusive results, this study provides valuable insights into challenges and benefits of using a meditation device, as well as potential methodological difficulties in studying habit formation with physical devices.

Keywords: meditation; habit; routine; meditation technology; meditation lamp

Citation: Kermavnar, T.; Desmet, P.M.A. Technology and Meditation: Exploring the Challenges and Benefits of a Physical Device to Support Meditation Routine. *Multimodal Technol. Interact.* **2024**, *8*, 9. https://doi.org/10.3390/mti8020009

Academic Editor: Wei Liu

Received: 21 December 2023
Revised: 24 January 2024
Accepted: 25 January 2024
Published: 29 January 2024

1. Introduction

Digital technology used to support meditation (hereinafter referred to as "meditation technology") is becoming increasingly popular in the Western world, especially among beginners of meditative practices who seek guidance to increase the effectiveness of their practice (see [1]). Meditation technology is available in the form of mobile applications (hereinafter referred to as "apps") and physical devices which are often supported by apps. Among the latter are various types of lamps (e.g., [2]), stroboscopic lights with hypnagogic effects (e.g., [3]), wearable biofeedback devices (e.g., [4]), EEG headsets (e.g., [5]), audio-visual stimulation devices (e.g., [6]), and neurostimulation devices (e.g., [7]). This diversity notwithstanding, apps appear to be substantially more popular, presumably due to their accessibility. Apps are commonly used for guidance by novices who are still learning to meditate, and mainly as "timers" by more advanced meditators [8,9]. Expert meditators, on the other hand, tend to avoid using meditation technology altogether and view it only as a distraction [9,10].

In addition to studies investigating meditators' attitudes toward meditation technology (e.g., [9]) and technology in general (e.g., [11]), several researchers attempted to assess the efficacy and/or effectiveness of meditation apps, and their findings have been

summarized in existing reviews (e.g., [12,13]). On the other hand, investigations into the efficacy/effectiveness of meditation devices are very scarce (e.g., [14,15]). In general, evaluations are most often based on improvements in psychological well-being, especially in relation to perceived tension/stress, anxiety, and/or depressive symptoms. Some studies also address the effects of technology-supported meditation on mood or emotional states, attentional control, mindfulness, or health behaviors, such as healthy nutrition, physical activity, sleep hygiene, and psychoactive substance use. The results of these assessments appear to be promising, although they should be interpreted with caution [12].

The most important reasons why people begin to meditate are to experience contentment and clarity, to calm down, to feel better, or to further personal growth [16]. These reasons tend to differ between novice and expert meditators, in that novices meditate to reduce negative affect, stress, and difficulties sleeping, whereas expert meditators prioritize enlightenment, spiritual experiences, and nurturing compassion for others [16]. This suggests that people's reasons to meditate may change over time, and that psychological profiles of meditators differ depending on the level of expertise.

Expert meditators typically engage in daily meditation for a number of years and habitually, whereas novice meditators often struggle most with establishing a meditation routine [17–19]. Habits develop gradually over 1–36 weeks [20–23] with consistent repetition of the target behavior; the likelihood of repetition depends on how rewarding the behavior is [24]. According to Basso et al. [25], the benefits of meditation only emerge after 8 weeks of daily practice, which may explain why about two-thirds of people who begin to meditate discontinue the practice [26]. Namely, habit formation requires motivation, and this can be negatively affected when progress toward the set goal is slow and/or when the reward is delayed (e.g., long-term health benefits) [27].

Surprisingly, only a limited number of studies to date have looked into the use of technology in support of meditation habit formation (e.g., [28,29]). Moreover, these studies focused on meditation apps which mainly support repetition via reminders; however, relying on reminders can actually hinder habit development [30,31].

An alternative, more effective source of motivation to adhere to meditation practice could be contextual cues, such as routine events, locations, and meaningful objects [32–35], the role of which has been extensively studied in the context of health-related habits (e.g., medication adherence [36–38], addiction [39–41], dietary behaviors [21,42], and physical activity [42,43]). Although contextual cues initially function as reminders, consistent reinforcement of cue–behavior associations eventually leads to automatic triggering of the behavior [44,45]. Thus, the advantage of meditation devices over apps may be their potential to facilitate habit formation simply by being physically present as *meaningful objects* in *meaningful locations* at the opportune moment for meditation.

To the best of our knowledge, the effectiveness of such contextual cues has not been studied to date. Thus, the aim of the present longitudinal study was to test whether technology-generated contextual cues can support the formation of meditation habits. We sought to use a realistic meditation-supporting device that would serve as a meaningful object consistently present in the user's meditation-dedicated personal space. An example of such a device is Prana, an interactive wall lamp designed to guide the user through their meditation session with the use of calming and immersive light effects. With Prana, *object* and *location* cues are utilized, and habit formation may be further expedited by pleasurable esthetic experiences that function as intrinsic rewards [46]. We were interested in the effects of 8 weeks of Prana use on the frequency and subjective experience of meditation in novice meditators interested in establishing a routine.

2. Materials and Methods

2.1. Study Design

This study employed a mixed-methods triangulation design (for an overview, see [47]). Quantitative data were obtained via psychometric scales and by recording the frequency and duration of participants' use of Prana. Qualitative data were obtained from partici-

pants' daily diary entries and semi-structured post-use interviews. The study design is summarized in Figure 1 and detailed in Section 2.3.

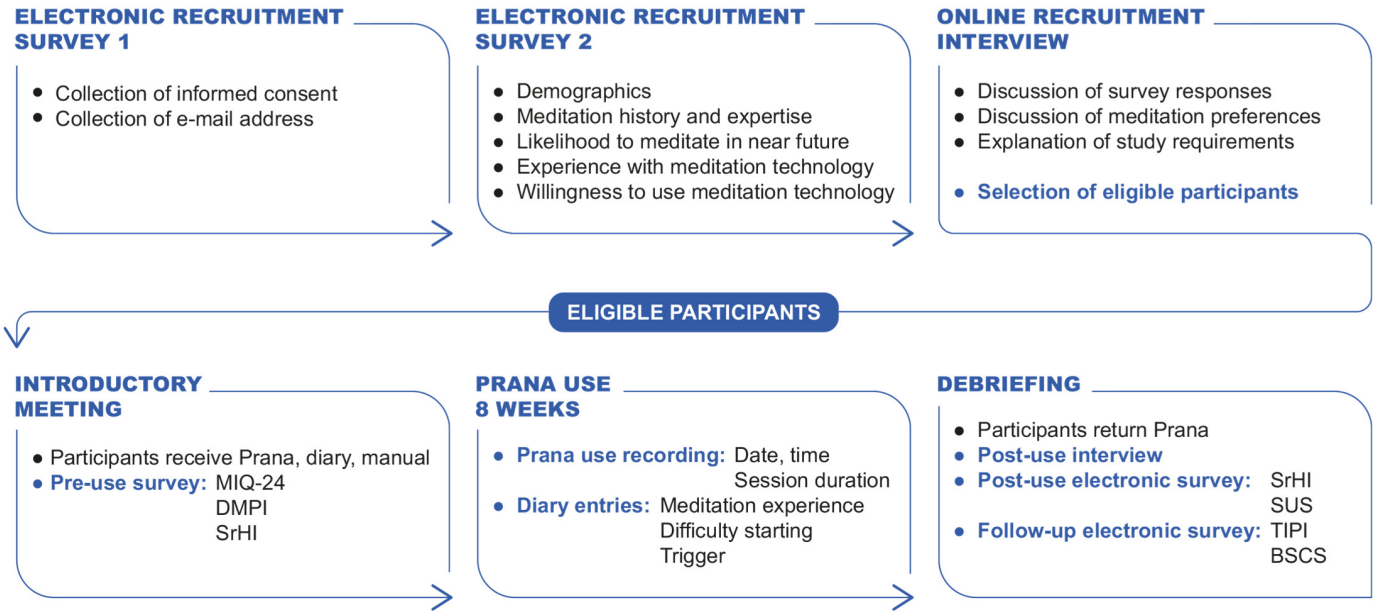

Figure 1. Study design. BSCS = brief self-control scale; DMPI = Determinants of Meditation Practice Inventory [48]; MIQ-24 = Meditation Intentions Questionnaire-24 [49]; SrHI = self-report habit index [50]; SUS = system usability scale [51]; TIPI = ten-item personality inventory.

2.2. Study Participants

Due to the small number of available prototypes and the extensive duration of the study, we aimed to recruit 5 participants. All participants were recruited using convenience sampling, as detailed in Section 2.3. People who were interested in meditation but experienced difficulties establishing a meditation routine were eligible to participate. Exclusion criteria were severe visual impairment, photophobia, and epilepsy; we also excluded those who did not have sufficient time or physical space to commit to the study.

