Reducing daily stress: Breaking a habit

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Effectiveness of a smartphone-based worry-reduction training for stress-reduction: A randomized controlled trial

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ABSTRACT

Objectives

Perseverative cognition (e.g., worry) and unconscious stress are suggested to be important mediators in the relation between stressors and physiological health. A randomized controlled trial was conducted to examine whether a smartphone-based worry-reduction training improved a physiological marker of stress (i.e., increased heart rate variability [HRV]) and unconscious stress.

Methods

Individuals with high work stress (*n* = 136) were randomized to the experimental, control, or waitlist condition (resp. EC, CC, WL). The EC and CC registered emotions 5 times daily for 4 weeks. The EC additionally received a worry-reduction training with mindfulness exercises. Primary outcome was 24-hr assessments of HRV measured at pre-, mid-, and post-intervention. Secondary outcomes were implicit affect and stress. The effect on heart rate and other psychological outcomes was explored.

Results

A total of 118 participants completed the study. No significant change from pre- to post-intervention was observed for the primary or secondary outcomes. The change over time was not significantly different between conditions.

Conclusions

Findings suggest that the training was not effective for improving HRV or psychological stress. Future studies may focus on alternative smartphone-based stress interventions as stress-levels are high in society, and there is a need for easy interventions and smartphones offer great possibilities for this.

INTRODUCTION

Work stress is known to be a risk factor for the development of decreased mental [198] and physical health, including cardiovascular disease (CVD) [21, 22]. One viable pathway through which (work) stressors exert their unhealthy effects is via prolonged physiological stress responses, including prolonged low levels of heart rate variability (HRV) [10, 25]. According to the perseverative cognition hypothesis, worry is the mechanism that mediates this negative relation between stressors and HRV (e.g., [25, 34]). Interventions that target worries are therefore of interest when aiming to increase HRV, which is an indirect measure of autonomic cardiac control and a marker of CVD risk [36, 199].

Recently the perseverative cognition hypothesis was extended with the hypothesis that a large part of perseverative cognitions are unconscious and that this 'unconscious stress' is also responsible for the prolonged physiological effects of stressors [38, 39]. One could say that worry continues in an unattended fashion. To date no interventions for unconscious stress have been reported. Mental exercises such as cognitive training and meditation, however, have been shown to lead to automatized (i.e., unconscious) cognitive-behavioral changes that are subserved by alterations in the brain—just as with learning skills, like riding a bike [66]. We therefore argue that a brief smartphone-based worry-reduction training, through frequent daily repetition, will lead to automatization of the targeted cognitive changes that will ultimately result in reductions of unconscious stress.

The present study aimed to increase HRV levels and decrease unconscious stress by reducing worry. To do so, we provided people with a worry-reduction intervention in daily life using an ecological momentary intervention (EMI) [72]. EMIs are typically delivered in daily life using a smartphone and this has the advantage of offering the training when people actually experience worry. Moreover, EMIs can be specifically used to provide easy-to-apply and potentially highly cost-effective interventions. Importantly, EMIs have been found to be effective for improving mental health [72]. The stand-alone worry-reduction EMI that was used in the present study consisted of a worry-reduction training [87, 89] and included mindfulness exercises [200]. These short mindfulness exercises were offered to train present moment awareness in daily life. We reasoned that these short, daily mindfulness exercises are easier to implement in the daily lives of individuals than the longer exercises that form part of formal mindfulness-based stress reduction programs. Notably, EMIs with short mindfulness exercises have been found to be effective for improving mental health parameters [72]. Even though the combination of worry-reduction and mindfulness has not been previously studied,

it seems empirically and theoretically plausible to combine cognitive and acceptance-based strategies. To begin with, both strategies are independently associated with decreased worrying [87, 89, 117, 201]. Borkovec et al. [89] suggested that the present moment awareness—that is learned in mindfulness practice—may strengthen the worry-reduction training. Not only is the intervention likely to increase ones attentional control by learning to shift attention from worrisome thoughts to the present moment, but the intervention is also likely to shorten or normalize the experience of stress—and thus the physiological responses—by promoting an accepting attitude towards these present moment experiences. Both the increased attentional control and the reduced stress reactivity are potential pathways through which the intervention may have its effect [202]. By combining a worry-reduction training with mindfulness exercises—thus a strategy focused on change and acceptance respectively—individuals can learn to substitute their habit to worry with a more deliberate and flexible response (for a full rationale on combining cognitive-behavioral treatment strategies with mindfulness, see [203]). Initial evidence suggests that cognitive and acceptance-based strategies can indeed be effectively combined [204, 205]. The EMI was expected to affect HRV via two pathways. First, worry is negatively associated with HRV [34], and reducing worry was therefore expected to increase HRV by shortening the stress response. Second, mindfulness exercises have been shown to increase HRV(e.g., [206, 207]). A pilot study showed that the smartphone-based worry-reduction training with mindfulness exercises is feasible in high-worrying students and is potentially effective for increasing HRV [208]. However, the effectiveness needs to be determined in a larger sample including a waitlist condition.

To this end, a randomized controlled trial (RCT) was conducted. To allow HRV to increase as a result of the EMI, an individuals' level of HRV needs to be low at baseline (because otherwise change is not possible). As physiological screening for study inclusion is laborious, this study recruited individuals based on their level of work stress, because this is negatively associated HRV [209]. Primary aim was to examine the effect of the EMI on HRV assessed for 24 hr at pre-, mid-, and post-intervention. On these days participants also completed assessments of unconscious stress as secondary outcomes.

Testing the effects of the EMI on unconscious stress was important for two reasons. First, not all individuals are able to adequately report their emotional experiences and these individuals are called 'emotionally unaware' [49]. It was hypothesized that not only conscious stress, but also unconscious stress would be associated with low HRV. By measuring unconscious stress, the effectiveness of the EMI on stress could also be determined in individuals who are less aware of their

stress levels [210]. Thus, assessing unconscious stress provided information about the effectiveness of the EMI that was additional to self-reported psychological stress. Second, a reduction in unconscious stress was expected due to the EMI. To explain, the EMI teaches individuals to become aware of experiences and emotions in the present moment. Increasing awareness of emotions is crucial for differentiating between emotions and this is fundamental for emotion regulation [211]. Moreover, the exercises help individuals to be more accepting towards these present-moment experiences. Such an attitude of acceptance can decrease emotional reactivity to stressors and repetitive thoughts [200], and might therefore also be effective for reducing unconscious stress.

