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Yue Qi Germaine TNG
Singapore Management University, germainetng.2020@phdps.smu.edu.sg

Xun Ci SOH

Xun Ci SOH
Singapore Management University, xunci.soh.2021@socsc.smu.edu.sg

Andree HARTANTO

Andree HARTANTO
Singapore Management University, andreeh@smu.edu.sg

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Efficacy of Digital Mental Health Interventions for PTSD Symptoms:

A Systematic Review of Meta-Analyses

Germaine Y.Q. Tng[1], Jerica Koh[1], Xun Ci Soh[1], Nadyanna M. Majeed[1,2], Andree Hartanto[1]

[1]Singapore Management University

[2]National University of Singapore

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Address correspondence to:

Germaine Y.Q. Tng.
School of Social Sciences
Singapore Management University
10 Canning Rise
Singapore 179873
Email: germainetng.2020@phdps.smu.edu.sg (G.Y.Q.T.)

Abstract

Background: The present systematic review aimed to synthesize the results of meta-analyses which examine the effects of digital mental health interventions (DMHIs) on post-traumatic stress disorder (PTSD) symptoms, and investigate whether intervention characteristics (i.e., technique, timeframe, and therapeutic guidance) and methodological characteristics including outcome measures and sample inclusion criteria (age, gender, socioeconomic status, country, comorbidity) moderate the efficacy of digital interventions.

Methods: A systematic search of various sources (ECSCOhost PsycInfo, PubMed, Web of Science, Scopus, EBSCOhost ERIC, Google Scholar, ProQuest Dissertations & Theses) including five peer-reviewed journals was conducted to identify relevant meta-analyses up to December 2023, and 11 meta-analyses were included in the final review.

Results: Overall, our review elucidates that DMHIs are appropriate for alleviating PTSD symptoms in adults, with more consistent evidence supporting the efficacy of cognitive behavioral therapy (CBT)-based, compared to non-CBT-based, interventions when compared to control conditions. However, we found inconclusive evidence that the efficacy of DMHIs varied according to intervention timeframe, therapeutic guidance, or sample characteristics.

Limitations: A relatively limited number of different populations was sampled across meta-analyses. Further, while our review focused on PTSD symptoms to indicate the efficacy of digital interventions, other indices of effectiveness were not examined.

Conclusion: Our findings indicate the clinical utility of DMHIs for managing PTSD symptoms particularly when CBT-based intervention techniques are employed.

Keywords: posttraumatic stress disorder; digital mental health interventions; meta-analysis

1. Introduction

Posttraumatic stress disorder (PTSD) involves acute distress associated with a traumatic event, and is primarily characterized by (1) involuntary, intrusive re-experiencing (e.g., memories, dreams, flashbacks) of the traumatic event, (2) persistent avoidance of associated stimuli, (3) negative alterations in associated cognitions and affect, and (4) marked alterations in associated arousal and reactivity; wherein a traumatic event constitutes direct or indirect exposure to actual or threatened death, serious injury, or sexual violence (APA, 2013). Considering that lifetime prevalence rates of traumatic event exposure range from 54% to 73.8% globally (World Mental Health Surveys; Atwoli et al., 2015), PTSD is arguably a common psychiatric disorder cross-nationally (Gillihan et al., 2014). Further, PTSD symptoms bear adverse implications for the development of physical health conditions (Keyes et al., 2013; Pacella et al., 2013), comorbid mood disorders (Spinhoven et al., 2014), as well as risk of suicidal behaviors (Nepon et al., 2010; Wilcox et al., 2009). In view of the severe repercussions associated with PTSD, further research is warranted to understand the efficacy of relevant intervention efforts. While the importance of evidence-informed interventions for PTSD (e.g., trauma-focused cognitive behavior therapy) has gained increasing recognition (Sareen et al., 2011; Sareen, 2014; Watts et al., 2013), recent systematic and literature reviews have identified several barriers that hinder their implementation. These include temporal and financial constraints, trauma-specific barriers such as avoidance related to trauma disclosure, and concerns related to stigmatization and adverse social consequences (Finch et al., 2020; Kantor et al., 2017; Kazlauskas, 2017; Trusz et al., 2011).

In light of these barriers, emerging research has identified the potentials of digital mental health interventions in circumventing constraints associated with traditional treatment (Bakker et al., 2016; Chandrashekar, 2018). These refer to psychological interventions—

delivered via mobile applications or web-based platforms—that incorporate therapeutic techniques including, inter alia, psychoeducation, coping skills training, trauma-focused or non-trauma-focused cognitive restructuring, expressive writing, and cognitive training. In particular, digital mental health interventions may either be self-managed or therapist-assisted, with the latter involving synchronous (e.g., immediate feedback via virtual meetings) or asynchronous (e.g., delayed feedback via an electronic messaging platform or online discussion forum) therapeutic support to intervention users. Notably, these digital interventions can be administered independent of time and place (Struthers et al., 2015), are more cost-efficient than traditional treatment options (Binhadyan et al., 2016; Oyebode et al., 2020), and allow for discreet or even anonymous access to mental healthcare (Lal & Adair, 2014), hence critically addressing barriers of accessibility and stigmatization associated with traditional PTSD interventions (Koh et al., 2022). Moreover, digital interventions have the potential to complementarily augment therapeutic outcomes through functions such as psychoeducation (Sander et al., 2020), symptom monitoring (Hwang et al., 2021), and automatic reminder notifications which facilitate habit-tracking and goal attainment (Donker et al., 2013; Oyebode et al., 2020). Given burgeoning support for the advantages of digital mental healthcare, it is crucial that we gain deeper insight into the efficacy of digital mental health interventions for the treatment of PTSD symptoms.

While a handful of meta-analytic reviews demonstrate support for the efficacy of digital interventions for PTSD symptoms (e.g., Simblett et al., 2017; Wang et al., 2018), others present inconclusive results (e.g., Goreis et al., 2020; Kuester et al., 2016; Sander et al., 2020; Weisel et al., 2019). For example, Simblett et al.'s (2017) meta-analysis of randomized controlled trials (N = 3832, K = 38) found significant reductions in PTSD symptoms in active web-based intervention conditions (i.e., interventions with varying levels of therapeutic guidance) compared to waitlist or active controls, in a sample of adults who had experienced

at least a single traumatic event. In contrast, in Goreis et al.'s (2020) meta-analytic review of the effects of self-managed smartphone-based apps on PTSD symptoms in adults with varying PTSD symptom severity, they demonstrated a moderate reduction in PTSD symptoms across pre-post comparison studies (209 unique participants across 4 studies), but inconclusive results based on randomized controlled studies (169 unique participants across 2 studies).

These inconsistent findings may be attributed to heterogeneity in features of specific interventions examined (e.g., provision of therapeutic guidance), outcome measures used, and inclusion criteria used across meta-analyses. More specifically, meta-analytic reviews of digital PTSD interventions vary in two key aspects. First, characteristics of digital mental health interventions examined vary across meta-analyses in terms of therapeutic techniques applied (e.g., CBT-based versus non-CBT-based interventions; Lewis et al., 2019, Sijbrandij et al., 2016, Simon et al., 2021), intervention timeframes across included studies (i.e., ranging from 4 to 24 weeks; Lewis et al., 2019; Steubl et al., 2021), and the provision of therapeutic guidance in interventions (Kuester et al., 2016; Wang et al., 2018).

Given the heterogenous characteristics of examined interventions across meta-analyses, we sought to examine how each characteristic moderates the efficacy of digital interventions in alleviating severity of PTSD symptoms. Notably, the provision of therapeutic guidance in digital interventions, which refers to electronically-delivered human guidance related to therapeutic content, has been found to promote stronger adherence to interventions and enhance treatment outcomes (Baumeister et al., 2014; Moshe et al., 2021; Richards & Richardson, 2012). Further, some meta-analytic evidence suggests that internet-based interventions with a greater number of sessions are associated with lower attrition rates and stronger effects on symptoms of stress and pathological grief (Spijkerman et al., 2016; Wagner et al., 2020); though it remains unclear whether the timeframe of digital interventions

for PTSD moderate their effectiveness (Sijbrandij et al., 2016; Lewis et al., 2017). Moreover, though digital interventions vary in their therapeutic approach—including cognitive behavior therapy, expressive writing, and cognitive training—existing meta-analyses are equivocal as to whether therapeutic techniques moderate their effects on PTSD symptoms (e.g., Barak et al., 2008; Kuester et al., 2016; Steubl et al., 2021). Given that therapeutic technique, intervention timeframe, and provision of guidance are key modifiable characteristics of digital mental health interventions, it is thus important that we examine their role in the efficacy of interventions aimed at reducing PTSD symptom severity.