2.3. Tools and Equipment

2.3.1. Prana

The meditation lamp Prana was developed in 2021 by Gijs Spierings as part of his master's thesis at the Delft University of Technology (TU Delft; [52]). It consists of a 3D-printed custom frame (Ø = 364 mm; Figure 2A) produced by fused filament fabrication (FFF) of polylactic acid (PLA). The frame supports nine internal LED strips (Figure 2D) that light up the front of Prana, and an external LED strip (Figures 2E and 3B) that illuminates the wall behind the lamp. The front of the lamp is covered by a 3 mm structure diffuser (Figure 2B) and a 2 mm matte acrylic sheet (Figure 2C). The frame is hung on the wall by means of a simple wall mount (Figure 3A).

When plugged into the power socket, Prana is in a "stand-by" mode. It is activated ("on" mode) by the press of a pushbutton at the back of the device (Figure 3E). After activation, the program will run in three consecutive stages (Figure 4). In the first stage, Prana lights up following a specific "breath pacer" sequence for 90 s to help the meditator gradually decelerate their breathing. This facilitates physical and mental relaxation and prepares the user for meditation. Then, the meditation session (second stage) is automatically activated, during which the user meditates according to their personal preference, while being triggered by a bright light notification ("focus trigger") every 2 min to prevent them from getting lost in thought. In the third stage, the session ends with a 60 s colorful light effect ("light show") which is intended to be calming and immersive, and helps the meditator transition from the meditative state back to everyday life. At the end of the

program, Prana automatically returns to the "stand-by" mode. A demonstration can be viewed online (https://youtu.be/QuHX_0NOh24) (accessed on 20 January 2024).

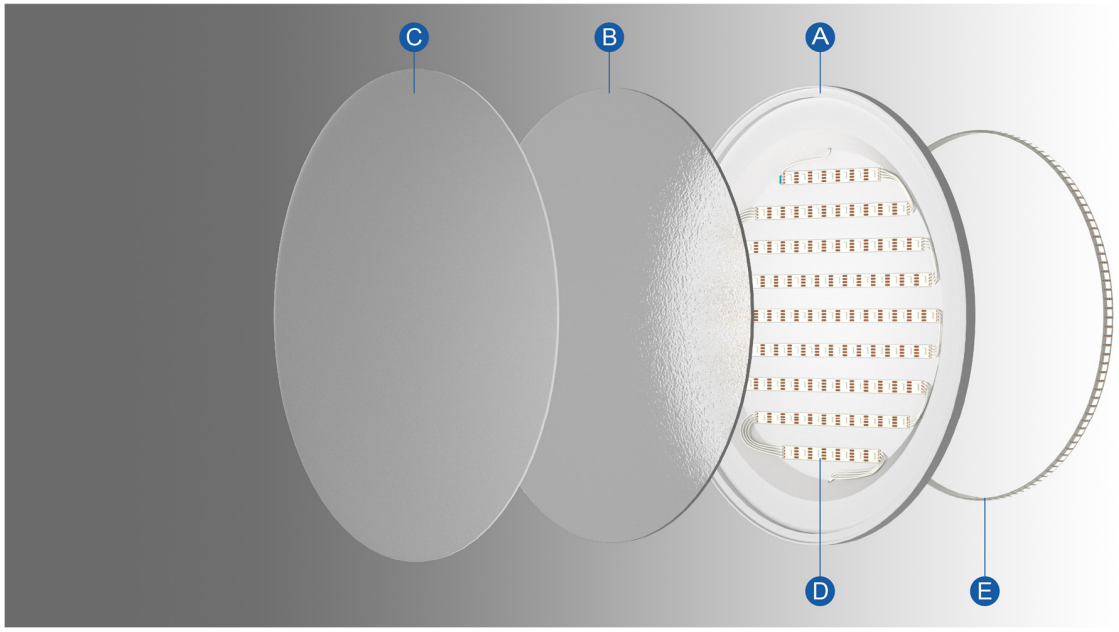

Figure 2. Exploded front view of Prana. A = frame; B = 3 mm structure diffuser; C = 2 mm matte acrylic sheet; D = internal LED strips; E = external LED strip.

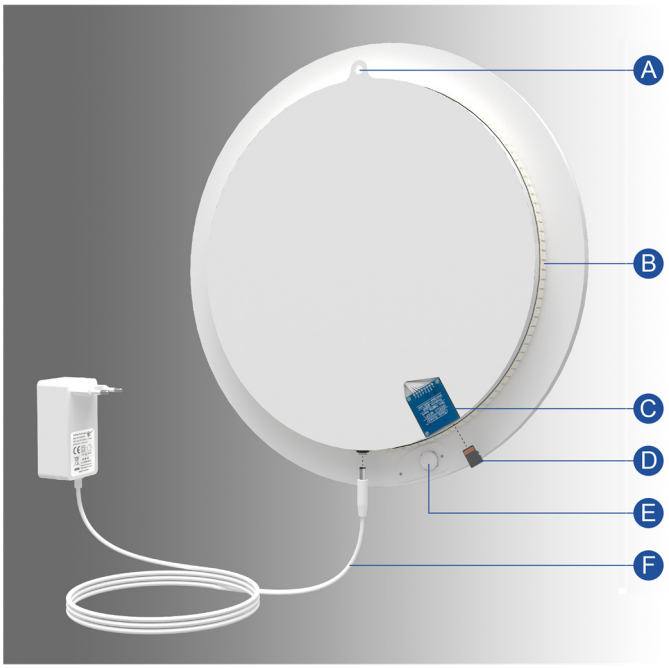

Figure 3. Back view of Prana. A = wall mount; B = external LED strip; C = SD/RTC module; D = micro SD card; E = power button; F = power cable with AC/DC adapter.

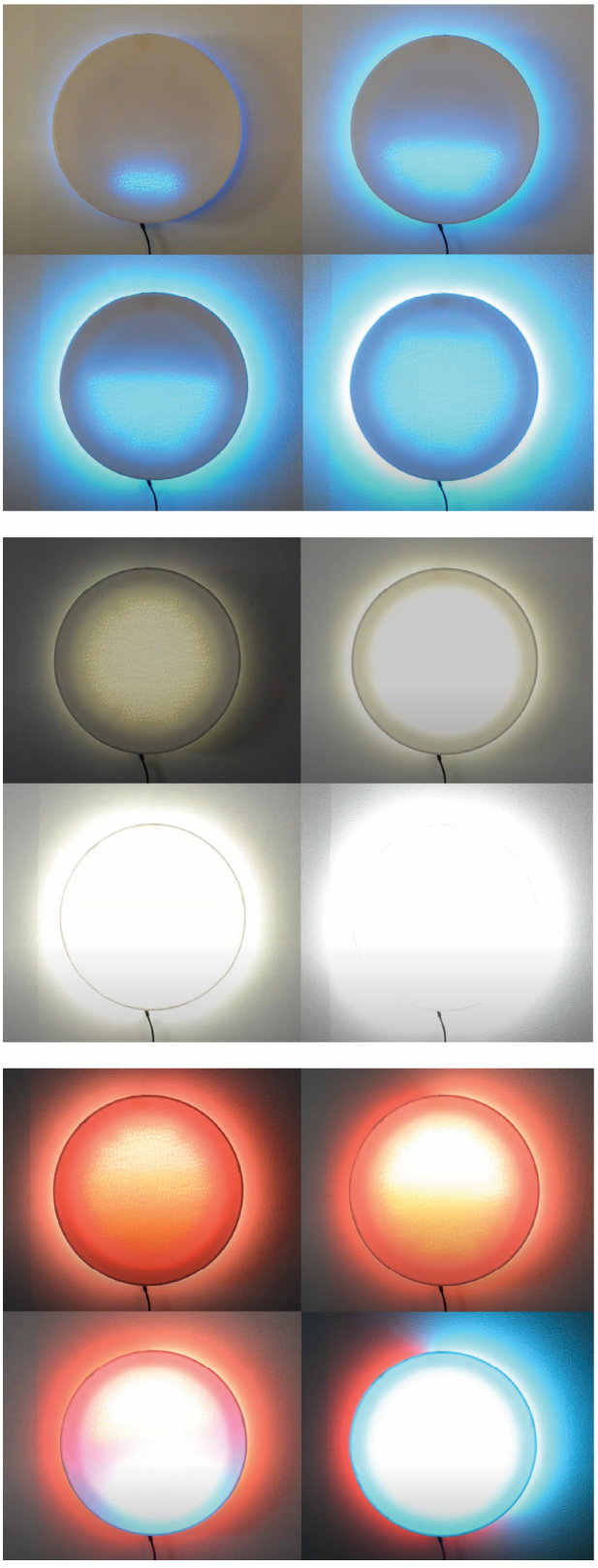

Figure 4. The three main stages of the Prana program. The chronological sequence of images for each stage is top-left, top-right, bottom-left, and bottom-right.

