Mindfulness on-the-go: Effects of a mindfulness meditation app on work stress and well-being

*Sophie Bostock[a,1], *Alexandra D. Crosswell[b], Aric A. Prather[b], & Andrew Steptoe[c]

[a] Department of Epidemiology and Public Health, University College London, London WC1E 6BT, United Kingdom; [b] Department of Psychiatry, University of California San Francisco, San Francisco, CA 94118, USA; [c] Department of Epidemiology and Public Health, University College London, London WC1E 6BT, United Kingdom

*Authors contributed equally.

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Corresponding Author:

Correspondence concerning this article should be addressed to Alexandra D. Crosswell, Phone: +1 (415) 476-7421; Email: Alexandra.Crosswell@ucsf.edu

Conflict of interest:

Headspace® provided access to the app for free and provided app usage data. Headspace® employee Andy Puddicombe led the 'introductory talk' for participants at the start of the study,

[1] Present affiliation: University of Oxford, Oxford OX1 3BD, UK; Big Health Ltd, London, UK

and then had no contact with subjects, involvement in data analysis, or drafting of the manuscript. Sophie Bostock currently works for Big Health, Ltd, which designs behavioural medicine apps.

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Abstract

We investigated whether a mindfulness meditation program delivered via a smartphone application (app) could improve psychological well-being, reduce job strain, and reduce ambulatory blood pressure during the workday. Participants were 238 healthy employees from two large UK companies that were randomized to a mindfulness meditation practice app or a wait-list control condition. The app offered 45 pre-recorded 10-20 minute guided audio meditations. Participants were asked to complete one meditation per day. Psychosocial measures, and blood pressure throughout one working day, were measured at baseline and 8 weeks later; a follow-up survey was also emailed to participants 16 weeks after the intervention start. Usage data showed that during the 8-week intervention period, participants randomized to the intervention completed an average of 17 meditation sessions (range 0 to 45 sessions). The intervention group reported significant improvement in well-being, distress, job strain, and perceptions of workplace social support compared to the control group. In addition, the intervention group had a marginally significant decrease in self-measured workday systolic blood pressure from pre to post intervention. Sustained positive effects in the intervention group were found for well-being and job strain at the 16-week follow-up assessment. This trial suggests that short guided mindfulness meditations delivered via smartphone and practiced multiple times per week can improve outcomes related to work stress and well-being, with potentially lasting effects.

Introduction

High levels of psychosocial work stress have major implications for both the employee and the employer. Epidemiological studies consistently demonstrate associations between high work stress and worse self-reported mental and physical health, including depression, anxiety, cardiovascular disease, and type 2 diabetes (Ganster & Rosen, 2013). In the United States, it's estimated that 5-8% of annual healthcare costs are attributable to work-related stressors (Goh, Pfeffer, & Zenios, 2016). In the United Kingdom, the overall annual cost of work-related stress to employers is estimated to be over £26bn, driven by increased staff turnover, performance degradation, and absenteeism (The Sainsbury Centre for Mental Health, 2007).

Job strain, a combination of high demands (workload and intensity) and low control (discretion over work tasks), is one of the most widely studied models used to define psychosocial stress at work (Karasek, 1979). Epidemiological studies and meta-analyses of decades of research have found that job strain is associated with worse mental and physical health, including anxiety and depressive disorders, increased blood pressure, cardiovascular events, and metabolic syndrome (Chandola, Brunner, & Marmot, 2006; Landsbergis, Dobson, Koutsouras, & Schnall, 2013; Madsen et al., 2017; Steptoe & Kivimäki, 2013). Mechanisms linking job strain to poor physical health include worse health behaviors, obesity, and allostatic load (Chandola et al., 2008; Ganster & Rosen, 2013; Nyberg et al., 2013).

The potential stress-reduction and psychological well-being benefits of teaching mindfulness in the workplace has received increased attention and initial empirical support (Jamieson & Tuckey, 2017). There are many conceptualizations of mindfulness. Here we define being 'mindful' as being in a state in which one is paying full attention to their present moment experience with openness and non-judgmental acceptance (Kabat-Zinn, 1982). Meta-analyses have reported that mindfulness-based psychological interventions decrease stress in healthy non-clinical populations, and improve psychosocial outcomes for people with clinical disorders such as anxiety and depression (Bohlmeijer, Prenger, Taal, & Cuijpers, 2010; Chiesa & Serretti, 2009; Hofmann, Heering, Sawyer, & Asnaani, 2009; Kuyken, Warren, Taylor, & Whalley, 2016). Mindfulness-based trainings delivered in the workplace have been shown to decrease global perceptions of psychological stress in healthy working adults (Virgili, 2015).

Mechanisms proposed to explain the stress reduction benefits of mindfulness-based therapies include an improved capacity to cope with stressful situations and enhanced attention regulation (Hölzel et al., 2011). Mindfulness training may promote the positive reappraisal of stressful circumstances as benign or meaningful (Garland, Gaylord, & Park, 2009), and can improve recovery from negative emotional events (Crosswell et al., 2017). In a work context, these enhanced coping abilities may lead to the reappraisal of demands as manageable and work stressors as within one's control, leading to decreased job strain. Good et al. (2016) present an integrated model of the effects of mindfulness training on outcomes relevant for the workplace in which improved attention stability, control, and efficiency lead to improvements in cognitive, emotional, behavioral, and physiologic domains, which ultimately improve job performance, workplace relationships, and well-being. There is initial support for this model from evidence that dispositional mindfulness is positively associated with many of these psychological and social factors. However, workplace mindfulness intervention trials have primarily focused on decreasing psychological stress, with limited empirical evidence showing that mindfulness training indeed leads to improvements in the other domains of the model.

