Hacking meditation

the effects of biofeedback-aided meditation on psychological outcomes

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Hacking Meditation: The Effects of Biofeedback-aided Meditation on Psychological Outcomes

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HACKING MEDITATION: THE EFFECTS OF BIOFEEDBACK-AIDED MEDITATION ON PSYCHOLOGICAL OUTCOMES

Abstract

Meditation has been shown to induce a specific pattern of heart-rate variability, physiological coherence, that has been associated with a range of positive psychological and physiological outcomes. This study investigated how recent innovations in biofeedback could influence the perceived outcomes of meditation in everyday life, through biofeedback-aided meditation practices. Earlier studies have shown that biofeedback can effectively train the self-regulation of physiological states. It was thus expected that biofeedback-aided meditation would facilitate the attainment of desirable psychophysiological states, and thus have greater positive outcomes on everyday life compared, particularly amongst novice meditators. A within-participant study of non-meditators assessed the effects of meditating with and without biofeedback for a week each, 10 minutes a day, on the perceived psychological outcomes of meditation in everyday life. Results show a significant improvement in outcomes in both meditation conditions compared to baseline, but found no evidence of difference between biofeedback-aided meditation and meditation-only conditions. Nonetheless, exploratory findings indicate a need for further research to validate these results.

Keywords: Biofeedback, Meditation, Psychophysiology, Wellbeing, Personal Informatics

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HRV – Heart rate variability

MT – Meditation training

BMT – Biofeedback-complemented meditation training

EOM-EL – Effects of Meditation in Everyday Life scale

EOM-DM – Effects of Meditation during meditation scale

1. Introduction

The holistic health movement redefines the concept of wellness from one of an absence of physical illness to one of maximizing joy and wellbeing in all areas of life (Gross, 1980). Central to this ideology is mind-body connection, a domain that has slowly been taking root in the mainstream of scientific research (Astin, Shapiro, Eisenberg, & Forys, 2003; Brower, 2006; Littrel, 2008;). Meditation is a compelling practice in this scope. It is primarily considered to the mind what exercise is to the body, and yet its reach seems to stretch out far beyond just the mind. In recent decades, it has received significant attention from the scientific community for its purported enhancement of quality of life.

Walsh and Shapiro (2006) describe meditation as practices that exercise focused attention and awareness in order to self-regulate mental and physical processes. Numerous studies have found meditation to have positive effects on overall wellbeing. It has been associated with a number of psychological outcomes, such as reductions in stress and anxiety (Kemper, Powell, Helms, & Kim-Shapiro, 2015), improved emotional and attentional regulation (Gillespie, Mitchell, Fisher, & Beech, 2012; Sahdra et al., 2011; Zeidan, Martucci, Kraft, Gordon, McHaffie, & Coghill, 2011), compassion (Condon, Desbordes, Miller, & DeSteno, 2013), and decision making (see Sun, Yao, Wei, & Yu, 2015 for a review). Moreover, a meta-analysis of 163 meditation studies on non-clinical populations conducted by Seldmeier and colleagues (2012) confirmed meditation practices to have significant positive effects compared to relaxation groups on social and emotional, cognitive, and attentional outcomes, with a gross effect size comparable to behavioral treatments or psychotherapy.

In addition to these psychological effects, meditation has been shown to have physiological correlates (Conklin et al., 2018; Fennell, Benau, & Atchley, 2016; Kemper,

Powell, Helms, & Kim-Shapiro, 2015; Takahashi et al., 2005; Tang, Tang, Rothbart, & Posner, 2019). Its impact on heart-rate variability (HRV) and physiological coherence are of particular interest. HRV refers to the variations in intervals between heartbeats and acts as a good indicator of the balance between the sympathetic and parasympathetic components of the autonomous nervous system (Moss, 2014). Previous studies have found that higher HRV is linked to more positive emotional responses and better emotional regulation (Butler, Wlhelm, & Gross, 2006; Segerstrom & Nes, 2007; Zhu, Ji, & Liu, 2019;) and cognitive functioning (Mather & Thayer, 2018; Winkelmann, Thayer, Pohlack, Nees, Grimm, & Flor, 2016). More generally, extensive studies suggest HRV to be an indicator of psychological and physical resilience, hence contributing to overall wellbeing (Caldwell & Steffen, 2017; Krygier et al., 2013). While numerous studies have reported meditation to increase HRV (Arya, signh, Malik & Mehrotra, 2018; Lo, Tsai, Kang, & Tian, 2017; Krygier et al., 2013; Matzner, 2003), others propose heart coherence to be a more accurate depiction of the specific HRV states attained through meditation (Kim, Lee, Kim, Whang and Kang, 2013).

Heart coherence, also known as cardiac coherence or physiological coherence (used interchangeably in this paper) refers to HRV peaks at 0.1 Hz typically in the lower frequency range, whereby oscillating regions of heart and brain are entrained (Pfurtscheller et al., 2017), and thus functioning optimally (Moss, 2014; Tiller, McCraty, & Atkinson, 1996). McCraty and Zayas (2014) emphasize that coherent heart rhythms are different from heart rhythms that reflect relaxation states, as it does not solely depend on a slow respiration rate (Kim et al., 2013; McCraty & Zayas, 2014), though this does have a significant impact (Bernardi, Porta, Gabutti, Spicuzza, & Sleight, 2001). Physiological coherence can also be induced through cultivating positive emotions, such as in loving-kindness meditation (Hofmann, Grossman, & Hinton, 2011; McCraty & Tomasino, 2006).

Research in physiological coherence, paired with developments in portable electronics, has sparked recent innovations in biofeedback applications. Due to the similarities in the overarching goals of biofeedback interventions and meditation practices (self-regulation), it is plausible that biofeedback technologies could complement meditation practices in order to help individuals reach physiologically coherent states. Biofeedback allows individuals to monitor and regulate mostly unconscious physiological processes and responses by providing information about their internal states (Glueck & Stroebel, 1975; The Association for Applied Psychophysiology and Biofeedback, 2018). By introducing an external feedback loop, biofeedback can catalyze the learning (both conscious and unconscious) of self-regulation patterns (Schwartz, 1977). According to Green, Green, Walters, Sargent, and Mayer (1975), the self-regulation that results from biofeedback interventions occurs through the process of *passive volition*, whereby an individual becomes objectively aware of their state and is then able to gain control without emotional involvement. This is similar to the Mindfulness or Vipassana approach to meditation, where individuals are encouraged to become aware of their state in a non-judgmental and detached manner. It is theorized that biofeedback can facilitate detachment by objectifying the underlying physiological states and providing immediate feedback on these (Green et al., 1975). This could suggest that the addition of biofeedback would be valuable, particularly for novice meditators, who are often agitated by emotional responses during meditation (Russ, Maruyama, Sease, & Jellema, 2017).

Biofeedback can additionally foster interoceptive accuracy. A study comparing biofeedback intervention to meditation practice found that participants in the biofeedback group developed increased cardiac interoceptive accuracy, while those in the meditation group did not (Meyerholz, Irzinger, Witthöft, Gerlach, & Pohl, 2019). Seeing as interoception

can modulate subjective experiences (Dunn et al., 2010), and is linked to mental disorders and other psychophysiological conditions (Myerholz et al., 2019), it is plausible that the addition of biofeedback to meditation can improve the outcomes of meditation as mediated through improved interoceptive accuracy. Furthermore, older studies have found that successful biofeedback interventions can improve internal locus of control compared to other self-regulation techniques (Smith & Womack, 1987; Zaichkowsky & Kamen, 1978), which in turn has been associated with better health and coping strategies (Kesavayuth, Poyago-Theotoky, Tran, & Zikos, 2020).

While several studies compare biofeedback interventions to meditation (Cuthbert, 1981; De Bruin, Zwen, & Bögels, 2016; Ratasiripong et al., 2015; Zaichkowsky & Kamen, 1978), only one older study (that we could find) explored the effects of biofeedback-aided meditation compared to meditation alone. The study by Hafner (1982) found that the effect of biofeedback-aided meditation did not differ from regular meditation treatment on the regulation of blood pressure amongst patients with essential hypertension. This, however, could be due to several methodological shortcomings. First, both treatment groups had training sessions once weekly, during which they were informed of their blood pressure readings. This means that the meditation only group also received some feedback on their progress, which is unlikely in regular meditation scenarios. Secondly, the biofeedback employed signaled physiological arousal, not blood pressure (which was the target outcome), and participants in the biofeedback-aided meditation condition were not able to practice with biofeedback in-between the training sessions. Despite this, they did find that blood pressure was reduced more rapidly at the start of the study amongst the biofeedback-aided treatment group. Hafner (1982) suggests this may motivate participants to adhere to treatment for

longer periods of time, an important consideration given high drop-out rates in meditation practices (Jerčić & Sundstedt, 2019).

However, no research has been done to investigate the effects of meditating with biofeedback technologies on broader perceived psychological outcomes in daily life. Hence, we currently do not know what benefit complementing meditation with biofeedback would bring. We argue that this necessitates attention in order to understand biofeedback's potential in enhancing meditation's impacts on quality of life for the general population, especially given the increasing number of biofeedback feedback applications entering the market. If it indeed proves beneficial, the low costs of these new technologies would result in accessible, holistic health interventions.

1.1 The current study

The primary goal of this study was to investigate the influence of biofeedback-aided meditation (BMT) on the everyday life outcomes of meditation for novice meditators. Thus our research question was, ***what is the influence of BMT (versus MT) on the effects of meditation in everyday life?*** Based on previous biofeedback research, we hypothesized that complementing meditation with biofeedback would enhance the outcomes of meditation. Firstly, this is due to the added feedback loop that could accelerate learning in novice meditators (Schwartz, 1977). Additionally, the feedback could provide meditators with objective insight on their physical states, facilitating the attainment of physiological coherence through passive volition (Green et al., 1975). Second, biofeedback could improve interoceptive accuracy (Myerholz et al., 2019) and internal locus of control (Smith & Womack, 1987; Zaichkowsky & Kamen, 1978), both of which positively impact self-regulation, and in a broader sense, wellbeing.

The secondary goal of this study was to explore the effects of BMT on the quality of the meditation during the meditation practice itself. This would allow us to narrow down on which aspects BMT would be more or less effective, helping us gather a first scientific understanding of the mechanisms behind BMT. As far as we are aware, this is the first study that evaluates the subjective experience of BMT. An additional novelty lies in the biofeedback technology used, which provides participants with logs of their biofeedback data. We thus complemented our findings with qualitative interviews in order to probe into how people react and interact with such technology.

2. Method

2.1 Experimental Design

This study employed a within-participant experimental design, whereby each participant was subject to a sequence of two treatments over a two-week (fourteen-day) period. The two treatment conditions were meditation training (MT) and biofeedback-complemented meditation training (BMT). In each treatment condition required participants to practice 10 minutes of meditation daily for a week while wearing chest straps. Participants were randomly assigned to an order group, determining the order in which they experienced each condition, in order to counter order effects. The effects of the MT and BMT on everyday life was measured using the Effects of Meditation in Everyday Life (EOM-EL) score (the *dependent variable*), by asking participants to fill out a questionnaire at three time points; once at baseline, and once after each treatment condition.

Due to scheduling logistics, participants wound up practicing the meditation trainings for a period of five to seven days, as opposed to seven days. For simplicity, we still refer to this period as a week. Efforts were made to ensure an equilibrium of days in the two treatment conditions and orders.

2.2 Participants

Participants were recruited according to the following selection criterion: little to no experience with meditation (this was expanded to include people who had previous, but not regular, experience with meditation and have not been meditating recently), aged between 18-40, and having access to an iOS device (iPhone or iPad) due to software compatibility.

A sensitivity analysis was conducted through G*Power to establish the discoverable effect size based on the time and number of devices allocated for this study. Using the parameters of alpha = 0.05, power = 0.80, total sample size = 40, the discoverable effect size

for an analysis of variance (ANOVA) with repeated measures was f = 0.20. Due to further time constraints, a total of twenty-four participants took part in the study, with an equal distribution of males (n = 12) and females (n = 12). Their ages ranged 18 to 38 years (M = 34.25, SD = 4.42). Around a third (30%) of participants had absolutely no experience with meditation (n = 7), half of the participants had less than an hour of experience (N = 13), and around a sixth (16%) had more than two hours of meditation experience in the past (n = 4), but had not been meditating regularly in the past months. Participants were recruited via the Eindhoven University of Technology's local participant database, flyers around the campus educational buildings, and word-of-mouth. See Appendix A for study invitation materials.

2.3 Materials

2.3.1 Stimuli

A video was made to introduce participants to meditation. This acquainted participants with diaphragmatic breathing, progressive relaxation, and cultivating positive emotions. These were chosen as key concepts as they are associated with modifying HRV towards physiological coherence (Moss, 2004). The video can be found at https://bit.ly/37yHIg6.