2.3.2. Daily Diary

We collected participants' subjective experiences after each meditation session by means of a daily diary. The diary included three questions and an empty field for recording

any additional thoughts (Figure 5A). The first question assessed the quality of participants' meditation experience on a 5-point "faces" response scale from "Awful" (coded as "1" for the analysis) to "Fantastic" (coded as "5" for the analysis). The second question asked about the difficulty in starting to meditate, as perceived by participants, and was rated on a 5-point response scale (1 = very easy to 5 = very difficult). The third question was open and asked the participants to specify what triggered them to meditate.

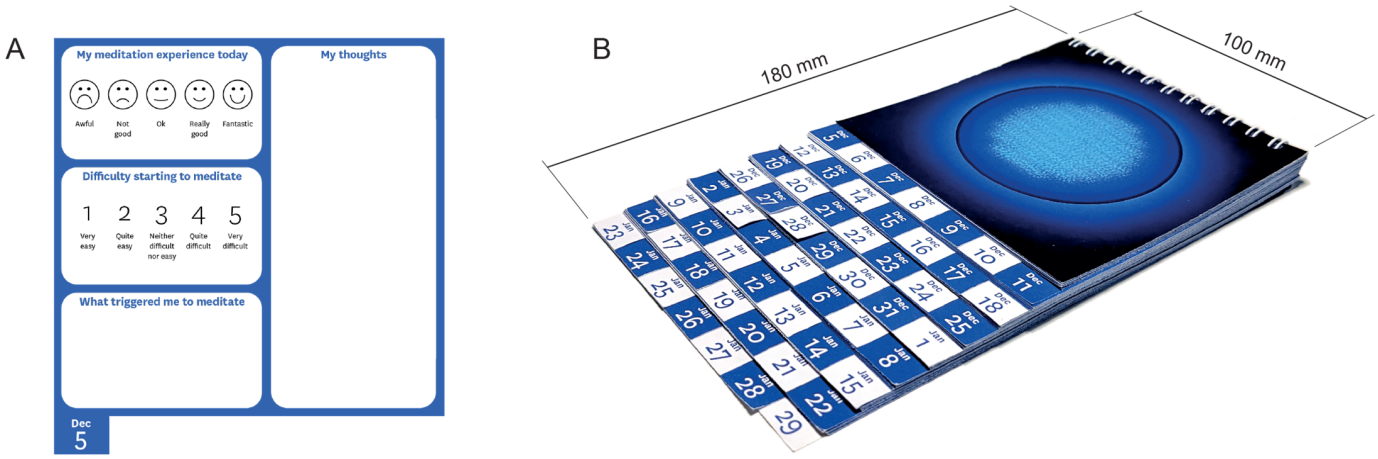

Figure 5. Diary design: (**A**) content; (**B**) physical appearance.

The diary was intended to be compact and quick to fill out. To avoid influencing participants' meditation intentions and motivations, it was designed as a 56-page daily calendar booklet with one page dedicated to each day of the 8-week study (Figure 5B). All dates were visible, but not the content; thus, unless the participants intentionally searched for this information, they did not have an overview of their previous meditation sessions. Because the starting date of the study was different for each participant, the diaries were customized to begin on their individual starting dates.

2.3.3. Questionnaires

Meditation Intentions Questionnaire-24 (MIQ-24 [49]) is a validated 6-factor, 24-item scale assessing people's goals and intentions for meditation practice on the following subscales: cognitive enhancement (4 items), increased emotional control (4 items), greater positive affect (4 items), stress relief (4 items), spiritual discovery (4 items), and psychological discovery (4 items). The items are preceded by the following instruction: "*Consider the following items and use the below five-point scale to indicate how important each goal is for you to achieve through your current meditation practice*". A sample item is: "*. . . Better regulate my emotions*". All items are rated on a 5-point response scale (1 = "Not at all a goal" to 5 = "A leading goal"). Subscale scores are calculated by averaging the ratings of the corresponding four items.

Determinants of Meditation Practice Inventory-Revised (DMPI-R [53]) is a validated 4-factor, 12-item scale assessing people's perceived barriers to meditation on the following subscales: low perceived benefit (4 items), perceived inadequate knowledge (2 items), perceived pragmatic barriers (3 items), and perceived sociocultural conflict (3 items). The items follow the stem "*It will be difficult for me to meditate because . . .*". A sample item is "*. . . I prefer to be accomplishing something*". All items are rated on a 5-point bipolar Likert-type response scale (1 = "Strongly disagree" to 5 = "Strongly agree"). Subscale scores are computed by averaging the scores of corresponding items; higher scores reflect higher levels of perceived barriers to meditation.

Self-report habit index (SrHI [50]) is a validated 12-item scale assessing the repetition and automaticity of a certain behavior, and the extent to which it corresponds with one's self-identity. The items follow the stem "*Behavior X is something . . .*" which is adapted for different behaviors (in our case, "*Meditation is something . . .*"). A sample item is "*. . . I*

do frequently". The items are rated on a 7-point Likert-type response scale (1 = "Strongly agree" to 7 = "Strongly disagree"). Item scores are averaged to obtain an overall SrHI score between 1 and 7.

System usability scale (SUS [51]) is a validated 10-item scale for rapid determination of the usability of a newly designed system. The items are preceded by the following instruction: "*Please select the answer that best expresses how you feel about each statement after using X today*"; for the purpose of our study, we replaced "X" with "Prana". A sample item is "*I think I would like to use X frequently*". The 10 items are rated on a 5-point Likert-type response scale (0 = "Strongly disagree" to 4 = "Strongly agree"), and 5 of them are reverse-scored. The sum of scores is multiplied by 2.5 to convert the original values of 0–40 to 0–100; the resulting values are considered only in terms of their percentile ranking [54].

Likelihood to recommend Prana to others. At the end of the SUS, we added the item "*How likely are you to recommend Prana to others?*" which was rated on a 10-point response scale (1 = "Not at all likely" to 10 = "Extremely likely").

Ten-item personality inventory (TIPI [55]) is a validated 10-item measure of the Big Five personality dimensions. The items are preceded by a common stem, "*I see myself as:*", and consist of two descriptors. Each dimension is assessed by two items, one of which is reverse-scored; examples for assessing extraversion are "*Extraverted, enthusiastic*" and "*Reserved, quiet*". The 10 items are rated on a 7-point Likert-type response scale (1 = "Disagree strongly" to 7 = "Agree strongly"). For each pair of items, the scores are averaged and compared to existing gender- and age-specific norms [56].

Brief self-control scale (BSCS [57]) is a validated 13-item measure intended to assess individual differences in self-control. The items are preceded by the following instruction: "*Using the scale provided, please indicate how much each of the following statements reflects how you typically are*". A sample item is "*I am good at resisting temptation*". The 13 items are rated on a 5-point Likert-type response scale (1 = "Not at all" to 5 = "Very much"), and 9 of them are reverse-scored. The total score is calculated by adding the raw scores from each item.

2.4. Procedure

Volunteers interested in the study were recruited via the university mailing list, as well as by means of recruitment pamphlets posted across various TU Delft facilities and yoga/meditation centers in Rotterdam (see Appendix A, Figure A1). They were asked to fill out a short survey regarding their meditation history for the purpose of eligibility assessment. To avoid collecting responses together with personally identifiable information, the recruitment survey was conducted in two steps: the respondents were first presented with an electronic consent form and asked to provide their e-mail address; following this, a link to the second part of the recruitment survey was sent to each e-mail address together with a unique participant ID number.

An invitation to a short online interview was e-mailed to eligible respondents. The purpose of the interview was two-fold: to allow the researchers to gather additional information regarding the respondents' eligibility; and to inform the interviewees about the requirements of the study, so they could decide whether they were willing to commit to it.

Individual in-person meetings were held with eligible participants. At these meetings, the participants received a Prana prototype, a personalized diary, and a 3-page illustrated instruction manual (see Appendix A, Figure A2), and were asked to complete a paper survey comprising the MIQ-24, DMPI, and SrHI. Three aspects of Prana were then adjusted to their personal preferences: (1) color of light, (2) pace of breathing, and (3) duration of meditation. The participants were asked to take Prana home and mount it on the wall in a room appropriate for meditation. They were instructed to position the lamp at their eye level during meditation, to sit at least 100 cm away from it during use, and to keep it plugged into the power socket at all times to avoid any interference with data recording. Finally, we asked the participants to try to meditate every day at approximately the same time for the next 8 weeks and reflect on each meditation session using the diary.

As Prana was in the early stages of development, the participants were instructed to report any technical issues they might experience during the study so we could resolve them in time. In addition, we contacted all of them one week after receiving Prana regarding this issue.

