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Meta-analysis of Technology-Enabled Mindfulness-Based Programs for Negative Affect and Mindful Awareness

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Abstract

Objective Existing meta-analyses of mindfulness-based programs (MBPs) suggest inconsistent effects, and few focus on technology-enabled MBPs. Technology-enabled MBPs are programs delivered via the Internet in web apps, which are accessed through Internet browsers, or native apps, which are applications installed directly on smart mobile devices. This meta-analysis provides an updated synthesis of technology-enabled MBPs' effects on negative affect and mindfulness and discusses the role of moderators in these effects.

Methods A search was conducted through August 2019 of databases PubMed, Ovid MEDLINE, PsychINFO, and the website MINDFULNET.org for original randomized clinical trials focused on technology-enabled MBPs. Additional inclusion criteria included English language publications and outcome measures of negative affect and/or measures of mindful awareness.

Results A medium effect was observed of technology-enabled MBPs on stress (Hedges $g = -0.47$, 95% CI -1.02 to 0.21 , $p < 0.01$). Small effects were observed on symptoms of anxiety (Hedges $g = -0.21$, 95% CI -0.39 to -0.03 , $p = 0.02$) and depression (Hedges $g = -0.25$, 95% CI -0.37 to -0.12 , $p < 0.01$) as well as mindful awareness ($g = 0.4$, 95% CI 0.54 to 0.07 , $p < 0.01$). Multivariate regressions and general linear models revealed that intervention duration, percentage of women participants, human-supported interventions, and type of control condition contributed significantly to effect size variability.

Conclusions Technology-enabled MBPs included in this analysis demonstrated small to medium effects on outcomes of negative affect and mindfulness. Variability in study outcomes appears to be related to experimental and intervention characteristics.

Keywords Mindfulness · Online · Meta-analysis · Randomized

Mindfulness-based programs (MBPs) have been shown to effectively diminish symptoms of anxiety, stress, and depression, and improve quality of life in clinical (Shapero et al. 2018) and healthy non-clinical populations (Khoury et al. 2015). While traditional, in-person MBPs have helped establish the current evidence base, logistical issues such as scheduling and medical problems are frequently cited as reasons for dropping out (Martinez et al. 2015). Technology, also advancing significantly during the past decade, has been increasingly

used to help reduce certain challenges associated with traditional, in-person instruction (Kazdin and Blase 2011). Just as technology-assisted psychotherapeutic interventions have demonstrated growing feasibility and efficacy to prevent and reduce symptoms of depression and anxiety in accessible, affordable, and tailored ways (Basnet 2014; Davies et al. 2014; Deady et al. 2017), so too have technology-enabled MBPs (Spijkerman et al. 2016).

Several mindfulness-focused meta-analyses published over the past decade suggest promising, yet inconsistent effects of MBPs, contributing to concerns regarding methodology and reporting of outcomes (Farias and Wikholm 2016). Three meta-analyses focusing on technology-enabled MBPs for reducing negative affect (Jayewardene et al. 2017; Sevilla-Llewellyn-Jones et al. 2018; Spijkerman et al. 2016) illustrate this inconsistency. Effects on anxiety range from small ($g = 0.22$, $p = 0.01$) (Spijkerman et al. 2016) to medium ($g = -0.44$, $p < 0.01$) (Sevilla-Llewellyn-Jones et al. 2018); effects on depression range from small ($g = 0.29$, $p < 0.01$)

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(Spijkerman et al. 2016) to medium ($g = -0.61$, $p < 0.01$) (Sevilla-Llewellyn-Jones et al. 2018); effects on stress are within the medium range ($g = 0.43$, $p < 0.01$) (Jayewardene et al. 2017) and ($g = 0.51$, $p < 0.01$) (Spijkerman et al. 2016); and effects on mindfulness range from small ($g = 0.276$, $p < 0.01$) (Jayewardene et al. 2017) to medium ($g = 0.72$, $p < 0.01$) (Sevilla-Llewellyn-Jones et al. 2018). During the time frame in which these meta-analyses were conducted (2015 to mid-2018), a surge in publishing of technology-enabled MBP results has occurred. The largest and most inclusive of these meta-analyses includes articles published only through March 2015 (Spijkerman et al. 2016), suggesting the need for an updated synthesis and discussion of these cumulative scientific data.

The current meta-analysis examines the strength of technology-enabled MBPs' effects on symptoms of negative affect (e.g., depression, anxiety, stress) and mindful awareness across clinical and healthy non-clinical populations. To minimize heterogeneity in meta-analyses and ensure the greatest likelihood of including high-quality studies, only randomized controlled trials (RCTs) are included. While causality is impossible to prove, well-constructed RCTs are considered the "gold standard" of effectiveness research as the rigorous designs minimizes bias (Hariton and Locascio 2018), allowing the current meta-analyses to result in more precise estimates of the effect technology-enabled MBPs on outcomes (Haidich 2010). Due in part to the concurrent rapid progress made in MBPs and technology, RCTs combining the two involve a number of variables (e.g., intervention duration, gender, age, use of human support, type of control, type of MBP), which area also explored here in order to examine the effects of moderators on effect size estimates.

Methods

This meta-analysis was conducted in accordance with PRISMA guidelines (Liberati et al. 2009) and the PRISMA Explanation and Elaboration (Liberati et al. 2009), as well as Cochrane's method for assessing risk of bias (Higgins et al. 2008).

Eligibility Criteria

Publications included in this meta-analysis were original studies published in peer-reviewed journals. All studies involved RCT designs for technology-enabled MBPs and included at least one outcome measure of negative affect and/or mindful awareness. Availability of pre- and post-intervention outcome data was required (e.g., mean, standard deviation, sample size) for treatment and control groups, either within the publication itself or by request to the corresponding author.

Information Sources

A literature search was conducted using the following databases and websites: PubMed, Ovid MEDLINE, PsycINFO, and MINDFULNET.org. While preparing for the meta-analysis, searches were repeated several times from the earliest available record in each database. The present analysis includes publications available through August 2019.

Article Search

The following terms were used in database searches: (mindfulness) AND (online OR web OR internet OR technology OR mhealth OR ehealth). The PubMed and Ovid MEDLINE databases were filtered for "randomized controlled trials" type articles. Per Cochrane's search strategies, because the PsycINFO database does not specifically classify RCT methodology, the PsycINFO search was expanded to all text within the article and synonymous words and phrases were used to filter for RCT studies (Watson and Richardson 1999). More specifically, the phrase "SU.EXACT ("Treatment Effectiveness Evaluation") OR SU.EXACT.EXPLODE ("Treatment Outcomes") OR SU.EXACT ("Placebo") OR SU.EXACT ("Followup Studies") OR placebo* OR random* OR "comparative stud*" OR clinical NEAR/3 trial* OR research NEAR/3 design OR evaluat* NEAR/3 stud* OR prospectiv* NEAR/3 stud* OR (singl* OR doubl* OR trebl* OR tripl*) NEAR/3 (blind* OR mask*)" was used. The terms "online," "web," "internet," "technology," "mhealth," and "ehealth" were used in a text search of the MINDFULNET.org research webpage.

Study Selection

Search results of all databases exported in comma-separated values (CSV) files were opened in Microsoft Excel and compiled in one worksheet. Results from the iterative search and MINDFULNET.org were added to this sheet in an ongoing basis. Using Microsoft Excel's sorting function, articles were arranged by title and duplicates were removed, leaving 411 unique articles. Remaining titles were reviewed, and promising abstracts were read independently by at least two reviewers (DV, CM, NS, LW, CS). In order to capture all studies that might update existing meta-analyses, the following broad inclusion criteria were employed: (1) web app or native app-delivered programs founded upon mindfulness and (2) RCT design. MBPs on any duration sharing an emphasis on mindfulness meditation as the key active ingredient in teaching such as mindfulness-based stress reduction (MBSR), mindfulness-based cognitive therapy (MBCT), and acceptance and commitment therapy (ACT) (Crane et al. 2017), as well as their derivatives were included. Dialectical behavior therapy (DBT) was not included because it is

founded primarily on cognitive behavioral treatment (Chapman 2006).