Previous studies of workplace mindfulness interventions have been limited in other ways as well. First, randomized controlled trials of workplace mindfulness trainings have not examined the specific construct job strain, instead relying on general measures of global perceived stress and psychological distress. Thus, they may be missing the direct impact of a workplace intervention on the work-relevant outcomes they are most trying to change. Second, previous studies have largely focused on self-reported health, with few measuring objective indices of physical health, which may better capture subtle changes in biological functioning.

Blood pressure is an important biomarker to examine in workplace stress reduction interventions given the associations between job strain and higher resting, ambulatory, and sleeping blood pressure (Chandola et al., 2008). Only two studies to our knowledge have examined changes in blood pressure after participating in a workplace mindfulness intervention (Roeser et al., 2013; Wolever et al., 2012). Both studies found no significant change, though the lack of an effect may be because blood pressure in both studies was measured on a single occasion in the clinic. Measuring blood pressure throughout the day may more accurately capture a true representation of the patient's daily blood pressure, and is a better predictor of future cardiovascular events than single in-clinic blood pressure readings (Conen & Bamberg, 2008; Landsbergis et al., 2013; Pickering, White, & American Society of Hypertension Writing Group, 2008). Thus, measuring blood pressure multiple times throughout the day using self-monitor devices before and after mindfulness training may be a more sensitive approach to capturing potential intervention-induced changes.

A final limitation of previous workplace mindfulness interventions is that they have been resource intensive as they have relied on trained meditation teachers to lead the practices live (either in-person or online), in group-based settings. This approach requires significant time from employees and a trained instructor, limiting the ability for workplaces to scale this intervention efficiently. Mindfulness training delivered via self-guided smartphone app may offer a convenient alternative to group sessions. App-based treatments to improve mental health are an increasingly popular method of service delivery, though research on the efficacy of these apps is limited (Donker et al., 2013; Fairburn & Patel, 2017). Initial evidence of technology-driven delivery of standard treatment protocols for clinical disorders such as Cognitive Behavioral Therapy for anxiety have demonstrated effect sizes comparable to conventional standard of care (e.g. Berger, Boettcher, & Caspar, 2014; Titov et al., 2011). Three small studies using smartphone apps to deliver mindfulness interventions to healthy adults found benefits comparable to traditional delivery methods on outcomes of subjective well-being, depressive symptoms, and compassion (Howells, Ivtzan, & Eiroa-Orosa, 2016; Lim, Condon, & De Steno, 2015; Ly et al., 2014). App-based interventions also offer the benefit of standardization of instruction across participants in the experimental group, ability for participants to control where and when they access the intervention, and objective measures of adherence to the intervention via data collected on the app's backend rather than self-report.

The purpose of this study was to examine the effects of a mindfulness meditation program delivered via smartphone on outcomes related to work stress. Specifically, we measured subjective well-being, mood over one working day, anxiety and depressive symptoms, job strain, and blood pressure over a workday in a sample of healthy employed adults. We recruited office-based employees from the United Kingdom (UK) offices of two Fortune 500 companies to participate in a randomized wait-list controlled trial. Half of participants were randomized to use the mindfulness meditation app every day for 8 weeks, and the other half was randomized to a wait-list control condition. Both groups had access to the app after the 8-week intervention period. Before and after the intervention period, participants self-reported their level of well-being (as indicated with a subjective well-being scale and positive affect ratings throughout one working day), psychological distress (anxiety and depressive symptoms), job strain, workplace social support, and mindfulness. In addition, participants captured their own blood pressure readings 5 times throughout one working day at pre-set intervals; blood pressure captured in a naturalistic environment throughout the day may more accurately capture what is happening in daily life compared to one lab-based reading (Landsbergis et al., 2013). We hypothesized that individuals randomized to mindfulness training would show improvements in psychosocial outcomes and self-measured blood pressure compared to those randomized to an enhanced wait-list control condition. We hypothesized that completing a greater number of meditation sessions, as measured objectively with data captured from the app, would be associated with greater improvements in study outcomes.

Methods

Participants

Eligible participants were employees at two UK companies that each had over 900 onsite employees: Company A was a pharmaceutical firm and Company B was a high-tech company. This intervention was designed to decrease work stress and thus participants were excluded if they reported no work stress (scored zero on a 6-item work over commitment scale; example item: As soon as I get up in the morning I start thinking about work problems; Siegrist et al., 2004). Participants were excluded if they self-reported a clinical diagnosis of depression, hypertension, heart disease, or cancer because treatment for these diseases may have influenced our outcomes. Participants who did not own an Android or iPhone smartphone were excluded because the app was only accessible on these devices. Participants who refused to be randomly assigned to the intervention or control condition were also excluded.

We screened 341 employees for eligibility and randomized 238 (n=120 from Site A and n=118 from Site B) to either the intervention group (Group 1; n= 128) or the control condition (Group 2; n=110). All participants completed psychosocial questionnaires at the baseline (t1) visit, although blood pressure was not obtained from seven participants due to difficulties in data collection. At the primary endpoint (t2), 229 participants completed the questionnaire assessment and 206 completed the blood pressure readings, yielding a follow-up rate of 96% at the primary endpoint for the psychosocial outcomes. At the second follow-up time point (t3), 105 (82%) of the intervention participants and 81 (74%) of the control participants completed the psychosocial questionnaires. Numbers of participants at each stage of the trial are illustrated in Figure 1.

Participants' mean age was 35.5 years (SD=7.7, range 23-61), 59.2% were female, 15.5% smoked, 40.3% were overweight or obese (BMI>25). Ninety-six percent (n=229) worked full-time. The majority (80%) had blood pressure within a healthy range (systolic BP <120 mmHg and diastolic BP <80 mmHg) based on self-measured pre-intervention blood pressure readings. Demographic and work factors by group assignment are presented in Table 1. Groups did not differ significantly on any of these factors.