Taken together, we expected the EMI to increase HRV and, secondly, to reduce unconscious stress. Additionally, unconscious stress and worry were examined as potential mediators of the effect on HRV. Finally, the effect on heart rate (HR), work stress, anxiety, depression, mindfulness, and explicit affect was explored.

METHOD

Trial Design

A three-arm parallel group RCT was conducted—from September 2014 until June 2016—in Dutch participants who experienced work stress. The study was approved by the institutional review board of Leiden University (nr. CEP 5097802079) and was registered in the Dutch trial register (nr. NTR4758). After the trial was started two changes were made. In August 2015 a change was made to the inclusion criteria (see Eligibility Criteria) and in October 2014 the timing schedule for the measures and training was adjusted. Specifically, the last measure or training was offered at 9:30 PM instead of 10:30 PM.

Participants and Recruitment

A power analysis [212] was conducted to estimate the number of required participants and for the repeated measures analysis a small to medium effect size was used (d = .30). This was based on two previous—related—studies [135, 156] and is in agreement with a meta-analysis that found small to medium effects of EMIs on psychological outcomes [72]. Per condition 31 participants were required with alpha set at .05 and 80% power. To deal with potential dropout we aimed to include 60 participants per condition. Recruitment was stopped before the pre-specified sample size was reached, but the sample size of 136 participants was sufficient based on the power analysis.

Participants were recruited at a healthcare company, by contacting local companies, via advertisements in local and national newspapers, via the newsletter and

website of Leiden University, and by mention on the local and national radio. Interested individuals were directed to the website http://www.piekeren.com for information. Individuals could complete the initial screening questionnaire on the website. A total of 588 participants completed the questionnaire; 74% was female with a mean age of 43.60 (SD = 11.39).

Eligibility Criteria

Participants were included if they were: (a) 18 years or older, (b) employed, (c) competent in using a smartphone, and (d) experienced work stress thereby making it a clinically relevant sample. Work stress was operationalized as an imbalance between effort and reward (i.e., high effort and low rewards), and was measured using the Effort-Reward Imbalance questionnaire (ERI) [213]. An ERI index of greater than 1.00 was chosen as cut-off score since it is associated with adverse health effects (e.g., [209, 214]). During the study the ERI criterion was lowered to 0.89 to increase the influx of new participants. The new ERI criterion was based on the 216 individuals who had completed the screening questionnaire up until August 2015 and the criterion was set 20% below the median of this group.

Individuals were excluded when they: (a) were receiving treatment for psychological or psychiatric problems, (b) had or have had a CVD, (c) used medication that can influence cardiac activity, (d) abused substances, (e) had a history of or current severe psychological disorder (e.g., schizophrenia), and (f) had a latex allergy (i.e., participants had to wear a HR monitor which contained latex). Additionally, (g) individuals who reported suicidal ideation in the past 2 weeks were excluded and referred to their general practitioner for counseling.

Randomization

Eligible participants were randomized into the EC, CC, or WL using a random number generator (https://www.random.org). Each number referred to a study condition and was put in a sealed envelope by a research assistant not involved in the data collection. Once a participant was included in the study, the allocated condition was disclosed to the researcher. On day 1 of the study, participants were told whether they were allocated to a training or WL condition.

Training

The smartphone application MovisensXS (https://xs.movisens.com) was used to offer the training in the CC and EC. During each training session, all CC and EC participants had to rate their emotions on a visual analogue scale (VAS) ranging from ‘not at all’ to

'very much' (i.e., 'To what extent are you experiencing happiness, anger, sadness, and anxiety?'). The CC was told that the training consisted of simply registering emotions and that this can increase the ability to recognize and describe emotions, which in turn is important for reducing stress. After emotion registration, the EC received a worry-reduction training in which a series of questions were presented (see, [208]). The aim was to help individuals recognize when they were worrying and to address these worries in a pre-structured way [87]. Next, participants completed a mindfulness exercise using the VGZ mindfulness coach application (https://www.vgz.nl/mindfulness-coach-app). The application automatically selected an exercise, but participants were free to select a specific exercise based on, for instance, their preference (i.e., from 41 different audio-based exercises varying in length from 1 to 37 min). The application contains (a) breathing exercises that encourage a slow and deliberate breathing, (b) body scans to help individuals focus their attention on the bodily sensations whilst keeping an accepting attitude towards these experiences, and (c) mindful-attention exercises to increase moment-to-moment experiences, for instance, by focusing on the direct environment. The application was previously found to be effective for increasing mindfulness and decreasing general psychiatric complaints [215].

Primary Outcome Measure

Ambulatory assessed cardiac activity. The ekgMove sensor (Movisens GmbH, Karlsruhe, Germany), which is worn on a chest belt underneath the clothes, measured cardiac activity continuously on the three test days. The sensor collected single channel ECG data with a resolution of 12 bits and a sampling rate of 1024 Hz. The sensor recorded movement acceleration data in *g*. The sensors' accuracy in detecting R-peaks—based on the sensor sensitivity and positive predictive value—was comparable to a medical standard measurement system [216]. Movisens data-analyzer software processed the raw data using an automated error detection algorithm to clean the ECG signal from artifacts. HRV and HR in beats per minute (BPM) were calculated using the cleaned ECG signal. As an index of HRV, the root mean square of successive differences (RMSSD) was used [35]. This HRV index is recommended in ambulatory assessment studies [188]. RMSSD, HR, and movement acceleration were calculated in 30 s intervals. Intervals were excluded when HR was below 30 or above 200 BPM (e.g., [189]), or when artifacts had been detected within that interval. The remaining intervals were aggregated into hourly averages, but only for hours that consisted of at least 30 min of reliable data.

Secondary Outcome Measures

Unconscious stress. Unconscious stress was operationalized as implicit affect (i.e., increased implicit negative and decreased implicit positive affect) and as increased implicit stress measured with the stress Implicit Association Test (IAT) [217].