Second, with regard to heterogenous methodological characteristics, meta-analyses employ different outcome measures to assess treatment efficacy (e.g., self-reported questionnaires vs. clinician-administered interviews; Lewis et al., 2019; Simblett et al., 2017; Simon et al., 2021; Zhou et al., 2021) and varying inclusion criteria related to sample characteristics (e.g., age, gender, SES). For instance, Steubl et al. (2021) focused on adults with PTSD or subthreshold PTSD assessed by a validated clinician-administered or self-rated measure of PTSD symptoms, whereas Simblett et al. (2017) examined adults who had experienced a possible single-event trauma and did not impose restrictions in terms of pre-intervention severity of PTSD symptoms.

Hence, it is vital that we examine how various user characteristics shape the effects of specific digital interventions for PTSD.

1.1 Present study

In this systematic review, we sought to provide a synthesis of meta-analyses published up till 27 December 2023 which investigate the effects of digital mental health interventions on PTSD symptoms. Further, we sought to explore the moderating effects of specific intervention characteristics (i.e., intervention technique, intervention timeframe, and therapeutic guidance) and methodological characteristics including intervention outcome

measures assessed and sample inclusion criteria used (i.e., age, gender, SES, country, symptom severity, and trauma characteristics). In so doing, we seek to synthesize a comprehensive scope of published evidence to discern the clinical outcomes of digital mental health interventions for PTSD symptoms across various populations and therapeutic approaches. Furthermore, we aim to advance understanding into a) whether and how modifiable features of digital interventions (e.g., intervention timeframe or provision of therapeutic guidance) shape the efficacy of DMHIs, and b) how users from varying populations (e.g., those from clinical vs. nonclinical populations) can be matched with compatible interventions that optimize their treatment outcomes (Cuijpers et al., 2013; Donker et al., 2013). These insights serve to inform existing or novel digital mental health interventions for PTSD symptoms to improve their clinical outcomes.

2. Method

2.1 Search Strategy

Systematic searches were conducted from various sources for meta-analyses available by three authors (GYQT, JK, and XCS). An initial search was conducted on 27th May 2022, and updated on 27th December 2023. Using predefined search terms developed by and agreed upon by all authors, we collected records from a total of five databases, five journals, and two sources of unpublished literature.

The following keywords were used for searches in EBSCOhost PsycInfo, PubMed, Web of Science, Scopus, and EBSCOhost ERIC: *("mental health app*" OR "e%mental health" OR "self%management intervention*" OR "internet%based intervention*" OR "mobile%based intervention*" OR "app%based intervention*" OR "application%based intervention*" OR "smartphone%based app*" OR "smartphone%based intervention*" OR "web%based intervention*" OR "internet%delivered cognitive behavioural therapy" OR*

"internet intervention" OR "online therapy" OR "digital health" OR "mHealth") AND ("PTSD" OR "trauma*" OR "post%traumatic" OR "posttraumatic" OR "stress") AND ("meta%analysis" OR "meta%analytic review" OR "quantitative synthesis").*

Next, manual screening was conducted in five peer-reviewed academic journals in the field of traumatic stress for titles which included "PTSD" and "meta-analysis". Specifically, we screened the five most recent issues of the following journals: *European Journal of Psychotraumatology; Journal of Medical Internet Research; Journal of Traumatic Stress; Trauma, Violence & Abuse;* and *Psychological Trauma: Theory, Research, Practice, And Policy*. To capture unpublished literature, we additionally screened *Google Scholar* and *ProQuest Dissertations & Theses* using the following keywords: *("mental health apps*" *AND PTSD AND meta-analysis)*, and retrieved the first 200 records from each database.

2.2 Selection Criteria

After performing the systematic searches, two authors (JK and XCS) independently excluded duplicates, and reviewed titles and abstracts of the remaining records according to the following inclusion criteria:

1. Records were included if they were published in English.
2. Records were included if they were meta-analyses of primary studies retrieved from a systematic search procedure (i.e., quantitative systematic reviews).
3. Meta-analyses were included if they focused on the effectiveness of digital mental health interventions (i.e., mental health interventions delivered via mobile- and/or computer-based platforms).

Meta-analyses were included regardless of sample demographics. Hence, their primary studies could include participants sampled from populations of any age group, gender, and ethnicity. In addition, meta-analyses were included regardless of location. That is, their primary studies could examine e-mental health interventions globally, in a particular

country, or in a particular region. Meta-analyses were also included regardless of their peer review status. That is, both peer-reviewed and non-peer-reviewed meta-analyses were included.

We achieved an agreement rate of 92% between the two authors for our review of titles and abstracts; agreement rates were 100% and 82% for criteria 2 and 3, respectively. Disagreements were resolved through discussion with the first author (GYQT) based on all three inclusion criteria. Upon consensus to exclude records, full-text copies of the remaining records were independently reviewed by JK and XCS to decide on eligibility with reference to these additional inclusion criteria:

4. Meta-analyses were included if their constituent primary studies focused on the effectiveness of digital mental health interventions (i.e., mental health interventions delivered via mobile- and/or computer-based platforms).
5. Meta-analyses were included if their primary studies assessed PTSD symptoms (i.e., self-reported or clinically diagnosed symptoms) using validated self-report or clinician-administered measures including but not limited to the PTSD Checklist (PCL), Impact Event Scale (IES), Posttraumatic Diagnostic Scale (PDS), and the Clinician-Administered PTSD Scale (CAPS) (Foa et al., 1997; Horowitz et al., 1979; Weathers et al., 2018; Weiss & Marmar, 1997).

In our review of full-text records, the two authors observed an agreement rate of 97%; agreement rates were 97% and 100% for criteria 4 and 5, respectively. Where consensus was not reached, discrepancies were resolved via discussion with the first author (GYQT) based on the two additional inclusion criteria.

2.3 Data Extraction

Two authors (JK and XCS) independently extracted quantitative and qualitative data from the included studies. The items extracted were: author(s), publication year and

publication status, magnitude and type of effect sizes, total unique sample sizes and number of primary studies examined, characteristics of digital interventions examined (i.e., intervention technique, intervention timeframe, and provision of therapeutic guidance, measures of intervention outcomes), and sample characteristics. The two authors achieved an overall agreement rate of 80% based on their independent coding, and discrepancies were resolved via discussion with the first author (GYQT). For records wherein the type of effect size indexed was not specified, this information was obtained via email requests to the corresponding authors, or, in the event of no response, by assuming default effect size of the respective statistical program used in each meta-analyses as stated in their Methods section. Effect sizes in the current review (Hedge's standardized g) were calculated such that negative values indicate that individuals who underwent an e-mental health intervention reported lower degrees of PTSD symptoms compared to a control or pre-intervention condition. Due to limited reporting of the between-study heterogeneity variance ($\hat{\tau}^2$) and standard error of the pooled effect ($SE_{\hat{\mu}}$) in included meta-analyses, we were unable to compute the prediction intervals for the effects of digital mental health interventions on PTSD symptoms.

2.4 Quality Assessment

Methodological quality assessment of the included meta-analyses was conducted according to the JBI critical appraisal tool for systematic reviews (JBI, 2017). Using this tool, 11 items were each rated as "yes", "no", "unclear", or "not applicable". The items in question provided methodological evaluations of each record's (1) clarity of review questions, (2) inclusion criteria, (3) search strategy, (4) sources and resources to search for studies, (5) criteria for appraising studies, (6) independent critical appraisal of studies, (7) methods to minimize errors in data extraction, (8) data synthesis, (9) assessment of publication biases, (10) recommendations for how findings may be applied to policy and/or practice, and (11) specific directives for further research. Two authors (GYQT and JK) evaluated each meta-

analysis independently, achieving an agreement rate of 88%, and resolved any discrepancies through discussion until a consensus was reached.

2.5 Data Synthesis

We narratively synthesized the findings of the final included meta-analyses by examining overall efficacy of digital mental health interventions, as well as how efficacy varied by: (a) types of intervention (i.e., therapeutic technique, intervention timeframe, provision of therapeutic guidance), (b) outcome measures (i.e., assessments of PTSD symptoms), and (c) sample characteristics (i.e., age, gender, SES, country, clinical versus non-clinical sample).

2.6 Transparency and Openness

The current work adhered to the Preferred Reporting Items for Systematic reviews and Meta-analyses (PRISMA) statement (Page et al., 2021). Relevant materials for our review, including details (i.e., publication details, title, abstract, inclusion decision) of the 342 titles and abstracts and 43 full-text records reviewed, have been made publicly available on ResearchBox (https://researchbox.org/742). The present review was not pre-registered.