Procedure

The opportunity to participate in a research trial to reduce stress and improve well-being was publicized at both companies via fliers, an online staff noticeboard, and an announcement in a company e-newsletter (for Company A). Interested employees completed an online eligibility screener. Eligible participants were invited to attend a baseline assessment (t1) where they signed consent, completed psychosocial questionnaires, had their height and weight measured, and were trained to use an Omron R2 wrist blood pressure (BP) monitor to capture BP over the course of a single day. Participants were asked to take two BP readings at 5 timed intervals over one working day before and after the intervention period. These intervals were: before breakfast, before lunch, in the late afternoon at work, in the early evening, and before bed. Participants within each company were randomized either to the intervention (Group 1) or to a wait-list condition (Group 2) using a random number generator software program. Follow-up assessments were completed between 9 and 11 weeks after the baseline visit (t2). Participants in the intervention group continued to have access to the app after their follow-up time point, and control group participants were given access to the app after completing their follow-up visit. To assess longer-term trajectories, all participants were sent an online psychosocial questionnaire 8 weeks later (t3). The trial took place at Company A from March to August 2012 and Company B from August 2012 to January 2013. The study was approved by University College London Research Ethics Committee (IRB).

Assessments

Assessments were conducted before random assignment (t1) and after 8 weeks of the intervention period (t2), which was the primary endpoint of the trial. T2 assessments took place within two weeks of the end of the intervention period (study weeks 9-11). Participants completed online psychosocial questionnaires and one day of self-monitoring blood pressure at t1 and t2. Participants were also sent a follow up survey 16 weeks after their first visit (t3).

Intervention

The commercially available Headspace® (www.headspace.com) app was chosen by the research team (S.B., A.S.) because of its great functionality and user-friendly design. A subsequent empirical examination of the quality of commercially available meditation apps confirmed the positive qualities of Headspace®; it was rated the number one mindfulness app out of 23 apps based on criteria including engagement, functionality, visual aesthetics, and information quality (Mani, Kavanagh, Hides, & Stoyanov, 2015). Participants randomized to the intervention received email instructions to download the app, and inviting them to a 1-hour in-person introductory talk about meditation. In addition, the app contained several short introductory videos that explained the rationale for mindfulness meditation and described classic mindfulness techniques (e.g. focusing attention on the breath, observing thoughts without reacting to them).

The mindfulness training program consisted of 45 meditation sessions lasting from 10 to 20 minutes. Participants could chose to meditate at any time during the day. In each session, listeners were instructed to sit in a chair and were led through pre-recorded mindfulness meditations. Each session was designed to be used once per day, for 45 days, to cultivate a state of mindful awareness and teach mindfulness skills. These meditations are in line with a two-component model of mindfulness, for which the first component is the regulation of attention in order to focus it on the present moment (e.g. through paying attention to the breath), and the second component is open monitoring in which thoughts and emotions that arise are treated with curiosity, openness, and acceptance (Bishop et al., 2004). The program begins with ‘Take 10’, 10 days of 10-minute meditation sessions, followed by ‘Take 15’ (15 days of 15 minute meditations) and then ‘Take 20’ (20 days of 20 minute meditations). Participants must complete the meditations in the sequential order set by the program, and must complete each component before starting the next (e.g. Take 10 must be completed before Take 15 begins). Longer sessions included more time for silent meditation. Participants were given free access to the app, and no additional incentives. Participants in the intervention group received a weekly reminder email from research staff to encourage use of the app. Participants in the control condition did not receive reminders. After completing the follow-up assessment (t2), participants were able to continue using the app and reported at t3 whether they had used it at all between visits t2 and t3 (with a yes / no question: did you continue using the app?).

The wait-list control group (Group 2) was sent a link to National Health Service online advice for work stress[2] after their baseline assessment in order to provide educational information about stress reduction. This group controlled for naturally occurring changes in well-being and distress, job characteristics, and blood pressure over the assessment period. After completing the t2 assessment, participants assigned to the waitlist control condition were given free access to the app.

Psychosocial Measures

Well-being. Psychological well-being was assessed with the Warwick Edinburgh Mental Well-being Scale (WEMWBS; Tennant et al., 2007). This scale consists of 14 positively worded items on a 5-point scale ranging from 1 (none of the time) to 5 (all of the time). This scale assesses both hedonic and eudemonic global well-being within the last two weeks. Example items are: I've been feeling optimistic about the future; I've been feeling relaxed; I've been feeling close to other people. Scores are calculated as a sum of all items with a total score range from 14 to 70, and higher ratings indicating greater subjective well-being. This scale was the primary study outcome. This measure was included at t1, t2, and t3.

Daily well-being was assessed with positive emotions ratings provided five times throughout one working day following daily diary methodology (Almeida, 2005; Bolger, Davis, & Rafaeli, 2003). Participants were asked how they were feeling right now on three emotions: happy, relaxed, and interested or engaged, on a 5-point scale from 1 (don't feel this way at all) to 5 (feeling is extremely strong). Participants completed this in a paper-and-pencil diary at the

[2] http://www.nhs.uk/Conditions/stress-anxiety-depression/Pages/workplace-stress.aspx

same time they recorded their blood pressure readings. These positive emotions were averaged across the day to create one daily positive emotion score. This measure was included at t1 and t2.

Psychological distress. Anxiety and depressive symptoms were assessed with subscales of the Hospital Anxiety and Depression Scale (HADS; Zigmond & Snaith, 1983). The anxiety subscale consists of 7 items, such as: I feel tense or 'wound up'; I get an apprehensive feeling, as if something awful is about to happen. The depressive symptoms subscale consists of 7 items, including: I still enjoy the things I used to enjoy; I have lost interest in my appearance. Responses are on a 4-point scale from 0 (absence of symptom) to 3 (extreme presence of symptom). Scores are the sum of all items after recoding to have all items in the same direction with a possible range of 0-21, and higher scores indicating greater symptoms. These measures was included at t1 and t2.