Implicit affect. The Implicit Positive and Negative Affect Test (IPANAT) [191] measured implicit affect. The IPANAT presented six nonsense words (e.g., RONPE) and each word was presented with an emotional adjective. Participant indicated on a 6-point scale ranging from 'doesn't fit at all' to 'fits very well' to what extent the nonsense word represented the emotion. Each nonsense word was coupled with three positive emotions (e.g., happiness) and three negative emotions (e.g., tense). The tendency of participants to rate the nonsense words as sounding positive or negative determines the level of implicit positive and negative affect respectively. Positive and negative affect were considered implicit, because participants were unaware of the construct that was measured [191]. The IPANAT was adjusted for ambulatory assessment. Specifically, each nonsense word was presented at a different time during the day [218]. Internal consistency, test-retest reliability, and construct and criterion based validity were adequate among students [191]. The between-person reliability coefficients per test day were good for both implicit negative and positive affect (i.e., R_{kf} .91 or higher), which means that the ratings reflect individual differences and are stable across test days [190].

Implicit stress. The IAT was adapted to measure implicit stress. The IAT is a computer task with five blocks. In each block participants are presented with words that have to be categorized—as fast as possible—into their corresponding categories using a corresponding key. Block 3 and 5 are the critical blocks and consisted of 20 practice and 60 actual trials. In these blocks participants were shown five self-related words, five other-related words, five stress-related words, and five relaxed-related words (see Appendix 1). One word was presented at a time and the category labels—into which the words had to be categorized—were displayed at the top left and right side of the screen. In block 3 the words *self* and *stress* were displayed on the left, and the words *other* and *relaxed* are displayed on the right side of the screen. In block 5 the *self* and *other* labels switched sides. A scoring algorithm was used to calculate an IAT score, with higher scores reflecting higher levels of implicit stress [219]. The IAT has acceptable internal consistency, test-retest reliability, and predictive validity [220, 221].

Work stress. The 22-item ERI assessed work-related effort, reward, and overcommitment. An ERI index—as indication of work stress—was computed by dividing the effort by the reward score, whereby the latter was corrected to account for the unequal number of items. Psychometric properties were satisfactory [213] and

Cronbach's alpha of the scales ranged from .67 to .81 in this study.

Trait worry. The 16-item Penn State Worry Questionnaire (PSWQ) [94] measured trait worry. Internal consistency, test-retest reliability, and predictive validity are considered good [94, 95, 222]. Cronbach's alpha ranged from .89 to .91.

State worry and stressors. Using ambulatory assessments, participants were asked whether they had worried and if they had experienced a stressful situation since the last measure. This specific instruction was used in previous research (e.g., [218]). If a positive response was given, participants also indicated the frequency, duration, and severity of those episodes on 5-point scale ranging from 'not at all severe' to 'very severe.' Frequency, duration, and severity of state worry were used as dependent variables.

Anxiety and depression. The 7-item Generalized Anxiety Disorder scale (GAD-7) [223] and the 9-item Patient Health Questionnaire (PHQ-9) [224] measured respectively self-reported anxiety and depression in the past 2 weeks. The questionnaires have good internal consistency and validity in both the clinical and the general population [225]. In the present study Cronbach's alpha ranged from .78 to .83 for anxiety and from .67 to .75 for depression.

Mindfulness. The 39-item Five Facet Mindfulness Questionnaire (FFMQ) [226] assessed the tendency of individuals to be mindful in their daily lives. The sum of all items was used as the outcome variable. Psychometric properties are acceptable in the general population and in meditating samples [226, 227]. Cronbach's alpha ranged from .85 to .90.

Explicit affect. Using ambulatory assessments, participants indicated to what extent they experienced the four basic emotions on a scale from 'not at all' to 'very much.' Anger, anxiety, and sadness were averaged to represent negative affect, and the happiness-rating represented positive affect. Affect measured on the test days was used as dependent variable. Between-person reliability, per test day [190], was good (i.e., R_{kf} .96 or higher). Indicating that ratings were stable across test days and capable of detecting individual differences.

Treatment credibility. The 6-item Credibility / Expectancy Questionnaire (CEQ) [228] examined treatment expectancy and credibility of the treatment rationale. Internal consistency and test-retest reliability are considered good [228]. Cronbach's alpha was .77 for the credibility scale and .51 for the expectancy scale. Considering the low internal consistency of the expectancy scale, we used a single item to represent expectancy (i.e., 'By the end of the therapy period, how much improvement in your symptoms do you think will occur?').

Feasibility. Study feasibility was defined as the experience of participants

with the study period and with the training. It was examined at post-intervention using forced-choice and open-ended questions that were answered on a smartphone.

Procedure

Interested individuals completed an online screening questionnaire that checked the majority of the inclusion and exclusion criteria, and contact information was obtained. Ineligible individuals were notified and eligible participants were called by phone to check for latex allergy, medication use, suicidal ideation, and whether the individual was currently receiving psychological treatment. Eligible individuals were explained that the study lasted 4 weeks and that an appointment was scheduled at the start, halfway, and on the final day of the 4 weeks. Each appointment was scheduled on a weekday before 11:00 AM and the researcher traveled to the participant for the appointment. The appointment days were called test days, because on these days participants completed different assessments and no training was scheduled. When participants did not own a smartphone or when the operating system of a participants smartphone was not Android or IOS, a smartphone was lend to the participant.

During the first appointment participants were consented, asked to complete a demographic questionnaire, and informed whether they were allocated to a training-condition (i.e., CC or EC) or to the WL (i.e., only assessments on the three test days). Details about the scheduled assessments were provided (see Figure 1).

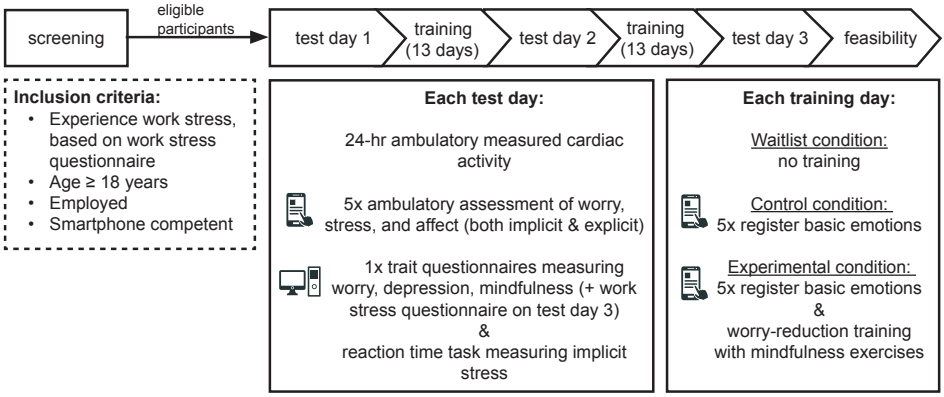

FIGURE 1 Study overview

First, ambulatory cardiac activity was assessed continuously for 24 hr from 11:00 AM onward. Second, trait questionnaires and the task assessing implicit stress were completed online. Third, ambulatory assessments of state worry, stress, and affect