3. Results

3.1 Selection of Meta-Analyses

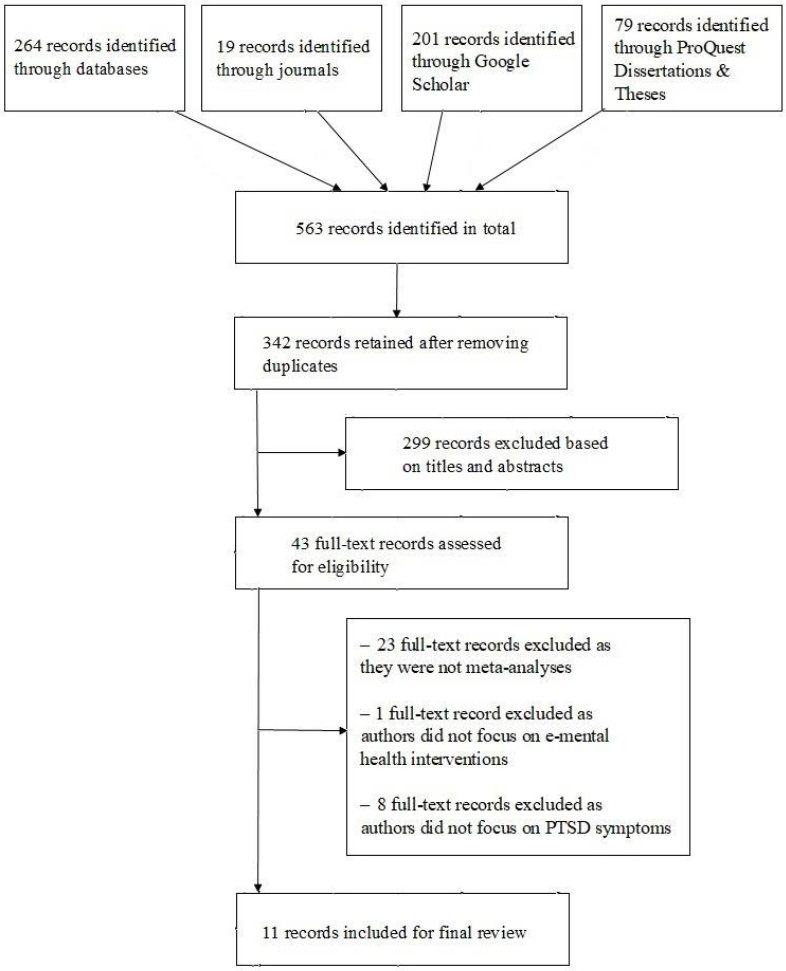

Figure 1. PRISMA diagram of records selected for inclusion in the review

Our initial search returned 563 records (Figure 1), where 221 duplicates were identified and removed. Thereafter, the titles and abstracts of the remaining 342 records were reviewed to determine initial eligibility based on our aforementioned inclusion criteria, and an additional 299 records were removed. The remaining 43 records were reviewed in full, and a total of 32 articles were removed as they were not meta-analyses (N = 23), did not examine digital mental health interventions (N = 1), or did not assess PTSD symptoms (N = 8). As a result, a total of 11 articles were included in the final review.

3.2 Quality Assessment

The score (i.e., number of "yes" ratings out of 11) of the included meta-analytic reviews ranged from 4 to 10 (*Mdn* = 9); four reviews reported a score of 10, three reviews reported a score of 9, and the remaining four reviews reported scores of 4–8 (see Table 1 for detailed quality assessment results). Our quality assessment identified that items four ("*Were the sources and resources used to search for studies adequate?*"; five out of eight 'yes' ratings) and seven ("*Were there methods used to minimize errors in data extraction?*"; five out of eight 'yes' ratings) had the lowest number of "yes" ratings (see Figure 2 for quality assessment chart). This highlighted two common facets for methodological improvements of meta-analyses in this area: (1) capturing grey literature when searching for primary studies; and (2) minimizing errors in the data extraction process.

Table 1. Quality assessment results.

Meta-analysis	(1) Review question	(2) Inclusion criteria	(3) Search strategy	(4) Sources	(5) Appraisal criteria	(6) Independent appraisal	(7) Data extraction	(8) Synthesis	(9) Publication bias	(10) Recommen-dations	(11) Research directives	Overall score
Bröcker et al. (2023)	Y	Y	Y	N	Y	Y	Y	Y	N	N	Y	8
Goreis et al. (2020)	Y	Y	Y	Y	Y	Y	N	Y	Y	Y	Y	10
Jonsson et al. (2023)	Y	Y	Y	N	Y	Y	Y	Y	Y	Y	Y	10
Kuester et al. (2016)	Y	Y	Y	Y	N	N	N	Y	Y	N	Y	7
Lewis et al. (2019)	Y	Y	Y	Y	Y	Y	N	Y	N	Y	Y	9
Paiva et al. (2023)	Y	Y	Y	Y	Y	Y	Y	Y	N	Y	Y	10
Sijbrandij et al. (2016)	?	?	Y	N	Y	Y	N	Y	Y	Y	Y	7

Simblett et al. (2017)	?	Y	Y	N	Y	N	N	N	N	?	Y	4
Simon et al. (2021)	Y	Y	Y	Y	Y	Y	Y	Y	Y	?	Y	10
Steubl et al. (2021)	Y	Y	Y	N	Y	Y	N	Y	Y	Y	Y	9
Zhou et al. (2021)	Y	Y	Y	N	Y	Y	Y	Y	N	Y	Y	9

Note. Y = Yes; N = No; ? = Unclear.
Item 1 = *Is the review question clearly and explicitly stated?*; Item 2 = *Were the inclusion criteria appropriate for the review question?;* Item 3 = *Was the search strategy appropriate?;* Item 4 = *Were the sources and resources used to search for studies adequate?;* Item 5 = *Were the criteria for appraising studies appropriate?;* Item 6 = *Was critical appraisal conducted by two or more reviewers independently?;* Item 7 = *Were there methods used to minimize errors in data extraction?;* Item 8 = *Were the methods used to combine studies appropriate?;* Item 9 = *Was the likelihood of publication bias assessed?;* Item 10 = *Were recommendations for policy and/or practice supported by the reported data?;* Item 11 = *Were the specific directives for new research appropriate?; Overall score refers to the total number of "yes" ratings for each record.*

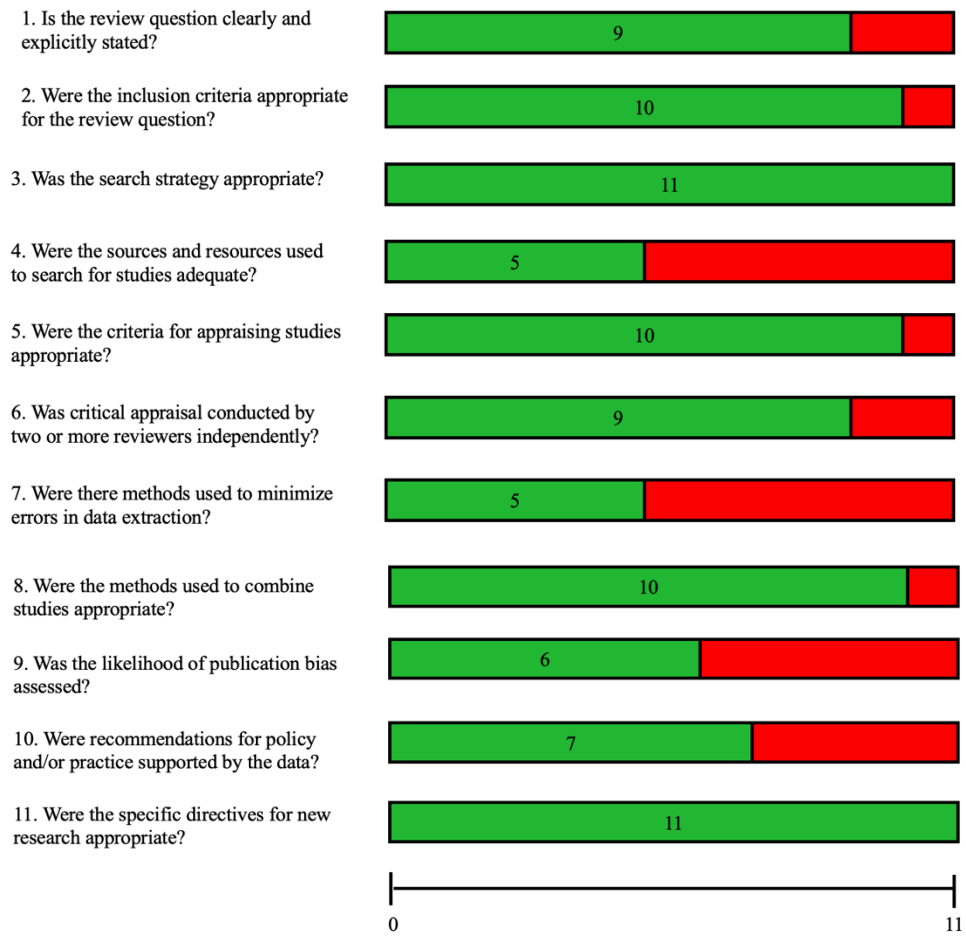

Figure 2. Quality assessment chart.