Participants were provided a selection of four 10-minute long instrumental music tracks to accompany their meditation training. They could choose to use these, or silence, during their meditations. A handful of participants (n = 4) preferred to meditate in silence. The advantage of this approach is that it allows the participant the freedom to learn from their experiences and adapt their practice. A voice-guided audio track would have limited the self-learning capacity and could have, furthermore, resulted in a ceiling effect. Notwithstanding, several participants reported using guided meditation videos found on Youtube (n = 4).

In the MT treatment condition, participants wore an electrode-fitted chest strap with a dummy measurement device during their meditation training, as shown in Figure 1. They were told that the device was measuring their HRV in order to ensure comparability between the treatment conditions and limit a possible Hawthorne effect.

Figure 1. Dummy chest strap (MT condition)

Figure 2. Evolve Biologix chest strap (BMT condition)

In the BMT treatment condition, participants were provided with an electrode-fitted chest strap with a heart rhythm variability measurement device (HS2) provided by Evolve Biologix Inc (Vancouver, CA), as shown in Figure 2. This strap was connected to the Evolve iOS mobile application via Bluetooth, providing participants with a live score (labeled as E-Score) based on a measure of their physiological coherence, as shown in Figure 3. Participants could scroll through the graph to see their daily scores, and further see their

scores from the past week by tapping on the insights tab. The Evolve app contains meditation training, which the participants were asked not to use as their daily meditations. They were instructed instead to use the music tracks provided by the researcher. Despite this, a few participants used the in-app training for their daily meditations (n = 3).

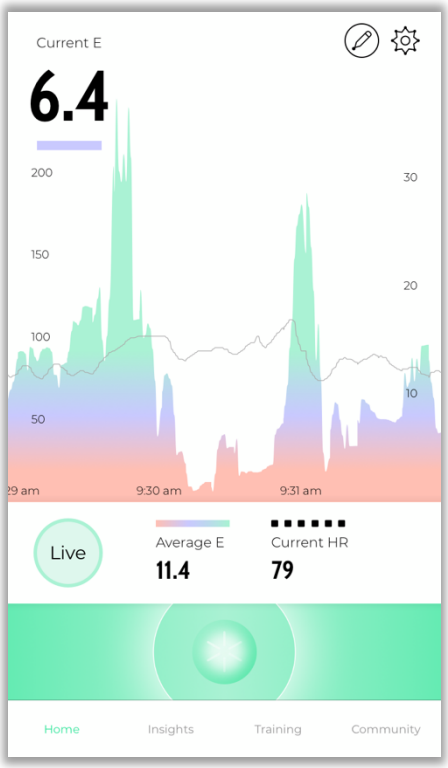

Figure 3. Home screen of the Evolve application showing E-Score

2.3.2 Measures

Prior to the study, participants filled out a demographic questionnaire. This assessed their gender, age, previous meditation experience, and any medical conditions. As discussed in the Introduction, novice meditators are more likely to experience difficulties in their meditation practices (Russ et al., 2017), and we therefore expect them to benefit the most from biofeedback. Medical conditions, on the other hand, may also impact both the

meditation experience and outcomes thereof. This questionnaire can be found in Appendix B. All questionnaires were deployed through LimeSurvey, an online surveying platform.

To assess the general perceived psychological outcomes of the meditation training in daily life that a participant experienced, we used the validated Effects of Meditation – Everyday Life (EOM-EL) questionnaire by Reavley and Pallant (2009). The construct validity of this scale was assessed on The Mindful Attention Awareness Scale (MAAS), the Spiritual wellbeing scale of the Functional Assessment of Chronis Illness Therapy (FACIT), and the Profile of Mood States Short Form (POMS-SF). This scale comprises of 35 Likert items loaded onto seven factors representing different dimensions of everyday life that are impacted by meditation; physical, emotional, consciousness, social relations, cognitive ability, acceptance, and behavioral aspects of everyday life. A revision by Skipper and colleagues (2015), however, indicated better validity as a unidimensional construct. This revision was, therefore employed for the hypothesis test in this study. Participants responded to these items on a six-point Likert scale, ranging from 1 – *Not true for me* to 6 – *True for me*. In order to adapt to the context of the current study, participants were asked to consider how true for them these statements were in relation to their past week. The full scale can be found in the Appendix B. Items from the seven dimensions were randomly combined and separated on five pages of the questionnaire to limit respondent fatigue. The scale was employed at three measurement points; once before the study (for a baseline), once after the MT condition week, and once after the BMT condition week. A factor analysis was conducted for the EOM-EL scale at each measurement point. By averaging a participant's answer to these 35 questions, we were able to construct a reliable (Cronbach's alpha = .94) measure for general perceived psychological outcomes of the meditation training in daily life. This variable served as our primary dependent variable. Likewise, by averaging a participant's answer to

the five questions on each of the seven original factors of Reaveley and Pallant (2009), we were able to construct reliable (Cronbach's a > 0.75) measures for each dimension of the EOM-EL scale.

For the secondary, explorative, aim of the study, we assessed the quality of meditation experience as measured by Skipper et al.'s (2015) revision of the validated Effects of Meditation - During Meditation (EOM-DM) scales (Reavley & Pallant, 2009). The EOM-DM consists of 19 Likert items loaded onto five factors representing the different dimensions of meditation: cognitive effects, mystical experiences, emotional effects, physical discomfort, and relaxation. The final factor, relaxation, was found to have poor factor loading and is thus excluded in this study (Skipper et al., 2015). Participants responded to the items in these dimensions on a six-point Likert scale, ranging from 1 – *Almost never* and 6 – *Almost always*. The full scale can be found in Appendix B. The scale was employed at two points; after the MT condition week, and after the BMT condition week. No baseline measure was assessed for the EOM-DM, as it relates directly to the experimental manipulation of meditation training. The *emotional* and *physical effects* scales were reverse coded. By averaging a participant's answer to the remaining 15 questions (after excluding the relaxation factor), we were able to construct a reliable measure for *emotional effects* (Cronbach's a > 0.80), *mystical experiences* (Cronbach's a > 0.83) and *cognitive effects* (Cronbach's a > 0.63). We did not find an acceptable internal consistency for *physical effects* (Cronbach's a < 0.49). The scale did not contain sufficient items for exclusion and was therefore dropped from further analyses.

To gauge the extent to which participants felt like their best selves, the current study used the Inclusion of the Other in the Self (IOS) scale by Aron, Aron, and Smollan (1992). In the original, participants choose a Venn diagram, which best represents their sense of

closeness to the 'other'. The current study replaces 'other' with 'Best self', referring to the participants' own imagined potential best-self. The identification with the best self is recorded at three measurement points; baseline, after the MT condition week, and after the BMT condition week.

Following each treatment week, participants were interviewed in order to gain a qualitative outlook on their subjective experiences with the meditation training. This was firstly done to explore any factors of importance that may not have been encompassed by the EOM-DM and EOM-EL scales. Secondly, to gain insight on possible factors affecting the quantitative results. During analyses, two identified patterns were deemed fit to include in exploratory quantitative analyses and were thus converted into variables and matched to the participants' quantitative data. These are; whether or not the participant used guided meditations, and whether they preferred meditating with or without biofeedback. Last but not least, the interview sessions granted an evaluation of the participant's experience receiving biofeedback using the Evolve application. In the last experimental session, the interviews allowed the participants to reflect on the two weeks and compare their experiences. These interviews were conducted in a semi-structured fashion. This was chosen for its compromise between consistency between participants, and freedom to allow for new themes to emerge (Leech, 2002). Questions were formulated so as to limit the suggestibility of answers. The interviews were conducted at two points, once after each treatment week. The interview script can be found in Appendix B.

2.4 Procedure

This study was first advertised on December 3rd, 2019. The studies ran from December 5th to December 23rd, 2019, in the Eindhoven University of Technology (NL) labs. Participants were required to attend three experimental sessions, each lasting 30

minutes. We ensured that each scheduled session was five to seven days apart. The researcher personally contacted each registered participant to verify whether they met the selection criterion before the first session.

During the first session, participants read an informed consent form describing the procedure and data use involved in the study, and Evolve Biologix Inc.'s privacy policy about the application use. They then filled out the pre-questionnaire, the baseline EOM-EL measure, and the best-self questionnaire at a desktop computer in the lab. Next, they watched the introduction to meditation video. Consequently, participants were given their instructions for the week both verbally and in writing and presented with the chest strap and heart measurement device for their assigned treatment condition. Participants were shown, through the help of a diagram (see experiment instructions in Appendix C), how to wear the chest strap and tried it on.

In the MT condition, the experimenter performed a bogus test to check whether the device was working and asked the participant to moisten the electrodes for better connectivity. The participants were asked to wear the chest strap while they performed their meditation training at home. In the BMT condition, participants downloaded the Evolve application, were guided through the account creation process and pairing of the heart monitoring device to the application. Additionally, they were briefly introduced to the application and the E-Score. Participants were asked to wear the strap during their meditation training. They were required to check their score at least once before starting their meditation, and at least once after. They were permitted to wear the strap outside of the meditation training if they wished.

Participants were then guided through a practice meditation training by the experimenter. The training lasted seven minutes and applied the key concepts introduced in

the meditation video. See Appendix C for a script of the guided meditation. Following this, the instructions for the week were reiterated, and participants had the opportunity to ask any questions. Participants were sent a selection of music tracks, a copy of the introductory video, and the experiment instructions via email.

Between the experimental sessions, participants practiced at least 10 minutes of meditation every day while wearing their chest straps. They were advised that practicing around the same time each day would be optimal. Some participants chose to wear the chest strap for longer periods, e.g., half a day, or a few hours before or after the meditation.

In the second and third experimental sessions, participants returned the respective chest straps, and once again filled out the EOM-EL scale questionnaires, the EOM-DM scale questionnaire, and the best-self questionnaire on a desktop computer in the lab. Consequently, they were interviewed about their week, and experiences meditating. All participants were reminded that their data would not be traced back to them and that they were able to withdraw their data up to 24 hours after recording.

During the second experimental sessions, the interviews were followed with instructions and chest-strap fitting for the next treatment condition. After the interviews in the third experimental session, participants were debriefed and compensated for their time. The compensation rate was €10 per hour, and thus most participants were compensated with €15. Participants could alternatively obtain study credits for one of the sessions, which two participants did, and were thus compensated by study credits and €10. Participants were offered an opportunity to ask additional questions before the end of the session.

2.5 Analyses

Quantitative data

To prepare for hypothesis testing, data were pre-processed and tested for assumptions. All analyses were carried out using Stata/IC 16.0. First, data from each experimental session were reformatted and labelled appropriately. The internal validity of the EOM-EL and EOM-DM scales were tested by means of factor analysis and new items were created. Lastly, the three datasets were combined, and two binary variables identified in the qualitative data (guided meditations and preference) were added.

Hypothesis test

To answer the research question "What is the influence of biofeedback-aided meditation training (versus meditation-only training) on the effects of meditation in everyday life?", a repeated measures ANOVA with condition as the within-participant variable and EOM-EL score as the dependent variable was deemed appropriate. The data was first converted into a long format. No outliers were detected using the interquartile range method. The assumption of sphericity was violated, as demonstrated by the Huynh-Feldt epsilon value (*H-F* $\varepsilon = 0.74$). Therefore, we used Huynh-Feldt corrected *F* and *p* values to interpret the results. The test was conducted both including and excluding participants with more than two hours of past meditation experience ($n = 4$), participants using guided meditations during the week ($n = 4$), and participants with medical conditions ($n = 2$). Seeing as removing these observations had no significant effect on the results, we present the analyses including all observations.

To include the effect of condition order on EOM-EL scores, we ran a mixed ANOVA with condition as the within-participant factor, and order as the between-participants factor (order 1 referring to a MT-BMT sequence, and order 0 referring to a BMT-MT sequence). As

the dependent variable, we used the EOM-EL scores for the MT and BMT conditions, minus the baseline EOM-EL scores (henceforth referred to as the EOM-EL difference scores). This gave us two EOM-EL difference scores per participant. The assumption of normality was violated for the BMT EOM-EL score ($W = 0.91$, $p = 0.03$). We thus transformed the EOM-EL difference scores by adding a constant and then applying a square-root function. The assumption of normality was finally met for the BMT EOM-EL difference scores, based on Shapiro-Wilk's normality test ($W = 0.95$, $p = 0.32$).

Exploratory tests

We explored whether effects of condition differed across the different dimensions of the EOM-EL scale, as originally determined by Reavely and Pallant (2009). A factor analysis revealed acceptable internal consistency in all seven sub-scales, with Cronbach's $\alpha > 0.075$. Thus, seven new items were created representing each dimension. A repeated measures ANOVA was conducted for each dimension. To avoid capitalizing on chance, a Bonferroni corrected p-value was used to interpret the data ($p < 0.007$). The assumption of sphericity was only met in dimension 2 and hence the Huynh-Feldt corrected F and p values were used for interpretation.