Data Items and Collection Process

Data extraction was independently undertaken by four authors (CM, NS, LW, and CS). The following items were extracted for each included study: (1) publication characteristics—first and second author names, publication year, country of publication; (2) population characteristics—type of sample (i.e., community versus medical referral), age, sex, medical or psychological symptom-related inclusion criteria, and number of participants per condition; and (3) intervention characteristics—delivery platform (i.e., desktop, smartphone, or both), guidance (i.e., with or without support), adherence measures, duration in weeks, control or comparison group (i.e., inactive waitlist, treatment as usual), mindfulness program underlying study intervention, and outcome measures for depression, anxiety, stress, and mindfulness.

Risk of Bias in Individual and Across Studies

Methodological quality of studies was independently assessed by multiple authors (CM, NS, KL, CS), who used the following six criteria based on Cochrane's tools for assessing risk of bias in clinical trials (Higgins et al. 2008): (1) adequate randomization mechanism; (2) adequate concealment of allocation from those involved in enrollment and study arm assignment; (3) adequate blinding of participants and study personnel (those involved in intervention delivery) to study arm assignment; (4) adequate blinding of outcome assessors; (5) adequate statistical handling of incomplete or missing outcome data; and (6) absence of selective outcome reporting or selective withholding of non-significant results. Recognizing that assessment of blinding success is rarely reported and methodologically controversial (Hróbjartsson and Boutron 2011), criteria were considered to be adequately met if articles described procedures that would likely result in successful blinding. In keeping with Cochrane principles, as RCTs, all studies were presumed to be of "low" risk of bias unless evidence indicated reason for concern. Using RevMan 5 (Collaboration 2014) software, risk of publication bias was visually assessed by plotting standard error against effect size (standardized mean difference) for each outcome of interest (stress, anxiety, depression, and mindfulness). The scatter patterns of each resulting funnel plot were checked for symmetry and expected shape.

Summary Measures

The summary measure used was the standardized mean difference (SMD, calculated as Hedge's g) of change in effect size (rounded to hundredths) from baseline to intervention

completion. The Windows 64-bit version of OpenMetaAnalyst (Byron et al. 2012) was used for calculating SMD. Effect sizes measured in Hedge's g are corrected for small samples (Lakens 2013) because Hedge's g calculates SMD by dividing the difference between treatment and control group population means by the average population standard mean difference. Four separate meta-analyses were completed for stress, anxiety, depression, and mindfulness. Outliers were defined as those studies with 95% confidence intervals 1.5 interquartile ranges (IQRs) outside the group SMD IQR (Dawson 2011). Additional meta-analyses were run after removal of outliers for comparison purposes.

In order to explore the role of reported symptoms as a moderator, subgroups of studies requiring symptoms of negative affect or pain for participation, and studies requiring lack of symptoms for participation were created. Four exploratory meta-analyses of outcomes (stress, anxiety, depression, and mindfulness) were run for subgroups of studies requiring reported symptoms. Additional analyses were completed after identification and removal of outliers.

Synthesis of Results

For stress, anxiety, and depression, a negative effect size (SMD) indicated that the intervention group reported greater reduction in the measured negative affect symptom. For mindfulness, a positive effect size (SMD) indicated that the intervention group reported a greater increase in mindfulness-related qualities. Based on standard interpretations of effect size for behavioral interventions, SMDs of 0.2 were considered small, 0.5 moderate, and 0.8 large (Cohen 1988).

Confidence intervals (CI, set to 95% and reported from lower to upper bounds) and p values were calculated for each meta-analysis in OpenMetaAnalyst. In order to better understand SMDs, we also calculated heterogeneity (calculated in OpenMetaAnalyst as I^2). Based on generally accepted benchmarks, I^2 values of 0.25, 0.5, and ≥ 0.75 were interpreted as small, moderate, and high levels of heterogeneity, respectively (Borenstein et al. 2017).

Additional Analyses

Additional analyses were conducted in order to describe the role of moderators or how treatment effects might respond to changes in variable vectors. Multivariate regression of scaled variables of interest (intervention duration, percentage women, mean age, and number of participants at intervention start) was used to describe the relationship between these vectors and SMDs. Univariate analysis of variance (ANOVA) of categorical variables of interest (use of human support vs. no support, comparison conditions, and mindfulness program underlying study intervention) were used to describe possible relationships between these factors and SMD.

Results

Selection of Studies

Our search resulted in the identification of 411 unique articles. Following subsequent review of titles and abstracts, 367 results were excluded. The remaining 44 articles were reviewed and an additional 6 were discarded, leaving 38 articles meeting all inclusion criteria (Fig. 1).

Description of Included Studies

Studies were based in Europe, the USA and Canada, and China. Most studies employed community-based recruitment methods ($n = 31$) while others ($n = 7$) sought participants with specific medical conditions (e.g., fibromyalgia). Previous psychiatric

diagnosis and/or mental health referral were not required for participation in any study. However, nearly one-third ($n = 12$) required that participants report some level of distress and/or meet a cutoff criteria on a standardized mental health measure. More specifically, symptoms of anxiety, depression, or stress reported on a standardized measure (Boettcher et al. 2014; Bostock et al. 2019; Dahlin et al. 2016; Henriksson et al. 2016; Ly et al. 2014; Pots et al. 2016; Wabbeh et al. 2016; Wolever et al. 2012; Zernicke et al. 2014), self-reported stress (Vesa and Liedberg 2016), or distress (Rasanen et al. 2016) and meeting criteria for clinical diagnoses of generalized anxiety disorder (Dahlin et al. 2016) or a major depressive episode (Lappalainen et al. 2015) via telephone interview were used as inclusion criteria. Nearly one-fifth ($n = 7$) required that participants be a recent patient of a medical clinic (Buhman et al. 2013; Westenberg et al. 2018) or have a specific medical diagnosis