3.3. Overall effect sizes

The number of primary studies included in each meta-analysis ranged from 2 to 38 (*Mdn* = 8). Across the included meta-analyses, the total sample size ranged from 209 to 5421 (*Mdn* = 608). Figure 3 and Table 2 summarize the effects of digital mental health interventions on PTSD symptoms reported within each included meta-analysis. Nine of the included meta-analyses reviewed the effectiveness of internet-delivered interventions including interventions based on CBT techniques, expressive writing, psychoeducation, and cognitive training (Jonsson et al., 2023; Kuester et al., 2016; Lewis et al., 2019; Paiva et al., 2023; Sijbrandij et al., 2016; Simblett et al., 2017; Simon et al., 2021; Steubl et al. 2021; Zhou et al, 2021). Two meta-analyses reviewed mobile applications including PTSD Coach, LifeArmor,

PE Coach, Eventful, Positive Activity Jackpot, Tactical Breather, Daily Yoga, and Simple Yoga (Bröcker et al., 2023; Goreis et al., 2020).

Across the 11 records, 10 meta-analyses reported that groups which underwent digital mental health (i.e., internet-delivered and smartphone-based) interventions reported significantly less severe PTSD symptoms compared to active control, inactive control, or pre-intervention groups; with overall effect sizes ranging from g = -1.18 to g = -0.20. As an exception, Jonsson et al.'s (2023) meta-analysis of two primary studies found that internet-delivered CBT interventions showed nonsignificant effects in reducing PTSD symptoms compared to treatment-as-usual conditions.

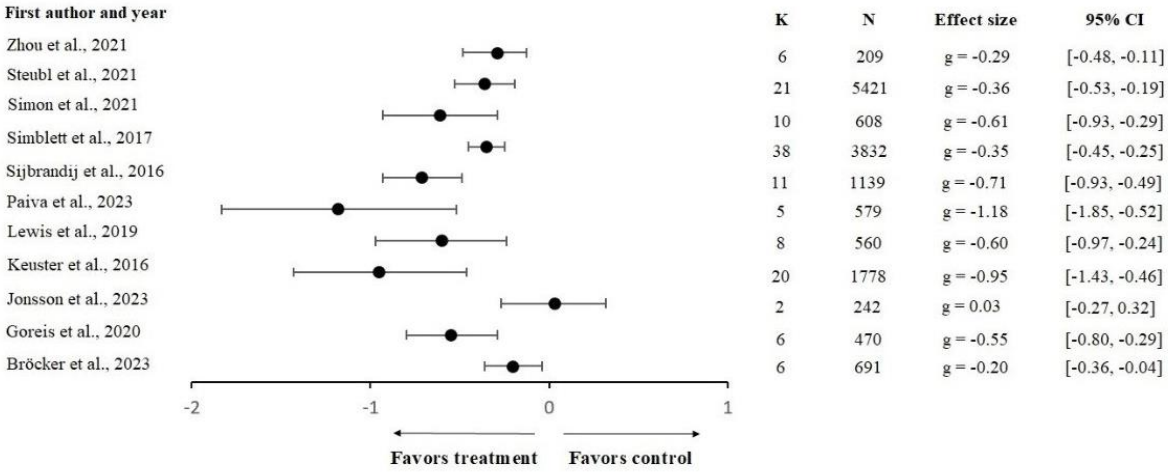

Figure 3. Effect sizes and confidence intervals reported within all included meta-analyses. *Note. K* = number of studies, *N* = total unique sample size. For studies where type of effect size was not specified, and authors had not responded to our email inquiry, we assumed default effect size of statistical program used.

Table 2. Overall effect sizes

Meta-analysis	Intervention condition *(Ncomp)*	Comparator	Effect size	95% CI	[a]Q *(df)*	[b]I^2
Bröcker et al. (2023)	Web- and mobile-based interventions (*N* = 6)	Inactive controls	**g = -0.20**	**[-0.36, -0.04]**	8.36 (df = 5) *p* = .140	40
Goreis et al. (2020)	App-based interventions (*N* = 6)	Pre-intervention and inactive controls	**g = -0.55**	**[-0.80, -0.29]**	6.38 (df = 5), *p* = .271	31.47
Jonsson et al. (2023)	Internet-delivered CBT-based interventions (*N* = 2)	Active controls	g = 0.03	[-0.27, 0.32]	-	-
Kuester et al. (2016)	Internet-delivered CBT-based interventions (*N* = 8)	Inactive controls	**g = -0.95**	**[-1.43, -0.46]**	80.07, *p* < .001	91.26
Lewis et al. (2019)	Internet-delivered CBT interventions (*N* = 8)	Inactive controls	**g = -0.60**	**[-0.97, -0.24]**	-	76
Paiva et al. (2023)	Internet-delivered CBT-based interventions (*N* = 5)	Inactive controls	**g = -1.18**	**[-1.85, -0.52]**	-	89.8
Sijbrandij et al. (2016)	Internet-delivered CBT-based interventions (*N* = 11)	Inactive controls	**g = -0.71**	**[-0.93, -0.49]**	-	64.52
Simblett et al. (2017)	Internet-delivered interventions (*N* = 38)	Active and inactive controls	**g = -0.35**	**[-0.45, -0.25]**	-	81

Simon et al. (2021)	Internet-delivered CBT-based interventions (*N* = 11)	Inactive controls	**g = -0.61**	**[-0.93, -0.29]**	-	69
Steubl et al. (2021)	Internet-delivered interventions (*N* = 21)	Active controls	**g = -0.36**	**[-0.53, -0.19]**	-	82
Zhou et al. (2021)	Internet-delivered interventions (*N* = 6)	Active and inactive controls	**g = -0.29**	**[-0.48, -0.11]**	-	0

Note. N_{comp} = number of comparisons made between intervention and comparison conditions; CIs = confidence intervals; CBT = cognitive behavioral therapy. Significant effect sizes are bolded.

[a]Q-statistic represents significance of heterogeneity across primary studies.

[b]I^2-statistic estimates the proportion of the observed variance across primary studies that reflects true differences in effect sizes. Values of 25%, 50%, and 75% may be interpreted as low, moderate, and high levels of heterogeneity, respectively.

3.4 Moderators of the effect sizes

Results across meta-analyses were synthesized according to intervention characteristics (i.e., intervention technique, intervention timeframe, therapeutic guidance) and methodological characteristics (i.e., outcome measure, sample characteristics). See Table 7 for detailed characteristics of each included meta-analysis.

3.4.1 Intervention technique

Seven of the 11 included meta-analyses examined whether the effectiveness of internet-delivered interventions varied according to therapeutic technique, by distinguishing studies of CBT-based interventions from studies of non-CBT-based interventions (e.g., expressive writing, cognitive training). See Table 3 for detailed results of relevant meta-analyses according to intervention techniques.

Subgroup analyses suggested more consistently significant effects of CBT-based, as opposed to non-CBT-based, internet-delivered interventions in alleviating PTSD symptoms when compared to inactive control conditions (i.e., waitlist, minimal attention conditions). Four of the included meta-analyses found that CBT-based internet-delivered interventions consistently reduced PTSD symptoms (with effect sizes ranging from g = -95 to -0.60) compared to inactive control conditions (Kuester et al., 2016; Lewis et al., 2019; Simon et al., 2021**;** Sijbrandij et al., 2016). Furthermore, four meta-analyses additionally showed that interventions based on non-CBT-based therapeutic techniques, including expressive writing, cognitive training, and psychoeducation, reported nonsignificant effects on PTSD symptoms compared to either active or inactive controls (Kuester et al., 2016; Simblett et al., 2017; Steubl et al., 2021; Zhou et al., 2021). For instance, Zhou et al.'s (2021) subgroup analyses indicated that internet-based interventions based on CBT with peer support significantly reduced PTSD symptoms compared to controls (g = -0.36, 95% CI [-0.61, -0.11]), while interventions based on psychoeducation (g = -0.35, 95% CI [-0.82, 0.12]) and trauma-focused

psychotherapy (g = -0.12, 95% CI [-0.47, 0.24]) did not result in significant changes in PTSD symptoms. Similarly, Steubl et al. (2021) conducted subgroup analyses according to therapeutic approach (i.e., therapeutic writing, neurocognitive training, CBT), and found that digital CBT interventions (g = -0.54, 95% CI [-0.98, -0.10])—rather than writing (g = -0.26, 95% CI [-0.61, 0.08]) or training (g = -0.32, 95% CI [-0.67, 0.03]) interventions—resulted in significant reductions in PTSD symptoms compared to active controls.