To investigate the effects of MT and BMT on the experience of meditation during meditation, we used a paired sample t-test between each of the EOM-DM dimensions. We used a Bonferroni corrected p value of $p < 0.03$, with three one-tailed tests, and an α error probability of 0.05. To investigate the effect of order and condition over the three EOM-DM dimensions and interactions amongst these, we used a mixed ANOVA with order as the between-subjects factor and condition as the within-subject factor.

In order to see how the conditions affected participants' perception of being their best self, a repeated measures ANOVA was performed with condition as the within-subject factor and best-self rating (from 1 – *lowest* to 7 – *highest*) as the dependent variable.

The qualitative data contributed an additional measure that was interesting to compare with the quantitative results; whether participants preferred to meditate with (coded as 1) or without (coded as 0) biofeedback. To explore the effects of preference on outcomes of meditation in everyday life across the conditions, a mixed ANOVA was used, with preference as a between-subjects variable and condition as the within-subject variable. The assumption of sphericity was violated, as demonstrated by the Huynh-Feldt epsilon value (*H-F* $\varepsilon = 0.86$). Therefore, we used Huynh-Feldt corrected *F* and *p* values to interpret the results.

Qualitative data

To analyze the transcripts of the interviews, the thematic analysis (TA) method was chosen for its flexibility and accessibility (Nowell, Norris, White & Moules, 2017). In contrast to other methodologies, TA does not limit itself to specific theoretical perspectives (Maguire & Delahunt, 2017), and was therefore particularly fitting for exploratory analyses. We followed Braun and Clarke's (2012) six-phase framework for conducting TA; familiarizing with data, generating initial codes, searching for themes, reviewing potential themes, defining and naming themes, reporting. As suggested by various guidelines (Braun & Clarke, 2012, Maguire & Delahunt, 2017; Nowell et al., 2017), the process of TA was iterative around the phases rather than linear. Detail of how TA was employed in this study can be found in Appendix D.

3. Results

3.1 Quantitative results

3.1.1 Hypothesis testing – EOM-EL

Our hypothesis was that after a participant performed BMT, participants would score higher on the EOM-EL scale than after they performed MT or before they performed any meditation at all (baseline). he repeated measures ANOVA showed that the main effect of condition was statistically significant, with $SS_{condition} = 6.78$, $F(2,46) = 9.84$, $p < 0.001$, and $\eta_p^2 = 0.30$. Seeing as we only have one factor, $\eta_p^2 = \eta^2$. Condition thus explained around a third (30%) of the total variance in EOM-EL scores. A post-hoc pairwise comparison with Bonferroni correction showed statistically significant differences between MT ($M = 3.98$, $SD = 0.90$) and baseline ($M = 3.46$, $SD = 0.93$),$p = 0.002$, and between BMT ($M = 4.01$, $SD = 0.89$) and baseline, $p \leq 0.001$. We thus reject the null hypothesis that BMT has no effect on EOM-EL scores. However, the difference between conditions MT and BMT was not found, $p = 1.00$. We thereby find no evidence supporting our alternative hypothesis that BMT would lead to higher EOM-EL scores than MT. These results showed that on average, meditation training improved psychological outcomes on everyday life, but the addition of biofeedback brought no statistically significant improvement.

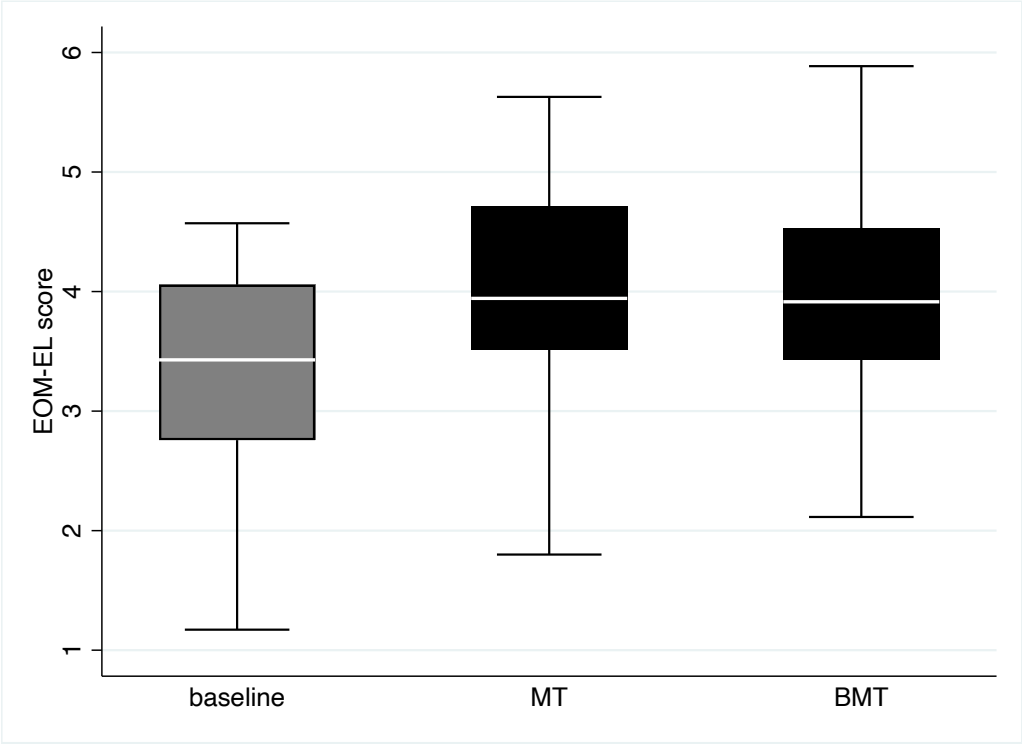

Figure 4. Mean EOM-EL scores at baseline, and after each condition

Order effects

As described in section 2.4, we computed the EOM-EL difference scores between baseline and MT ($M = 0.63$, $SD = 0.98$) and baseline and BMT ($M = 0.67$, $SD = 0.92$). As seen in Figure 5 below, participants subject to order 1 (MT first) had lower EOM-EL difference scores in both the MT ($M = 0.45$, $SD = 0.90$) and BMT ($M = 0.68$, $SD = 0.96$) conditions compared to participants subject to order 0 (BMT first). The latter had higher EOM-EL difference scores in their first week following BMT ($M = 0.65$, $SD = 0.92$), and also saw the highest overall increase in EOM-EL scores in the second week, following MT ($M = 0.81$, $SD = 1.06$). The mixed ANOVA revealed no statistically significant effect of order on EOM-EL difference scores, with $SS_{order} = 0.03$, $F(1,22) = 0.22$, $p = 0.64$. There was no statistically significant interaction effect between order and condition, with $SS_{condition*order} = 0.04$, $F(1,22) = 2.80$, $p = 0.11$.

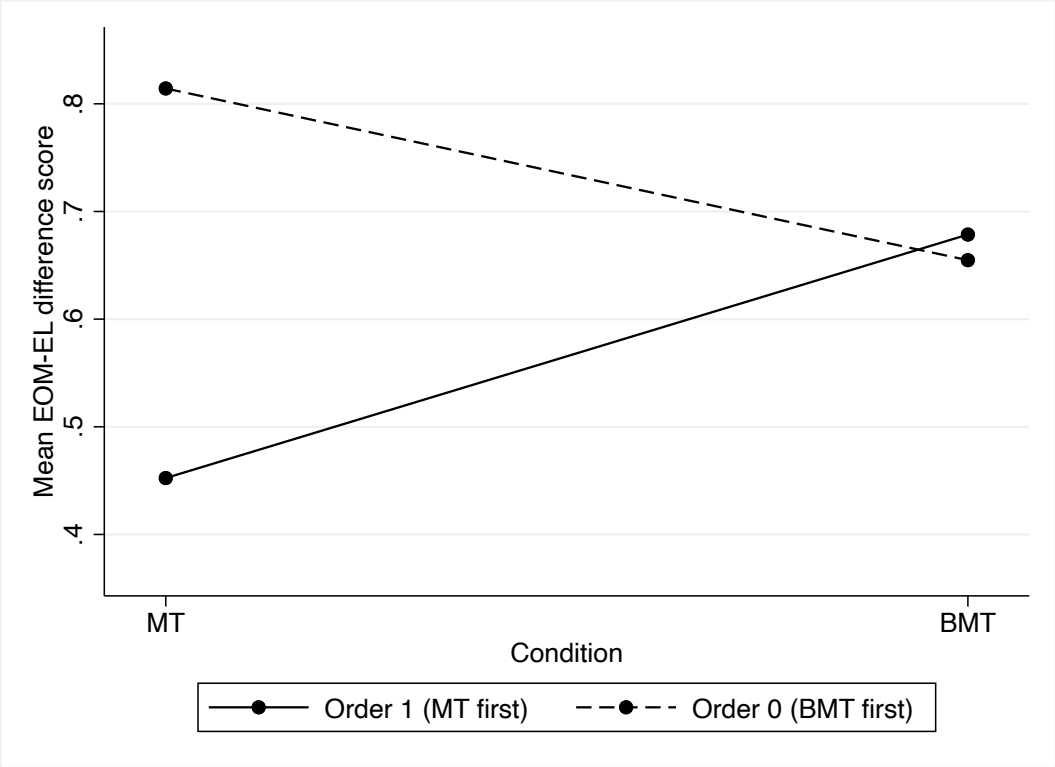

Figure 5. Mean EOM-EL difference scores in the MT and BMT conditions by order

3.1.2 Exploratory results

EOM-EL dimensions

We investigated whether effects of condition could be found across the different dimensions of the EOM-EL scale determined by Reavely and Pallant (2009). Descriptive statistics are shown in Table 2. The results showed a significant difference between conditions on the Physical dimension ($SS_{condition}$ = 14.72, $F(2,46) = 16.06$, $p < .000$), the Behavioral dimension ($SS_{condition}$ = 8.00, $F(2,46) = 9.41$, $p < .000$), the Cognitive dimension ($SS_{condition}$ = 8.64, $F(2,46) = 9.61$, $p < .000$), and the Emotional dimension ($SS_{condition}$ = 11.4, $F(2,46) = 9.81$, $p < .000$). No significant difference of condition was found in the Non-

judgmental acceptance, Expanded consciousness, or Social dimensions, and no differences were found between the MT and BMT conditions.

Table 1

Chronbach's alpha, means, standard deviations, and p-values for each EOM-EL dimension

		Baseline		***MT***		***BMT***	
EOM-EL dimension	***Cronbach's α***	***Mean***	***SD***	***Mean***	***SD***	***Mean***	***SD***
Physical	$\alpha > 0.75$	3.12	0.99	4.11 *	0.99	4.06 *	0.84
Behavioral	$\alpha > 0.83$	3.24	1.06	3.83 *	0.98	4.03 *	1.99
Cognitive	$\alpha > 0.85$	3.28	1.05	3.89 *	1.04	4.10 *	1.00
Nonjudgmental-acceptance	$\alpha > 0.79$	3.48	1.01	3.96	0.84	4.07 *	1.09
Emotional	$\alpha > 0.85$	3.18	1.20	4.08 *	1.07	3.95 *	1.00
Expanded-consciousness	$\alpha > 0.77$	3.40	1.10	3.87	0.93	3.79	1.01
Social	$\alpha > 0.82$	3.71	1.00	4.12	0.95	4.09	0.95

* Statistically different from baseline at $p < 0.007$

EOM-DM scale

Next, we examined the difference between the MT and BMT conditions on the three EOM-DM dimensions; Cognitive, Emotional, and Mystical. The paired sample t-test revealed a significant difference in the EOM-DM-Cognitive scores for the MT ($M = 3.90$, $SD = 0.70$) and BMT ($M = 4.19$, $SD = 0.75$) conditions with $t(23) = -2.37$, $p = .013$, and effect size $d_z = 0.48$. This showed that on average, participants experienced more clarity of mind while meditating in the BMT compared to the MT condition, as reflected by higher scores of the items of the EOM-DM-Cognitive scale. No statistically significant differences were found

between the EOM-DM-Emotional scores in the MT (M = 3.97, SD = 1.08) and BMT (M = 4.19, SD = 1.14) conditions, with $t(23)$= -1.30, p = 0.10. The differences in EOM-DM-Mystical scores were also not statistically significant between the MT (M = 2.60, SD = 1.04) and BMT (M = 2.78, SD = 1.19) conditions, with $t(23)$ = -0.90, p = 0.19.