After 8 weeks, the participants were individually invited to attend a 30-min semi-structured interview where in-depth information was obtained regarding their experience with Prana and its potential to facilitate the development of a meditation routine. All interviews were scheduled within 10 days to minimize participants' misrecollection of their experience. After the meeting, they returned the prototypes and were asked to complete an online post-use survey comprising SrHI and SUS.

Once the obtained data were analyzed, we wondered whether participants' personality traits could explain any of the results, which is why we followed up with them to ask that they also complete the TIPI and BSCS. As personality traits tend to be stable over long periods of time, the fact that we collected this information after the study was formally completed was not of concern.

2.5. Data Analysis

In this mixed-methods study, we collected and analyzed both qualitative and quantitative data. *Quantitative* data included the following:

- Pre-use responses to MIQ-24 and DMPI-R (survey responses);
- Pre- and post-use responses to SrHI (survey responses);
- Post-use responses to SUS, TIPI, and BSCS (survey responses);
- Recorded dates and times of Prana use (SD card);
- Satisfaction with meditation experience (diary entries);
- Difficulty in starting to meditate (diary entries).

Responses to questionnaires were analyzed in line with the respective authors' instructions. For the SrHI, the differences between pre- and post-use responses were calculated for each participant to assess whether meditation became more or less habitual for them over the studied 8 weeks. Due to the small sample size, all survey results are presented using only descriptive statistics.

Temporal data regarding Prana use were collected to visually identify any newly emerging patterns in meditation frequency. For this purpose, a 56-day timeline with completed meditation sessions was constructed for each participant. To analyze the impact of meditation experience and difficulty in starting to meditate on the likelihood of meditating the next day, we assigned a value of 0 = "did not meditate next day" or 1 = "did meditate next day" to each data entry and calculated point-biserial correlation between the variables of interest. Criteria for assessing the strength of correlation were based on the following [58]: coefficients between |0.1| and |0.3| were considered to imply *weak* correlation, those between |0.4| and |0.6| *moderate* correlation, and those equal to or above |0.7| *strong* correlation. The cut-off value for statistical significance was set at 5%.

Qualitative data were analyzed by means of thematic analysis and included the following:

- The trigger to meditate on each occasion (diary entries);
- Other relevant thoughts after each meditation session (diary entries);
- Subjective experience with Prana (post-study interview).

3. Results

3.1. Study Participants

Twelve volunteers responded to the recruitment call, seven of which (four females, three males) participated in the study. Their age ranged from 21 to 34 years; two participants were of Dutch nationality, two were Russian, and the others came from Bulgaria, India, and Italy. One participant was *interested in meditation, but without previous experience*; four identified as *novice meditators with difficulties establishing a meditation routine*; and two as *intermittent meditators interested in establishing a meditation routine.* Five participants had prior

experience with meditation apps, but none with meditation-supporting physical devices. They were all open to using meditation technology. Details regarding their meditation practice are presented in Table 1.

Table 1. Participants' experience with meditation practice.

ID	Meditation History	Currently Practicing	Likelihood to Meditate in Near Future
P1	Meditated regularly or semi-regularly for <1 month	No	Extremely likely
P2	Meditated regularly or semi-regularly between 1 and 5 years	Yes	Extremely likely
P3	Meditated regularly or semi-regularly between 1 and 6 months	Yes	Very likely
P4	Meditated regularly or semi-regularly between 7 and 11 months	No	Very likely
P5	Meditated once or occasionally, but never on a regular/semi-regular basis	No	Quite likely
P6	Meditated once or occasionally, but never on a regular/semi-regular basis	No	Very likely
P7	Meditated regularly or semi-regularly for <1 month	No	Extremely likely

The participants mainly used meditation for stress relief and emotional control, whereas spiritual discovery was the least likely goal (Table 2; MIQ-24). Prior to Prana use, they generally did not experience difficulties in relation to meditating, except for P5 who perceived some pragmatic barriers (Table 2; DMPI-R).

Table 2. Participants' survey scores.

Scale (Score Range)	Dimension	P1	P2	P3	P4	P5	P6	P7	Median	Mean
MIQ-24 (1–5)	Cognitive enhancement	3.8	2.3	2.8	2.5	1.0	4.5	4.8	2.8	3.1
	Emotional control	4.3	3.8	4.0	5.0	3.0	2.5	4.0	4.0	3.8
	Greater positive affect	4.3	4.5	3.8	2.8	3.5	3.3	4.0	3.8	3.7
	Psychological self-discovery	4.0	3.8	4.5	3.0	2.0	2.0	4.0	3.8	3.3
	Spiritual discovery	2.0	1.3	1.5	1.3	1.0	2.0	3.3	1.5	1.8
	Stress relief	3.8	4.0	4.0	4.3	3.5	4.0	4.0	4.0	3.9
DMPI-R (1–5)	Low perceived benefit	2.3	2.3	1.8	2.3	2.3	1.3	2.8	2.3	2.1
	Perceived inadequate knowledge	2.0	1.5	2.5	2.5	2.0	3.0	1.5	2.0	2.1
	Perceived pragmatic barriers	2.3	2.0	1.7	2.3	3.7	1.3	3.0	2.3	2.3
	Perceived sociocultural conflict	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
SrHI (1–7)	Pre-use score	2.5	4.2	3.7	3.4	2.0	1.8	3.0	3.0	2.9
	Post-use score	4.2	4.4	2.7	4.6	4.0	2.5	4.0	4.0	3.8
	Difference	1.7	0.2	−1.0	1.2	2.0	0.7	1.0	1.0	0.9
SUS (1–100)	Total score (percentile)	70th	65th	68th	75th	93rd	93rd	80th	75th	78th
/ (1–10)	Likelihood to recommend Prana	6	3	3	7	7	7	7	7.0	5.7

DMPI-R = Determinants of Meditation Practice Inventory-Revised; MIQ-24 = Meditation Intentions Questionnaire-24; SrHI = self-report habit index; SUS = system usability scale.

3.2. Quantitative Data

3.2.1. Meditation Frequency and Experience

The timelines of participants' meditation with ratings of experience and difficulty in starting are presented in Figure 6. In total, they meditated between 9 (16%) and 47 times (84%) during the 56-day study. The frequency of meditation decreased with time for P1, P2, P5, and P6, all of whom meditated on 30% of days or less. It decreased after the first 2–3 weeks with a subsequent increase 2 weeks later for P4 and P7; for P4, a decline in frequency occurred around the time of code revision and may be associated with negative user experience due to technical issues. Meditation frequency remained relatively stable for P3 who meditated the most regularly out of all participants.