Nonetheless, there was limited and inconclusive evidence that CBT-based interventions showed stronger effects on PTSD symptoms in studies which directly compared the effects of CBT-based and non-CBT based (e.g., Internet-delivered psychoeducation, Internet-delivered supportive counselling) interventions (Lewis et al., 2019; Sijbrandij et al., 2016; Simon et al., 2021; Zhou et al., 2021). Specifically, Lewis et al. (g = -0.08; CI [-0.52, 0.35]) and Simon et al. (g = -0.08, 95% CI [-0.52, 0.35]) found nonsignificant differences in the effects of CBT-based interventions and non-CBT-based interventions (e.g., interventions based on psychoeducation, psychotherapy, and stress management) on PTSD symptoms, and Zhou et al.'s subgroup analyses similarly showed nonsignificant differences in the effects of CBT-based and non-CBT-based interventions on PTSD symptoms (p = .530). Of note, Sijbrandij et al. (2016) found a marginally significant advantage (g = -0.28, 95% CI [.00, .56], p = .050) of iCBT interventions to other interventions (i.e., Internet-delivered psychoeducation, Internet-delivered supportive counselling, and iCBT without exposure) in reducing PTSD symptoms, although no subgroup analyses were conducted due to insufficient data per subgroup. Taken together, these results suggest that CBT-based rather than non-CBT-based internet-delivered interventions may observe more consistent effects on PTSD symptoms when compared to control conditions, though the differential effects of CBT-based and non-CBT-based interventions are weakened when directly compared with each other.

Table 3. Intervention technique

Meta-analysis	Subgroup *(Ncomp)*	Comparator	Effect size	95% CI	[a]*Q* (df)	[b]I^2	[c]*p*
Kuester et al. (2016)	CBT-based intervention (*N* = 8)	Inactive controls	**g = -0.95**	**[-1.43, -0.46]**	80.07, $p < .001$	91.26	Not provided
	Expressive writing intervention (*N*=1)	Inactive controls	g = -0.43	[-0.90, 0.03]	-	-	
	CBT-based intervention (*N*=3)	Active controls	g = -0.09	[-0.36, 0.19]	0.30, $p = .862$	0	.491
	Expressive writing intervention (*N*=2)	Active controls	g = -0.24	[-0.59, 0.11]	0.64, $p = .420$	0	
Lewis et al. (2019)	CBT-based intervention (*N*=8)	Wait-list/usual care/minimal attention	**g = -0.60**	**[-0.97, -0.24]**	-	76	NA
	CBT-based intervention (*N*=5)	i-non-CBT interventions	g = -0.08	[-0.52, 0.35]	-	-	NA
Simblett et al. (2017)	Trauma-focused CBT (*N*=11)	Active and inactive controls	**g = 0.34**	**[-0.48, -0.21]**	-	92	Not provided

	Non-TF-CBT (*N*=18)	Active and inactive controls	**g = -0.36**	**[-0.50, -0.22]**	-	62	
	Expressive writing intervention (*N*=5)	Active and inactive controls	g = -0.04	[-0.88, 0.79]	-	0	
Simon et al. (2021)	Internet-based CBT intervention (N=10)	Inactive waitlist controls	**g = -0.61**	**[-0.93, -0.29]**	-	69	Not provided
	Internet-based CBT intervention (N=2)	non-CBT internet-based intervention	g = -0.08	[-0.52, 0.35]	-	19	
Sijbrandij et al. (2016)	iCBT intervention (*N*=11)	Inactive controls (waitlist and TAU)	**g = -0.71**	**[-0.93, -0.49]**	-	64.52	Not provided
	iCBT intervention (*N*=3)	non-CBT internet-based intervention	**g = -0.28**	**[-0.56, -0.00]**	-	-	
Steubl et al. (2021)	CBT-based digital intervention (*N*=6)	Active control	**g = -0.54**	**[-0.98, -0.10]**	60.62, (df = 5) $p < .001$	92	Not provided
	Digital intervention based on therapeutic writing	Active control	g = -0.26	[-0.61, 0.08]	15.11, (df = 4) $p = .004$	74	

	(*N*=5)						
	Digital intervention based on cognitive training (*N*=5)	Active control	g = -0.32	[-0.67, 0.03]	9.02, (df = 4) *p* = .060	56	
Zhou et al. (2021)	Psychoeducation-based intervention (*N*=2)	Active and inactive controls	g = -0.35	[-0.82, 0.12]	-	0	
	Psychotherapy-based intervention (*N*=2)	Active and inactive controls	**g = -0.12**	**[-0.47, -0.24]**	-	0	.530
	iCBT intervention with peer support (*N*=2)	Active and inactive controls	**g = -0.36**	**[-0.61, -0.11]**	-	0	
Goreis et al. (2020)	App-based (PTSD Coach/ psychoeducation) intervention (*N*=6)	Pre-intervention and inactive waitlist controls	**g = -0.55**	**[-0.80, -0.29]**	6.38, (df = 5) *p* = .271	31.47	

Note. N_{comp} = number of comparisons made between intervention and comparison conditions; CIs = confidence intervals. Significant effect sizes are bolded.

[a]Q-statistic represents significance of heterogeneity across primary studies.

[b]I^2-statistic estimates the proportion of the observed variance across primary studies that reflects true differences in effect sizes.

[c]*p*-values indicate the significance of effect size differences between subgroups.

3.4.2 Intervention timeframe

Nine of the 11 meta-analyses reported their intervention timeframes in terms of absolute duration, ranging from one to twenty-four weeks (Bröcker et al., 2023; Goreis et al., 2020; Jonsson et al., 2023; Kuester et al., 2016; Lewis et al., 2019; Paiva et al., 2023; Simblett et al., 2017; Simon et al., 2021; Steubl et al., 2021). Sijbrandij et al. (2016) reported the intervention timeframe of included randomized controlled trials (RCTs) in terms of number of sessions (6 to 10 sessions), while Zhou et al. (2021) did not report the intervention timeframes of included RCTs.

Notably, two meta-analyses conducted subgroup analyses examining whether the effects of internet-delivered interventions varied according to the number of intervention sessions administered (Kuester et al., 2016; Sijbrandij et al., 2016), and showed mixed results. On one hand, Sijbrandij et al. (2016) found that iCBT interventions with more than eight sessions had a significantly (p = .030) larger pooled effect on PTSD symptoms (g = -0.95, 95% CI [0.71, 1.19]), compared to those with eight or fewer sessions (g = -0.49, 95% CI [0.28, 0.71]). On the other hand, Kuester et al.'s (2016) subgroup analyses showed a nonsignificant difference (p = .098) in the pooled effect sizes of longer (i.e., at least ten sessions; g = -1.33, 95% CI [0.47, 2.19]) compared to shorter (i.e., less than ten sessions; g = -0.57, 95% CI [0.33, 0.82]) internet-based interventions. See Table 4 for detailed results of relevant meta-analyses according to intervention timeframe.

Table 4. Intervention timeframe

Meta-analysis	Subgroup *(Ncomp)*	Comparator	Effect size	95% CI	[a]*Q (df)*	[b]I^2	[c]*p*
Sijbrandij et al. (2016)	iCBT intervention with > 8 sessions (*N* = 5)	Inactive waitlist control	**g = -0.95**	**[-1.19, -0.71]**	4.83 (df = 4)	17.17	**.030**
	iCBT intervention with ≤ 8 sessions (*N*= 6)	Inactive waitlist control	**g = -0.49**	**[-0.71, -0.28]**	8.27 (df = 5)	39.51	
Kuester et al. (2016)	iCBT intervention with ≥10 sessions (*N* = 4)	Inactive waitlist control	**g = -1.33**	**[-2.19, -0.47]**	65.09, *p* < .001	95.39	.098
	iCBT intervention with <10 sessions (*N* = 4)	Inactive waitlist control	**g = -0.57**	**[-0.82, -0.33]**	3.31, *p* = .346	9.37	

Note. N_{comp} = number of comparisons made between intervention and comparison conditions; Cis = confidence intervals. Significant effect sizes are bolded.

[a]Q-statistic represents significance of heterogeneity across primary studies.

[b]I^2-statistic estimates the proportion of the observed variance across primary studies that reflects true differences in effect sizes.

[c]*p*-values indicate the significance of effect size differences between subgroups.

3.4.3 Therapeutic guidance

Seven included meta-analyses examined studies of digital mental health interventions which varied in their provision of therapeutic guidance (Kuester et al., 2016; Lewis et al., 2019; Sijbrandij et al., 2016; Simblett et al., 2017; Simon et al., 2021; Steubl et al., 2021; Zhou et al., 2021). See Table 5 for detailed results of relevant meta-analyses according to therapeutic guidance.