were scheduled five times during each test day—randomly between 11:00 AM and 9:30 PM—with 75 min between assessments. Assessments were triggered using the smartphone application MovisensXS. In between the test days, in the CC and EC, five training sessions were randomly triggered between 9:00 AM and 9:30 PM with at least 90 min between sessions. Triggers could be delayed for 30 min or dismissed. Participants were entered into a lottery to win prizes (e.g., tablet) when they answered at least 75% of the triggers, thereby stimulating full and complete participation. Their chance of winning increased when they answered more triggers. The CC and EC additionally completed the Credibility / Expectancy Questionnaire. At the end of the first appointment the smartphone applications were installed. Participants received a booklet with study procedure information and a fully charged sensor to measure cardiac activity. During the second and third appointment participants were reminded which assessments took place and a charged sensor was provided. On the final test day participants were reminded to complete the feasibility questionnaire on their smartphone at post-intervention.

Statistical Analyses

Multilevel modeling was used to examine the effect of the intervention on RMSSD, unconscious stress, HR, work stress, trait worry, worry severity, anxiety, depression, mindfulness, and explicit affect. Using the nlme-package in R (version 3.0.3) two models were fitted per outcome variable. Model 1 examined how individuals changed over time by including the predictor time (i.e., 0 = test day 1, 1 = test day 2, 2 = test day 3). Model 2 examined whether the change over time was significantly different between conditions by additionally including the predictor condition (i.e., 0 = WL, 1 = CC, 2 = EC) and the Time x Condition interaction. A random intercept and slope was included in all models, and a continuous time autoregressive structure was used to account for autocorrelation. In case of convergence problems, the random slope was removed to reduce the models' complexity. All the models that included a cardiac outcome were corrected for movement acceleration as it naturally accounts for a part of the variance in HRV.

The count variables (state) worry frequency and duration were analyzed using generalized linear mixed models. To allow for overdispersion, a negative binomial distribution was used. In line with the above-described analyses, two models were fitted: model 1 included the predictor time and model 2 included the predictor time, condition, and Time x Condition interaction.

To examine whether the change in the primary outcome variable RMSSD was mediated by worry or unconscious stress, mediation analyses were done when

relevant based on the results of the multilevel models [229]. That is, when there was a significant association between (a) predictor (i.e., condition) and outcome variable, (b) predictor and mediator, and (c) mediator and outcome variable.

We additionally checked for group differences at baseline, examined whether study attrition was different across conditions and was related to age, gender, or level of work stress. Further, study and training acceptability, and training adherence was compared across conditions. A reliable change index (RCI) [194] was calculated for an outcome variable when a significant change from pre- to post-intervention was found, and the RCI estimates how many participants showed a reliable change.

Work stress and the RMSSD data were not normally distributed and were therefore log-transformed. In the Results, the untransformed means and standard deviations are reported. An IPANAT response was excluded from the analyses when each emotional adjective that was coupled to a nonsense word—so both positive and negative emotional adjectives—was scored identical (e.g., 2-2-2-2-2-2) as this indicates false responding.

RESULTS

Descriptive Statistics

Hundred and thirty-six participants were included and randomized across conditions (see Figure 2). Table 1 displays the descriptive statistics of the excluded and included participants. The groups did not differ on age, gender, or on whether they had experienced psychological complaints in the past. Compared to excluded participants, included participants had higher levels of work stress ($t(402.41) = -3.93$, $p < .001$). Eight participants dropped out before the start of the study, resulting in a final sample size of 128 participants. Dropout prior to the first test day was not related to condition.

In the final sample, the baseline level of trait worry was high [104]. Moreover, depression and anxiety were mild [223, 224], and both correlated positively with implicit stress (resp. $r = .21$, $p = .018$ and $r = .26$, $p = .004$). The baseline clinical characteristics were for the most part similar across conditions. Only implicit positive and negative affect differed significantly, with $F(2,121) = 10.96$, $p < .001$, $\eta_p^2 = .15$ and $F(2,121) = 5.18$, $p = .007$, $\eta_p^2 = .08$. Specifically, the EC had higher implicit negative affect compared to the WL, and had higher implicit positive affect compared to both the WL and CC (resp. $p = .005$, $p = .007$ and $p < .001$). The means and standard deviations of the primary and secondary outcome variables are reported in Table 2. The other outcome variables are reported in Appendix 2.