Job strain. Job strain was assessed with 16 items extracted from the Whitehall II study questionnaire (Bosma et al., 1997; Kuper & Marmot, 2003) that includes two subscales: job demands and job control. The job demands subscale consists of 4 items, such as: e.g. Do you have enough time to do everything; Do you have to work very intensively. For the job control subscale, we chose 12 items from the 15-item job control subscale; example items are: Do you have a choice in deciding how you do your work; My working time can be flexible; I have a great deal of say in planning my work environment.)[3] Responses are on a 4-point scale ranging from 1 (often) to 4 (never, or almost never). Scores for the two subscales were calculated as the sum of the item scores after recoding all items in the same direction. Cronbach's alpha at the baseline assessment for the demands subscale was .65 and for the control subscale was .81. To create a continuous measure of job strain, we followed the quotient approach by dividing the job

[3] Items that were not included are: I have a say in choosing with whom I work; Does your job provide you with a variety of interesting things?; Do you have the possibility of learning new things through your work?

demands subscale score by the job control subscale score, with higher scores indicating greater strain (Landsbergis, Schnall, Warren, Pickering, & Schwartz, 1994). This measure was included at t1, t2, and t3.

Job status was captured with a single item: How would you describe your level of seniority at work on a scale of 1-10 if 10 represents the most senior managers in the UK and 1 represents the most junior employees? This measure was asked at t1.

Workplace social support. Social support at work was assessed using five statements ranked on a 4-point scale anchored at strongly disagree (1) and strongly agree (4) (Unden, Orth-Gomer, & Eofsson, 1991). Example items are: I get on well with my co-workers; I have a good relationship with my line managers(s); There is good group cohesion in my workplace. Scores are the sum of all items after recoding to have all items in the same direction. This measure was included at t1 and t2.

Mindfulness. To assess whether the intervention did indeed increase mindfulness as expected, participants completed seven items selected from the Freiburg Mindfulness Inventory (Walach, Buchheld, Buttenmüller, Kleinknecht, & Schmidt, 2006) at each assessment. This measure was included at t1 and t2. This measure was included as a manipulation check for the intervention, and was not considered a study outcome.

Blood Pressure

Self-monitoring devices (Omron R2 wrist blood pressure monitor; Omron Healthcare, Inc) were used to capture blood pressure at five time points over the course of one working day. These time points were: in the morning (06:30-08:30), before lunch (11:00-12:00), afternoon (16:00-17:00), evening (19:00-20:00), and before bed (22:00-23:00). Following the manufacturer's instructions, participants were told to avoid eating, bathing, smoking, or exercising for 15 minutes before taking their blood pressure measurement. To take the reading, they were told to sit in a chair with their feet on the ground with their arm relaxed and unrestricted, and to relax. Participants completed two readings at each time point, with a 2-3 minute pause between readings. These were averaged to create one score for each time point. Readings across the five time points were then averaged across the day to create one systolic and one diastolic blood pressure summary score for t1 and one for t2. Participants returning fewer than four time-matched readings (matched at t1 and t2) were excluded from analyses (9% missing).

Statistical Analyses

We used Chi-square and *t*-tests to examine group difference in baseline demographic and work characteristics. Intervention effects on each outcome were tested using analysis of covariance (ANCOVA). Time (t1 and t2) was included as a within-person factor and intervention group as a between-person factor. BMI and age were the covariates in the model assessing change in blood pressure from t1 to t2 because of their influence on blood pressure. List-wise deletion was used for the few instances of missing data. Alpha's were set at .05 for each outcome. We used eta-squared as our effect size index. We used Pearson correlations to examine whether the number of practice sessions was associated with baseline psychological outcomes, age, and work hours.

To investigate dose response effects, we grouped the intervention participants based on number of meditation sessions completed. We used three categories following the Headspace® program segments of Take 10, Take 15, and Take 20. Thus, categories were: 1) completed less than 10 sessions meditation sessions (n=41); 2) completed 10 – 24 sessions (n=52); 3) completed 25 – 45 sessions (n=35). For these analyses, we used 2 x 3 repeated measures ANOVA with time (t1 and t2) as the within-subjects factor and practice amount group as the between-subjects factor.

Finally, we examined whether scores on several psychosocial outcomes remained the same at the 16 week assessment (t3) using paired t-tests comparing t2 to t3 scores. Analyses were only run for the intervention group as the control group had the option to start using the meditation app after the study's primary endpoint (t2) and thus no longer operated as a control condition useful for comparison. Analyses were conducted in SPSS Version 24 and STATA 13.1.

Results

Intervention Effects at Primary Endpoint (t2)

Participants assigned to the intervention condition completed an average of 16.6 meditation sessions (SD=12.9, range 0-45 days) over 8 weeks. Thirteen participants did not use the app; three cited technical reasons and ten cited lack of time. Nearly three quarters of participants (74%) completed 6 sessions (which is approximately 60 minutes of meditation), 68% completed Take 10 (>100 total minutes), 23% completed both the Take 10 and Take 15 (>325 total minutes) and 2% completed all 45 sessions (725 min). Number of sessions completed was positively correlated with age (r=.27, p=.002), and was not correlated with work hours or baseline psychological outcomes.

Outcomes were subjective well-being (measured via a global well-being scale and daily positive emotions ratings), psychological distress (anxiety and depressive symptoms), job strain, workplace social support, and blood pressure. Group by time interactions were significant for well-being, daily positive emotions, anxiety symptoms, depressive symptoms, job strain, and workplace social support (all p's <.05), with the intervention group reporting significant improvement in these outcomes from baseline to the primary endpoint (t2). Job strain is calculated from two subscale scores, job demands and job control. When these subscales were examined individually, the group by time interaction for job demands was not significant (p=.291) while the interaction for job control was (p=.018). At closer examination of the group means, we see that job control increased slightly for the intervention group while remaining stable for the control group, suggesting that an increase in job control (and not a change in job demands) is what led to the significant effect of the intervention on job strain.

The group by time interactions for systolic blood pressure was marginally significant, p=.071, and not significant for diastolic blood pressure, p=.262. An examination of the model estimates showed that BMI accounted for a large variance in blood pressure.