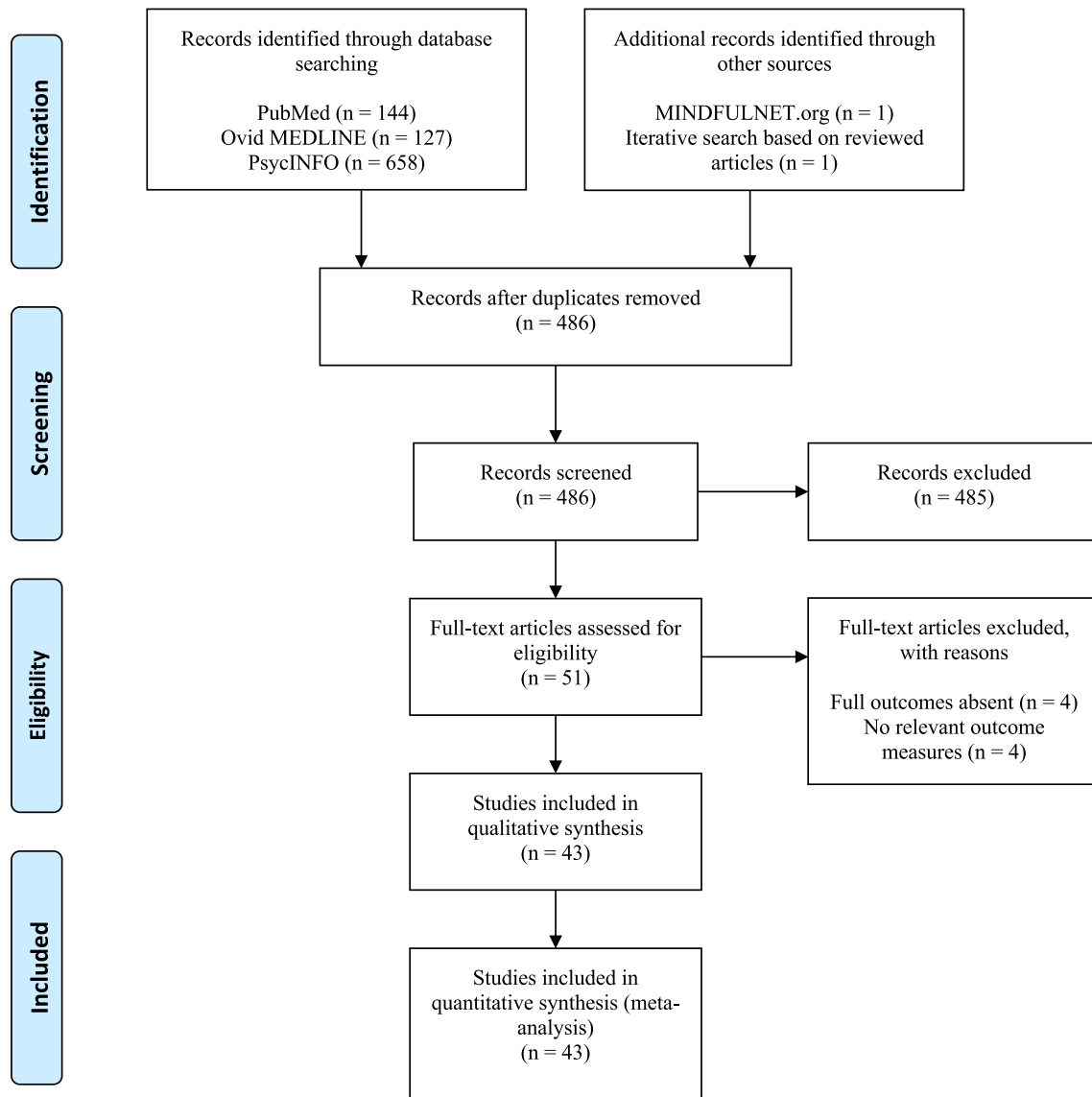


Fig. 1 Study selection flow diagram

(Cavalera et al. 2018; Dowd et al. 2015; Hearn and Finlay 2018; Matvienko-Sikar and Dockray 2017; Simister et al. 2018). Another subgroup ($n = 7$) sought participants reporting stable mental health, specifically requiring no psychiatric illness (Bhayee et al. 2016; Economides et al. 2018; Gluck and Maercker 2011; Ivtzan et al. 2016; Mak et al. 2017; Stjernsward and Hansson 2017) or untreated psychiatric symptoms (Wahbeh and Oken 2016). The remaining studies ($n = 12$) did not specify existence of negative affect or lack thereof.

Population Characteristics

A total of 38 studies, involving 6673 participants, were selected. The mean percentage of female participants was 75%, including two studies in which all participants were female and excluding one study that did not report the number of female participants. The average participant age was 40.5 years. This includes estimated average age for two studies that reported age ranges and excludes four studies that did not report age at all or for some participants.

Intervention Characteristics

The average intervention duration was 6 weeks. Intervention periods of exactly 8 weeks were employed by 16 studies, while 18 studies had interventions lasting less than 8 weeks. The remaining four studies' interventions lasted longer than 8 weeks. Thirty-two studies employed Internet-based programs accessible by a traditional desktop Internet browser. Five studies employed treatment interventions utilizing mobile technology, accessible by smartphone or tablet web browser or app. One treatment intervention was accessible both via desktop and mobile technology (Tables 1, 2, 3, and 4).

Study interventions were founded upon manualized programs (e.g., MBSR, MBCT, ACT) or MBSR-derived modern mindfulness meditation (MMM) principles. Twelve interventions were based on MBSR or MBCT; one was based on a related program, mindfulness-based self-help (MBSH), and one another MBSR-inspired mindfulness-based pain management program. One study intervention was based on a combination of MBSR and Buddhist principles, while another study intervention combined MBCT and ACT. Eight study interventions were based on ACT. The remaining 20 interventions were based on MMM principles.

Outcome Measure Characteristics

Stress Seven different outcome measures were used in the 18 studies included in the stress meta-analysis. The majority utilized the Perceived Stress Scale (PSS; $n = 13$), a 10-item measure of the degree to which experiences during the past month were appraised as stressful. Other measures included the Perceived Stress Questionnaire (PSQ; $n = 2$), the stress scale

of the Depression Anxiety Stress Scale (DASS; $n = 3$), the Stress Overload Scale (SOS; $n = 1$), the Prenatal Distress Questionnaire (PDQ; $n = 1$), the Calgary Symptoms of Stress Inventory (CSOSI; $n = 1$), and the Zung Self-Rating Depression Scale (SDS; $n = 1$).

Anxiety Nine different outcome measures were used in the 17 studies included in the anxiety meta-analysis. The most frequently used measure was the Anxiety Scale of the Hospital Anxiety & Depression Scale (HADS; $n = 7$). The HADS Anxiety Scale is comprised of 7 items in which respondents indicate how frequently (0–3, from “only occasionally” to “a great deal of the time”) anxiety-related thoughts and feelings were experienced in the past week. Other measures include the Anxiety Scale of the DASS ($n = 4$), the Beck Anxiety Inventory (BAI; $n = 2$), the Generalized Anxiety Disorder 7-item Scale (GAD-7; $n = 1$), the German Brief Symptom Inventory (GSI; $n = 1$), the Mental Health Inventory (MHI; $n = 1$), an Emotion Thermometer (ET) rating ($n = 1$), the Brief Symptom Inventory (BSI; $n = 1$), and the Zung Self-Rating Anxiety Scale (SAS; $n = 1$).

Depression Eleven different outcome measures were used in the 27 studies included in the depression meta-analysis. The most frequently used measure was the Center for Epidemiologic Studies Depression Scale (CESD; $n = 8$), a 20-item scale in which respondents indicate how frequently (0–3, “rarely or none of the time” to “most or almost most of the time”) symptoms of depression were experienced during the past week. Other measures include the Beck Depression Inventory II (BDI-II; $n = 5$), the Depression Scale of the HADS ($n = 5$), the Depression Scale of the DASS ($n = 3$), an ET rating ($n = 1$), the BSI ($n = 1$), the Beck Depression Inventory (BDI; $n = 1$), the Patient Health Questionnaire 9-item Scale (PHQ-9; $n = 1$), the Edinburgh Postnatal Depression Scale (EPDS; $n = 1$), the Isolation Scale of the Self-Compassion Scale-Short Form (SCS-SF-I; $n = 1$), the Edinburgh Depression Scale (EDS; $n = 1$), and the Zung Self-Rating Depression Scale (SDS; $n = 1$).

Mindfulness Seven different outcome measures were used in the 21 studies included in the mindfulness meta-analysis. The majority used the Five Facet Mindfulness Questionnaire (FFMQ; $n = 13$), a 39-item measure spanning five facets of mindfulness (observing, describing, acting with awareness, non-judging of inner experience, and non-reactivity to inner experience). Other measures include the Mindful Attention Awareness Scale (MAAS; $n = 4$), the Freiburg Mindfulness Inventory (FMI; $n = 3$), the Acceptance & Action Questionnaire-II (AAQ-II; $n = 1$), the Cognitive and Affective Mindfulness Scale-Revised (CAMS-R; $n = 1$), the Comprehensive Inventory of Mindfulness Experiences (CHIME; $n = 1$), and the Philadelphia Mindfulness Scale (PHLMS).