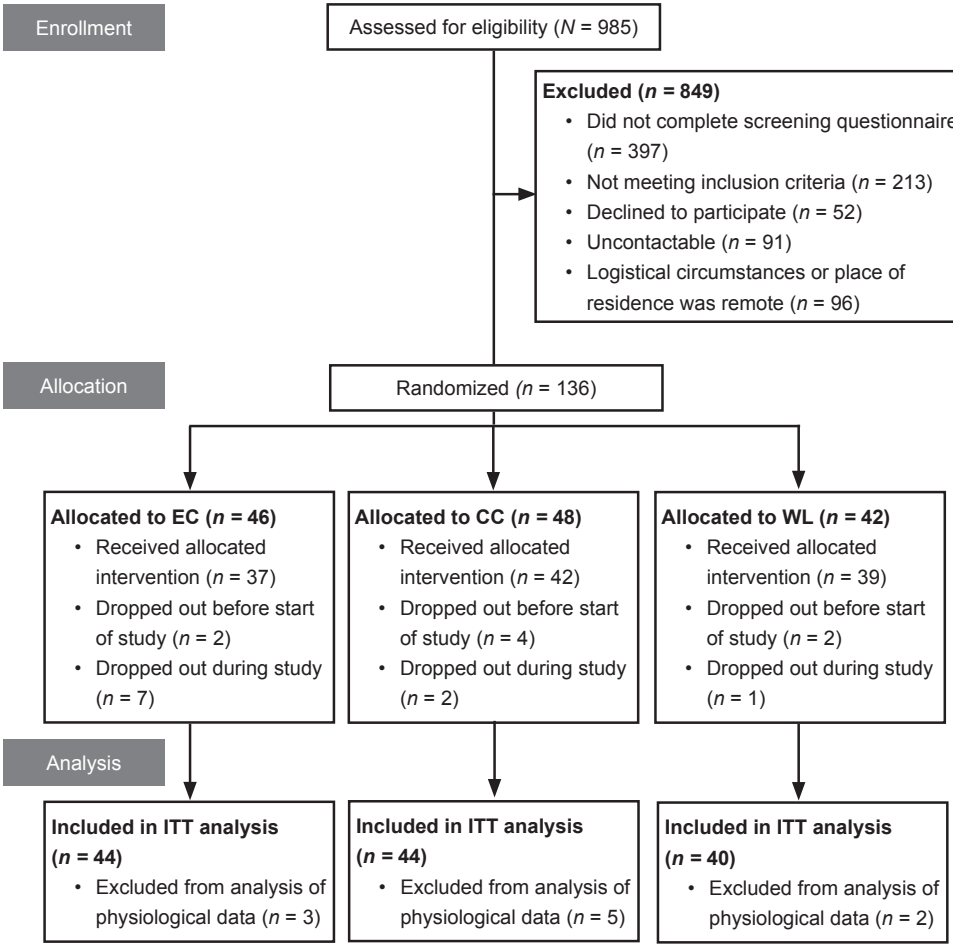

FIGURE 2 Flow diagram

Even though we screened for medication use, ten participants used medication during the study that can influence cardiac activity (e.g., temazepam). Therefore this physiological data was excluded, although the results did not change as a result of their exclusion. So, physiological data of 118 participants was analyzed. Cardiovascular activity at baseline was comparable across conditions and values were within the normal range [35, 199]. Moreover, the average baseline level of RMSSD was comparable to the averages of other populations who experienced work stress [209]. Baseline RMSSD and HR were not associated with work stress (resp. $r = .07$, $p = .573$ and $r = .17$, $p = .144$).

At post-intervention, the attrition rate was 8% (10/128). A Fisher's exact test indicated that attrition during the study was more likely in the EC compared to the

grouped CC and WL condition (p = .031, ϕ = .22). Gender and age were not related to attrition, but dropout participants had higher baseline levels of work stress (M = 1.37, SD =0.36) compared to study completers (M = 1.16, SD = 0.17) with t(126) = -3.01, p = .003.

At pre-intervention, the average credibility and expectancy of the training did not differ between the EC and CC. Participants in both conditions reported a medium credibility (M = 6.90, SD = 1.05; scale from 1 - 9) and moderate expectations (M = 57%, SD = 18.73).

TABLE 1 Means (SDs) and percentages of demographic and clinical characteristics of the included and excluded participants at baseline

	Excluded sample (n = 452)	Included sample (n = 136)
Demographic variables		
Gender	75% female	71% female
Age	43.71 (11.39)	43.23 (11.39)
Nationality (% Dutch nationalities)	—	95%
Education level (% completed first stage of tertiary education)	—	70%
Clinical characteristics		
Work stress	1.08 (0.35)	1.18 (0.20)
Psychological complaints: past[a]	48%	46%
Psychological complaints: current[a]	29%	14%
Psychological complaints: treatment[a]	27%	0%

[a] Indicated with the percentage of positive responses.

Training Adherence and Acceptability

The mean number of completed training sessions per day was significantly higher in the CC compared to the EC, with t(60.42) = 2.62 and p = .011.The CC completed on average 75% of the daily training sessions (3.74/5, SD = 0.76) and the EC completed on average 63% of the daily training sessions (3.15/5, SD = 1.18). Training frequency was unrelated to gender, age, or baseline levels of work stress.

Considering the importance of daily practice, adherence was operationalized as completing at least one training session on each of the 26 training days. A total of 46 participants in the EC and CC adhered (i.e., 58% of the 79 participants). In the CC, 74% (i.e., 31/42) achieved complete adherence compared to 41% (i.e., 15/37) in the EC. This difference was significant (t(72.84) = 3.11, p = .003).

At post-intervention, 101 participants (i.e., 32 in EC, 36 in CC, and 33 in WL) completed the feasibility questionnaire. In general, participants experienced the study

period between neutral and very positive (M = 66.62, SD = 14.07), found it relatively easy to complete the assessments and the training on the smartphone (M = 73.19, SD = 23.71; VAS ranging from 0 to 100), and completed the ambulatory assessments seriously (M = 82.09, SD = 14.24; VAS ranging from 0 to 100). There was no significant difference between conditions. The level of interference that participants experienced in their daily lives due to the training or assessments did differ between conditions ($F(2,99) = 17.38$, $p < .001$, $\eta_p^2 = .26$). The EC experienced higher levels of interference compared to both the CC and WL ($p < .001$). Specifically, the CC and WL scored the level of interference between 'not at all' and 'neutral' (resp. M = 30.04, SD = 19.17 and M = 28.54, SD = 25.25), whilst the EC scored close to 'neutral' (M = 56.47, SD = 19.84; on a VAS ranging from 0 ['not at all'] to 100 ['very much']). Additionally, the extent in which the participants believed that the training had helped them to 'deal with stress' was scored around neutral in the EC and CC (M = 47.36, SD = 21.20; VAS ranging from 0 to 100), and did not differ significantly between conditions ($t(63) = -1.91$, $p = .061$). The training duration was significantly higher in the EC compared to the CC, with $t(65) = -3.16$, $p = .002$. On average, the duration was 3 min and 53 s (SD = 3.95) in the CC and 7 min (SD = 4.51) in the EC. The EC and CC reported that they completed the training sessions seriously, with a score between 'neutral' and 'very serious' (resp. M = 69.00, SD = 16.66 and M = 84.28, SD = 14.67). The difference between the EC and CC was significant, with $t(64) = 3.96$, $p < .001$.

Primary Outcome Measure

RMSSD did not significantly change from pre- to post-intervention in model 1 or 2 (resp. B = -0.02, $p = .507$ and B = -0.05, $p = .206$) and the change over time was not significantly different between conditions (B = 0.03, $p = .251$). The models—and the models for the secondary outcomes—are reported in Appendix 3. The average amount of movement remained constant over time and did not differ between the conditions.

Secondary Outcome Measures

No significant Time x Condition interactions were found for unconscious stress (i.e., both implicit affect and implicit stress). Indicating that the change over time was not significantly different between conditions. Implicit stress did decrease over time for all participants in model 1 (B = -0.04, $p = .019$), with four participants showing a reliable change (↓= 3 in EC; ↑= 1 in EC).