Results of group by time interactions, including effect sizes, as well as means and standard deviations at t1 and t2 for all outcomes are presented in Table 2. The intervention and control groups did not differ at baseline on any of the outcomes.

Practice Time Effects

We next examined the influence of number of meditation sessions on the outcomes. Intervention group participants were categorized into three practice amount groups as described earlier. The interaction testing the effect of practice amount on change was significant for global well-being, $F(1, 121)=3.45$, p=.035, daily positive affect, $F(1,104)=3.26$, p=.042, anxiety symptoms, $F(1, 121)=10.24$, p<.001, and depressive symptoms, $F(1, 121)=3.76$, p=.026. Follow up contrasts testing differences between pre and post intervention scores within in each meditation practice group (t-tests) showed that those who completed greater than 10 meditations sessions showed significant improvement in these outcomes, while those who completed less than 10 sessions had no change from pre to post assessment in any outcome. This can be shown visually in Figure 2a-d. The effect sizes for these models were moderate to large: global well-being, η_p^2=.054, daily positive affect, η_p^2=.059, anxiety, η_p^2=.145 and depressive symptoms, η_p^2=.058. The interaction testing the effect of practice amount on change was not significant for job strain (p=.602), workplace social support (p=.911), systolic BP (p=.261), or diastolic BP (p=.316).

Intervention Effects at Second Follow-up Assessment (t3)

Next we examined whether the effect of the intervention remained at the t3 assessment. To do this we tested whether there were statistically significant mean differences between the psychosocial outcomes scores at t2 and t3 in the intervention group. Mean scores between the two time points for global well-being, depressive symptoms, and job strain were not significantly different, indicating that the increases in these outcomes from t1 to t2 remained consistent at t3 (for global well-being, $t(106)$=-.878, p=.382; for depressive symptoms, $t(105)$=.391, p=.696; for job strain, $t(103)$=-.152, p=.879). Anxiety symptom scores increased slightly, $t(104)$ =-2.053, p=.04. Other outcome measures could not be tested since they were not captured at t3 (i.e. workplace social support, positive affect, blood pressure). Almost half (49%) of the intervention group participants who completed the t3 questionnaire self-reported continuing to use the app after t2, though whether or not they continued using the app did not alter the results of the change in outcomes from t2 to t3.

Participants initially randomized to the control group (Group 2) were given access to the app after t2, and sent the online questionnaire at t3. Thus, we were able to compare scores from t2 to t3 in this set of participants (using *t*-tests) to examine the impact of the intervention in a second sample. Results were parallel to what we found in the intervention group results (Group 1); participants in Group 2 reported an increase in global well-being (p=.007), and a decrease in anxiety symptoms (p=.01), depressive symptoms (p=.001), and job strain (p=.01). Other outcomes were not measured at t3 (i.e. daily positive affect, social support, blood pressure).

Discussion

Results showed that listening to brief mindfulness meditations delivered via phone app multiple times a week for 8 weeks improved well-being and decreased distress in a working sample of midlife adults. Specifically, practicing short guided mindfulness meditation sessions improved global well-being, daily positive affect, anxiety and depressive symptoms, job strain, and workplace social support compared to the effects of having access to minimal education about stress reduction. The improvements in global well-being, depressive symptoms, and job strain were sustained two months after the primary intervention endpoint. We also found a dose response relationship between amount of meditation practice and improvements in our outcomes, with participants completing the greatest number of meditation sessions receiving the greatest health benefit.

We found small-to-moderate effects of the intervention on global well-being and positive affect over one working day. This is only the second study to our knowledge to demonstrate that almost daily use of a mindfulness app can improve positive affect. Howells et al. (2016) found increases in positive affect as measured by the traditional Positive and Negative Affect Schedule (PANAS) after 10 days of using the same mindfulness app used in this study in a small online community sample (n=57 for intervention group, n=64 for control condition). One strength of our study was the use of daily diary methodology in which positive mood was assessed in real-time at multiple time points throughout the day. This approach better captures daily mood compared to traditional measures that ask participants to reconstruct their week and provide an overall rating of affect as it reduces recall and heuristics biases (Miron-Shatz, Stone, &

Kahneman, 2009). Our results add to a small body of empirical evidence showing that meditation practice can improve positive emotions during the work day. Fredrickson & colleagues (2008) found that a workplace intervention that taught employees Loving Kindness Meditation via six group sessions increased daily positive emotions and positive relations with others. Positive well-being is thought to have advantages for psychological resilience and cardiovascular health that are distinct from the absence of negative affect (Boehm & Kubzansky, 2012). Increasing global well-being and positive affect specifically may be especially relevant in the context of work. According to the Broaden-and-Build theory, experiencing frequent positive emotions widens attention and thinking, which can lead to creativity and innovation, and to the accumulation of psychological resources in order to better manage stress (Fredrickson, 2001).

Workplace mindfulness interventions to date have typically included content which explicitly targets work-related stress (e.g. Malarkey, Jarjoura, & Klatt, 2013; Wolever et al., 2012). However, the mindfulness mobile app we chose contained no explicit teachings on dealing with stress at work and still resulted in improved positive affect over a working day, decreased job strain, and improved workplace social support. At closer examination of the measurement of job strain (made up of job control and job demands subscales), we found that job control increased for the intervention group while remaining stable for the control group, and job demands remained stable in both groups. This suggests that an increase in job control and not a change in job demands is what led to the significant decrease in job strain in the intervention group. Practicing mindfulness may have led to increased sense of job control by increasing the participants' self-efficacy over handling work-related demands (Loucks et al., 2015), ability to control attention (Jha et al., 2015), or control emotional responses to stressful situations. Improved emotion regulation abilities are a frequently cited explanation of how mindfulness meditation leads to improvements in psychological health (Roemer, Williston, & Rollins, 2015), and there is initial evidence that mindfulness training can improve one's ability to recover psychologically and physiologically from acute negative affect (Crosswell et al., 2017). Increasing job control is especially meaningful given the association between low job control and higher ambulatory blood pressure (Steptoe & Willemsen, 2004). Future studies should explore potential mechanisms of workplace mindfulness trainings and tailor interventions to target those mechanisms.