Table 1 Characteristics of included studies

Study characteristics		Measurement tools			Intervention characteristics			Select demographics		Population
Author	Year	Stress	Anxiety	Depression	Mindfulness	Length (weeks)	Control	Program	% women	Mean age
Aikens	2014	PSS				7	WLC	MBSR	-	-
Alexandre	2016	PSS			MAAS	8	WLC	MM	83.2	40.0
Blayee*	2016		BSI	BSI	FMI	6	Math training	MM	27.9	32.7
Boettcher**	2014		BAI	BDI-II		8	Discussion forum	MBSR	71.4	38.0
Bostock**	2018		HADS	HADS		8	WLC	MM	59.2	35.5
Buhrman***	2013		HADS	HADS		7	Discussion forum	ACT	59.2	49.1
Cavalera***	2018		HADS	HADS		8	Psychoeducation	MBSR	64.5	42.7
Cavanagh	2013	PSS			FFMQ	2	WLC	MBSH	88.5	24.7
Champion	2013	PSS				4	WLC	MM	55.4	39.4
Dahlin***	2016		GAD-7	PHQ-9		9	WLC	ACT	83.5	39.5
Dowd***	2015				MAAS	6	Psychoeducation	MBSR	90.3	44.5
Economides*	2018	SOS				4	Audio book	MM	44.3	30.7
Eustis	2018	DASS	DASS	DASS	PHLMS	4	WLC	ACT	78.8	25.4
Flett	2019	PSS	HADS	CESD	CAMS-R	1.5	Note taking app	MM	70.5	20.8
Gluck*	2011	PSQ	GSI	HADS	FMI	2	WLC	MM	73.5	35.4
Hearn***	2018		HADS	HADS	FFMQ	8	Psychoeducation	MBPM	47.4	44.4
Henriksson**	2016			CESD	FFMQ	8	Discussion Forum	MBSR	93.5	51.0
Howells	2016			CESD	FFMQ	1.5	List-making app	MM	88.1	40.3
Ivtzan*	2016	PSS		BDI-II	FMI	8	WLC	MM	78.7	40.8
Krieger**	2019			CESD	CHIME	8	TAU	MM	77.1	37.4
Kvillemo	2016			CESD		8	Expressive writing	MBSR	73.7	-
Lappalainen**	2015			BDI-II	FFMQ	7	WLC	ACT	71.8	51.9
Levin	2016		DASS	DASS		3	Psychoeducation	ACT	78.9	21.6
Ly**	2013		BAI	BDI-II	AAQ-II	8	Behav activation	MBCT	70.4	36.1
Ma*	2018		SAS	SDS	FFMQ	8	Discussion & WLC	MBCT	57.9	27.8
Mak	2015	DASS	DASS	DASS	FFMQ	8	WLC	MBSR	66.3	22.8
Mak*	2017		MHI	EPDS	MAAS	8	WLC	MBSR	74.3	32.6
Matvienko-Sikal***	2017	PDQ		BDI		3	TAU	MM	100.0	33.8
Meyer	2009				MAAS	9	TAU	ACT & MBSR	78.3	34.8
Morledge	2013	PSS				8	Inactive control	MBSR	88.9	42.0
Nguyen-Feng	2017	DASS	DASS	DASS		4	Psychoeducation	MM	75.0	-
O'Leary	2015	PSS		EDS		3	WLC	MM	100.0	28.4
Pots**	2016		HADS	CESD		9	Expressive writing	ACT	75.8	46.9
Räsänen**	2016	PSS	DASS	BDI-II	FFMQ	7	WLC	ACT	85.3	24.3
Simister***	2018			CESD	FFMQ	8	TAU	ACT	95.5	39.7
Stjernsward*	2017	PSS		SCS	FFMQ	8	WLC	MM	88.1	53.8
van Emmerik	2018				FFMQ	8	WLC	MM	96.0	44.7
Vesa**	2016	PSQ	HADS	HADS	FFMQ	2	WLC	MM	92.9	-
Walbeh & Goodrich**	2016	PSS		CESD	FFMQ	6	Psychoeducation	MM	50.0	76.2
Walbeh**	2016	PSS		CESD	FFMQ	6	Guided meditation	MM	87.2	41.5
Westenberg***	2018		ET	ET		0	Psychoeducation	MM	49.6	54.5
Wolever**	2012	PSS		CESD	CAMS-R	12	Inactive control	MM	49.7	44.3
Zernicke**	2014	CSOSI				8	TAU	MBSR	72.6	58.0

AAQ-II, Acceptance & Action Questionnaire-II; BAI, Beck Anxiety Inventory; BDI, Beck Depression Inventory; BSI, Brief Symptom Inventory; CAMS-R, Cognitive and Affective Mindfulness Scale-Revised; CES-D, Center for Epidemiologic Studies Depression; CHIME, Comprehensive Inventory of Mindfulness Experiences; CSOSI, Calgary Symptoms of Stress Inventory; DASS, Depression, Anxiety, and Stress Scale; EDS, Edinburgh Depression Scale; EPDS, Edinburgh Postnatal Depression Scale; ET, Emotion Thermometer; FFMQ, Five Factor Mindfulness Questionnaire; FMI, Freiburg Mindfulness Inventory; GAD-7, Generalized Anxiety Disorder-7; GSI, German Brief Symptom Inventory; HADS, Hospital Anxiety & Depression Scale; MAAS, Mindful Attention Awareness Scale; MHI, Mental Health Inventory; PDQ, Prenatal Distress Questionnaire; PHLMS, Philadelphia Mindfulness Scale; PHQ-9, Patient Health Questionnaire 9; PSQ, Perceived Stress Questionnaire; PSS, Perceived Stress Scale; SAS, Zung Self-Rating Anxiety Scale; SCS-SF-I, Self-Compassion Scale-Short Form-Isolation; SDS, Zung Self-Rating Depression Scale; SOS, Stress Overload Scale; WLC, Waitlist Condition; TAU, Treatment as Usual; MBSR, mindfulness-based stress reduction; MBCT, mindfulness-based cognitive therapy; MBSH, mindfulness-based self-help; MBPM, mindfulness-based pain management; ACT, acceptance & commitment therapy; MMM, MBSR-derived modern mindfulness meditation principles

*Excludes participants with significant psychiatric symptoms or diagnosis

**Requires some level of negative affect symptoms

***Requires a medical diagnosis or symptoms

Adherence

Intervention adherence was addressed in 23 studies. Most studies used one of three operational definitions: (1) average percentage of intervention completion/compliance; (2) percentage of participants completing 100% of the intervention; and (3) percentage of participants completing more than 75% of the intervention. When adherence was defined as completing 100% of the intervention, adherence ranged from 2 to 85% (Bostock et al. 2019; Buhrman et al. 2013; Dahlin et al. 2016; Dowd et al. 2015; Hearn and Finlay 2018; Henriksson et al. 2016; Kvillemo et al. 2016; Ly et al. 2014; Mak et al. 2017; Rasanen et al. 2016; Simister et al. 2018; Vesa and Liedberg 2016). When adherence was defined as completing at least 75% of the intervention, adherence ranged from 20 to 82.5% (Aikens et al. 2014; Allexandre et al. 2016; Bhayee et al. 2016; Meyer et al. 2009; Morledge et al. 2013). When adherence was defined as average percentage of treatment completion, averages of completion ranged from 50 to 71% (Boettcher et al. 2014; Cavallera et al. 2018; Wahbeh et al. 2016; Zernicke et al. 2014). Because of automatic withdrawal due to non-compliance, 100% of participants in one study completed at least 43% of the treatment (Gluck and Maercker 2011). Using at least 50% completion of treatment as an operational definition, another study reported 51% adherence (Stjernsward and Hansson 2017). For remaining studies not addressing adherence specifically, frequency of treatment interaction (e.g., frequency of app use per day (van Emmerik et al. 2018) or number of diary entries (Matvienko-Sikar and Dockray 2017)) without assigning adherence qualification was sometimes discussed.

Control Groups

Study designs employing active control groups ($n = 21$) were more common than inactive control groups ($n = 17$). Active control conditions included psychoeducation ($n = 7$), treatment as usual (TAU; $n = 4$), online discussion forums ($n = 3$), expressive writing ($n = 2$), behavioral activation training ($n = 1$), an audiobook ($n = 1$), meditation training ($n = 1$), a list-making mobile app ($n = 1$), and math training ($n = 1$). Waitlist ($n = 15$) and no treatment ($n = 2$) conditions were used as inactive control groups.