Furthermore, the effect of the intervention on HR, work stress, worry (both trait and state), anxiety, depression, and mindfulness was explored. As the analyses are exploratory, no corrections were employed for multiple testing. Again, no significant

Time x Condition interactions were found. Several main effects of time were found across all participants. Specifically, trait worry decreased over time in both model 1 and 2 (resp. B = -1.36, $p < .001$ and B = -1.18, $p = .014$). State worry severity and mindfulness increased over time in model 1 (resp. B = 0.18, $p = .001$ and B = 1.47, $p = .016$), but not in model 2 when condition was accounted for. Eleven participants had a reliable change in trait worry (↓= 7 in EC, 1 in CC, 3 in WL), four participants had a reliable change in state worry severity (↓= 1 in EC; ↑= 2 in EC, 1 in WL), and eight participants had a reliable change in mindfulness (↓=1 in EC, 1 in CC; ↑= 4 in EC, 3 in CC, 1 in WL).

TABLE 2 Means (SDs) of primary and secondary outcome variables at pre-, mid-, and post-intervention for each condition

	Experimental condition	Control condition	Waitlist condition
***n* at each time point**			
Pre-intervention[a]	44 | 41	44 | 39	40 | 38
Mid-intervention[a]	37 | 34	42 | 37	39 | 35
Post-intervention[a]	37 | 34	42 | 34	39 | 37
Outcome variables	**Mean (SD)**	**Mean (SD)**	**Mean (SD)**
RMSSD			
Pre-intervention	37.17 (20.01)	40.46 (23.48)	41.84 (19.50)
Mid-intervention	39.54 (18.94)	39.74 (19.90)	49.20 (28.66)
Post-intervention	42.97 (24.55)	37.56 (22.91)	44.83 (28.67)
Implicit negative affect			
Pre-intervention	1.52 (0.78)	1.25 (0.61)	1.03 (0.59)
Mid-intervention	1.83 (0.77)	1.44 (0.73)	1.09 (0.78)
Post-intervention	1.54 (0.75)	1.24 (0.63)	1.01 (0.65)
Implicit positive affect			
Pre-intervention	2.19 (0.88)	1.46 (0.69)	1.68 (0.60)
Mid-intervention	2.16 (0.77)	1.23 (0.75)	1.61 (0.76)
Post-intervention	2.34 (0.68)	1.64 (0.78)	1.75 (0.71)
Implicit stress			
Pre-intervention	-0.41 (0.33)	-0.38 (0.28)	-0.39 (.0.38)
Mid-intervention	-0.51 (0.35)	-0.34 (0.33)	-0.47 (0.24)
Post-intervention	-0.49 (0.28)	-0.42 (0.30)	-0.50 (0.23)

Note. RMSSD = root mean square of successive differences.

[a]The first sample size reflects the number of participants that was available for analyses of the psychological outcomes and the second sample size reflects the number of participants that was available for the physiological data analysis.

Mediators of Treatment Effect

No mediation analyses were performed, because the change in RMSSD was not predicted by condition and that was the first requirement.

DISCUSSION

This RCT investigated whether a worry-reduction EMI with mindfulness exercises could be used to increase HRV and unconscious stress in individuals with high levels of work stress. No change over time was found on the primary outcome HRV. Furthermore, the change over time was not different between conditions and therefore we were unable to test whether changes in HRV were mediated by trait worry or unconscious stress. Likewise, no differential effects were found for the secondary outcome unconscious stress or for any of the other outcome variables.

A decrease over time in implicit stress and trait worry and an increase in state worry severity and mindfulness was found for all participants. Yet after controlling for condition, only the time effect for trait worry remained with the majority of reliable change occurring in the EC (7/11, 64%). Even though a decrease in trait worry can be expected in the EC, this finding is somewhat remarkable for participants in the WL condition (3/11, 27%). The time effect is therefore more likely the result of a phenomenon called measurement reactivity, whereby self-monitoring of a behavior at time one can alter monitoring of that behavior at time two [103].

Contrary to our expectation, the findings suggest that the EMI was not effective for improving HRV or unconscious stress. This may be explained by the fact that the proposed mediators worry and unconscious stress did not decrease as a result of the intervention. Nor did mindfulness increase in the EC. Both of these findings suggest that the EMI was not successful in its current format.

The intervention may have been ineffective, because the length of the actual training sessions was too short to accomplish change (i.e., average duration was 7 min in the EC). However, exploratory results—which are not reported—suggest that the duration of the mindfulness exercises was not a moderator of effect, nor was the total number of training sessions, the mean number of daily training sessions, or the level of initial work stress. Instead of increasing the length of the training sessions, future studies could individualize the exact dosage of the intervention, because learning a new skill may take variable amounts of time in practice among individuals. Future studies should also consider incorporating support from a mental health professional into the EMI protocol as this additional support can increase the effectiveness of EMIs [72].

A second potential reason for the inefficacy of the EMI is the adherence to

the training frequency. Notably, daily practice was considered important, yet only 41% of participants in the EC adhered to at least one training session per day. This could suggest that some participants were unmotivated and/or were unable to complete a stand-alone intervention without additional support. It could also indicate that the EMI was not well suited for the current population. To illustrate, these stressed individuals received a training also during work hours. These individuals, however, already perceive work demands that exceed their coping capacities. Adding the training—during work hours—might actually have the opposite effect and increase their level of experienced stress. This calls for careful consideration of EMI characteristics that relate to the implementation of the EMI into the daily life of individuals.

Another reason for the inefficacy of the EMI could be specifically related to the way in which mindfulness skills were trained. Participants were free to choose which mindfulness exercise they wanted to do. This could have been problematic, as it may have offered too much variability in both the type and duration of the exercises. Perhaps a more structured intervention is necessary that specifies which exercise of what length should be done at what time. Even though the intervention would lose its flexibility, it may be necessary to first train foundational mindfulness skills using more prolonged exercises. Potentially more flexibility in the intervention could be integrated at a later stage.

Regarding the generalizability of the findings this study used a new combination of interventions (i.e., worry-reduction with mindfulness exercises) and a new delivery method (i.e., EMI). Our null results do not rule out the possibility that other self-contained worry-reduction or mindfulness interventions are effective, although the literature seems to favor a combination of the two strategies. It is also possible that the combination of the interventions that we used is actually effective, but not when provided as an EMI. Given the exponential rise in EMIs, future studies are needed to determine whether different combinations of worry-reduction strategies with mindfulness are useful and what platform can best be used to implement the training.