Results from our study also found that the intervention group reported a significant increase in perceptions of connection and support from work colleagues. This supports theoretical perspectives of mindfulness suggesting that in addition to improving an individual's psychological well-being, practicing mindfulness improves one's relationship with others (Brown, Ryan, & Creswell, 2007). Initial evidence suggests that practicing meditation is associated with increases in prosocial behavior (e.g. coming to the direct aid of someone in pain, Condon, Desbordes, Miller, & DeSteno, 2013; Lim et al., 2015). Having a greater capacity to show compassion towards others may be the mechanism by which mindfulness training improves perceptions of social connection and social support (Cosley, McCoy, Saslow, & Epel, 2010). It is also possible that increased social connection is a result of participants in the intervention group discussing their experience meditating, or even meditating together, though we did not ask participants to report on this. Future studies should explore the mechanisms by which practicing mindfulness leads to improved social relationships, and whether these improved relationships lead to improvements in other work outcomes such as team cohesion, problem solving, and navigating conflicts.

Additionally, we found a marginally significant decrease in systolic BP in the intervention group from pre to post intervention compared to the waitlist control condition; the intervention group systolic BP decreased from 110.8 to 110.5 mmHg. Although the change in systolic BP was small, and not clinically significant, this finding supports a growing literature demonstrating that mindfulness practice is associated with reductions in blood pressure (for a meta-analysis see Shi et al., 2017), which is essential for decreasing the risk of cardiovascular disease. Two previous studies found no changes in blood pressure after workplace mindfulness interventions (Roeser et al., 2013; Wolever et al., 2012) which may have been because a single measure of blood pressure was used versus capturing blood pressure at multiple points throughout the day as we did. We did not recruit individuals with high blood pressure and our sample was relatively young, thus, this intervention may be more impactful in older adults and/or those with elevated blood pressure at baseline (Goldstein, Josephson, Xie, & Hughes, 2012).

A significant strength of using a mobile app to deliver the mindfulness intervention was that the number of meditation sessions completed could be objectively captured. Understanding the association between practice time and improved outcomes is important since effective shorter programs could widen opportunities for participation. Previous studies have relied on self-reported practice diaries and found inconsistent associations with outcomes. A review of MBSR trials found no correlation between class attendance and outcomes (Carmody & Baer, 2009), though this may be because the practice time outside of class was not accounted for. We found that number of meditation sessions was indeed associated with our outcomes. Specifically, there was only a benefit of the intervention for participants who completed more than 10 meditation sessions within the 8 weeks. Because we did not randomize participants to complete different segments of the program, it is possible that the group of people who completed this many meditation sessions have personality characteristics that make them both more likely to complete more meditation sessions and to report greater improvement in psychosocial outcomes.

The main limitations of the trial are the lack of an active control condition, the short-term follow-up, and the reliance on self-administered blood pressure readings. In order to examine causality, it is important to include an active expectation-controlled control condition. However, we were unable to identify an existing active comparison app that was structurally equivalent, in terms of the number and duration of sessions, with a plausible therapeutic rationale. We thus used a simple alternative treatment by providing access to stress reduction educational material as our control condition, and gave control participants access to the app after they completed the primary study endpoint. We were unable to track usage of the educational material sent to the control group, including how many control participants read the material and how long they spent engaging with it.

A second limitation is that participants were not tracked beyond several weeks post-intervention. Thus, it remains unknown whether participants continued using the app, and what the long-term effects of the intervention or continued app use were. Tracking participants for longer would allow researchers to see whether there are specific demographic or psychosocial characteristics that make someone more likely to continue using a mobile app intervention, potentially informing who should be targeted in future interventions.

Another limitation is the use of self-administered blood pressure readings as there are several concerns with this approach. First, participants may also have not followed the appropriate protocol for collecting blood pressure readings, such as sitting quietly and in the same (or similar) environment for each reading. There is also potential bias in the times participants selected to capture their own blood pressure readings. Although we gave them time windows to complete their readings, participants in the intervention group may have conducted the readings at times when they were feeling more relaxed, they may have intentionally relaxed for longer before taking the reading (a specific number of minutes to wait was not set), or taken the reading after meditating. Future studies should rely on ambulatory blood pressure monitors which have pre-programmed and automated reading times (Pickering, White, & American Society of Hypertension Writing Group, 2008).

A more general limitation of teaching meditation to reduce work stress is that it places the ownership to reduce stress on the individual employee instead of emphasizing organization-level changes that might be needed in the workplace to improve well-being across all employees (Moen et al., 2016). Future interventions should seek to combine changes in larger organizational/job factors together with building individual capacity for mindfulness (Jamieson & Tuckey, 2017).

This trial demonstrates for the first time that mindfulness meditation training can be effectively delivered to a healthy working population at scale via a self-guided smartphone app. This is consistent with other recent studies demonstrating the effectiveness of mindfulness trainings delivered outside of the traditional group face-to-face delivery format (Glück & Maercker, 2011; Howells et al., 2016; Krusche, Cyhlarova, King, & Williams, 2012; Ljótsson et al., 2011; Wolever et al., 2012), and extends these findings by using a commercially available app that can be accessed via personal smartphone. Interventions delivered via app offer a convenient, low-cost, flexible alternative to asking participants to attend sessions face-to-face. A next step in this line of research is to directly compare in-person and app-based treatments.