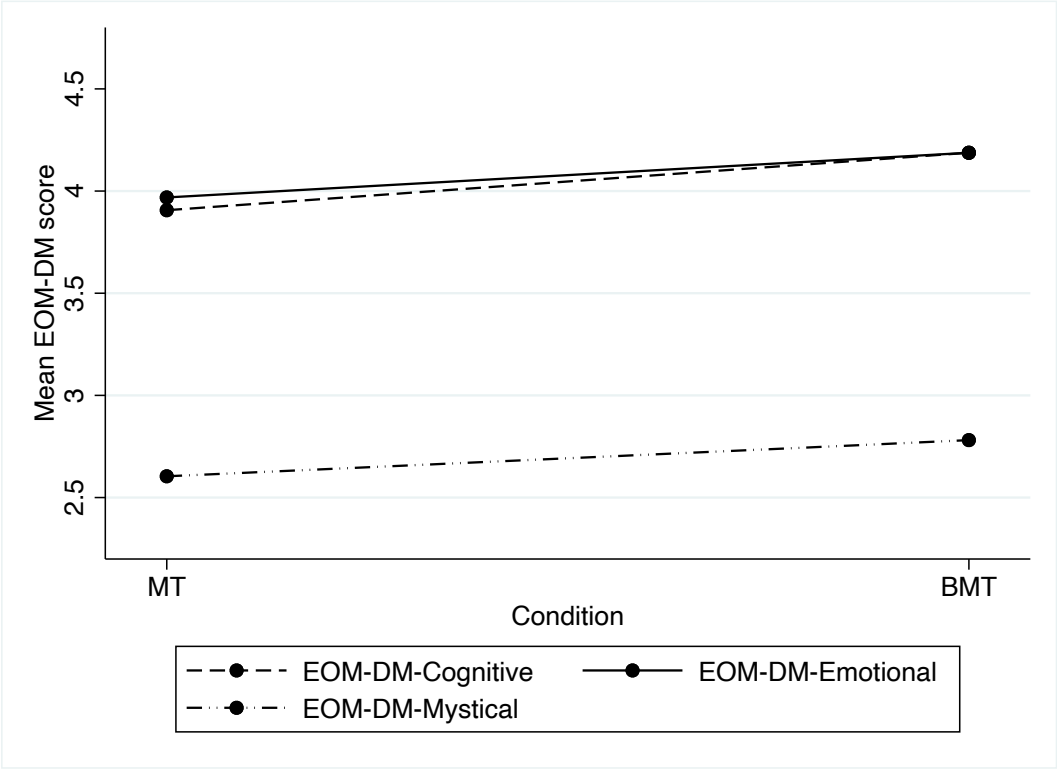

Figure 6. Mean EOM-DM scores in the MT and BMT conditions for each EOM-DM dimension

The examination of the effects of order and condition across the EOM-DM dimensions, revealed no significant effect of order with SS_{order} = 0.01, $F(1,44)$ = 0.00, p = 0.95. There was no significant effect of interaction between order and condition with $SS_{order*condition}$ = 0.42, $F(1,44)$ = 1.27, p = 0.27, and between order and dimension $SS_{order*dimension}$ = 0.38, $F(2,44)$ = 0.14, p = 0.87. The effect of condition was significant, with $SS_{condition}$ = 1.83, $F(1,44)$ = 5.61, with p = 0.03. The interaction between condition and

dimension, however, was not significant with $SS_{condition*dimension} = 0.07$, $F(2,44) = 0.11$, and $p = 0.90$. There is therefore no evidence that the effect of condition is different across the dimensions.

Best-Self

The results show a significant effect of condition, with $SS_{condition} = 3.36$, $F(2,46) = 5.81$, $p > 0.006$ and $\eta^2_{partial} = 0.20$. A post-hoc pairwise comparison showed significant differences between baseline ($M = 3.38$, $SD = 1.38$) and MT ($M = 3.83$, $SD = 1.52$) with $p = 0.015$, and significant differences between baseline and BMT ($M = 3.83$, $SD = 1.58$), with $p = 0.015$. There was no difference between MT and BMT conditions, with $p = 1.00$.

Preferences

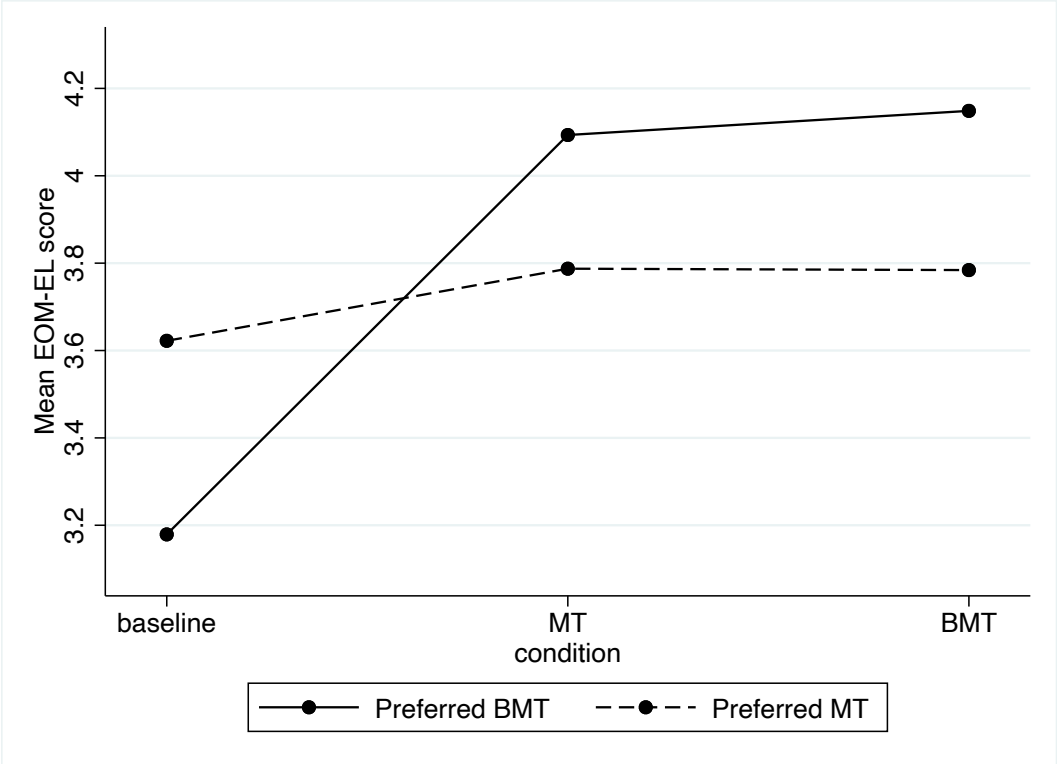

Figure 7. Mean EOM-EL scores by condition and participant preference.

The majority of participants preferred meditating with biofeedfack (n = 15) than without (n = 9). Results showed a significant effect of condition, with SScondition = 4.93, $F(1,44) = 7.45$, $p = .003$, and η^2 partial = 0.25. The interaction effect between condition and preference was significant, with $SS_{condition*preference} = 2.28$, $F(2,44) = 3.70$, $p = 0.04$. There was no significant effect of preference, with $SS_{preference} = 0.10$, $F(1,44) = 0.05$, $p = 0.82$. A post-analysis delineated the direction of this interaction. As illustrated in Figure 7, participants who preferred meditating with biofeedback saw increases in EOM-EL scores after both the MT (M = 4.09, SD = 0.90) and BMT (M = 4.19, SD = 1.01) conditions compared to (M = 3.18, SD = 1.01). On the other hand, participants who preferred meditating without biofeedback did not experience much increase in EOM-EL scores after either the MT (M = 3.79, SD = 0.92) or BMT (M = 3.78, SD = 0.61) conditions compared to baseline (M = 3.62, SD = 0.76). We thereby find evidence that the effects of condition vary across participant's preferences.

3.2 Qualitative results

The TA resulted in three global themes; *Experiencing meditation, Self-Development*, and *Influencing factors*. These are only summarized for brevity. A full report of the themes supported by excerpts by participants, can be found in the Appendix D.

Experiencing Meditation

The first global theme, experiencing meditation, describes the experiences that participants had in direct relation to the meditations, and the outcomes thereof. The majority of participants had positive preconceptions of meditation, although a few were more skeptical whether they would benefit from it. Overall, participants experienced numerous benefits, spanning from physical, (more energy and better sleep) to mental (more aware and productive) and emotional (increased appreciation and emotional management) factors.

Participants also faced some difficulties with meditation. The most common was mind-wandering, which some participants met with resistance. A few participants struggled with meditating for the full 10 minutes, however, this improved over the course of the week.

Self-Development

The second global theme, self-development, reflects the global interest of self-improvement amongst the participants in the study, and how this was impacted by meditation with biofeedback. Participants purposefully experimented with elements of their meditation practice, such as seating position, time of day, attitude towards mind wandering, and breathing techniques in order to improve their practice, with varying degrees of success. This occurred more often during the BMT week than the MT week. In the BMT week, some participants managed to find specific ways to increase their score.

Participants expressed curiosity towards the score, and most wanted to see their score improve. Many enjoyed seeing the score as it gave them a tangible record of their performance, and found that it motivated them to meditate more seriously. However, they were also confused by the score, as the score did not always reflect their subjectively perceived states of mind and body. Almost all participants did not understand fully what the score was based on and would have liked more directed feedback to know how to improve it.

Some participants on the other hand disliked the idea of being motivated by a score, and were of the opinion that the meditation practice should stem from a deeper and inner will to self-improve. These participants also thought that meditation should be left uncontaminated from the already prevalent overload of technology.

Influencing factors

The third global theme, influencing factors, corresponds to factors during the study which may have affected the overall findings of this research. The most apparent was the

personal context of participants; some participants were experiencing difficult life situations during one, or both weeks of the study. In fact, the majority of participants reported joining the study as a means of helping them deal with stress and mental health related difficulties. A few participants admitted that their circumstance may have impacted their adherence to the study.

While the study itself was designed to create comparable conditions between the conditions, not all participants adhered to the instructions. Some participants used voice-guided meditations or the in-app meditation trainings. The latter was used by three participants, who reported that it brought significant improvements to their meditation experience by making them more focused.

There were additional issues caused by the materials used in the study. For many participants, the chest strap caused some physical discomfort, as the fit was too tight or too loose. During the MT week, some participants were worried that their data was not being recorded, as the dummy device did not indicate when it was on. During the BMT week, some participants who had notifications enabled were interrupted by notifications from the application (indicating that they were hitting a high score) during their meditations.

4. Discussion

Earlier research showed that meditation has many psychological and physiological benefits that affect the quality of life. In particular, studies have found that meditation can induce states of physiological coherence (Kim et al., 2013). In turn, physiological coherence, determined by specific HRV measurements, represents optimal cardiac functioning and balance in the autonomous nervous system, which contributes to wellbeing (Moss, 2014). Additional research provided evidence that biofeedback training can be used to achieve specific physiological states (Schwartz, 1977). We posited that biofeedback might be a fruitful addition to meditation practices in order to maximize its outcomes. One study investigated the effects of meditation complemented with biofeedback (Hafner, 1982). However, this was only studied concerning direct effects (blood pressure), and not on broad everyday life outcomes. The current research, therefore, aimed to investigate the impact of meditating with biofeedback (versus meditation without biofeedback) on the perceived psychological outcomes of everyday life. This was studied in a within-subject two-week experiment whereby each participant spent one week meditating with and one week without biofeedback. Outcomes were assessed using the EOM-EL scale after each condition, and our findings were complemented with exploratory analyses and interviews. We hypothesized that participants would have higher scores on the EOM-EL scale following a week of meditating with biofeedback compared to meditating without biofeedback, and baseline measures. We did not find evidence for our hypothesis. Our results indicated that after meditating with biofeedback, participants had higher EOM-EL scores than their baseline measure, but not significantly higher scores than when they meditated without biofeedback. Thus, we found no empirical evidence that biofeedback-aided meditation improves the everyday life outcomes

of meditation. Nonetheless, interviews raised some interesting considerations which will be shortly discussed.

4.1 Main findings

Results provided evidence that meditation training improved perceived psychological outcomes in everyday life on the EOM-EL scale, supporting the findings of Reavley and Pallant (2009). As illustrated by the global theme *Outcomes of Meditation* in Section 3.2, many participants experienced calmness, better sleep, more focus, and gratefulness amongst numerous other benefits since starting to meditate. This finding is in line with the vast existing literature on meditation that demonstrates the positive effects of meditating on these outcomes (Seldmeier et al., 2012).

However, biofeedback-aided meditation was not found to improve these compared to meditation alone. There are several plausible explications for this finding that were highlighted during interviews with the participants. The first, and arguably most crucial, relates to how participants interpreted and interacted with the biofeedback. Although participants were briefed on the score (relating to HRV and physiological coherence), most were still confused at what it symbolized. Seeing as the majority expected the score to signal relaxation, they were often confused by incoherencies between the scores their subjective experience. Besides, the relative nature of the coherence scores to one's physiology (Kim, Lee, Kim, Whang & Kang, 2013) meant that participants had no reference point to compare their scores to, other than their own. Consequently, they did not know how to improve their scores even if they wanted to and advocated for more substantial feedback.