Several other limitations need to be considered when interpreting the results. First, participants were recruited based on their level of work stress, which was expected to be associated with HRV. In contrast to previous studies [209], the results showed that high work stress was not associated with lower HRV. This indicates that screening for low HRV, using the work stress questionnaire, might not be a good substitute for physiological screening and future studies should consider incorporating physiological screening into their study protocol. The absence of an association between work stress and HRV might also be the result of the method we used to assess cardiac activity. To explain, the ambulatory assessment of cardiac activity might not be as accurate or as

sensitive to assess small changes compared to well-controlled laboratory monitoring. For instance, because less contextual information for data interpretation is available [230]. A third limitation is that we cannot rule out that explicit stress increased as a result of becoming aware of the stress and that this awareness for stress, in turn, masked potential reducing effects of the intervention. Future studies could address this by measuring stress continually.

In this study a low dropout rate was found. Low dropout rates are a strength in intervention studies and it could suggest that it is possible to implement an experimental intervention in daily life even when there is limited contact with researchers and none with a therapist. Nevertheless, the low adherence rates suggest that participants withdrew from the intervention without actually withdrawing from the study. Future studies need to carefully study how adherence to and effectiveness of the intervention can be optimized without resulting in higher dropout rates.

In summary, this is one of the first large-scaled RCTs looking at the effect of an EMI in sample with high stress levels. Findings suggest that the worry-reduction EMI with mindfulness exercises was not more effective in improving HRV or unconscious stress in individuals with high levels of work stress compared to individuals who repeatedly registered their emotions or a waitlist control group.

APPENDIX 1 Words used in the Implicit Association Test measuring implicit stress

Self category	Other category	Positive category	Negative category
ik (I)	zij (they)	boos (angry)	kalm (calm)
mij (me)	hen (their or theirs)	geïrriteerd (irritated)	evenwichtig (balanced)
mijn (mine)	hun (their or theirs)	gespannen (tense)	geduldig (patient)
mijzelf (myself)	het (it)	bang (afraid or scared)	vredig (peaceful)
zelf (self)	ander (other)	piekeren (worry)	rustig (calm or quiet)

APPENDIX 2 Means (SDs) of heart rate, work stress, worry, anxiety depression, mindfulness, and explicit affect at pre-, mid-, and post-intervention for each condition

	Experimental condition	Control condition	Waitlist condition
***n* at each time point**			
Pre-intervention[a]	44 | 41	44 | 39	40 | 38
Mid-intervention[a]	37 | 34	42 | 37	39 | 35
Post-intervention[a]	37 | 34	42 | 34	39 | 37
Outcome variables	**Mean (SD)**	**Mean (SD)**	**Mean (SD)**
Heart rate			
Pre-intervention	73.84 (9.42)	69.45 (8.27)	70.59 (10.58)
Mid-intervention	71.33 (10.46)	73.40 (10.57)	66.71 (9.06)
Post-intervention	72.40 (10.21)	71.47 (11.81)	69.57 (9.77)
Work stress			
Pre-intervention	1.19 (0.26)	1.18 (0.15)	1.17 (0.15)
Mid-intervention	—	—	—
Post-intervention	1.16 (0.23)	1.18 (0.27)	1.16 (0.29)
Trait worry			
Pre-intervention	54.02 (9.05)	52.49 (11.00)	50.80 (10.75)
Mid-intervention	52.50 (9.86)	53.18 (10.92)	50.00 (11.27)
Post-intervention	49.68 (8.03)	51.00 (11.49)	48.44 (10.78)
State worry – frequency[b]			
Pre-intervention	4.16 (9.12)	3.44 (8.51)	3.20 (6.09)
Mid-intervention	4.61 (11.46)	2.98 (4.26)	4.41 (12.31)
Post-intervention	2.27 (5.19)	2.48 (6.20)	2.03 (3.17)
State worry – duration[c]			
Pre-intervention	20.57 (24.31)	22.63 (40.92)	12.25 (16.75)
Mid-intervention	21.72 (33.11)	26.51 (52.31)	18.22 (29.06)
Post-intervention	17.59 (37.15)	18.98 (41.54)	14.47 (26.11)
State worry – severity			
Pre-intervention	1.35 (0.51)	1.24 (0.45)	1.29 (0.67)
Mid-intervention	1.94 (0.72)	1.76 (0.91)	1.58 (0.82)
Post-intervention	1.88 (0.85)	1.52 (0.50)	1.61 (0.77)
Trait anxiety			
Pre-intervention	5.75 (3.03)	5.72 (3.09)	5.48 (3.43)
Mid-intervention	6.09 (3.48)	5.53 (3.26)	4.70 (3.32)
Post-intervention	5.16 (2.95)	6.08 (3.58)	5.33 (4.12)
Trait depression			
Pre-intervention	6.50 (2.95)	5.58 (3.28)	5.63 (3.85)
Mid-intervention	6.74 (3.31)	5.65 (3.40)	5.05 (3.54)
Post-intervention	5.51 (3.13)	5.79 (3.92)	5.14 (3.11)

	Experimental condition	Control condition	Waitlist condition
Mindfulness			
Pre-intervention	124.07 (14.73)	127.40 (17.17)	127.85 (14.23)
Mid-intervention	128.15 (15.93)	127.50 (17.53)	125.19 (13.86)
Post-intervention	129.84 (16.60)	130.61 (18.83)	126.83 (17.70)
Explicit negative affect			
Pre-intervention	24.91 (14.62)	26.16 (13.93)	23.55 (11.75)
Mid-intervention	25.89 (14.00)	22.85 (15.06)	24.21 (13.69)
Post-intervention	24.97 (14.99)	20.65 (12.85)	22.47 (15.54)
Explicit positive affect			
Pre-intervention	57.29 (16.20)	55.28 (15.75)	58.89 (13.52)
Mid-intervention	56.01 (18.21)	56.49 (19.67)	59.16 (16.27)
Post-intervention	57.20 (19.74)	57.68 (21.23)	62.02 (15.96)

[a]The first sample size reflects the number of participants that was available for analyses of the psychological outcomes and the second sample size reflects the number of participants that was available for the physiological data analysis.