Several studies ($n = 6$) included more than two intervention arms. To account for this, within each study, each arm was compared against other study arms, resulting in more analyses than publications. Examples of these additional arms included a supportive or behavioral component ($n = 4$) such as weekly meeting groups and expert clinical support (Allexandre et al. 2016), behavior change training (Mak et al. 2015), an online message board (Morledge et al. 2013), and training in “present control,” which teaches skills for modifying controllable

Table 2 Summary of meta-analyses

Outcomes	Analyses	Number of comparisons	Effect size (g)	95% confidence interval	Significance (<i>p</i>)	Heterogeneity (<i>I</i> ²)*
Stress	All studies	29	− 0.61	− 1.02 to 0.21	0.003	96.11
	Outlier removed	28	− 0.47	− 0.76 to − 0.19	0.001	92.16
Anxiety	All studies	28	− 0.09	− 0.39 to 0.20	0.54	93.44
	Outlier removed	27	− 0.21	− 0.39 to − 0.03	0.02	81.27
Depression	All studies	38	− 0.21	− 0.49 to 0.08	0.16	94.11
	Outlier removed	36	− 0.25	− 0.37 to − 0.12	< 0.001	66.83
Mindfulness	All studies	33	0.4	0.54 to 0.07	< 0.001	66.7

**I*² values of 0.25, 0.5, and ≥ 0.75 were interpreted as small, moderate, and high levels of heterogeneity, respectively (Borenstein et al. 2017)

aspects of a stressor, such as thoughts about the stressor, in the present moment (Nguyen-Feng et al. 2017).

Outcome Analysis Groups

Outcome measures were administered as follows: stress in 24 comparisons, anxiety in 21 comparisons, depression in 30 comparisons, and mindfulness in 24 comparisons. Outcome measures were repeated after outlier removal, resulting in the following: stress in 23 comparisons, anxiety in 20 comparisons, and depression in 29 comparisons. All outcome instruments have been validated and found have good psychometric properties.

Study Quality and Publication Bias

None of the studies was found to demonstrate low risk of bias across the six areas outlined below. All 38 studies are included in following quality analysis (Fig. 2). Similar ratios of low, medium, and high risk in each of the six areas were found for the subgroups of studies included in individual meta-analyses.

Randomization Most studies (*n* = 34) demonstrated low risk of bias due to randomization. A simple statement of

participant randomization without description of the process caused the remaining studies (*n* = 4) to have questionable risk of bias in this area.

Allocation Concealment Nearly half of the studies (*n* = 17) demonstrated low risk of bias due to allocation concealment. Lack of clarity in language describing automatic allocation led to several studies (*n* = 3) to have questionable risk of bias in this area. Direct involvement of study personnel participating in outcome measures or analysis caused remaining studies (*n* = 18) to have high risk of bias in this area.

Participant and Personnel Blinding Satisfactory methods for blinding of participants and personnel were not disclosed by any study. High risk of bias in this area was predominantly due to the nature of the interventions and study designs (e.g., waitlist control arms). However, nearly one-third of studies (*n* = 12) simply did not discuss blinding of study personnel.

Outcome Assessor Blinding Most studies (*n* = 31) demonstrated low risk of bias due to outcome assessor blinding. Delivery of some measures in person or via semi-structured telephone interview with study personnel caused several studies (*n* = 3) to be of questionable risk of bias in this area. Unspecified or

Table 3 Summary of multivariate regressions

	Predictor variable standardized beta weight				Variance explained and significance	
	Intervention duration	Percentage women	Mean age	<i>N</i> at intervention start	Adjusted <i>R</i> ²	Significance (<i>p</i>)
Stress	− 0.56	− 0.02	− 0.05	0.41	0.16	0.14
Anxiety	− 0.57**	− 0.19	0.02	− 0.2	0.53	0.007
Depression	− 0.67*	− 0.32**	0.26	0.14	0.39	0.001
Mindfulness	0.53**	0.38**	0.07	− 0.12	0.25	0.018

**p* < 0.01

***p* < 0.05

Table 4 Effect size differences by study characteristics

	Stress Mean (SD)	Anxiety	Depression	Mindfulness
Intervention support				
Supported ($n = 21$)	− 0.2 (0.49)*	− 0.07 (0.88)	− 0.12 (0.93)	0.37 (0.42)
Unsupported ($n = 7$)	− 1.63 (1.8)*	− 0.14 (0.47)	− 0.46 (0.79)	0.37 (0.6)
Inclusion criteria				
Medical symptoms ($n = 10$)	− 1.59 (1.0)*	− 0.39 (0.39)	− 0.51 (0.66)	0.59 (0.5)*
Without symptoms ($n = 18$)	− 0.39 (0.59)*	0.08 (0.92)	− 0.001 (0.99)	0.25 (0.33)*
Underlying program				
MBSR based ($n = 10$)	− 1 (1.9)	− 0.32 (0.65)	− 0.25 (0.44)	0.38 (0.37)
ACT based ($n = 6$)	− 1.24 (1.38)	− 0.31 (0.37)	− 0.49 (0.28)	0.43 (0.35)
General mindfulness ($n = 11$)	− 0.46 (0.82)	0.24 (1)	− 0.18 (0.91)	0.38 (0.51)
Type of control				
Active ($n = 17$)	− 0.37 (1.46)	0.12 (0.87)	0.05 (0.95)*	0.22 (0.41)
Inactive ($n = 11$)	− 0.83 (0.77)	− 0.41 (0.57)	− 0.64 (0.62)*	0.48 (0.42)

MBSR, mindfulness-based stress reduction; ACT, acceptance and commitment therapy; sample sizes vary depending on the specific outcome

* $p < 0.05$

simply not discussed delivery method caused the remaining studies ($n = 4$) to be at high risk of bias in this area.

Incomplete Outcomes Many studies ($n = 15$) demonstrated low risk of bias due to incomplete outcomes. Use of simple imputation (e.g., last observation carried forward) for missing data caused some studies ($n = 9$) to be of questionable risk of bias. Failure to appropriately employ the Intention-to-Treat analysis method caused the remaining studies ($n = 14$) to be at high risk of bias in this area.

Selective Reporting Most studies ($n = 35$) demonstrated low risk of bias due to selective reporting. A measure reported in the “Results” section but not in “Methods” section led to questionable risk of bias ($n = 1$) and the reverse, a measure indicated in study methods, but not reported in results, led to a high risk of bias in the remaining studies ($n = 2$).

Publication Bias Four separate funnel plots using standard error and effect size (SMD) were created for studies presenting stress, anxiety, depression, and mindfulness outcomes. Slight asymmetry and cylindrical appearances were observed, suggesting the possibility that smaller studies with smaller effects were not published (Fig. 3).

Meta-analyses

Stress For stress (29 comparisons), a medium effect was observed ($g = -0.61$, 95% CI -1.02 to 0.21 , $p < 0.01$). The level of heterogeneity was high ($I^2 = 96.11$). One outlier was detected (Zernicke et al. (2014); SMD = -4.83 , 95% CI -5.86 to $-$

3.8). After omitting this study from the analysis, we found a small effect ($g = -0.47$, 95% CI -0.76 to -0.19 , $p < 0.01$) and the level of heterogeneity remained high ($I^2 = 92.16$) (Fig. 4).