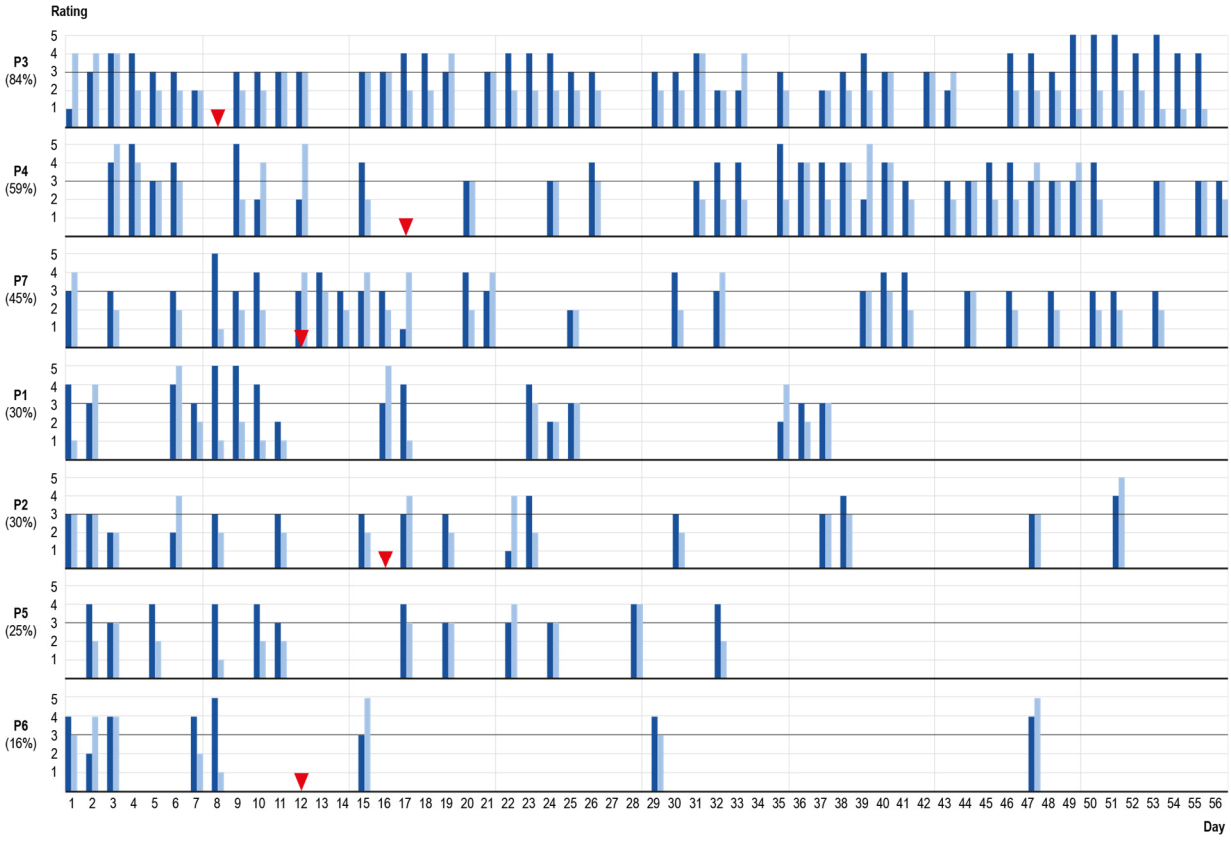

Figure 6. Ratings of meditation experience across 8 weeks. ▮ = Meditation experience (1 = awful to 5 = fantastic); ▮ = difficulty in starting to meditate (1 = very easy to 5 = very difficult); ▼ = Prana code revision.

Across all participants, the daily meditation experience was relatively positive (mean score on a 5-point scale 3.4 ± 0.8, median 3—"Ok"), and the difficulty to start meditating was relatively low (mean score on a 5-point scale 2.7 ± 1.0, median 2—"Quite easy"). Interestingly, the highest ratings for experience were reported by the two participants who meditated the least (i.e., P5 and P6). The most difficulty in starting was reported by P6 who only meditated 16% of the time.

No relevant correlation was found between the perceived difficulty in starting to meditate and meditation experience overall. Among individual cases, moderate positive correlation was significant for P1 (r_{pb} = 0.049, p = 0.030), indicating that higher perceived difficulty to start was associated with better meditation experience for this participant.

The correlation between meditation experience and the likelihood to meditate the next day was positive and significant, but very weak overall (r_{pb} = 0.188, p = 0.020). It was significant and weak-to-moderate for P3 (r_{pb} = 0.325, p = 0.031), suggesting that better

meditation experience may have been associated to some extent with higher likelihood of meditating the next day for this participant.

3.2.2. Temporal Consistency of Meditation

Due to technical challenges, we were unable to record the time of day of all participants' meditation sessions. This was the case for P4, whose device stopped recording data on day 32 because of battery-related issues, and for P5, whose data were only recorded on day 8 for unknown reasons (Figure 7). The data that were recorded suggest that the chosen time of day for meditation was relatively consistent for P3 and P1 who meditated mostly at night. P2 meditated either in the afternoon (more common in the first month) or in the evening (more common in the second month); contrarily, P7 was more likely to meditate in the evenings during the first month and in the afternoons during the second. P6 initially meditated in the evenings but switched to mornings after the first two weeks of the study.

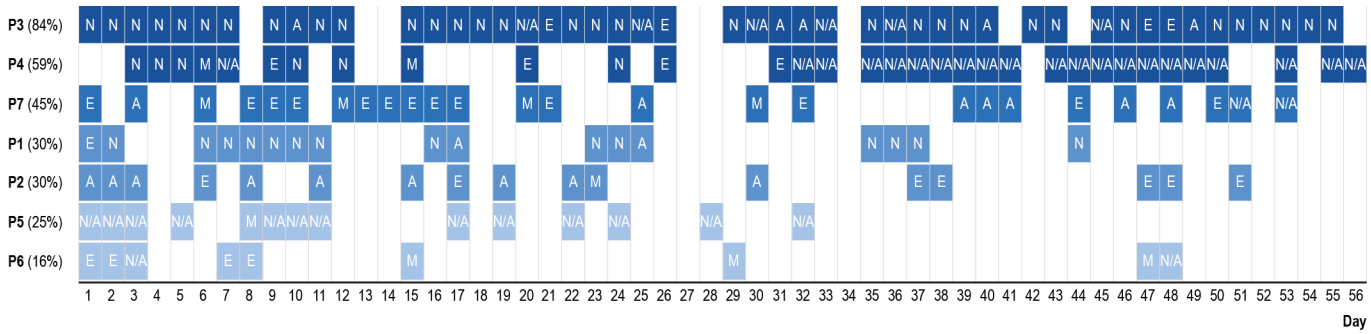

Figure 7. Chosen time of day for meditation across 8 weeks. M = morning (5:00–12:00); A = afternoon (12:00–18:00); E = evening (18:00–22:00); N = night (22:00–5:00); N/A = no data was recorded.

3.2.3. Self-Reported Changes in Meditation Habit

According to the results of the SrHI (Table 2; SrHI), the 8-week experience with Prana affected participants' meditation habits. Before the use of Prana, only P2 scored positively on the SrHI, and even this score was rather low (i.e., 4.2). After 8 weeks of Prana use, meditation became more habitual for all but P3, although positive scores were still rare. Only P1, P2, and P4 exceeded 4.0, while P5 and P7 remained neutral (i.e., 4.0). P6 started with a very low SrHI score of 1.8 and experienced some improvement with Prana use, although their score remained low (i.e., 2.5). P3, who meditated most frequently, on the other hand, experienced a decrease in automaticity of their meditation. The largest positive impact was observed for items "*Meditation is something I do frequently*", "*Meditation is something that belongs to my routine*", and "*Meditation is something that makes me feel weird if I don't do it*".

3.2.4. Prana Usability Evaluation

The SUS scores (Table 2; SUS) suggest that most respondents found Prana relatively easy to use (65th to 93rd percentile). The two participants who rated its usability the lowest (including P3) were rather unlikely to recommend Prana to others (3/10), whereas the other participants were more likely to recommend it than not (6/10 and 7/10).

3.3. Qualitative Data

A qualitative analysis of diary entries and post-study interview data revealed several key themes and insights regarding participants' interactions with Prana and its impact on their meditation practices. We identified 12 themes, including (1) attitudes toward using Prana for meditation; (2) motivation and (3) triggers to meditate; (4) routine building and (5) external factors influencing use; (6) usability of Prana; (7) technical issues; (8) breathing control; (9) focus triggers and light show, and (10) suggestions for improvement; (11) esthetics; and (12) diary.

3.3.1. Attitudes toward Using Prana for Meditation

Although Prana was considered relatively easy to use, the qualitative results indicate some tensions: (1) tension between guidance and customization, and (2) tension between the comfort of having technological support and the non-technological nature of meditation. On the one hand, participants appreciated clear, structured guidance, but on the other hand, they expressed a need for customization to harmonize with their distinct meditation customs and preferences. Although the participants were offered additional modifications of the settings if needed, a common complaint was not being able to control the duration of meditation, the pace of breathing, and light color and intensity themselves, especially as the preferences for these can vary across meditation sessions.

Participants' experiences also underscored the delicate nature of introducing a technological device into meditation practice. P2, for example, noted that mindfulness requires a balance between discipline and flexibility: one needs to be able to attend to their emotion in the moment of experiencing it, which is why it is difficult to attach meditation practice to a specific location. This is also in agreement with the experience of P7: "*It is easier to meditate when you feel you need it*". Similarly, P3 questioned the reliance on an external object for meditation, suggesting that it may be most useful in the beginning to help establish a routine. P2 was also skeptical about limiting meditation guidance to a visual object, and P5 reported missing "a voice" for guidance. Several participants viewed meditation with Prana as an option rather than a mandatory practice and used other tools to help them meditate (e.g., meditation apps and music). On the positive side, P7 mentioned that creating a calm/happy space at home is nice.

3.3.2. Motivation and Triggers to Meditate

We grouped the reported triggers for meditation into those that imply intrinsic motivation (IM; e.g., *desire to build a habit, to feel focused*), the Prana lamp itself (P), participation in the study (S), and other external triggers (OE; e.g., *reminder alarm, meditation cushion on the floor*); the latter three were considered to imply extrinsic motivation (Figure 8). P3, who meditated on 47 days in total, mainly recorded triggers associated with IM, especially as the study progressed. The practice of P4, who meditated on 33 days in total, was also largely associated with IM, but IM was present from the beginning. Slightly more instances of extrinsic motivation were observed in P7 who meditated on 25 days in total, although the balance was still in favor of IM. P1 (meditated on 17 days) was more often motivated by external triggers; in this case, extrinsic motivation became more pronounced with the progression of the study. P2 and P5 (meditated on 17 and 14 days, respectively) mainly reported extrinsic motivation; and P6 (meditated on 9 days) failed to report the trigger for most of their sessions.