Subgroup analyses according to the provision of therapeutic guidance presented equivocal findings. Three meta-analyses found advantages of therapist-guided, over self-guided, iCBT interventions (Lewis et al., 2019; Sijbrandij et al., 2016; Simon et al., 2021). In particular, in subgroup analyses by Sijbrandij et al. (2016) and Simon et al. (2021), significantly larger pooled effect sizes were found for therapist-guided, compared to self-guided, internet-based cognitive and behavioural therapy interventions, in comparison to wait-list conditions (p = .002, .006). In contrast, two meta-analyses suggested that internet/mobile-based interventions were similarly effective regardless of whether therapeutic guidance was provided (Kuester et al., 2016; Simblett et al., 2017). In particular, Kuester et al. (2016) found no significant differences between the effect sizes for internet-based interventions with or without therapeutic support (p = .584). Simblett et al. (2017) similarly found that subgroups with individual tailored feedback (g = -0.52, 95% CI [-0.76, -0.28]), individual technical support (g = -0.27, 95% CI [-0.40, -0.14]), and no guidance (g = -0.50, 95% CI [-0.76, -0.24]) all showed significant small-to-medium effects in favour of the active intervention condition; though differences in effect sizes between subgroups were not statistically tested.

Table 5. Therapeutic guidance

Meta-analysis	Subgroup *(Ncomp)*	Comparator	Effect size	95% CI	[a]*Q (df)*	[b]I^2	[c]*p*
Sijbrandij et al. (2016)	iCBT intervention with therapeutic guidance (*N* = 7)	Waitlist and treatment-as-usual controls	**g = -0.89**	**[-1.08, -0.70]**	7.18 (df = 6)	16.45	**.006**
	Self-guided iCBT intervention (*N* = 4)	Waitlist and treatment-as-usual controls	**g = -0.50**	**[-0.78, -0.22]**	5.18 (df = 3)	42.13	
Simon et al. (2021)	iCBT intervention with therapeutic guidance (*N*=8)	Inactive waitlist control	**g = -0.78**	**[-1.09, -0.47]**	-	52	**.002**
	Self-guided PTSD Coach intervention (*N*=2)	Inactive waitlist control	g = -0.09	[-0.39, 0.22]	-	0	

Lewis et al. (2019)	iCBT intervention with therapeutic guidance (*N* = 6)	Waitlist / treatment-as-usual–minimal attention controls	**g = -0.86**	**[-1.25, -0.47]**	-	-	Not provided
	Self-guided iCBT interventions (*N* = 2)	Waitlist / treatment-as-usual–minimal attention controls	-	-	-	-	
Kuester et al. (2016)	iCBT intervention with therapeutic guidance (*N* = 4)	Inactive waitlist control	**g = -0.80**	**[-0.98, -0.62]**	0.54, *p* = .909	0	.584
	Self-guided iCBT intervention (*N* = 4)	Inactive waitlist control	g = -1.12	[-2.27, 0.02]	76.53 *p* < .001	96.08	
Simblett et al. (2017)	Internet-based intervention with individual tailored feedback (*N* = 16)	Active and inactive controls	**g = -0.52**	**[-0.76, -0.28]**	-	90	Not provided

Internet-based interventions with individual technical feedback (*N*=2)	Active and inactive controls	**g = -0.27**	**[-0.40, -0.14]**	-	0
Internet-based intervention with online discussion forum (*N*=6)	Active and inactive controls	g = -0.26	[-0.53, 0.01]	-	72
Internet-based intervention with automated feedback only (*N*=1)	Active and inactive controls	-	-	-	-
Internet-based intervention with live group feedback	Active and inactive controls	-	-	-	-

(*N*=1)					
Internet-based intervention without guidance (*N*=13)	Active and inactive controls	**g = -0.50**	**[-0.76, -0.24]**	-	13

Note. N_{comp} = number of comparisons made between intervention and comparison conditions; CIs = confidence intervals. Significant effect sizes are bolded.

[a]Q-statistic represents significance of heterogeneity across primary studies.

[b]I^2-statistic estimates the proportion of the observed variance across primary studies that reflects true differences in effect sizes.

[c]*p*-values indicate the significance of effect size differences between subgroups.

3.4.4. Outcome measures

Among the included meta-analyses, the most commonly used measure of PTSD-related symptoms was the DSM-IV based PTSD checklist (including the brief PCL-5, Military PCL-M, Specific PCL-S, and Civilian PCL-C versions) which was employed in all 11 meta-analyses (Bröcker et al., 2023; Goreis et al., 2020; Jonsson et al., 2023; Kuester et al., 2016; Lewis et al., 2019; Paiva et al., 2023; Sijbrandij et al., 2016; Simblett et al., 2017; Simon et al., 2021; Steubl et al., 2021; Zhou et al., 2021), and cited as the most common measure for three meta-analyses (Bröcker et al., 2023; Goreis et al., 2020; Steubl et al., 2021). Other commonly employed assessment tools included the Impact Event Scale (including the IES; Horowitz et al., 1979; IES-R; Weiss & Marmar, 1997, and IES-D Dutch versions), the Posttraumatic Diagnostic Scale (PDS; Foa et al., 1997), and the Clinician-Administered PTSD Scale (CAPS; Weathers et al., 2018)—which were each cited in six included meta-analyses. The aforementioned self-report (PCL, IES, PDS) and structured diagnostic interview measures (CAPS) of PTSD symptoms commonly assess PTSD symptoms based on the Diagnostic and Statistical Manual of Mental Disorders (DSM-5); and hence assess three key clusters of symptomatology: (1) intrusion, (2) avoidance, and (3) arousal and hyperreactivity (APA, 2013).

One meta-analysis (Zhou et al., 2021) conducted subgroup analyses according to outcome measures of PTSD, and found that internet-based interventions only showed significant effects on PTSD symptoms assessed via the PTSD Checklist (PCL; g = -0.38, 95% CI [-0.60, -0.15]) but not the Clinician-Administered PTSD Scale (CAPS; g = -0.11, 95% CI [-0.45, 0.22]); though the difference in effect sizes between the respective subgroups was nonsignificant (p = .200). See Table 6 for detailed results of relevant meta-analyses according to outcome measures used.

Table 6. Outcome measures

Meta-analysis	Subgroup *(Ncomp)*	Comparator	Effect size	95% CI	[a]Q	[b]I^2	[c]*p*
Zhou et al. (2021)	Studies of internet-based interventions using Clinician-administered PTSD Scale (CAPS) (*N*=3)	Active and inactive controls	g = -0.11	[-0.45, 0.22]	-	0	.200
	Studies of internet-based interventions using PTSD Checklist (PCL) (*N*=3)	Active and inactive controls	**g = -0.38**	**[-0.60, -0.15]**	-	0	

Note. N_{comp} = number of comparisons made between intervention and comparison conditions; CIs = confidence intervals. Significant effect sizes are bolded.

[a]Q-statistic represents significance of heterogeneity across primary studies.

[b]I^2-statistic estimates the proportion of the observed variance across primary studies that reflects true differences in effect sizes.

[c]*p*-values indicate the significance of effect size differences between subgroups.

Sample characteristics

We examined whether the effectiveness of digital mental health interventions for PTSD symptoms differed by sample characteristics including age, gender, socioeconomic status (SES), country, and whether participants are sampled from clinical (i.e., meeting diagnostic criteria for PTSD) or nonclinical (i.e., exhibiting varying levels of PTSD symptoms which do not fulfil diagnostic criteria for PTSD) populations.

3.4.5.1 Age

Seven of the included meta-analyses examined samples of adult participants aged 16 years and above, while the remaining four meta-analyses did not implement age restrictions (Bröcker et al., 2023; Jonsson et al., 2023; Paiva et al., 2023; Sijbrandij et al., 2016). Notably, Paiva et al. (2023) highlighted that internet-delivered CBT interventions demonstrate comparable effectiveness in reducing PTSD severity across civilian samples of varying ages, with the mean age of included samples ranging from 28.1 to 71.40. No subgroup analyses examined whether the effectiveness of digital interventions varied by age.[1]

3.4.5.2 Gender

Regarding gender, seven out of the 11 included meta-analyses (Bröcker et al., 2023; Goreis et al., 2020; Jonsson et al., 2023; Simblett et al., 2017; Simon et al., 2021; Steubl et al., 2021; Zhou et al., 2021) provided information on the gender makeup of their individual study samples. Gender ratio varied widely within individual studies of each meta-analysis, with Steubl et al. (2021) and Zhou et al. (2021) having the largest range of 0–100% females. Overall, three meta-analyses (Goreis et al., 2020; Jonsson et al., 2023; Zhou et al., 2021) included mostly male samples (g = -0.55 to 0.03), while the remaining four meta-analyses (Bröcker et al., 2023; Simblett et al., 2017; Simon et al., 2021; Steubl et al., 2021) included

[1] As all included meta-analyses studied samples of adults, this precluded examinations of how age moderates the efficacy of digital mental health interventions for PTSD symptoms

mostly female samples (g = -0.61 to -0.20). We did not observe differences in the overall effect sizes of meta-analyses that included mostly male versus female samples. Further, as no subgroup analyses were carried out according to participants' gender, we were thus unable to assess differing effectiveness of PTSD interventions based on gender.