In conclusion, this trial suggests that app-based mindfulness training reduces factors associated with work stress. Future research should examine whether these improvements can be sustained over time, and if so, whether mindfulness meditation practiced via mobile app improves long-term psychological and physical health. Future studies should also recruit participants based on high levels of work stress or blood pressure, since that would leave more room for the intervention to change those outcomes. Improvements in psychosocial well-being following mindfulness interventions may also have implications for workplace factors not assessed in this study such as burnout, safety, teamwork, innovation, and economic outcomes. Future studies should examine these outcomes, as well as the mediators of workplace mindfulness interventions. Finally, in order to recommend the use of mindfulness apps to address workplace stress, studies need to be conducted to compare app-based delivery of mindfulness training to traditional group-based delivery, as well as compare mindfulness to other scalable stress-reduction techniques (e.g. lunchtime park walks; Sianoja, Syrek, de Bloom, Korpela, & Kinnunen, 2017). The strength of individual-level capacity building may also be enhanced if integrated within a larger organizational goal of fostering employee well-being.

Table 1.

Demographic and work characteristics of study participants.

Characteristic	Group 1 (Intervention) n=128	Group 2 (Control) n=110
Age, Mean (SD)	36 (8.3)	35 (6.9)
Female, N (%)	77 (60)	64 (58)
BMI, Mean (SD)	25.2 (4.5)	24.7 (3.9)
Job status	4.9 (2.0)	4.8 (1.8)
Study site, N (%)		
Company A	65 (51)	55 (50)
Company B	63 (49)	55 (50)
Working hours/ week, N (%)		
Fewer than 37	8 (6)	10 (9)
38 - 45 hrs	62 (48)	48 (44)
46 - 55 hrs	51 (40)	44 (40)
More than 55 hrs	7 (6)	8 (7)

Table 2.

Outcome scores by group at baseline (t_1) and follow-up (t_2), and test of change scores

	Mean score (SD)		Group x time interaction		
Outcome	Group 1 (Intervention)	Group 2 (Control)	F (1,227)	*p*	η_p^2
Global well-being (WEMWBS)					
t_1	47.6 (6.8)	46.9 (5.8)			
t_2	49.9 (6.7)	47.0 (7.5)	8.77	0.003	0.037
Positive affect throughout the day[a]					
t_1	3.22 (0.5)	3.15 (0.5)			
t_2	3.38 (0.5)	3.10 (0.5)	8.37	0.004	0.04
Job strain					
t_1	1.08 (0.21)	1.07 (0.24)			
t_2	1.04 (0.21)	1.08 (0.30)	5.39	0.021	0.023
Job control					
t_1	36.8 (4.4)	37.1 (5.2)			
t_2	37.8 (4.3)	37.2 (5.4)	5.71	0.018	0.025
Job demands					
t_1	13.1 (2.0)	12.9 (2.0)			
t_2	12.9 (1.9)	13.0 (2.2)	1.12	0.291	0.005
Anxiety symptoms (HADS)					
t_1	9.13 (3.9)	9.36 (4.0)			
t_2	7.44 (3.6)	8.86 (3.9)	7.78	0.006	0.033
Depressive symptoms (HADS)					
t_1	5.05 (3.4)	5.13 (3.2)			
t_2	3.6 (3.2)	5.18 (3.5)	15.6	0.0001	0.065
Workplace social support					
t_1	3.16 (0.5)	3.22 (0.5)			
t_2	3.30 (0.5)	3.21 (0.6)	4.61	0.033	0.020
Systolic BP, mmHg[b]					
t_1	110.8 (.85)	111.8 (.90)			
t_2	110.5 (.86)	112.6 (.91)	3.28	0.071	0.002
Diastolic BP, mmHg[b]					
t_1	69.2 (.64)	70.1 (.68)			
t_2	69.0 (.65)	70.5 (.69)	1.26	0.262	0.006

Notes. WEMWBS= Warwick Edinburgh Mental Well-being Scale; HADS= Hospital Anxiety and Depression Scale. The job control subscale included 12 items of the 15-item scale.

[a] F(1,199).

[b] $F(1,204)$. Means for blood pressure are adjusted and standard errors are presented instead of standard deviations.