These issues (lack of understanding of what the score symbolized, being confused by contradictory scores, and no reference points) relate to components of Bandura's (1991) self-regulation theory. Commonly ascribed to the effects of self-monitoring (Kersten-van Dijk,

Westerink, Beute, & Ijsselsteijn, 2017), the self-regulation theory outlines a structure of psychological sub-function that characterize the outcomes of self-directed change (see Figure. 8)

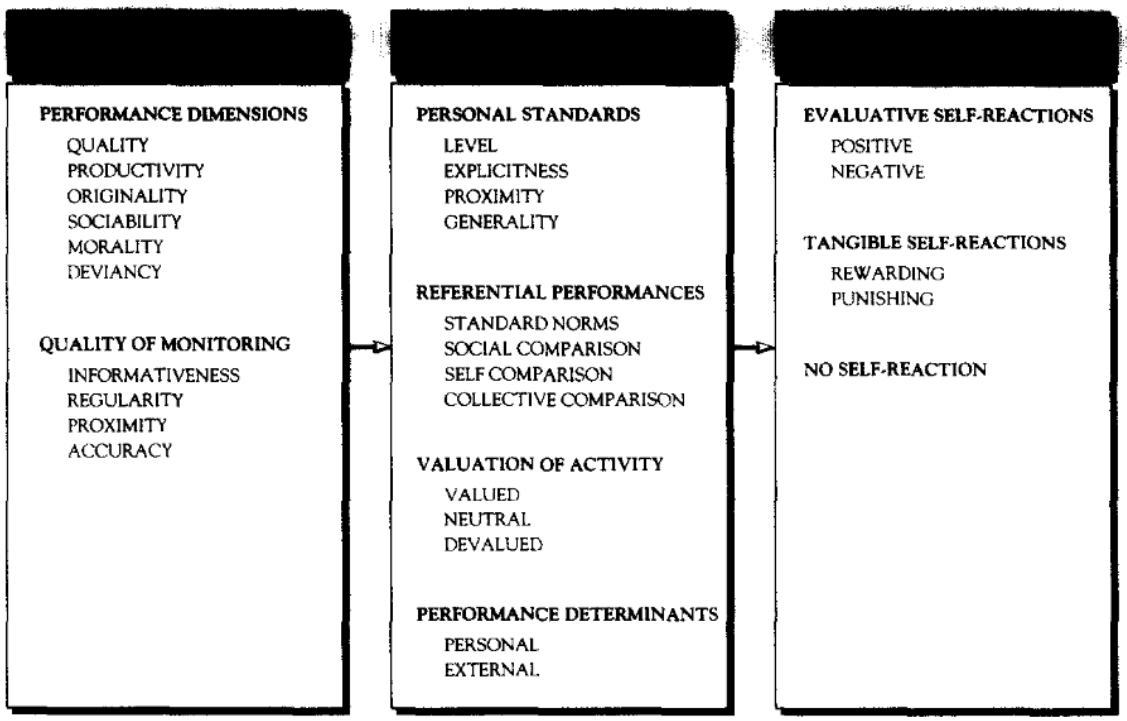

Figure 8 Psychological sub-functions in Bandura's (1991) self-regulation theory

The first sub-function, *Self-Monitoring*, emphasizes the quality of monitoring. The lack of meaning ascribed to the scores and the confusion derived from inconsistencies between subjective perception and scores relate to the *Informativeness* and *Accuracy* aspects of this sub-function. Bandura (1991) states that self-observation can only improve performance when there is minimal ambiguity about how one's actions affect the performance in the first place. The *Judgmental* sub-function refers to standards that can be self-derived or imposed. Participants did not have standards to relate their scores to and were uncertain whether their scores were standard, good, or bad, even on a personal level. This

corresponds to the *level*, *standard norms*, and *self-comparison* aspects of this sub-function. According to Bandura, standard referential norms are typically used as comparisons for participants to adjust their performance towards. The ambiguity surrounding the score and lack of standards may have resulted in no clear goal and thus have impacted participant's motivation and ability to improve their meditation practice.

The issues mentioned above suggest that participants were cemented in the *Discovery phase* of Li, Dey and Forlizzi's (2010) stage-based model of personal informatics systems. In this phase, which is part of a larger Reflection stage, participants do not have clear goals, nor do they know what influences their performance. The greater part of current consumer-facing personal informatics applications do not support the transition from this stage to the *Maintenance phase,* where both goals and actionables are clear (Rapp & Cena, 2014). It is also conceivable that participants did not have enough time to get well-acquainted with the score; previous biofeedback studies had participants train with biofeedback anywhere between four weeks to several months (Cutshall et al., 2011; Hafner, 1982; Henriques et al., 2011; Patel & Carruthers, 1977; Ratanasiripong et al., 2015; Walsh & Shapiro, 2006; Zaichkowsky & Kamen, 1978).

That being said, most biofeedback training methods do not necessitate precise comprehension on behalf of its users (see Bornemann, Kovacs, & Singer, 2019). An explanation may be that participants did not use the biofeedback as an active learning mechanism. Instead, the score was considered post-meditation as an indication of their performance, and only a handful of participants actively engaged with the scores to find what made it rise or fall between their meditation sessions. A similar finding was presented in Kersten-van Dijk and colleagues' (2017) review of personal informatics, self-insight and behavior change literature, where they reported that participants scarcely drew "if-this-then-

that insights" from their personal data (p.288). More often, participants gained awareness but did not act.

Despite these possible explanatory factors, we have no attestation that addressing these issues would result in improvements in outcomes of meditation with the use of biofeedback. Based on the present findings, however, we advise that biofeedback-aided meditation technologies provide more context for the feedback, and help users identify their goals.

4.2 Exploratory findings

Different from the findings of Reavley and Pallant (2009), our results showed no evidence that meditating improved outcomes on the EOM-EL-Expanded-consciousness and the EOM-EL-Social dimensions of the EOM-EL scale. By looking at the items composing these, we can see that these dimensions involve greater changes in the self in relation to the world that would require more time than two weeks to attain. As an example, the items *"I have more energy or vitality"* (EOM-EL-Physical) and *"I am able to think more clearly"* (EOM-EL-Cognitive) are much easier to judge and improve than *"I have noticed a change in my values and vision of life"* (EOM-EL-Expanded-consciousness) *or "My social networks have changed for the better"* (EOM-EL-Social). Indeed, the participants in Reavley and Pallant's (2009) spent a considerably higher amount of time meditating per week, and the majority had over five years of experience meditating. It is, therefore, no surprise that no improvement was found on these dimensions. In the EOM-EL-Nonjudgmental-acceptance dimension, on the other hand, our results found evidence for improvement following biofeedback-aided meditation, but not meditation alone. Examining the items in this dimension, we see items such as *"I have better understanding of myself and others"* and *"I recognize that thoughts are just thoughts rather than accurate reflections of reality"*. These

correspond to participants' sense of heightened awareness, objectivity in perception, and regard of the biofeedback score as an objective measure, in line with earlier biofeedback theories (Green, Green, Walters, Sargent, & Meyer, 1973). This may suggest that having access to biofeedback may have prompt participants to reappraise their subjective experiences more often.

We also found that biofeedback-aided meditation had better outcomes on the Cognitive dimension of the EOM-DM scale compared to meditation-only, indicating that participants experienced more focus and objectivity while meditating with biofeedback compared to without. This is in line with the findings of Cuthbert and colleagues (1981) and reinforces previous studies that found improvements in cognitive performance following HRV biofeedback interventions (Prinsloo et al., 2011). In our study, this difference may have arisen as a result of the participants who used the in-app meditation training during the BMT condition. These participants, as described in Section 3.2, reported that they were able to focus more by using these meditation trainings.

Another interesting finding relates to participants' preferences and their EOM-EL scores at the three measurement points. Our results found evidence that participants who preferred meditating with biofeedback improved their outcomes after both conditions compared to baseline. In contrast, participants who preferred meditating without biofeedback had no significant improvement from baseline. One possible interpretation of this finding is that participants who preferred meditating with biofeedback are also more likely to exert more effort in improving their performance, and thus reap more favorable results. This is based on the goal-setting theory of Bandura (1991), who states that individuals who set higher goals achieve more effort. It is also possible, however, that participants who preferred having biofeedback were more improvement-focused and thus biased to report improved

outcomes in line with their expectations and efforts, to avoid cognitive dissonance (Sedlmeier et al., 2012). One participant mentioned, "I'm maybe a bit biased towards meditation because I know I'm doing this, so whenever I feel or see something positive, I might relate it to 'oh this might happen due to the meditation which I have been doing a lot". Alternatively, it is conceivable that participants who experienced no improvement in their everyday life found no added value in biofeedback, seeing as their results with meditation were subsidiary in general. It is important to note that these possible interpretations are only speculations, and further research is needed to explore this area thoroughly.

The qualitative data gathered from participants highlighted other interesting effects of biofeedback-aided meditation. As outlined in Section 3.2, a portion of participants was more motivated to meditate when they had access to biofeedback. Regardless of outcomes, this is a valuable contribution of biofeedback, as it could improve adherence to meditation training in *wannabe* meditators who are struggling to commit to the practice. Hafner (1982) reported similar findings in their study; participants in the biofeedback meditation group trained more frequently than their counterparts and saw faster decreases in blood tension at the start of the study. This sentiment was reflected by some of the novice participants in the current study, who found the immediate, tangible results of biofeedback useful in their practice. Yet, we also discovered that several participants disliked feeling challenged and wanted to be more intrinsically motivated to engage in meditation. In this regard, some participants had adverse reactions to the feedback. This suggests that the success of such technologies also depends on the attitudes of its users, in line with previous studies showed that certain personality factors could predict biofeedback efficacy (Pardine & Napoli, 1977) and even aggravate impacts of negative feedback (van Dijk, Westerink, Beute & IJsselstein, 2015).

4.3 Strengths, limitations, and future work

This research is the first to study the effects of biofeedback-aided meditation on everyday life outcomes and thus presents valuable considerations for future research in this area. An advantage of this work is its ecological validity as a field study. Participants had access to a portable technology that allowed them to do the meditation trainings at their leisure in the comfort of their own homes, unlike previous biofeedback-aided meditation research (Hafner, 1982). However, although this research set out to study the impact of biofeedback, the interviews suggested that most participants interacted with the technology as a personal informatics system to track progress rather than an active biofeedback system. Our results, therefore, do not sufficiently reflect the real effects of biofeedback. Perhaps a repetition of this study could include a dedicated training for participants to familiarize themselves with the biofeedback mechanism. Furthermore, this opens up an interesting question as to how biofeedback without tracking would compare to the biofeedback used in this study, which provides aggregated and trackable data.

As disclosed in the Method, the final sample size was only half of that planned due to time constraints. Although 24 participants still resulted in an adequate power, a continuation of this research with more participants would reveal smaller effect sizes. Furthermore, longitudinal studies are needed to reveal the effects of biofeedback-aided meditation in the long run. This could examine whether biofeedback does indeed increase motivation to meditate (an emerging theme in the qualitative results) and whether this, in turn, leads to more adherence over time. This is important as previous studies have found that the lasting effects of meditation on everyday life were only present in groups of meditators who had consistent daily practice (Campanella, Cresentini, Urgesi, & Fabbro, 2014). The early hindrances meditation scale (Russ et al., 2017) could additionally be used to determine if the addition of biofeedback results in a lower barrier to meditate amongst beginner meditators.

We draw attention to the fact that the majority of participants joined the study in search of support for their mental health (as described in Section 3.2). This is not new for meditation studies (Seldmeier et al., 2012). Future research would benefit from including standardized measures of mental health constituents to complement findings. Additionally, compensating participants for the minutes spent meditating between the experimental sessions could homogenize the motivation of participants to comply with their meditation trainings during the study, and also motivate a more diverse array of participants to take part in the research.

As with all research utilizing self-measures in the form of questionnaires, there is the risk of response set consistencies and response bias (Podsakoff & Organ, 1986). In order to investigate the reliability of questionnaire responses and mitigate expectation effects, future work should consider the inclusion of objective measures, such as task-related performances and physiological variables in their study design. The extent of experimenter-participant interaction should also be considered, as this has been shown to affect outcomes in meditation (Cuthbert, 1981). It is advisable that future studies use a recorded guided meditation practice during the introductory session, or even employ the help of external professionals.

Finally, as introduced in Section 3.2, numerous participants were conflicted about the use of technology in meditation. This contention is not new (Derthick, 2014), and neither are such technologies. In line with Buie and Blythe (2013), we believe that more research is needed in order to understand technology acceptance in this domain, and thus provide better guidelines for designers. We also recommend that future research consider the ethical questions related to biofeedback. In this study, we found that incongruencies between participants' scores and their own subjective experiences led to considerable confusion,

provoking sometimes conflicting sentiments within participants. Should they trust themselves, or the technology? We stress the need for such technological interventions to be based in sound value-sensitive design principles and furthermore emphasize that such technology does not benefit everybody equally (van Dijk, Westerink, Beute & IJsselstein, 2015).