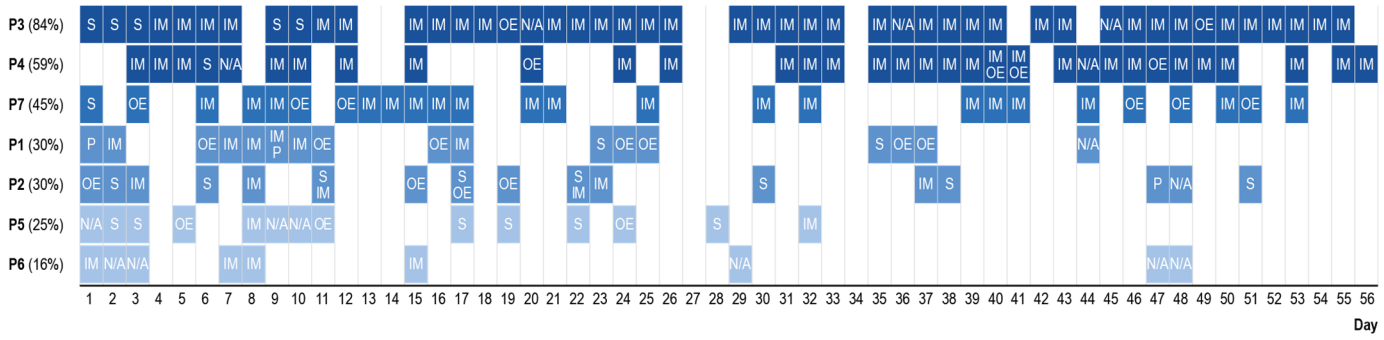

Figure 8. Triggers for meditation across 8 weeks. IM = intrinsic motivation; OE = other external trigger; P = Prana lamp; S = participation in the study; N/A = no triggers were reported.

The participants enrolled with the intention of initiating or enhancing their meditation routine. Throughout the study, commitment to the research itself and the act of participating served as the primary motivators. Interestingly, none of the participants mentioned Prana

as a source of motivation in the post-study interview. In fact, P7 shared that Prana had a somewhat negative motivational impact: they expressed reluctance to mediate when not at home to "save" their meditation practice for a moment with Prana due to the study.

Although Prana was not seen as a direct motivator, it did at times function as a reminder or trigger for mediation through its presence. With progression of the study, however, the triggering effect of Prana diminished; familiarity with its presence led to it losing its triggering role. Some respondents pointed out additional triggers, such as a yoga pillow, and some used smartphone alarms to remind them to meditate. P2 mentioned that Prana was a cue for feeling guilty about procrastinating on their meditation.

3.3.3. Routine Building

By the end of the study, only P3 successfully established a meditation routine with the help of additional guidance from meditation classes and music. P6 found routine establishment challenging, and P7 felt that their routine did not show improvement over the course of the study. External factors, such as time constraints and life events that demanded participants' attention and energy, were cited as reasons for meditation inconsistencies. P7 aimed to meditate in the evenings but was not always at home during that time.

3.3.4. User Experience

In general, participants found Prana to be user-friendly. At the beginning of the study, they encountered some technical glitches, but these challenges did not substantially demotivate them; they accepted these with understanding, acknowledging the early prototype status of Prana. However, P3 mentioned that technical issues had led to some frustration, affecting their meditation frequency.

Responses to guided breathing varied. P4 and P6 found it beneficial, while P2 experienced discomfort ("*Having to control breath can induce anxiety—one should observe their breath, not try to change it*"). P6 praised the well-developed nature of this feature, while P1, P4, and P5 noted that the breathing pace felt too slow.

Responses to the focus triggers and light show were also diverse. P5 enjoyed the focus triggers, P6 found them helpful at times and distracting on other occasions, and for P1, the lights were distracting and negatively influenced their meditation experience. By the end of the study, P3 stopped paying attention to the focus triggers and started relying on their meditation app. As for the light show, P5 reported positive experiences, P3 found it boring over time, and P1 did not consider it an integral part of the meditation experience.

Participants provided suggestions for improving the device, such as the incorporation of customizable settings (e.g., the possibility of adjusting breathing pace, meditation duration, and color and intensity of light to their changing requirements) and additional usage options (e.g., audio guidance and meditating in different body positions). However, they also expressed appreciation for the device's clear and simple design, which is why they recommended integrating customization options via an app rather than with physical buttons on the device.

3.3.5. Esthetics

Participants generally held a positive view of Prana's esthetics. Three of them explicitly expressed their appreciation, with P3 comparing the device to a piece of art. However, the minimalistic design and white color of Prana made it less likely to stand out when hung on a white wall, especially in the presence of other decoration, which negatively affected its function as a visual cue. Due to this, P3 noted that they would have appreciated a reminder light and sound at times when they usually meditated.

3.3.6. Daily Diary

Opinions on the diary component varied. One participant appreciated the introspective act of reflecting on their meditation, while another cautioned against evaluating one's meditation sessions due to potential negative impacts on motivation. Despite all efforts to

design the diary in a way that would make it difficult for them to have an overview of their previous meditation sessions, P1 found a way to circumvent this: they crossed out the days when they missed meditation, as shown in Figure 9.

Figure 9. Diary with crossed-out dates when the participant did not meditate.

3.4. Personality Traits

We only obtained responses to the TIPI and BSCS from five participants; their scores are presented in Table 3. P3, who meditated most frequently, scored relatively high on conscientiousness, agreeableness, neuroticism, and self-control. P4, who was second according to frequency of meditation, interestingly, scored very low on conscientiousness, neuroticism, and self-control, but very high on agreeableness. Next, P7 scored very high on extraversion, relatively high on openness to experience, and relatively low on self-control. P2 scored very high on conscientiousness, agreeableness, and self-control, relatively high on openness to experience, and relatively low on extraversion. And P5 scored very high on neuroticism, relatively high on extraversion, relatively low on conscientiousness, and very low on openness to experience and agreeableness.

Table 3. Participant scores on the Big Five personality traits and self-control scales.

ID	Meditated	TIPI					BSCS
		O	C	E	A	N	
P3	84%	5.5	5.5	3.5	5.0	5.5	41
P4	59%	5.0	2.5	4.0	6.0	2.5	24
P7	45%	6.5	4	6.5	4.5	3.5	36
P1	30%	N/A	N/A	N/A	N/A	N/A	N/A
P2	30%	6.0	6.5	3.0	6.5	4.5	44
P5	25%	2.0	4.0	5.5	2.5	7.0	41
P6	16%	N/A	N/A	N/A	N/A	N/A	N/A

A = agreeableness; BSCS = brief self-control scale; C = conscientiousness; E = extraversion; N = neuroticism; N/A = information not obtained; O = openness to experience; TIPI = ten-item personality inventory.

4. Discussion

This longitudinal study of meditation habit formation using the meditation lamp Prana revealed several tensions and methodological issues. Over the course of eight weeks, we expected to observe an increase in meditation frequency (i.e., the number of sessions per week) and the establishment of temporal patterns (i.e., increased consistency in time of

day for meditating and time elapsed between the subsequent meditation sessions). For the majority of novice meditators in the present study, this was not the case. An overall increase in frequency was only observed for one participant; it remained stable for the participant who meditated most frequently, but decreased with time for four other participants who meditated the least frequently. Overall, the participants' experience with meditation during the study did not affect the odds of meditating the next day.

The preferred times of day for meditation varied among participants. Two meditated mainly at night, and two preferred the afternoon and evening hours. Interestingly, only the participant who meditated the least (i.e., 16%) practiced in the mornings. Namely, a recent study of meditation app abandonment found that people who meditated in the morning were more likely to persist compared to those who meditated at other times of the day [29]. Temporal consistency was observed for two participants, and two others switched from afternoon to evening hours and vice versa mid-study. All participants who tried to associate their sessions with a certain part of the day meditated for at least 30% of the study (i.e., 84%, 30%, 30%, and 45%, respectively). This is in line with a recent study of meditation app use, which found temporal consistency to be a significant predictor of future behavior [28].

The collected qualitative data suggest that several factors influenced participants' motivation to meditate with Prana, including their personal motivations, the impact of documenting meditation experience, the impact of life events, personality traits, and technical glitches. As motivation has been found to play a vital role in habit formation by stimulating repetition of target behaviors [59], these factors may partly explain some of their struggles to adhere to a routine, as discussed below.