A multiple linear regression computed to predict stress SMD based on intervention duration, number of participants at intervention start, mean age, and percentage women did not result in a significant equation (adjusted $R^2 = 0.16$, $F(4, 18) = 2.02$, $p = 0.14$). A univariate ANOVA calculated to determine effects of moderators on stress SMD found a significant main effect of intervention support ($F(2, 26) = 5.55$, $p = 0.01$). Studies employing interventions without human support ($M = -1.63$, $SD = 1.8$) resulted in significantly greater decreases ($F(2, 26) = 5.55$, $p = 0.01$) in stress outcome measures than did studies employing human-supported interventions ($M = -0.2$, $SD = 0.49$). A univariate ANOVA calculated to determine the effect of symptom-related inclusion criteria found that studies requiring symptoms of negative affect or medical conditions ($M = -1.59$, $SD = 2$) also resulted in significantly greater decreases ($F(1, 27) = 6.72$, $p = 0.02$) in stress outcome measures than did studies requiring participants report “good” mental health ($M = -0.39$, $SD = 0.59$). Main effects of control condition ($F(1, 27) = 1.24$, $p = 0.28$) and mindfulness program underlying interventions ($F(2, 24) = 0.55$, $p = 0.66$) were not significant.

Anxiety For anxiety (28 comparisons), a significant effect was not observed ($g = -0.09$, 95% CI -0.39 to 0.2 , $p = 0.54$). One outlier was detected (Westenberg et al. (2018); SMD = 3.19 , 95% CI 2.66 to 3.72). After omitting this study from the analysis, we found a small effect ($g = -0.21$, 95% CI -0.39 to $-$

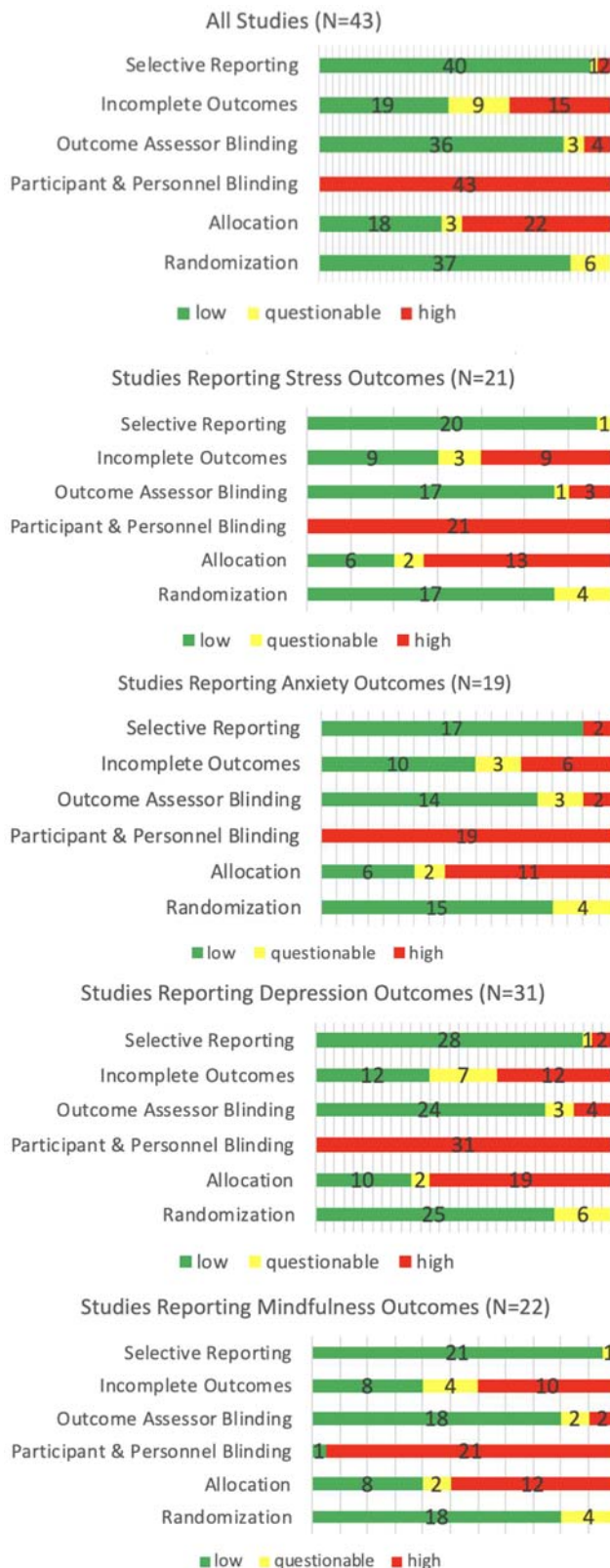


Fig. 2 Risk of bias indicators

0.03, $p = 0.02$) and the level of heterogeneity was high ($I^2 = 81.27$) (Fig. 4).

A multiple linear regression computed to predict anxiety SMD based on intervention duration, number of randomized participants, mean age, and percentage women resulted in a significant regression equation (adjusted $R^2 = 0.42$, $F(4, 18) = 4.98$, $p = 0.007$) such that increases in intervention duration predicted decreased anxiety outcome SMD ($\beta = -0.57$, $p = 0.003$). Percentage of women ($\beta = -0.19$, $p = 0.3$), mean age ($\beta = 0.28$, $p = 0.12$), and number of participants at intervention start ($\beta = -0.2$, $p = 0.24$) were not significant predictors of anxiety outcome measure SMD. A univariate ANOVA calculated to determine effects of moderators on anxiety SMD resulted in non-significant main effects of intervention support ($F(1, 26) = 0.04$, $p = 0.84$), control condition ($F(1, 26) = 3.2$, $p = 0.09$), type of mindfulness program underlying interventions ($F(3, 24) = 1.0$, $p = 0.39$), and symptom-related inclusion criteria ($F(1, 26) = 2.3$, $p = 0.14$).

Depression For depression (38 comparisons), a significant effect was not observed ($g = -0.21$, 95% CI -0.49 to 0.08 , $p = 0.16$). Two outliers were detected (Westenberg et al. (2018); SMD = 4.16, 95% CI 3.54 to 4.78, and Wolever et al. (2012); SMD = -2.47 , 95% CI -3.05 to -1.89). After omitting these studies from the analysis, we found a small effect ($g = -0.25$, 95% CI -0.37 to -0.12 , $p < 0.001$) and the level of heterogeneity became moderate ($I^2 = 66.83$) (Fig. 4).

A multiple linear regression computed to predict depression SMD based on intervention duration, number of randomized participants, mean age, and percentage women resulted in a significant regression equation (adjusted $R^2 = 0.39$, $F(4, 27) = 5.93$, $p = 0.001$) such that increased intervention duration predicted decreased depression outcome SMD ($\beta = -0.67$, $p < 0.001$), as did percentage women ($\beta = -0.32$, $p = 0.04$). Mean age ($\beta = 0.26$, $p = 0.09$) and number of participants at intervention start ($\beta = 0.14$, $p = 0.37$) were not significant predictors of depression outcome measure SMD. A univariate ANOVA calculated to determine effects of moderators on depression SMD resulted in a significant main effect of control condition ($F(1, 36) = 5.89$, $p = 0.02$). Studies employing inactive control conditions ($M = -0.64$, $SD = 0.62$) found significantly greater decreases in depression outcome measures than did studies employing active control conditions ($M = 0.05$, $SD = 0.95$). Main effects of intervention support ($F(1, 36) = 1$, $p = 0.33$), mindfulness program underlying interventions ($F(2, 33) = 0.59$, $p = 0.62$), and symptom-related inclusion criteria ($F(1, 36) = 3.11$, $p = 0.09$) were not significant.

Mindfulness For mindfulness (33 comparisons), a small effect was observed ($g = 0.4$, 95% CI 0.25 to 0.54 , $p < 0.001$) (Fig. 4). The level of heterogeneity was moderate ($I^2 = 66.7$). No outliers were detected.