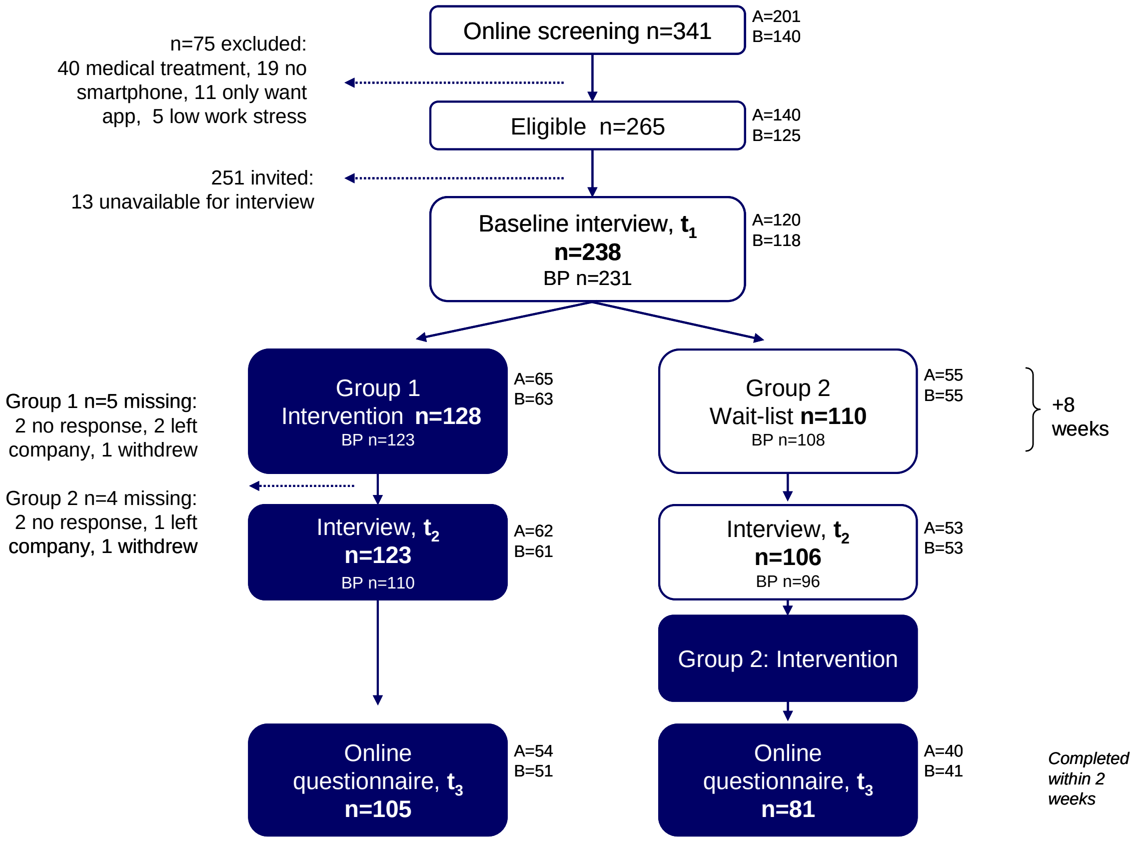
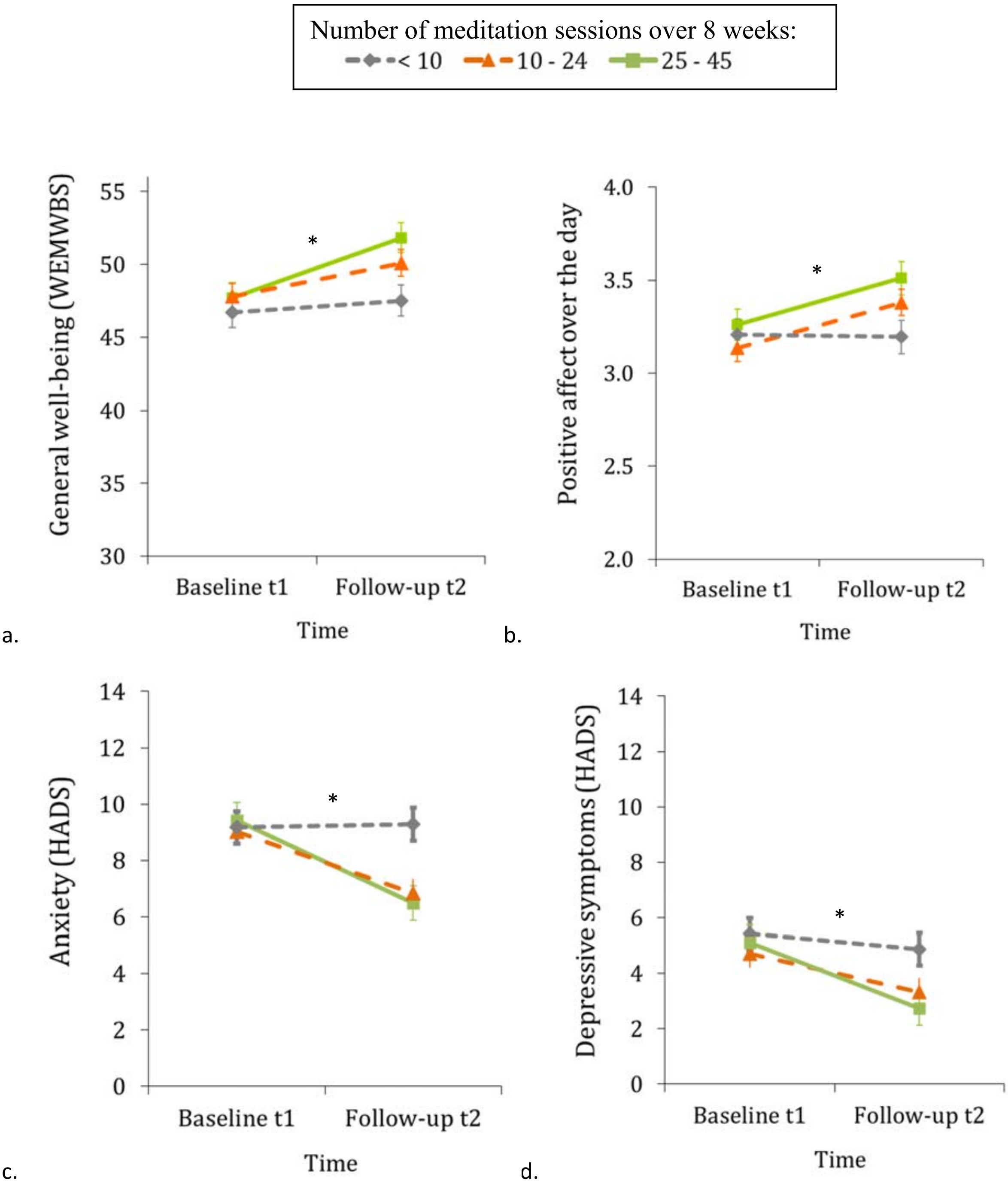


Figure 1.

This is a Consolidated Standards of Reporting Trials (CONSORT) diagram of the current study.



Figures 2a-d.

Means for (a) global well-being, (b) positive affect, (c) anxiety symptoms, and (d) depressive symptoms at different levels of meditation practice. Participants were grouped into three practice amount groups as described in the Methods. Overall interactions testing the effect of practice amount on change was significant for global well-being, $F(1, 121)=3.45$, $p=.035$, daily positive affect, $F(1,104)=3.26$, $p=.042$, anxiety symptoms, $F(1, 121)=10.24$, $p<.001$, and depressive symptoms, $F(1, 121)=3.76$, $p=.026$. Participants who completed greater than 10 meditations sessions showed significant improvement (all p's$<.05$) from pre to post intervention in all outcomes presented here.

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