4.1. Motivation and Routine

4.1.1. Personal Motivations

In the present study, participants identified as either novice or intermittent meditators and saw meditation as a means for stress relief and emotional control, which is in line with the findings reported in [16]. They stated diverse motivators for engaging in meditation during the study, most of which implied extrinsic motivation. For some, Prana initially served as a reminder to engage in their meditation sessions; however, its impact as a motivating factor diminished over time, as the novelty of the visual cues waned. The awareness of being part of a study emerged as the primary drive for most participants.

The existing literature suggests that extrinsic motivators are key to promoting repetition when levels of motivation are low [59–61]. The three participants who adhered most to their meditation during the study were intrinsically motivated—they continuously expressed a genuine intention to build a routine. The other participants mainly relied on extrinsic motivation, either throughout the study or toward the end of it. One participant even marked their diary with the intent to ensure they meditated for at least 50% of the study, but they also highlighted an issue with keeping a meditation diary, as explained below.

4.1.2. Impact of Keeping a Meditation Diary

A recent study on meditation participation in app subscribers found that rating your mood by using an emoji after completing a meditation session might increase participation; thus, the authors advised that the incorporation of such check-ins in meditation apps helps engage a wider range of users [62]. Although our study did not include a mobile application, we collected participants' experiences after each session by means of a daily diary. One of the more experienced participants expressed some reluctance toward this. They noted that advanced practitioners actually advise against critical reflection on one's meditation session, as this can influence motivation for future practice. Although not supported by the scientific literature, and at odds with some online recommendations, we find this observation relevant and worthy of future study.

4.1.3. Impact of Life Events

External life events, such as personal stressors, busy schedules, mood fluctuations, and physical health issues, had discernible impact on participants' meditation consistency and motivation. Some participants reported struggling to maintain their practice during challenging times, while others found meditation to be a helpful tool for emotional regulation during such periods. We also observed less consistency in meditation frequency during the weekends and holidays. This is in line with the findings of Lally et al. [20], who explained that adhering to habit formation plans tends to be more difficult when daily activities are less structured.

4.1.4. Impact of Personality Traits

No clear association was observed between participants' personality traits and the likelihood of establishing a meditation routine. Based on Gardner et al. [27], we expected to observe more success in participants who scored high on neuroticism and less success in those who scored high on conscientiousness; however, our findings did not confirm this. Researchers in the field of habit formation appear to have different views on how conscientiousness, in particular, affects this process. Some suggest that because people higher in conscientiousness show more control, they are more likely to maintain non-automatic regulation of their actions [63,64]; however, other evidence ties greater trait self-control to more habitual behavior [65]. In the present study, participants' success in establishing a meditation routine could not be explained by individual differences in trait self-control. As preference for routine has been linked to stronger habit formation [66] and the absence of structure in life to weaker habit formation [67], future research should consider these factors as well.

4.1.5. Impact of Technical Issues

At the beginning of the study, participants encountered technical glitches with Prana, although these challenges were generally accepted as part of the prototype nature of the technology. Code updates were appreciated for resolving some of the issues, and the technical setbacks did not appear to considerably demotivate the participants, as the majority of them continued to engage in meditation sessions despite these challenges. It should be noted, however, that fewer repetitions are typically required for a habit to peak when the target behavior is experienced as enjoyable [68–70]. Thus, it remains unclear as to what extent the technical issues negatively influenced participants' motivation to develop a meditation habit using Prana.

4.2. User Experience with Prana

Overall, participants' reactions to Prana were mixed, reflecting the intricate interplay between external cues, personal motivations, technical elements, and individual experiences. These diverse perspectives underscored the multifaceted nature of meditation practice, where the incorporation of technology can have variable effects. In the following sections, we briefly address the most prominent aspects of user experience.

4.2.1. Device Integration

Habit formation is the process during which a cue–response association is strengthened to the point where the cue prompts the desired action without conscious deliberation [23,69]. Visual cues provided by Prana were initially effective in prompting some participants to engage in meditation; however, over the course of the study, the novelty of Prana waned, participants became desensitized, and these cues lost their efficacy.

We expected a physical device like Prana to be more effective than apps in stimulating meditation habit formation due to its physical presence as a meaningful object in a meaningful location, but our findings suggest the opposite. Namely, the challenge of consistently associating meditation with a specific location was a common theme among participants. Some preferred flexibility in their meditation environment, adapting their practice to differ-

ent situations and positions, which is not well supported by a stationary, wall-mounted device. Previous research found actions that are performed rigidly in unvarying contexts to be the most appropriate targets for habit-forming interventions [27]. For novices, meditation is clearly not such an activity. For example, a study of mindfulness meditation app abandonment during the COVID-19 pandemic found the flexibility of time and location for meditation (i.e., "meditating whenever I can") to be associated with a lower risk of app abandonment [71]. Thus, a meditation device should at least be portable to allow the user to meditate whenever and wherever they need or wish to. In addition, cues must be perceived to generate action [27], so keeping a device like Prana in a meditation-dedicated space possibly decreases the likelihood of it being noticed when external motivation is needed. Designing meditation devices as wearables might be a solution to this problem, and some examples of jewelry-like products are readily available on the market. However, users of such wearable devices may become desensitized to the cues sooner due to constant exposure to the stimulus.

4.2.2. Meditation Guidance

Requests for more control over the breathing pace and the overall duration of the meditation session were voiced, with participants indicating a desire for adjustable settings that align with their individual preferences. Participants also expressed differing opinions on the role of external guidance, debating whether meditation should rely on such cues or be more internally focused. In line with [27], they saw the benefit of external support in the early stages of habit formation, but suggested that guidance should gradually decrease with the formation of a routine.

4.2.3. Esthetics

The esthetic design of Prana was widely appreciated; one participant mentioned that it was like a piece of art. However, while the esthetics garnered positive attention, its effectiveness as a consistent visual cue for meditation was questioned. For example, participants noted that the device blended into their environment over time, reducing its ability to serve as a distinct reminder for meditation practice.

Prana was originally intended to also trigger so-called "moments of mindfulness" by emitting short light signals at random times throughout the day. In its current developmental stage, this functionality is not yet available, but would be a welcome improvement according to some participants. In the case that "moments of mindfulness" became implemented, positioning Prana strategically would increase in importance, as these random visual cues would, again, need to be perceivable in order to stimulate the desired action.

4.2.4. Suggestions for Improvement

While the operational routine of Prana appeared straightforward, participants' evaluations revealed a myriad of nuanced aspects that did not entirely align with their individual practices. Various suggestions were provided for enhancing Prana's usability, including customizable settings, additional usage options, and the inclusion of sound cues to signal the end of meditation sessions. This underscores the tension between novice meditators' desire for structured guidance and the need for personalization, mirroring the broader challenge of developing technological tools that cater to the unique nuances of individual meditation practices.

4.3. Limitations and Future Directions

All efforts notwithstanding, we were unable to avoid certain methodological issues. Most notably, the participants' awareness of their enrollment in a study regarding habit formation clearly affected their motivation. While meditation app use data are relatively easy to collect and analyze without interfering with users' motivation, meditation devices are practically impossible to study without the participants' knowledge. Future research should therefore strive to overcome this obstacle.

Another important issue relates to the duration of the study. To ensure that the participants were able to commit to 8 weeks of Prana use, we allowed them to choose their preferred start date. Three of them opted for a start in December, a very festive month, which may have affected their ability to commit to meditating during the first 4 weeks. Others were affected by project submission deadlines for their study, and two participants experienced considerable health issues at some point during the 8 weeks. Such external life events should be accounted for in future longitudinal studies of habit formation.

Given the qualitative explorative focus of our study, we did not use a control group to compare the Prana-mediated meditation experiences with those conducted without the lamp. The absence of a control group restricted our capacity to discern whether the observed effects are attributable to Prana itself or influenced by other factors. Future research could explore this aspect by incorporating control groups to provide a more comprehensive understanding of the lamp's unique contributions to meditation practices.

Our research design did not include a comparison between Prana and other meditation supports, such as apps and traditional methods. In light of the growing diversity in meditation supports, future research could consider comparative analyses to study the unique benefits and limitations of each approach, contributing to evidence-based recommendations for practitioners and researchers alike.

In addition, while our findings provide insights into the contribution of a dedicated physical object to meditation habit formation, it is important to acknowledge the inherent limitations associated with our small sample size. Post hoc and sensitivity power analyses were performed for the point-biserial correlation test using G*Power 3.1.9.7 (https://www.psychologie.hhu.de/arbeitsgruppen/allgemeine-psychologie-und-arbeitspsychologie/gpower) (accessed on 14 January 2024) (*t*-tests; correlation: point biserial model; two-tailed). In the overall analysis, the cumulative number of entry points were 154; thus, at the power of 0.80, it was possible to detect small-to-medium differences (effect size of 0.22). The post hoc analysis suggested that for large effect sizes (i.e., 0.50), the test power was 0.99; for medium effect sizes (i.e., 0.30), the power was 0.97; and for small effect sizes, it was 0.24. Due to the small number of participants and the consequently limited number of data points, we found medium-to-large effect sizes to be acceptable. Analysis of data for each individual participant, however, showed that the statistical test only had sufficient power to reliably detect large differences for three participants (i.e., the calculated power was 0.96 for P3, 0.88 for P4, and 0.81 for P7). The number of data points for the other four participants were too small for the test to reach the power of 0.80.