4.4 Conclusion

Physiological coherence research has gained traction in recent years, and studies suggest numerous benefits of coherent states on human functioning and wellbeing (Edwards, 2014; McCraty & Zayas, 2014; Tiller et al., 1996). While self-inducing coherence has been a practice tied to meditative practices, recent technological developments capacitated biofeedback as another means to achieve this state. In this research, we contribute to the understanding of how the latter can support meditation practices, and appraise its effects on everyday life. This study confirms previous findings that meditation has beneficial impacts on the quality of everyday life. However, no evidence was found for improvement in these outcomes when meditation was complemented with physiological coherence biofeedback. Nonetheless, our results found evidence that biofeedback-aided meditation may improve the cognitive quality of meditation during meditation practice and foster non-judgmental reappraisal. Furthermore, our qualitative explorations suggest potential motivational impacts of biofeedback-aided meditation and highlights important considerations for the design of effective biofeedback delivery. In stating the limitations of this study, we put forward the need for further studies to explore biofeedback-aided meditation.

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Appendix A

Invitation materials

Dear [NAME],

****
****
IPHONE OR IPAD USERS ONLY
****
****

I would like to invite you to participate in a new study. In this study, you will be required to attend 3 sessions of 30 minutes, where you will be trained in a meditation technique and asked some questions. During the week between each session, you will be asked to practice the meditation techniques at home, while wearing a heart measurement device. The structure will go like this:

- 1st session
- 1st week of meditation
- 2nd session
- 2nd week of meditation
- 3rd session

You will get a compensation of €15.00 (€2.00 euros extra if you come from outside the TU/e or Fontys Eindhoven), after attending all three sessions. If you are a student from the Psychology & Technology or Sustainable Innovation bachelors, you may alternatively earn study credits for one of the sessions. At the end, you will have the opportunity to enter a raffle to keep using the meditation platform and biofeedback device (valued at $199), in return for participation in further surveys.

The experiment will take place in the Atlas building on the TU / e site, in lab 9.209. You will be picked up at the seats outside the room.

---- REQUIREMENTS ----
For this experiment, it is required that you are able to understand and speak English, and that you will be available for 3 experiment sessions. Please only sign up for this experiment if you have a phone that runs iOS.

The experiment will take place in one of the labs on the 9th floor in the Atlas building on the TU/e campus.

You can register online at [LINK_TO_ONLINE_BOOKING_SYSTEM]. The name of the experiment is Meditation and Biofeedback.
For now it is only necessary to register for the first session (but you may choose to register for the 2nd and 3rd sessions already). You will then receive a confirmation email. If you would like to participate, but these session dates don't work for you, please contact Djameela at k.d.dulloo@student.tue.nl, or by whatsapp +31621340258, and we can find an arrangement that suits you.

If you have any questions, please do not hesitate to contact Djameela Dulloo at k.d.dulloo@student.tue.nl. This study is supervised by Jaap Ham j.c.r.ham@tue.nl.

Sincerely,
Djameela Dulloo

PARTICIPANTS WANTED!

Join a study on Meditation with Biofeedback technology.
3 sessions over 2 weeks.

Little or no meditation experience

iPhone or iPad

Compensation €15

Contact Djameela: k.d.dulloo@student.tue.nl
(whatsapp) +31621340258

**"Meditation can bring you peace and serenity.
It also gives you an excuse to look busy doing nothing."**

Appendix B

Questionnaires

Pre-questionnaire

Meditation and Biofeedback Study - Session A

In this session, you will be asked a few general demographic questions, and then be asked to complete a survey on your everyday life. Please read the questions carefully and do not hesitate to ask the researcher if you have any questions.

Welcome to the Meditation and Biofeedback study. Thank you for choosing to participate. There are 12 questions in this survey.

[]What is your age? *

Only numbers may be entered in this field.
Please write your answer here:

Please enter a number.

[]What is your gender? *

Choose one of the following answers
Please choose **only one** of the following:

- ◯ Male
- ◯ Female
- ◯ Prefer not to say

[]How much previous experience do you have with meditation? *

Choose one of the following answers
Please choose **only one** of the following:

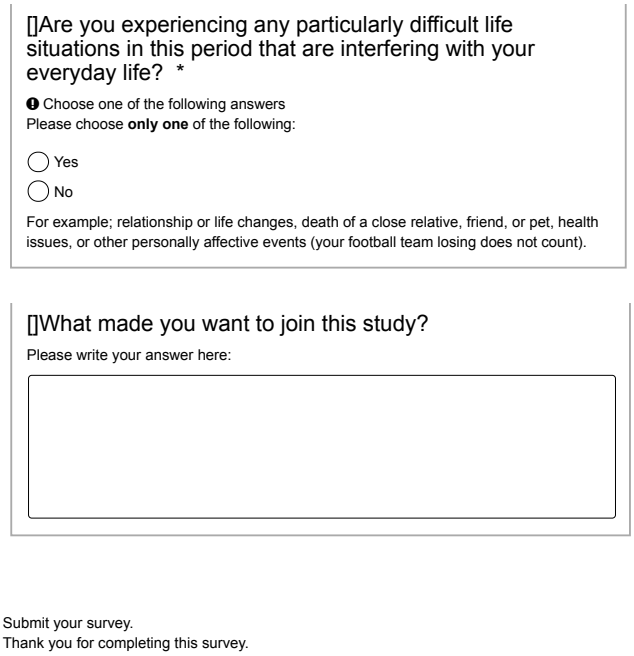
- ◯ None (0 hours of meditation)
- ◯ Less than 1 hour
- ◯ Between 1 and 3 hours
- ◯ Other

[]Do you have any current medical diagnoses?

Choose one of the following answers
Please choose **only one** of the following:

- ◯ Yes
- ◯ No

Make a comment on your choice here:



[]Are you experiencing any particularly difficult life situations in this period that are interfering with your everyday life? *

Choose one of the following answers
Please choose **only one** of the following:

◯ Yes
◯ No

For example; relationship or life changes, death of a close relative, friend, or pet, health issues, or other personally affective events (your football team losing does not count).

[]What made you want to join this study?

Please write your answer here:

Submit your survey.
Thank you for completing this survey.

Effects of Meditation – Everyday Life (EOM-EL) scale

Participants were asked to rate each item on a 6-point scale, ranging from 1 – *Not true for me* to 6 – *True for me*, in relation to their past week. The items were randomized on five pages, such that one item from each sub-scale appeared on each page.

"For the following questions, you will be presented with a series of statements. You will be asked to rate these statements on a scale from "Not true for me" to "True for me". During this exercise, please indicate how true or untrue these statements are to you in general since the start of the past week, compared to the weeks prior."

EOM-EL-Physical
elp1;I feel a sense of physical wellbeing
elp2;I have more energy or vitality
elp3;I sleep better
elp4;I am more aware of body sensations and responses
elp5;I experience fewer physical symptoms of stress

EOM-EL-Expanded consciousness
elec1;I experience more fulfilment and meaning in life
elec2;I have noticed a change in my values and vision of life
elec3;My spiritual life is more important to me
elec4;I am more able to trust my inner nature and wisdom
elec5;I feel a sense of inner peace and strength

EOM-EL-Emotional
ele1;I experience more happiness and joy in life

ele2;I generally feel calmer and more centred
ele3;I am less anxious
ele4;I am less depressed
ele5;I am less emotionally reactive

EOM-EL-Social
els1;I make more effort to avoid causing suffering to others
els2;My social networks have changed for the better
els3;I am less likely to act on my desires at the expense of others
els4;I have less conflict with others
els5;I am more compassionate and empathic

EOM-EL-Cognitive
elc1;I have better mental focus and concentration
elc2;I am able to think more clearly
elc3;My memory is better
elc4;I am more organised and efficient
elc5;I have better problem solving skills

EOM-EL-Non-judgemental acceptance
ela1;I recognise that thoughts are just thoughts rather than accurate reflections of reality
ela2;I am less judgemental of myself and others
ela3;I have a better understanding of myself and others
ela4;I have a different way of coping and responding to what is going on in life
ela5;I am more able to forgive myself and others and move on

EOM-EL-Behaviour
elb1;I am less affected by habits such as biting nails, teeth grinding etc.
elb2;I am less affected by fears and obsessive behaviour patterns
elb3;I have better control over my eating habits
elb4;I am less affected by strong desires or impulses
elb5;I have less destructive behaviour

Effects of Meditation – During Meditation (EOM-DM) scale

Participants were asked to rate each item on a 6-point scale, ranging from 1 – *Almost never* to 6 – *Almost always*, in relation to their meditation practices. The items were presented in a randomized order, but on the same page due to the limited number of items.

“For each of the following statements, please rate from 'Almost Never' to 'Almost Always' how often you encounter the situations described by the statement during your meditation practices in the past week.”

Cognitive effects
dmc1;I observe without judgement any positive thoughts or emotions that arise
dmc2;I observe my thoughts as an impartial observer

dmc3;My mind is alert and still
dmc4;My perceptions are clearer

Mystical Experiences
dmm1;I have an experience of contact with a higher power
dmm2;I have what I describe as a mystical experience
dmm3;I have a new awareness of the order in the universe I feel a sense of awe and wonder
dmm4;I feel a sense of awe and wonder

Emotional Effects
dme1;I experience fluctuating emotions
dme2;I experience feelings of sadness and depression
dme3;I experience feelings of anger
dme4;I experience feelings of tension and anxiety

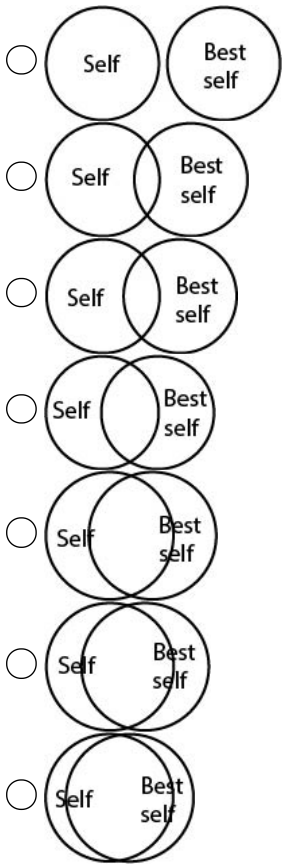
Physical discomfort
dmp1;I am aware of physical discomfort
dmp2;I feel restless or twitching of parts of my body
dmp3;I become aware of tightness in parts of my body

Best self

[]Imagine your potential 'best self'. This is an attainable version of yourself that is living optimally according to your goals and values. Please select the picture that best describes the relationship between your current self and your potential best self. *

Choose one of the following answers

Please choose **only one** of the following:



Interviews
Scope of research: This interview aims to provide a more general and context specific understanding of how participants experienced the effects of daily meditation in their everyday life.

Key focus for findings:
Struggles during the meditation practices
Sense of improvement of meditation practice
Outcome on quality of life

Interview Plan

Phase 1: Intro for Session 2 only

[Introduce yourself, ask for permission to record the interview, remind them that they can withdraw from the study at any point in time, and that their data will be anonymized]

1. Prior to this past week, what was you experience (if any) with meditation?
2. Did you have any preconceptions? (Has this changed since?)
3. Do you suffer from depression and/or anxiety?

Phase 2: Participants' week

4. Tell me a bit about what you did last week.
5. Did anything out of the ordinary, or memorable happen?
6. Do you feel like you faced any defeats or failures (small or big) during this week, and if so, how did you deal with it?
7. Do you feel like you had any achievements (small or big) during this week, and if so, what were they?

Phase 3a: Meditations MT

8. Describe to me how you meditated this past week
9. Did you follow a structure? Specific techniques?
10. At what times did you usually meditate?
11. Did you miss any days?
12. How did/do you feel about your daily meditation experience?
13. Was there anything in particular that you struggled with?
14. Was there anything in particular that went well?
15. Did your experience while meditating change along the course of the week?
16. What is your opinion about meditating in general, after this week?
17. How did you feel about wearing the chest strap?

Phase 3b: Meditations BMT (with evolve)

8. Describe to me how you meditated this past week
9. Did you follow a structure? Specific techniques?
10. At what times did you usually meditate?
11. Did you miss any days?
12. How did/do you feel about your daily meditation experience?
13. Was there anything in particular that you struggled with?
14. Was there anything in particular that went well?
15. Did your experience while meditating change along the course of the week?
16. What is your opinion about meditating in general, after this week?
17. How did you feel about wearing the chest strap?

18. How often did you wear the strap, and check your data?
19. Did you do anything differently in your daily life since using the platform?
20. What impact did having access to your EPI score have on you?