[b]Indicated with the number of worry episodes per test day.

[c]Indicated with the number of minutes per test day.

APPENDIX 3 Results of primary and secondary outcome variables in the sample that was included in the intention-to-treat analysis

	Model 1		Model 2			
	Constant	Time[a]	Constant	Time[a]	Condition[b]	Time x Condition
Multilevel model						
RMSSD[c]	3.67 (0.05)	-0.02 (0.02)	3.73 (0.07)	-0.05 (0.04)	-0.06 (0.06)	0.03 (0.03)
24-hr data	[3.58, 3.77]	[-0.06, 0.03]	[3.59, 3.86]	[-0.12, 0.02]	[-0.17, 0.05]	[-0.02, 0.09]
Implicit negative affect	1.32 (0.06)	0.01 (0.03)	1.03 (0.10)	-0.03 (0.04)	0.27 (0.07)**	0.04 (0.03)
	[1.19, 1.44]	[-0.04, 0.06]	[0.85, 1.22]	[-0.11, 0.06]	[0.13, 0.42]	[-0.02, 0.10]
Implicit positive affect	1.78 (0.07)	0.02 (0.03)	1.53 (0.11)	0.01 (0.05)	0.25 (0.08)**	0.00 (0.04)
	[1.65, 1.92]	[-0.04, 0.08]	[1.32, 1.74]	[-0.08, 0.11]	[0.09, 0.41]	[-0.07, 0.08]
Implicit stress	-0.39 (0.03)	-0.04 (0.02)*	-0.37 (0.04)	-0.04 (0.03)	-0.02 (0.03)	0.00 (0.02)
	[-0.44, -0.33]	[-0.08, -0.01]	[-0.46, -0.28]	[-0.10, 0.01]	[-0.08, 0.05)	[-0.04, 0.04]
Heart rate[c]	65.56 (0.91)	0.09 (0.48)	63.96 (1.33)	0.63 (0.59)	1.85 (1.07)[t]	-0.63 (0.48)
24-hr data	[63.79, 67.34]	[-0.85, 1.02]	[61.35, 66.56]	[-0.53, 1.79]	[-0.27, 3.96]	[-1.56, 0.31]
Work stress[d]	0.15 (0.01)	-0.01 (0.01)	0.15 (0.02)	-0.01 (0.01)	0.00 (0.02)	0.01 (0.01)
	[0.13, 0.18]	[-0.02, 0.01]	[0.11, 0.19]	[-0.04, 0.02]	[-0.03, 0.03]	[-0.02, 0.03]
Trait worry	52.58 (0.91)	-1.36 (0.30)***	50.89 (1.47)	-1.18 (0.48)*	1.64 (1.12)	-0.18 (0.37)
	[50.79, 54.37]	[-1.95, -0.77]	[48.00, 53.78]	[-2.12, -0.24]	[-0.58, 3.85]	[-0.91, 0.55]
State worry severity	1.39 (0.06)	0.18 (0.05)**	1.33 (0.10)	0.14 (0.09)	0.06 (0.07)	0.05 (0.07)
	[1.28, 1.51]	[0.07, 0.28]	[1.14, 1.52]	[-0.03, 0.31]	[-0.08, 0.21]	[-0.09, 0.18]
Trait depression	5.94 (0.30)	-0.25 (0.15)[t]	5.39 (0.48)	-0.16 (0.24)	0.54 (0.37)	-0.08 (0.18)
	[5.35, 6.53]	[-0.54, 0.047]	[4.43, 6.34]	[-0.63, 0.31]	[-0.19, 1.27]	[-0.44, 0.28]
Trait anxiety	5.62 (0.27)	-0.09 (0.16)	5.31 (0.44)	-0.05 (0.26)	0.30 (0.34)	-0.04 (0.20)
	[5.08, 6.15]	[-0.42, 0.23]	[4.44, 6.18]	[-0.57, 0.47]	[-0.37, 0.96]	[-0.44, 0.36]
Mindfulness	126.08 (1.33)	1.47 (0.60)*	127.67 (2.15)	0.16 (0.95)	-1.55 (1.64)	1.30 (0.74)[t]
	[123.46, 128.69]	[0.28, 2.66]	[123.44, 131.91]	[-1.72, 2.04]	[-4.79, 1.70]	[-0.16, 2.76]
Explicit negative affect	24.84 (1.17)	-1.02 (0.64)	24.30 (1.89)	-1.18 (1.03)	0.53 (1.44)	0.17 (0.80)
	[22.54, 27.14]	[-2.28, 0.25]	[20.60, 28.00]	[-3.19, 0.84]	[-2.33, 3.39]	[-1.41, 1.74]

	Model 1		Model 2			
	Constant	Time[a]	Constant	Time[a]	Condition[b]	Time x Condition
Explicit positive affect	57.22 (1.32)	0.66 (0.73)	58.06 (2.13)	1.18 (1.17)	-0.83 (1.63)	-0.54 (0.92)
	[54.63, 59.81]	[-0.78, 2.09]	[53.88, 62.24]	[-1.11, 3.48]	[-4.05, 2.39]	[-2.33, 1.26]
GLMM						
State worry frequency	1.30 (0.11)	-0.08 (0.07)	1.28 (0.17)	-0.14 (0.11)	0.03 (0.13)	0.07 (0.08)
	[1.10, 1.51]	[-0.21, 0.06]	[0.94, 1.62]	[-0.35, 0.07]	[-0.23, 0.28]	[-0.10, 0.23]
State worry duration	3.16 (0.10)	0.08 (0.08)	3.00 (0.17)	0.10 (0.14)	0.16 (0.13)	-0.00 (0.11)
	[2.96, 3.37]	[-0.08, 0.25]	[2.67, 3.33]	[-0.17, 0.37]	[-0.09, 0.41]	[-0.21, 0.21]

Note. For every predictor the coefficient (standard error) and [95% confidence interval] is reported; GLMM = generalized linear mixed model; RMSSD = root mean square of successive differences.

[a]Time was coded as: 0 = first test day, 1 = second test day, 2 = third test day.

[b]Condition was coded as: 0 = waitlist condition, 1 = control condition, 2 = experimental condition.

[c]The models fitted for cardiac activity were all corrected for movement (acceleration in *g*).

[d]Work stress is operationalized as an imbalance between effort and reward.

***$p < .001$.

**$p < .01$.

* $p < .05$.

[t]$p < .10$.