The qualitative nature of our research prioritizes depth and context specificity over statistical generalizability. Caution should therefore be exercised in generalizing the findings to broader populations, recognizing that the transferability of our findings lies in their relevance to similar contexts. For future studies, sample sizes can be increased, and participants can be intentionally recruited with a broader range of ages and varying levels of previous meditation experience to enhance the generalizability of our findings.

5. Conclusions

The present study aimed to evaluate the potential of the wall lamp Prana for assisting with meditation habit formation in novice users interested in building a meditation routine. Although the results are inconclusive, we gained important insights into the challenges and benefits of a physical device to support meditation routine.

Unsurprisingly, the lack of intrinsic motivation was among the most important obstacles to habit formation. For the majority of volunteers, participating in the study was the main motivator, although no incentives were offered to them during recruitment. Adherence to the planned routine could not be explained by the perceived difficulty in starting to meditate or meditation experience during the previous session, nor by participants' personality traits. Due to the duration of the study, personal motivations and external life events made it difficult for some to meet their goals.

Based on user experiences with Prana, meditation-supporting devices would need to offer the level of flexibility that stationary objects cannot provide. Being able to meditate whenever and wherever one chooses emerged as an important theme; thus, the portability of future meditation devices should be considered. In addition, meditators appreciate the possibility of adjusting the settings for meditation guidance (e.g., duration of meditation, breathing rate, and color of light) to their variable personal preferences, which was not possible with the tested prototype. Overall, the opinions of Prana as a tool for establishing a meditation routine were mixed, but the participants agreed that it was an esthetically pleasing design piece.

The proposition that technology can support meditation practices is contingent upon several assumptions. One of these posits that technology can facilitate individuals in establishing and sustaining routines and habit formation by providing guidance, cues, or reminders. The results of our study emphasize the daunting challenge of translating such assumptions, even when they have empirical support, into effective real-world applications. Reality is complex, and our study underscores the importance of acknowledging that the practical impact of meditation devices may strongly vary due to a multitude of personal and contextual factors. Our results confirm the challenge of inferring the applicability of studied devices in real-world settings, considering these factors. This finding stands in stark contrast to assertions occasionally advanced by producers and marketers of meditation technology. Notably, design details, even those that seem inconsequential, can exert a profound influence on a device's efficacy. Therefore, while understanding the mechanisms of meditation practice may inspire meditation device development, it can never be presupposed, without rigorous testing, that the device's impact aligns with the developers' assumptions. In addition, our study revealed various sensitivities, underscoring the delicate balance required to integrate technology into a traditionally non-technological domain. Participants questioned the necessity of external cues, reflecting on the fine line between using technology for support and preserving the intrinsic simplicity of meditation. In a broader context, this reflection advocates prudence in developing technology for the purpose of supporting, influencing, or shaping daily habits. Striking the correct balance becomes imperative in navigating the fine line between technological support and the preservation of the authenticity of our unmediated daily experiences.

Despite the fact that this study did not confirm our expectations, we find it of high importance to share our insights, especially regarding methodological issues, with the scientific community.

Author Contributions: Conceptualization, T.K. and P.M.A.D.; methodology, T.K. and P.M.A.D.; formal analysis, T.K. and P.M.A.D.; investigation, T.K.; resources, P.M.A.D.; data curation, T.K.; writing—original draft preparation, T.K.; writing—review and editing, T.K. and P.M.A.D.; visualization, T.K.; supervision, P.M.A.D.; project administration, T.K.; funding acquisition, P.M.A.D. All authors have read and agreed to the published version of the manuscript.

Funding: This research was supported by VICI, grant number 453-16-009, of The Netherlands Organization for Scientific Research (NWO), the Division for the Social and Behavioural Sciences, awarded to P.M.A. Desmet.

Institutional Review Board Statement: This study was conducted in accordance with the Declaration of Helsinki, approved by the Human Research Ethics Committee of TU Delft, the Netherlands (Letter of Approval 2486, 6 October 2022), and conducted in accordance with the Organic Law 3/2018 of 5 December on Personal Data Protection and Guarantee of Digital Rights.

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: Data produced in the present study are not accessible to the public due to privacy reasons but can be obtained upon request.

Acknowledgments: We would like to thank Gijs Spierings for providing the prototypes and technical support for this study.

Conflicts of Interest: The authors declare no conflicts of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript; or in the decision to publish the results.

Appendix A

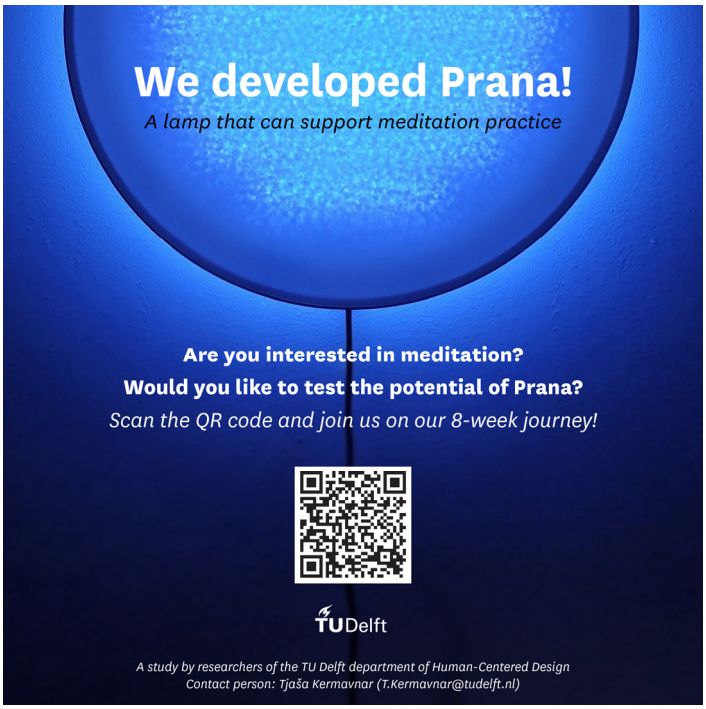

Figure A1. Recruitment pamphlet.

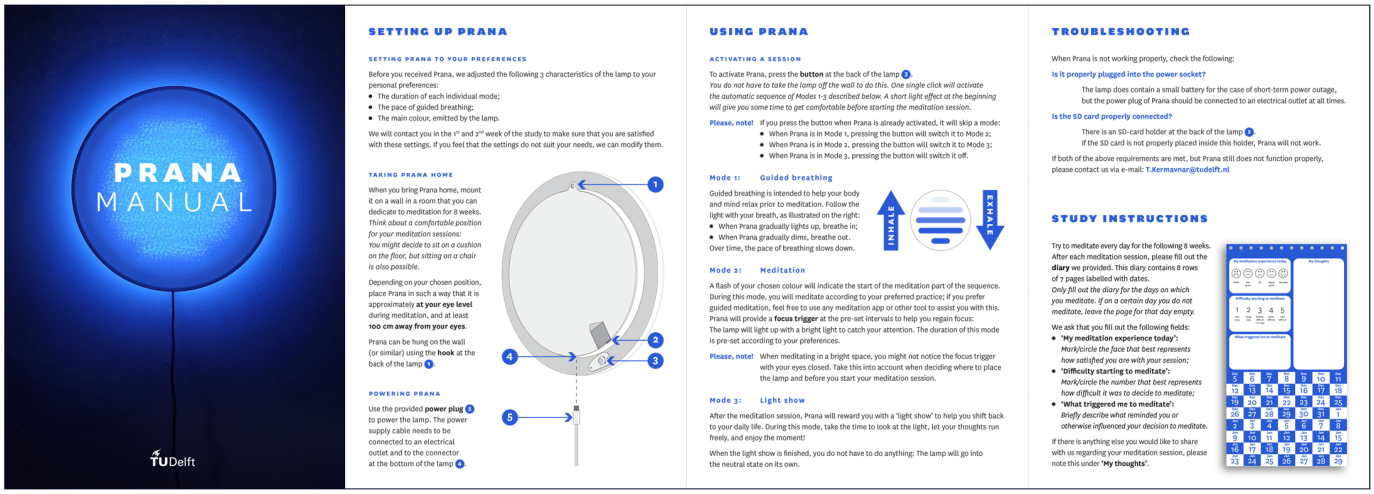

Figure A2. Instruction manual.

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