21. Was there anything about the app that you weren't expecting?
22. Was there anything that you would have expected, but wasn't in the app?
23. What did you like/dislike about the platform?

Conclusion

24. Overall, was your experience using the Evolve platform positive or negative?
25. Would you continue using it? (Why/why not)
26. If not, what functionalities would make you reconsider?
27. Is there anything else that you would like to add?

Final session

28. Did you prefer meditating with or without the app? (Why?)

[Thank you for your time]

Other: Try to find out if participants searched for more information online (about meditation, techniques, or general theory).

Appendix C
Experiment Materials

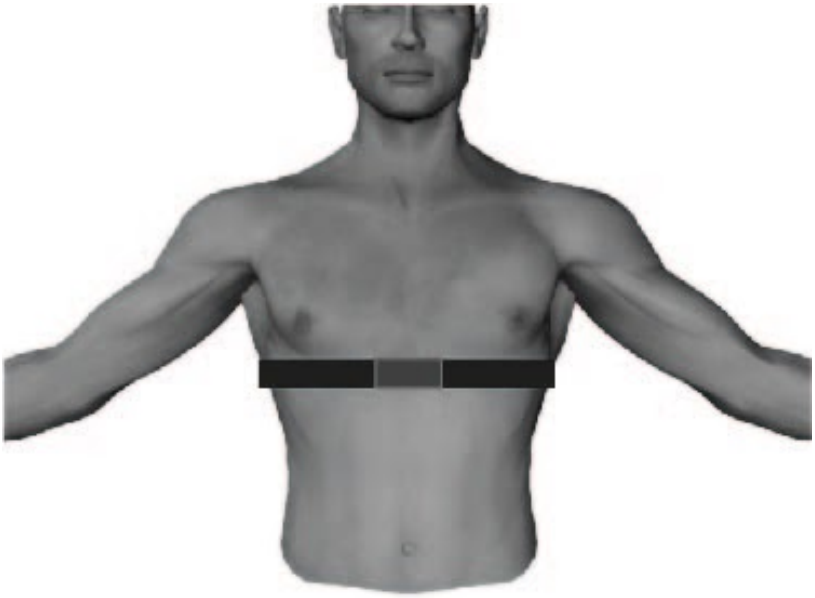
Experiment instructions MT

Thank you for choosing to participate in this study.

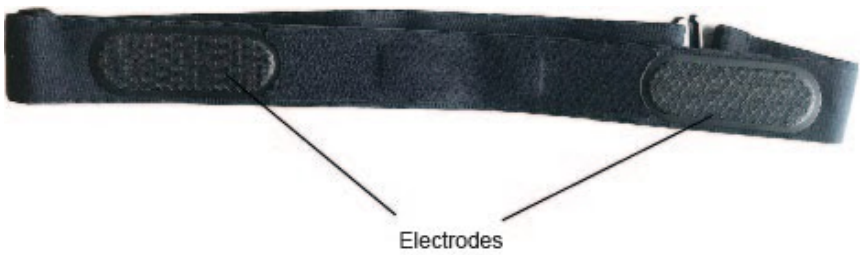
Here is your daily task for the coming week, starting today:

- Meditate for at least 10 minutes per day while wearing the chest strap.
- Please abide to this as much as possible. Your meditation activity will be recorded automatically by the device.

Make sure that the strap fits tightly and is not loose. The device will start measuring once the electrodes make contact with the skin. The strap should be positioned right below your pectorals, with the device on your solar plexus, as shown below:



Moisten the electrodes with a bit of water before wearing it, as shown in the session.



Caution:

- Do not expose the device to water
- Do not tamper with the device and strap

- Do not expose the device to high heat or flammable liquids

Some tips:

- Make sure that you are in a quiet place around no distractions while you meditate
- It is best not to meditate right after a big meal
- Use the guided meditation in the first session as a starting point, but feel free to adapt the meditation to what works best for you
- Do not get discouraged by the wandering mind. It is normal.
- You can review the Introduction to Meditation video that was presented to you in the first session here: https://drive.google.com/file/d/1VcwVcYATjLfBghRAHU6DIX3KwvLuacyk/view?usp=sharing

If you have any questions, or encounter some problems with the device, you can contact Djameela directly via
email: k.d.dulloo@student.tue.nl
whatsapp: +31621340258

See you in the next session!

Experiment instructions BMT

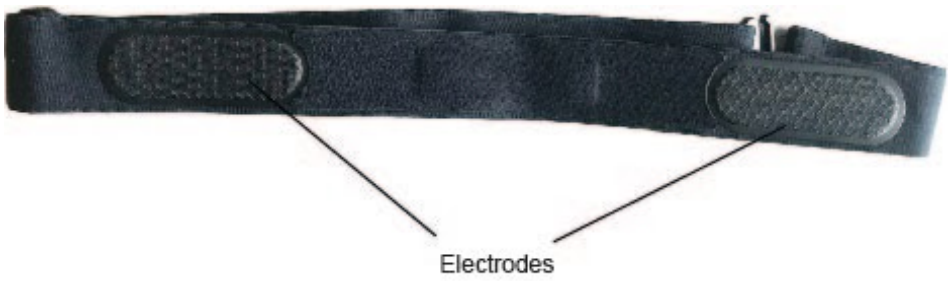
Thank you for choosing to participate in this study.

Here is your daily task for the coming week, starting today:

- Meditate for at least 10 minutes while wearing the chest strap
- Make sure that the device is connected to the Evolve app before you start
- Look at your data at least once before and once after your meditation
- Aim for high E-scores
- You may wear the chest strap and use the app throughout the day (or for however long) if you wish, although this is not obligatory

The strap should be positioned right below your pectorals, with the device on your solar plexus, as shown below:

Moisten the electrodes with a bit of water before wearing it, as shown in the session.



Cautions:

- Do not expose the device to water
- Do not tamper with the device and strap
- Do not expose the device to high heat or flammable liquids

Some tips:

- Make sure that you are in a quiet place around no distractions while you meditate
- It is best not to meditate right after a big meal
- Use the guided meditation in the first session as a starting point, but feel free to adapt the meditation to what works best for you
- To accompany your meditation, you may use one of the instrumental soundtracks provided in the email sent by the researcher
- Do not get discouraged by the wandering mind. It is normal.
- You can review the Introduction to Meditation video that was presented to you in the first session here: https://drive.google.com/file/d/1VcwVcYATjLfBghRAHU6DIX3KwvLuacyk/view?usp=sharing

If you have any questions, or encounter some problems with the device, you can contact me (the researcher) directly via
email: k.d.dulloo@student.tue.nl
whatsapp: +31621340258

See you in the next session!

Guided meditation script

First, you can find a comfortable position for yourself. Try to keep your back straight and shoulders relaxed. Feet flat on the floor. I like to stretch a little before I start. When you're ready, you can close your eyes.
Now give yourself a little moment to settle down, just being still. In our daily lives, we're so caught up in our thoughts, rushing from place to place. You might have a lot going on in your head, and that's normal.
Take a moment to just observe what is happening in your mind. You can let the thoughts fly by. The only thing you have to do is watch them.
Now gently bring your attention to your breath. We take the breath for granted a lot. The breath gives us energy every day, yet sometimes we allow it to get so shallow.
Try to see where you feel your breath the most. Maybe it's in your nostrils. Maybe it's in rise and fall of your belly.. or your chest. However it is, just observe how it feels to breathe.
And now, with your next breath, try to make the inhale just a little deeper, and the exhale, just a little longer. Taking a little pause at the top of your breath.
Feel yourself, with every deepening breath, becoming just a little more relaxed. Your body loosening, feeling a little heavier.
Settle into a breathing rhythm has feels natural to you.
If at any point, you notice that you are distracted by thoughts. Just know that that's okay. Simply watch it happen. And when you're ready, bring your attention back to your breath.
Now bring your attention to your body. Notice how your feet feel, sitting in your shoes, against the ground. Maybe there are some sensations there that you hadn't noticed before. Notice how your thighs feel, against the chair. Notice the contact between your hands and your legs. Allow yourself, to simply feel.
You might feel some discomfort. Know that's normal. Don't try to fight it, allow it to be. Experiencing all the sensations without judgement.
Gently bring your attention to your heart area, in your chest. Feel your breath, filling this area in with light.
Now, think of something, or someone, that you are grateful for, or feel love towards. Hold that image in your mind. Try to really feel- how does it feel to be grateful, or feel love. Allow that feeling to fill the area in your chest.
Remember, any time you notice your mind wandering. That's okay. Simply let it, watch it, and then bring it gently back to your breath.
Now you can start to slowly return to where you are. Aware of your surroundings, aware of being sat in this room, on this chair. Start by making little movements with your toes, with your fingers. Stretching out a bit. And when you're ready, you can open your eyes again.

Appendix D

Qualitative analysis

We clarified what form of TA was to be used, and why, to ensure consistency across all phases of the analysis (Nowell et al., 2017). TA can make use of inductive or deductive approaches. As Braun and Clarke (2012) describe, inductive approaches result in themes that stem directly from the data, while in deductive approaches, the researcher carries some pre-existing ideas into the analysis and uses those to analyze the data. However, analyses rarely only use one form. This study employed a combination of inductive and deductive approaches. The interview script contained several directed questions that pre-introduced themes. These included questions such as, "What were your opinions and expectations of meditation before you started this study?", "Did the structure of your meditation training change over the course of the week?", "Tell me a bit about your past week. Did anything out of the ordinary happen in your daily life?", or "Overall, did you prefer meditating with or without the feedback, and why?". Such questions introduced clear pre-conceived ideas, and thus called for a deductive approach. Nonetheless, an inductive take was beneficial throughout the data to uncover meaning within those themes. Macguire and Delahunt (2017) warn researchers to not fall into the trap of treating interview questions as themes. This latter would reflect a summary and organization of the data, rather than analysis. This sentiment is further reflected by Braun and Clarke (2012), and Nowell and colleagues (2017). Thus, all questions, both directed and open, involved an inductive analysis of the responses where semantic meanings were coded. Furthermore, it was important to clarify the goals of the qualitative research to narrow the scope of findings. As discussed in Chapter 2, the first aim was to explore factors that weren't encompassed by the quantitative data in relation to our research question. In this regard, there was a focus on finding the differences (if any) experienced by the participants in the two conditions. Consequently, we wished to uncover potential explanatory factors for the quantitative results. It is important to note that the qualitative analysis was carried out before the quantitative analyses to ensure minimal bias in the derivation of codes and themes. Additionally, we wanted to evaluate the use of the Evolve application and receiving biofeedback itself.

Phase 1, familiarizing oneself with the data, began during the interviews. The first codes were already in development during this process, consisting primarily of codes that would be later included as variables in the quantitative analyses. Notes were taken while listening to the audio recordings of the interviews and during transcription. After transcribing the interviews, we read through the transcripts once while taking sporadic notes. This painted an overall picture of the data and acquainted us more deeply with the participants, and their perspectives.

Next, the printed transcripts were revisited for coding. Here, we adopted a more critical stance, treating each piece of data (paragraph, sentence, phrase, or word) individually. One participant at a time, all relevant data were highlighted, and then coded. For each new piece of highlighted data, we first judged whether existing codes could apply to it. If not, a

new code was created. Codes identified attributes represented by the data, and were both semantic (descriptive) and latent (interpretative) in nature. This process resulted in 71 codes. As per the instruction of Attride-Stirling (2001), a coding framework was then constructed whereby codes were merged, redefined, or dropped in order to be more clearly defined and unique. The data was then revisited a second time and recoded accordingly. Codes that did not recur often in the data (at least three instances) were additionally discarded. This finally resulted in 63 codes.

Following this, the codes were clustered into themes by identifying commonalities. Some codes were found to construct more than one theme. These intersections are normal according to Braun and Clarke (2012), who highlight the value of these codes in connecting themes into one larger account. In this phase, we organized the themes into a thematic network (Attride-Stirling, 2001), with global themes encompassing organizing themes and sub-themes. Once these themes were collated, the data was revisited briefly to ensure the coherency of the groupings. Finally, nine themes were derived and organized into three global themes.

Global theme: Experiencing Meditation

The first global theme, experiencing meditation, describes the experiences that participants had in direct relation to the meditations, and the outcomes thereof.

Theme 1: Expectations

The vast majority of participants had positive preconceptions of meditation. They had either heard about it, read about it, known people who do it, or have tried it themselves in the past, and were mostly aware of the benefits that it claimed to bring. A few participants displayed skepticism ("*sometimes it's just bullshit*") and were curious to see whether their experience would live up to the reputation, whilst others had poor confidence in their own abilities to reach the benefits of meditation.

Theme 2: Outcomes

The interviews with participants made it clear that they experienced numerous effects of meditation in their daily lives. On a basic, physical level, participants reported being more relaxed, calm, and peaceful. Some, however, only experienced this during the meditation itself, and not in everyday life. For many participants, the most impacting outcome was better quality of sleep, if they meditated before sleep.