A multiple linear regression computed to predict mindfulness SMD based on intervention duration,

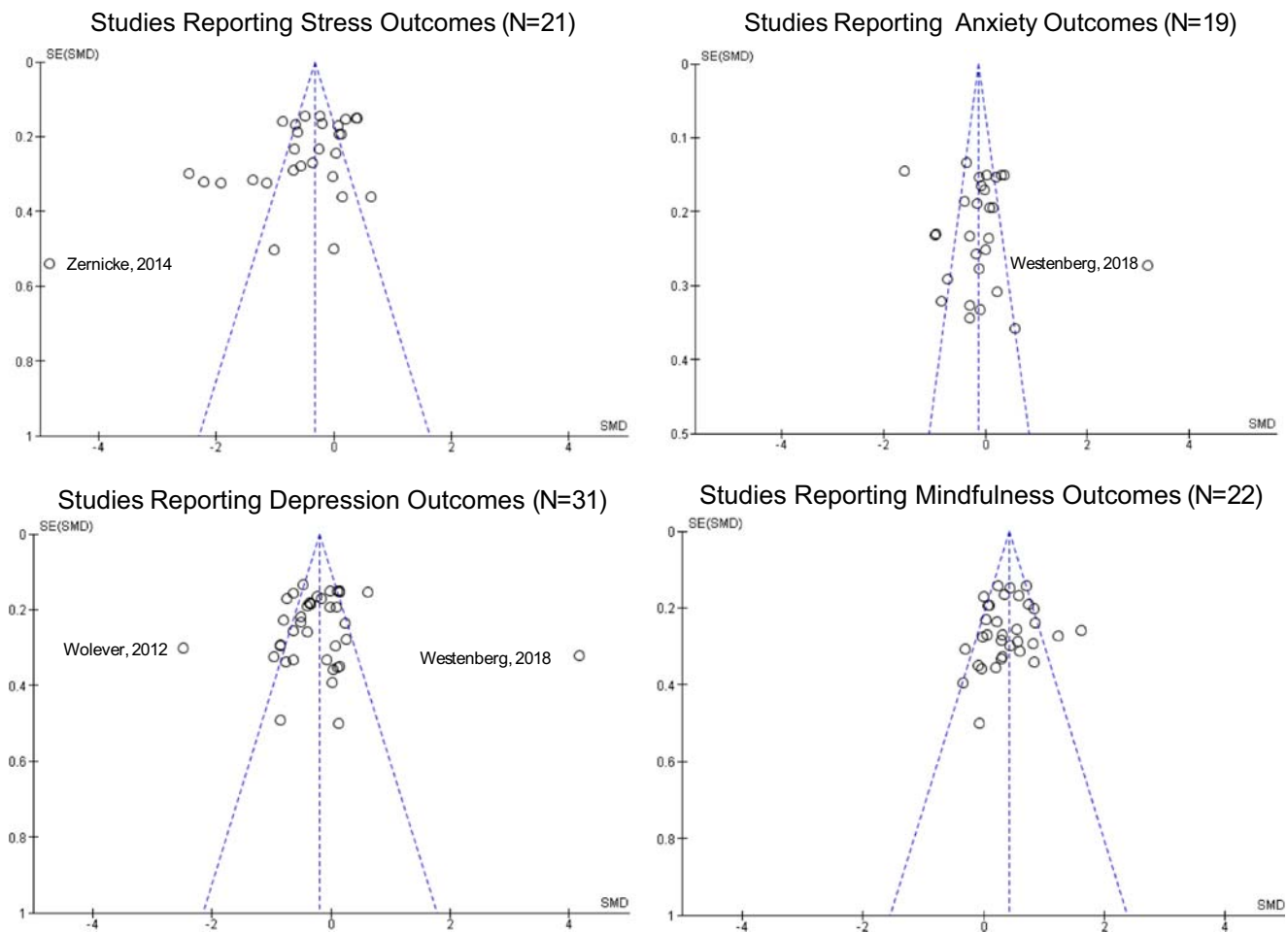


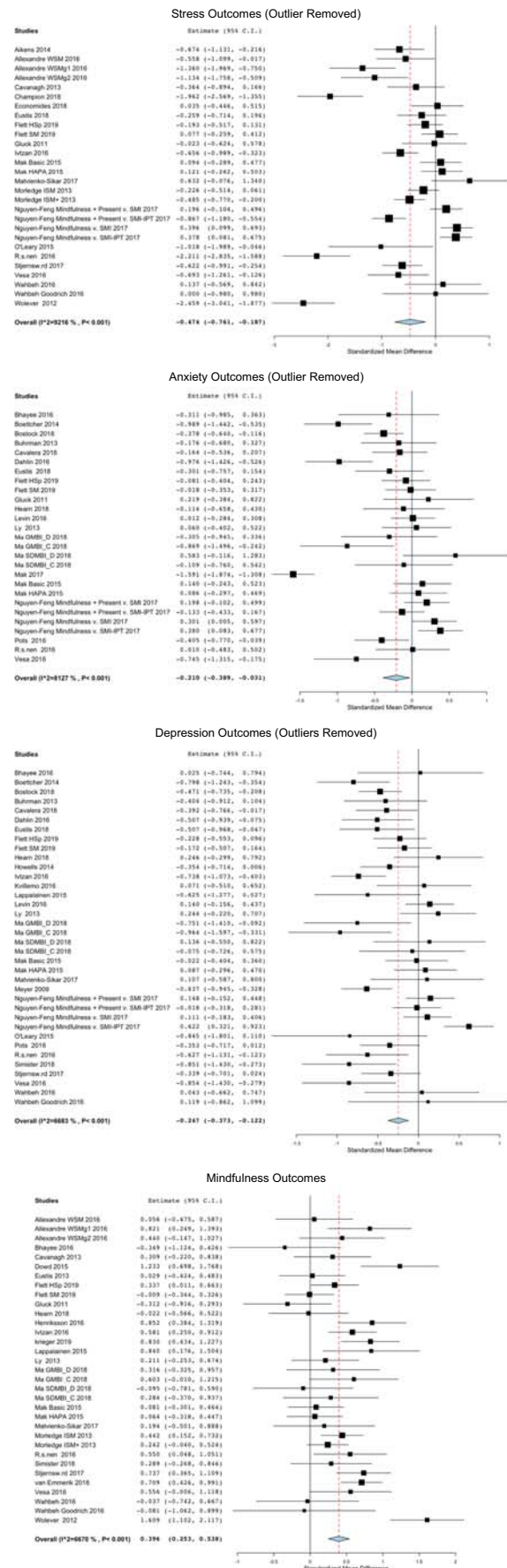
Fig. 3 Funnel plot asymmetry by outcome using a fixed effects model

number of randomized participants, mean age, and percentage women resulted in a significant regression equation (adjusted $R^2 = 0.25$, $F(4, 27) = 3.6$, $p = 0.02$) such that increased intervention duration predicted greater mindfulness outcome SMD ($\beta = 0.53$, $p = 0.007$), as did percentage women ($\beta = 0.38$, $p = 0.04$). Mean age ($\beta = 0.07$, $p = 0.68$) and number of participants at intervention start ($\beta = -0.12$, $p = 0.5$) were not significant predictors of mindfulness outcome measure SMD. A univariate ANOVA calculated to determine the effect of symptom-related inclusion criteria found that studies requiring symptoms of negative affect or medical conditions ($M = 0.59$, $SD = 0.5$) resulted in significantly greater increases ($F(1, 31) = 5.59$, $p = 0.03$) in mindfulness outcome measures than did studies requiring participants report “good” mental health ($M = 0.25$, $SD = 0.33$). A univariate ANOVA calculated to determine effects of moderators on mindfulness SMD resulted in non-significant main effects of intervention support ($F(1, 31) = 0.01$, $p = 0.99$), control condition ($F(1, 31) = 3.07$, $p = 0.09$), and mindfulness program underlying interventions ($F(2, 29) = 0.28$, $p = 0.84$).