3.4.5.3 Socioeconomic status

The socioeconomic status (SES) of participants was only presented for one out of the eight included meta-analyses; Simon et al. (2021) reported that the unemployment rate of included study samples ranged from 8.1% to 47.64% and attainment of university education ranged from 14.2% to 100%. Although formal statistical analyses were not conducted, the authors highlighted that an increased access to resources and higher levels of computer literacy associated with higher-SES individuals are possible factors which facilitate treatment effectiveness. Nonetheless, it remains unclear whether socioeconomic differences influenced the effectiveness of digital interventions for PTSD.

3.4.5.4 Country

All 11 included meta-analyses examined samples predominantly from Western countries, with Simblett et al. (2017) and Steubl et al. (2021) reporting the largest number of countries from which their samples were derived (i.e., nine countries each). In particular, Lewis et al. (2019) and Simon et al. (2021) pointed out that participants were mostly from American or European countries, and Bröcker et al. (2023) noted that all six primary studies were conducted in high-income countries including United States of America, Netherlands, and Sweden. This limits the generalizability of their findings to other parts of the world, a point we return to in the discussion section.

3.4.5.5 Sample inclusion criteria

The included meta-analyses varied in their inclusion of participants from clinical and nonclinical populations, whereby clinical populations meet the diagnostic criteria for PTSD

based on validated self-report or clinical administered measures, while nonclinical populations exhibit varying severity of PTSD symptoms but do not fulfil diagnostic criteria for PTSD. Six of the included meta-analyses (Bröcker et al., 2023; Goreis et al., 2020; Kuester et al., 2016; Sijbrandij et al., 2016; Simblett et al., 2017; Steubl et al., 2021) included participants with varying severity of PTSD symptoms, ranging from subclinical to clinical PTSD symptoms. Three meta-analyses (Jonsson et al., 2023; Paiva et al., 2023; Zhou et al. (2021) only included participants who met diagnostic criteria for PTSD, while two meta-analyses (Lewis et al., 2019; Simon et al., 2021) included studies whereby at least 70% of participants met diagnostic criteria for PTSD, assessed by a clinical interview or a validated questionnaire.

Furthermore, two of the meta-analyses (Goreis et al., 2020; Zhou et al., 2021) included studies that sampled veterans, military service members, and their relatives; while four other meta-analyses (Bröcker et al., 2023; Kuester et al., 2016; Paiva et al., 2023; Simblett et al., 2017) included diverse samples of university students, military service members and veterans, healthcare professionals, women diagnosed with breast cancer, victims of natural disasters, survivors of war trauma, and survivors of prenatal loss. The remaining five meta-analyses did not specify these sample characteristics, and included samples of adults from the wider community who met diagnostic criteria for PTSD or reported clinically elevated PTSD symptoms, regardless of the index trauma, severity and duration of symptoms, or length of time since trauma (Jonsson et al., 2023; Lewis et al., 2019; Sijbrandij et al., 2016; Simon et al., 2021; Steubl et al., 2021). Information on comorbidity was not provided by the included meta-analyses, with the exception of Zhou et al. (2021) whereby participants with comorbid psychopathology were included.

Table 7. Characteristics of included meta-analyses

Authors, year of publication	Intervention technique	Intervention timeframe	Therapeutic guidance	Outcome measures	Participant age	Gender[1]	Participant SES	Co-morbidity	Countries
Bröcker et al., 2023	Web-based and mobile application	3 days – 16 weeks	Present	Clinician administered /Self-report	Adults	63.23%	NIL	Did not mention	USA, Sweden, South Africa, Australia, Egypt
Goreis et al., 2020	Smartphone -based intervention	4 weeks – 4 months	Present	Self-report	Adults	3%–84%	NIL	Did not mention	USA, Sweden
Jonsson et al. (2023)	Internet-based CBT	5 weeks – 24 weeks	Present	Self-report	21 or older	7%-100%	NIL	Depression, anxiety	New Zealand, Sweden, Germany, Australia, Spain, USA, Finland, Canada, China, UK
Kuester et al., 2016	Mixed internet-delivered intervention	1 week – 12 weeks	Present	Self-report	Adults	NIL	NIL	Did not mention	USA, Germany, Netherlands, Australia, Switzerland, Great Britain,

									China, Middle East
Lewis et al., 2019	Internet-based CBT	4 weeks–14 weeks	Present	Clinician administered /self-report	16 or older	NIL	NIL	Did not mention	USA, Sweden, Iraq, UK
Paiva et al. (2023)	Internet-based CBT	5 weeks – 8 weeks	Present	Self-report	Adults (28.1 – 71.91 years old)	82%	NIL	Did not mention	Did not mention
Sijbrandij et al., 2016	Internet-based CBT	6 – 10 sessions	Present	Clinician administered / self-report	16 or older (exception of 6 studies with younger than 16 years old)	NIL	NIL	Did not mention	USA, Germany, Sweden, Netherlands, Australia, Europe, China
Simblett et al., 2017	Mixed internet-delivered intervention	10 days – 10 weeks	Present	Clinician administered / self-report	Adults	13.7%–100%	NIL	Did not mention	USA, Netherlands, Australia, Sweden, Germany, Switzerland, Canada, Poland, China
Simon et al., 2021	Internet-based CBT	3 weeks – 14 weeks	Present	Self-report	16 or older	14.3%–100%	Unemployment rate: 8.1%–	Did not mention	USA, Sweden,

							47.64%, Uni education: 14.2%–100%		Australia, UK, Iraq
Steubl et al., 2021	Mixed internet-delivered intervention	0.5 weeks – 24 weeks	Present	Clinician administered / self-report	18 or older	0%–100%	NIL	Did not mention	USA, Australia, Israel, Poland, Netherlands, Iran, Sweden, UK, China
Zhou et al., 2021	Mixed internet-delivered intervention	NIL	Present	Self-report	Adults	0%–100%	NIL	Depression, anxiety, substance use	USA, Germany

Note. SES = Socioeconomic status.
[1]Gender represents percentage of sample who identify as female

4. Discussion

Digital mental health interventions hold the potential to alleviate PTSD symptoms via internet or app-delivered treatment programs, hence circumventing barriers to traditional treatment associated with accessibility, efficiency, and stigmatization. However, prior research demonstrates equivocal support for the efficacy of digital PTSD interventions (e.g., Goreis et al., 2020; Kuester et al., 2016; Sander et al., 2020; Simblett et al., 2017; Wang et al., 2018; Weisel et al., 2019)—potentially owing to heterogeneity across existing meta-analytic reviews. Therefore, the present systematic review synthesized evidence from 11 meta-analyses published between 2016 and 2023, to investigate the efficacy of digital mental health interventions for PTSD symptoms, while accounting for variations in a) characteristics of examined interventions (i.e., technique, timeframe, therapeutic guidance) and b) methodology of meta-analyses including PTSD outcome measures and sample characteristics. Overall, our review indicates that digital mental health interventions across mediums (i.e., internet-delivered and app-based) consistently reduce subclinical to clinical-level PTSD symptoms in comparison with control conditions. Further, our results suggest that the effectiveness of these interventions may vary according to therapeutic technique (i.e., CBT versus other techniques); though it remains inconclusive whether intervention timeframe, therapeutic guidance, outcome measures, and sample characteristics moderate their efficacy. Major findings of the present review are discussed in turn.

First, our synthesis found that internet-delivered CBT-based, rather than non-CBT-based, interventions report more consistently significant reductions in PTSD symptoms compared to inactive (i.e., waitlist, minimal attention, or treatment as usual) control conditions (Kuester et al., 2016; Lewis et al., 2019; Simblett et al., 2017; Simon et al., 2021**;** Sijbrandij et al., 2016**;** Steubl et al., 2021; Zhou et al., 2021). This is consistent with recent reviews of empirical literature which have demonstrated that digital CBT-based interventions—rather than digital

interventions based on other therapeutic techniques (i.e., expressive writing, psychoeducation, mindfulness, cognitive tasks, and other psychosocial interventions—are more consistently effective in reducing PTSD symptoms relative to inactive (i.e., waitlist) controls (Andersson et al., 2019; Stefanopoulou et al., 2020). Hence, this lends support to the efficacy of internet-delivered interventions which incorporate general CBT approaches (i.e., adapting coping and stress management techniques) and trauma-focused CBT approaches (Bourdon et al., 2019; Lange et al., 2001) including a) self-confrontation (i.e., imagined or in vivo exposure to trauma-related stimuli), b) cognitive restructuring (i.e., detection and correction of dysfunctional beliefs associated with trauma-related stimuli), and c) social sharing/restoration (i.e., reflection on managing trauma-related stimuli in the future).