Meditation increased participant's awareness of their bodies during the practice, and helped them be more in touch with themselves as a result. For one participant suffering from Fibromyalgia and poor mental health, the meditation practice curbed their migraines, for which they usually had to take medication. For another participants, meditating in the morning reportedly gave them more energy throughout the day, enabling them to practice more physical activity at the end of their workday.

Participants benefitted mentally, too. Participants reported that they were able to focus better on their work and be more productive during the day. In some cases, they gained new insights on how to tackle their issues whilst coming out of a meditation session, or felt the urge to start working straight after. There was a high level of self-awareness demonstrated by

participants, and acceptance for issues that were beyond their control. Finally, several participants were actively attempting to better process and manage their emotions, and revealed an increase in gratefulness and appreciation for their lives.

During the meditation sessions, the most commonly reported struggle was the wandering mind. While some dealt with it in an accepting manner, others encountered it with resistance, which affected their sense of self-efficacy. A few participants experienced intrusive thoughts during their meditations, deterring them from wanting to meditate. Another major issue was scheduling the time for the meditation practices. Although participants acknowledged that 10 minutes was not a long time, it was not considered a priority by many. Furthermore, several participants found it hard to meditate for the full 10 minutes at the beginning of the study. However, this improved with practice, and towards the end of the study, some participants reported losing track of time.

Global theme: Self-development

The second global theme, self-development, reflects the global interest of self-improvement amongst the participants in the study, and how this was impacted by meditation with biofeedback. All participants chose to participate in the study in pursuit of bettering themselves, or learning new potentially beneficial things.

Theme 3: Learning

Most participants expressed interest in obtaining new knowledge, or modifying their current behaviors to achieve a certain goal. They purposefully experimented with elements of their meditation practice, such as seating position, time of day, attitude towards mind wandering, and breathing techniques in order to improve their practice. While these attempts did not always result in a better meditation quality, participants had learnt what did and did not work for them, or at least attempted to. Participants demonstrated *learning and adapting* more frequently in the BMT (n = 16) condition than in the MT condition (n = 6).

> *"Normally I do it before dinner. I tried it once before going to sleep and I tried it once really in the morning, like today one hour ago. And I saw before going to bed I had the highest e number, or- and in the morning I was more in my head with 'ok this is my to-do list, I want to do this, I want to do that'".*

Participants tended to also see progress in their meditation experience throughout the week or weeks, regardless of their attempts or condition. The majority of participants conveyed frustration in not knowing whether they are "*meditating right"* during the MT week, and wanting to improve, but not knowing how in the BMT week.

A handful of participants, like the one cited above, experimented with the feedback outside of their meditation sessions and found ways specific ways to then increase their score. Some wore the Evolve chest strap for a few hours during the day to see how their score fluctuated with their daily activities. As discussed in the Introduction, we expect to see this behavior more regularly amongst participants.

> *So I looked at the score and then I saw why the score goes up. So then I realize that there is a pattern of breathing which makes the score go up [...] by observing that and controlling that I could make the scores really go up.*

In reality, most participants interpreted the score passively by connecting it to subjective experiences, but did not to use it as a tool. The latter was not always by choice; many wanted to improve their score come the following session, but did not know how (this is described further in theme 3). Furthermore, participants suggested that had it been easier to compare sessions, they would have made more attempts. Interestingly, a few participants wrongly interpreted the scores (for example thinking a lower score would be better), yet still experienced more clarity with the scores compared to without.

Theme 3: Reacting to Feedback

Participants reacted in similar ways across the board, with some variation in attitudes towards their own reactions. Most participants were curious to know their scores after meditating, and sometimes expressed missing them during the MT week. There was a general agreement that it felt satisfying to scroll back through the graph and see the "*green peaks*" during their meditation sessions. However, this satisfaction was not always welcomed, as will be discussed in theme 4. When participants had lower scores, they ended up disappointed and put off from the feedback.

Nearly all participants were confused by the score at one point or another for various reasons. This is especially due to instances where the score didn't correspond to the participant's perceived state of mind or body. This either made the participant re-evaluate their subjective state, have less faith in the technology, or puzzled as to what the score was really representing.

Despite this, the majority of participants found correlations between their subjective experiences and the scores. Some participants expressed awe or surprise at how the application managed to measure their mental state, or even instilled more trust in the feedback from the application than their own judgement. For example, one participant stated "*Even if I felt it that I had a good meditation session, it might have not been true, but with a phone I would have known if it was a good session or not*".

In many cases, the score served to validate how their meditation session went. The lack of this validation became evident when participants had the feedback taken away from them. The score provided a metric that rendered the meditation experience quantifiable and thus more tangible. This was assuring for some, and led to feeling challenged to improve the scores. However, participants struggled to do this.

A lack of understanding about what exactly the score represented, how it was derived, and how exactly to improve it, was a universal sentiment. Participants acknowledged that the scores reflected (on average) a certain level of calmness and peace, but inconsistency in the scores roused confusion. Directed and specific feedback was desired by almost all subjects, as well as clearer indications of whether their performance was good or bad. As one participant said, *"I am not really sure how to interpret the score. I mean a lot of my days had low scores and I don't really know how if that's normal – you know, how it will look ideally."*

Theme 4: Motivation

While the pursuit of self-development prevailed across the participants, there was some contention on the form in which it manifested. As introduced previously, a great deal of participants felt motivated by the score and considered it an incentive to dedicate more to their meditation training.

> *I think it made me a little more dedicated to doing meditation as well as I possibly could. Because I saw a direct feedback that if I did it, I was really was able to let go of my thoughts and focus on my body and breath you would get such an immediate positive feedback on it.*

Aside from injecting fun to the process, the scores seemed to make their progress more concrete, and held them accountable for their practice. As one participant said,

> *When you have the app, you do not only rely on your own opinion, because when it's just you sometimes you actually kind of cheat or something. So like yeah, I'm doing this, maybe it's well enough but I don't really care. And when you do have the machine, you have something you look at, it's more tangible. It's different. It gets recorded so you can actually see it again.*

In contrast, some participants disliked the idea of being motivated by a score. They instead regarded meditation as something they wanted to do purely for themselves, stemming from a deeper will to self-improve. They further felt more conflicted in situations where the score did not reflect their subjective experience. One participant, for example, expressed that they should trust their own feeling and instincts, rather than what the application is telling them.

> *"I think that the thing with the app is that it's addictive somehow. Because you do your meditation, and then you're looking so forward to see how is your score. And if it's like really high you get excited, even though like you should trust yourself like what you felt during the meditation, and not the score that's shown on the app"*

These sentiments extended to the study itself, whereby some participants enjoyed having a "push" to make meditation a part of their routine, while for others it made meditation feel like a "chore" rather than something they are doing out of their own will. There were additionally many participants in the middle ground. These were people who liked receiving feedback, but also did not care much for it as they did not know what it meant.

> *It was really nice to have something you know measurable in front of me, though you do not have anything to compare it to. […] It was nice to know that this thing was on and I have done something I have done some progress […] But I think that it was just the additional motivation the thing. The device by itself was a big motivating factor to meditate. and I think that's what's more important.*

Theme 5: Technology's 'place'

Three sub-themes were identified to represent different perspectives on technology's role in the domain of meditation. First, is technology as a facilitator. From this perspective, participants valued the technology as it enabled them to monitor their progress. Seeing a log of their meditation sessions made the results more visible, and granted a sense of achievement. For some, it also made the habit of meditating more enjoyable.

> *I feel I really like it and the whole meditation thing. And using the score because you can actually see the difference. And for me it's really important if I do something so I see not just the results -- yes, the results as well. But the thing you can actually see like numbers […] I have a technician sort of brain so I always want to see numbers.*

The excerpt from the participant above also highlighted a difference between participants. We noticed that some participants tended to use specific numerals in their speech when talking about time, or about grades, whereas others use more generic terms, perhaps indicating a difference in personalities.

Next, is technology as a temporary support. Participants considered the biofeedback technology to be helpful to novice meditators, like themselves, but doubted whether it would add value down the line. This was expressed succinctly by the following participant.

> *I think I'm in the stage where I still need to practice how I meditate, and when it's going well and when it isn't. But I think that if you know a bit more on how you're doing it, and you're really trying to do it very seriously, and that then you might not benefit from an application. Because it's more about yourself and how you feel instead of a score that it gives you.*

Additionally, some participants remarked that the novelty wore off as they learnt what was expected of them. Many participants found the technology to be bonus, *"brownie points",* but not a necessity. After all, "*for many other people, they do meditate and they generally don't now and then look onto this technology thing, so they do it only for themselves*".

Finally, there was the notion of technology as interfering with the meditation practice. The most obvious evidence for this was the hassle of wearing the chest strap. While some participants were not disturbed by this and sometimes forgot they were wearing it, many reported discomforts with the positioning of the strap and difficulties with getting it to stay in place. This presented friction in the experience of meditation. Importantly, some participants found that the scores distracted them from their meditation training. Participants commonly suggested that a weekly reveal of their scores would have been less distracting.

> *If I had scores I would think about scores during meditation sometimes. Not like all the time. But like oh this is calm, I would like the see the scores! But now like I can't see the scores so I do not have those thoughts*

Additionally, some felt that meditation was a chance to disconnect from the daily technology overload and were reluctant to taint the practice with even more technology. In one case, the participant expressed a sense of magic pertaining to meditation which science would ruin through over-explanation.

> *About the score I think it is very quantitative and if you want to like really experience the true meditation, the score should not be there […] Because the scoring is like a competition. So I feel like I have to compete either with myself from yesterday or in the past or I have to compete with the others on the application […] I think meditation should be more real in a way that it should be disconnected from everything.*

Global theme: Influencing factors

The third global theme, influencing factors, corresponds to factors during the study which may have affected the overall findings of this study.

Theme 6: Personal context

The personal contexts of participants were seen to impact the experiences of meditation. To begin with, how challenging meditation training was perceived to be depended on individual life events. Busier or more stressful times were correlated with more difficulty staying focused, or being overwhelmed by emotions during the meditation sessions. The time at which participants meditated also impacted how well they feel the meditation went, but there was no consensus as to what time was better; the experience varied between participants.

Several participants were going through personally taxing life periods, were in therapy, suffered from chronic conditions or were more generally experiencing poor mental health (such as depression and anxiety). In fact, the majority chose to take part in this study as a means to help them through their difficulties. While some reported seeing positive outcomes in their situations as a result (such as diminishing migraines, remaining calm in the face of adversity, or feeling more peaceful), others admitted that their circumstance may have affected the study results, "*To be honest I haven't using it and doing much meditation because this week was a bit rough for me and I may be a liability for your experiment*".

Theme 7: The study

The current study was carefully designed to create comparability between the conditions, so as to isolate the effect of biofeedback. Nonetheless, not all participants adhered to the instructions. The most consequential deviation was the use of guided meditations and the in-app mediation training. The three participants who used the in-app meditation during the BMT week revealed that the in-app trainings brought important improvements in their meditation. This was in part due to the format of these trainings, which consisted of audio cues for rhythmical breathing and biofeedback (but no voice guidance). One participant stated that this improved their focus,

> *Last week, when I did it without any audio, and uhm not- trying to only focus on my breath or something in particular, my mind wandered off very frequently, and I could feel that this week it was more focused. And that also showed up in my week's performance at- like*

I told you, I'm doing an internship- so I was more productive this week than last week so that's good.

It so happened that my mind wandered off into thought, but I was able to observe that it had wandered off and I was able to bring it back to focus. That didn't happen [during the MT] week, so it was only after a long period of time that I realize oh my god I've been thinking and then I go back to- but this time [with the biofeedback] it was more controlled, I think I could control my mind better than last week, and that was good. The sounds really helped me a lot.

Besides this, using the in-app training reduced the inconvenience of opening the application to look at the scores before accessing the music tracks from another source, and then returning to the application once again.

In some cases, participants purposely did not experiment with their meditations, as they thought they had to adhere exactly to what was practiced during the first experimental session, and practiced at the same time every day, even if this was inconvenient.

Finally, some participants felt like they were subjects in a scientific experiment rather than meditating out of their own will, which gave rise to negative feelings.

Theme 8: Technical issues

We have already mentioned chest-strap related discomfort as a factor that interfered with meditations. More specifically, some participants had issues with the straps being either too tight or too loose. In the latter case, the strap would sometimes slide down and participants had to pull it back into place. However, some participants later realized that they could adjust the strap. Moreover, during the BMT condition, participants were sometimes interrupted by notifications from the application when they reached an exceptional score if the notifications were enabled. In addition, some participants reported connectivity issues when they did not moisten the electrodes beforehand. In the MT condition, the dummy devices also posed a distraction. Participants were often concerned whether the device was working or not, as there was no light to indicate that the device was on and that their data was being recorded.