Discussion

Technology-enabled MBPs continue to rise in popularity as alternatives to traditional in-person mindfulness training. While most recent meta-analyses on this topic covered both clinical (Sevilla-Llewellyn-Jones et al. 2018) and non-clinical (Jayewardene et al. 2017) healthy populations, even the largest (Spijkerman et al. 2016) was dated. All eight studies included in Jayewardene et al. (2017), 12 of the 15 studies analyzed by Spijkerman et al. (2016), and 3 of the 12 studies used by Sevilla-Llewellyn-Jones et al. (2018) were included in this meta-analysis. Reasons for not including specific studies are related to different primary outcomes (e.g., quality of life) and lack of focus on mindfulness in the primary intervention. The Spijkerman et al. (2016) analysis most closely resembles the goals and rationale of this current analysis, by including of studies with and without symptom-related criteria as well as a focus on outcomes of stress, anxiety, depression, and mindfulness. While content overlap is significant for Jayewardene et al. (2017), study search criteria (namely, a focus on community-recruited, predominantly asymptomatic populations) and outcomes of interest (only stress and

Fig. 4 Forest plots by outcome



mindfulness) differ from the current meta-analysis. A small amount of content overlap exists with Sevilla-Llewellyn-Jones et al. (2018), but study search criteria (namely, a focus on clinically diagnosed depression or anxiety) and outcomes of interest (only anxiety, depression, and mindfulness) differ from the current investigation. Our search and inclusion criteria incorporated 24 studies that are not found the aforementioned meta-analyses.

Overall, findings from this analysis indicate that technology-enabled MBPs contribute to the reduction of symptoms of negative affect and increase mindful awareness, with small to medium effects, when compared with both active and inactive controls. This updated, more comprehensive meta-analysis confirms previous findings of Spijkerman et al. (2016) regarding small but significant effects of technology-enabled MBPs on outcomes of depression, anxiety, and mindfulness in individuals with and without psychiatric symptoms. Incorporating studies with acute medical symptom-related inclusion criteria allows this analysis to go further, suggesting that these small but significant effects may also be found when including populations reporting current medical sequelae, such as chronic pain.

Exploration of symptom-related inclusion criteria as moderators revealed findings similar to those of Spijkerman et al. (2016) and Sevilla-Llewellyn-Jones et al. (2018), which both analyzed the impact of technology-enabled MBPs on negative affect and mindfulness in populations reporting symptoms of anxiety and/or depression. Our inclusion of studies requiring existing medical conditions/symptomology suggests that technology-enabled MBPs have a larger effect on stress and mindfulness not only in individuals reporting symptoms of negative affect but also in those reporting other medical conditions and symptoms, such as chronic pain.

As part of this meta-analysis, we used multivariate regression to better understand the possible role of study-specific factors on variability in outcomes. Significant regression equations were found in anxiety, depression, and mindfulness, which accounted for 52%, 48%, and 30% of heterogeneity in meta-analysis results, respectively. The effect of intervention duration was significant for all three meta-analyses, indicating that variability in intervention duration (ranging from less than 1 day to 12 weeks) contributed to heterogeneity in meta-analysis findings. The effect of percentage of female participants (ranging from 28 to 100%) was also significant for depression and mindfulness meta-analysis results, indicating that variability in percentage of women participants also contributed to heterogeneity.

Additional analyses further explored the role of study related variables as moderators in outcomes. The significant relationship between SMD in stress outcomes and availability of human support (or lack thereof) during the technology-enabled intervention suggests that independent use of technology-enabled MBPs resulted in greater stress reduction

(compared with controls) than did technology-enabled MBPs with human support. In other words, individuals using technology-enabled MBPs independently, compared with individuals who interacted with study staff as part of the technology-enabled MBP, reported greater reductions in stress. Reasons for this finding could center on scheduling time, which is necessary for interacting with human support, but also a significant stressor for many Americans (Fenwick and Tausig 2001) and commonly reported as a reason for dropping out of traditional in-person MBSR interventions (Martinez et al. 2015). Interestingly, significant relationships were not found between human support and other outcomes. The significant relationship between SMD in depression outcomes and types of control conditions (inactive control versus active control) indicates that greater differences in symptom change resulted from trials employing inactive control groups. That is, those who completed the technology-enabled MBP reported greater improvements relative to inactive control groups than relative to active control groups, suggesting that active control conditions, however well planned, elicit some symptom improvement. Challenges to designing rigorous control conditions for mind-body interventions, such as performance, expectation, detection, and selection bias, and non-specific factors (e.g., therapeutic environment, study staff attention) (Kinser and Robins 2013), may have contributed to this finding.

Limitations and Future Research

This meta-analysis is not without limitations. Potential risks of bias related to randomization, blinding, and missing data were observed. Individual studies were not rated on overall quality, and therefore, subgroup analyses comparing outcomes on different levels of quality were not conducted. Potential risk of publication bias was also observed, but may or may not be accurate in part because skewing caused by plotting SMD against the SMD-derived SE may cause the visual appearance of slight asymmetry where no publication bias exists (Zwetsloot et al. 2017). Certainty of publication bias may be particularly challenging because even more complex statistical methods, such as Egger's regression, are vulnerable to this phenomenon (Zwetsloot et al. 2017). Correcting for the bias is also challenging because while the trim-and-fill analyses have suggested as a method of correcting for "missing" publications (those unpublished, "file-drawer" studies), it too is subject to problems caused by using both SMD- and SMD-derived SE (Zwetsloot et al. 2017). Lastly, the somewhat cylindrical appearance of the funnel plots for anxiety and depression in particular suggests that heterogeneity is likely affecting the scatter patterns of these funnel plots and may contribute to the appearance of publication bias (Sterne et al. 2011).

Substantial heterogeneity was found across meta-analysis findings, but not unexpected given the impact of vast and

diverse applicability of internet delivery methods on program design. Some authors suggest that high heterogeneity is a reason for either devaluing results or modifying analyses by sequentially removing outliers until the desired level of heterogeneity is reached (Patsopoulos et al. 2008). While outliers identified using this method may help to explain heterogeneity, this method may also be misleading due to the statistics used to represent heterogeneity and the target threshold, which often lacks rationale and may appear arbitrary (Rücker et al. 2008). The I^2 statistic representing heterogeneity may be best described as a measure of inconsistency as it represents the approximate proportion of total variability that can be attributed to heterogeneity (Rücker et al. 2008). Within study characteristics related to intervention, exposure, outcomes, and sample size in particular are related to increases in heterogeneity measured in I^2 (Rücker et al. 2008). Alternatively, it has been suggested that provided study inclusion criteria are sound and data are correct, any amount of heterogeneity may be acceptable and may in fact invite exploration of constructs underlying heterogeneity (Rücker et al. 2008).

The variety of outcome measures used to quantify each outcome of interest was a significant challenge. Several measures quantified outcomes in only one study, while others were employed multiple times. Also, the number of items in each measure varied widely. This variability likely challenged meta-analysis homogeneity and also led to the exclusion of one study. More specifically, while the ET is a valid measure, the study (Westenberg et al. 2018) employing this tool for quantification of anxiety and depression outcomes was found to be an outlier in both anxiety and depression meta-analyses. The disparity that caused findings to appear as outliers could be due to the rather Spartan, single-item nature of the ET compared with the more complex structure of multi-item measures such as the DASS-21.

Overall, technology-enabled MBPs demonstrated small to medium levels of effectiveness in reducing negative affect and increasing qualities of mindfulness in individuals reporting depression, anxiety, or stress. This updated meta-analysis reinforces findings of previous analyses, despite advances in Internet and computer technology between mid-2015 and mid-2018. Future studies using technology-enabled MBPs should continue to examine the role of human support, as well as development of rigorous control condition designs.

Author's Contributions DV developed a conceptual plan for the manuscript, oversaw design and execution of the study and data analyses, and contributed to writing and editing of the manuscript. CS contributed in study execution and data analysis and led writing and editing of the manuscript. LW, CM, KL, and NS collaborated in study execution, writing, and editing of the manuscript.

Compliance with Ethical Standards

All procedures performed in this study were in accordance with the

ethical standards of the institutional review board of the participating institution.

Conflict of Interest The authors declare that they have no conflicts of interest.

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