In addition, in line with Stefanopoulou et al. (2020), we found little to no support for the advantages of CBT-based interventions when compared to another active non-CBT-based intervention including internet-delivered psychoeducation, internet-delivered supportive counselling, internet-delivered CBT without exposure, and face-to-face (CBT-based or non-CBT-based) psychotherapy (Lewis et al., 2019, Sijbrandij et al., 2016, Simon et al., 2021). Given that non-CBT-based internet-delivered interventions commonly include components of CBT approaches, including psychoeducation and stress management or mindfulness techniques (Carpenter et al., 2014; Lewis et al., 2019; Stefanopoulou et al., 2020; Steinmetz et al., 2012; Wang et al., 2013), overlapping approaches used in both types of interventions may have resulted in more consistent effects on PTSD symptoms across CBT-based and non-CBT-based internet-delivered interventions. Nonetheless, given the substantial heterogeneity in types of CBT-based interventions for PTSD symptoms (i.e., trauma-focused versus general approaches), further research is needed to understand how specific components of CBT-based digital interventions facilitate the treatment of PTSD symptoms.

Second, only two of the included meta-analyses examined whether intervention timeframe (i.e., number of sessions) influenced the efficacy of digital mental health interventions for PTSD symptoms, showing conflicting evidence for whether the effects of digital mental health interventions on PTSD symptoms vary according to the number of sessions administered (Kuester et al., 2016; Sijbrandij et al., 2016). Prior studies indicate that CBT interventions implemented over ten sessions show significantly greater effects in reducing PTSD symptom severity in military personnel compared to a minimal contact control condition comprising four weekly therapist phone calls (e.g., Foa et al., 2018). Given the paucity of relevant empirical evidence on this dose-response relationship, however, further exploration is required to investigate the optimal number of digital mental health intervention sessions required to effectively reduce PTSD symptom severity (Sijbrandij et al., 2016).

Third, regarding the therapist-guided or self-guided nature of digital mental health interventions, the present review reported inconclusive evidence that the provision of therapeutic guidance moderates the effectiveness of digital interventions in reducing PTSD symptoms. Specifically, three meta-analytic reviews reported stronger effect sizes of therapist-guided, compared to self-guided, CBT-based internet-delivered interventions in alleviating PTSD symptoms (Lewis et al., 2019; Sijbrandij et al., 2016; Simon et al., 2021), whereas two meta-analyses (Kuester et al., 2016; Simblett et al., 2017) found that subgroups of internet-delivered interventions with and without therapeutic support showed comparable effects on PTSD symptoms. In line with previous reviews, availability of therapeutic support at one's convenience (e.g., via on-demand support) and individually-tailored, interactive support based on user input are suggested to strengthen therapeutic alliance and digital intervention outcomes (Hillier, 2018; Tong et al., 2023). We also note that the effectiveness of therapeutic guidance in digital mental health interventions may be complicated by

challenges such as difficulties in interpreting and attending to users' emotional needs in real-time through digital interactions, which may impair therapeutic alliance and hinder intervention outcomes (Koly et al., 2022). Considering that therapeutic guidance varied by several factors including its frequency, availability, and content (e.g., degree of personalization or interactivity), further research is warranted to understand how these fine-grained factors moderate the effectiveness of digital mental health interventions for PTSD.

Fourth, our review found scant and inconclusive evidence that the efficacy of digital mental health interventions for PTSD symptoms varied according to sample characteristics. Across the included meta-analyses, we found that participants were primarily sampled from Western populations. In view of Rodriguez-Villa et al.'s (2021) qualitative study of individuals from India and the United States which revealed country-specific concerns associated with the use of mental health applications (e.g., data security, legitimacy, and access to mental health applications), it is crucial that future research samples individuals from more culturally diverse populations to understand whether the efficacy of digital mental health interventions varies across cultural contexts. Furthermore, although there was a dearth of subgroup analyses according to other sample characteristics (e.g., age, gender, socioeconomic status), these potentially moderate the effectiveness of digital mental health interventions as well. In low- and middle-income countries, the implementation of digital mental health interventions is likely hindered by issues such as low access to digital technology, less reliable technological infrastructure, and poor digital literacy (Karyotaki et al., 2023; Koly et al., 2022; Rodriguez-Villa et al., 2020). For instance, internet connectivity issues can interrupt the implementation of digital mental healthcare by breaching the flow of instant messaging sessions or psychoeducation sessions, which may adversely affect users' experiences (Koly et al., 2022). Therefore, further research is warranted to investigate if the

efficacy of digital mental health interventions varies by demographic characteristics of users including age, cultural context, and socioeconomic status.

Fifth, across the reviewed meta-analyses, we identified a lack of longitudinal studies which investigated the long-term effects (i.e., 6 months or longer post-intervention) of digital mental health interventions on PTSD symptoms. Specifically, primary studies which included follow-up assessments of PTSD symptoms primarily tracked symptoms up to 6 months post-intervention (Kuester et al. 2016; Lewis et al., 2019; Zhou et al., 2021). As an exception, Steubl et al. (2021) found significant effects of internet-delivered interventions for PTSD at 1 to 3 months post-treatment (g = -0.39, CI [-0.67, -0.10]; c.f. Jonsson et al., 2023) and 3 to 12 months post-treatment (g = -0.20, CI [-0.38, -0.01]), though there was no available data for long-term (i.e., more than 12 months) follow-up. Due to limited longitudinal data, the majority of the included meta-analyses noted lacking or inconclusive evidence to support the longer-term efficacy of digital mental health interventions for PTSD symptoms (Kuester et al., 2016; Lewis et al., 2019; Sijbrandij et al., 2016; Simblett et al., 2017; Simon et al., 2021).

Several limitations of the present review should be noted. First, due to the sample characteristics and subgroup analyses of the included meta-analyses, this precluded inferences about how demographic factors (e.g., age, cultural contexts, socioeconomic status) moderate the efficacy of digital interventions on PTSD symptoms. There was a relatively limited number of different cultural populations from which participants of primary studies were sampled, as reflected by the predominant inclusion of samples from American and European populations (e.g., U.K., Sweden, Germany)—with only a few exceptions including primary studies from China (Wang et al., 2013) and Iraq (Knaevelsrud et al., 2015). Furthermore, there was a dearth of subgroup analyses according to other demographic characteristics including age and socioeconomic status. Hence, the included meta-analyses may limit the generalizability of our conclusions regarding the efficacy of digital

interventions on PTSD symptoms across diverse populations. Second, given that this review focused on the assessment of PTSD symptoms to indicate effectiveness of digital mental health interventions, we did not consider other indices of intervention efficacy including attenuation of affective symptoms (e.g., depressive and anxiety symptoms), user engagement, or user satisfaction. Third, besides comparing the efficacy of CBT-based versus non-CBT-based digital mental health interventions, it was not feasible for us to compare the efficacy of psychotherapeutic techniques versus other forms of psychological support. This was due to a) the lack of relevant subgroup analyses and b) the combination of multiple psychotherapy techniques (e.g., behavioral activation vs. coping skills training vs. cognitive restructuring) implemented in most intervention programs examined. Finally, it should also be acknowledged that meta-analyses may have included overlapping references (e.g., Kersting et al., 2013; Spence et al., 2011; Steinmetz et al., 2012; Wang et al., 2013); hence, it was not feasible to synthesize our results statistically or estimate a reliable overall effect size.

While digital mental health interventions for PTSD symptoms—including internet-delivered and app-based interventions—have been argued to strengthen therapeutic outcomes of traditional intervention methods, previous studies have demonstrated inconclusive evidence for their effectiveness. In light of this, the present systematic review provides evidence that digital mental health interventions consistently alleviate subclinical to clinical-level (i.e., meeting diagnostic criteria) PTSD symptoms in adults, assessed by validated clinician-administered or self-report measures. Notably, CBT-based, compared to non-CBT-based, internet-delivered interventions are associated with more consistently significant reductions in PTSD symptoms relative to inactive control conditions, though the advantages of CBT-based interventions are nonsignificant when compared to an active non-CBT based intervention. Nonetheless, we recommend further research to examine the role of intervention timeframe, features of therapeutic guidance (e.g., intensity, frequency, content) and user

characteristics (i.e., age, gender, cultural background, SES) in moderating the effectiveness of digital mental health interventions for PTSD symptoms. The findings from this review may be applied to guide the formulation and implementation of digital mental health interventions for PTSD symptoms.

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