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# Advances in PTSD Treatment Delivery: the Role of Digital Technology in PTSD Treatment

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## Abstract

*Purpose of review* Post-traumatic stress disorder (PTSD) is a common mental health disorder affecting about 7% of the general population during their lifetime. PTSD typically has a chronic course, is often comorbid with other psychiatric disorders, and negatively impacts functioning and quality of life. This review examines the evidence for several digital technology–based applications being used to deliver PTSD interventions, including video telehealth, Internet-based interventions, virtual reality exposure therapy, and mobile apps.
*Recent findings* A number of randomized controlled trials (RCTs) have examined the use of video telehealth, Internet-based interventions, and virtual reality exposure therapy for PTSD. Relatively few RCTs have investigated mobile apps for PTSD.
*Summary* Evidence reviewed shows that PTSD therapy delivered by video telehealth is as good as that delivered in person, but samples were almost exclusively comprised of military veterans. Internet-based interventions as well evidence strong support for their use. There is strong evidence for virtual reality exposure therapy as well, but it is limited by small samples mostly of male military service members and veterans. Lastly, the evidence for mobile apps is promising but inconclusive given the lack of published full-scale RCTs. The implications of these findings for future research directions and clinical practice are discussed.

## Introduction

Posttraumatic stress disorder (PTSD) is a common mental health disorder having an estimated lifetime prevalence rate of 7% among adults in the United States (US) [1], with about three and a half percent of this population having PTSD each year [2]. Women are two to three times more likely to have PTSD than are men, and prevalence rates are even higher among high-risk groups, such as military veterans who have been deployed to warzones [3–5]. In addition to those with the full disorder, it is estimated that another 10% of trauma survivors will experience significant PTSD symptoms and impairment (labeled subthreshold, subclinical, or partial PTSD), nearly 20% of whom will develop full PTSD within 2 years [6]. It is estimated that more than 80% of those with PTSD have at least one comorbid psychiatric disorder, including major depressive disorder, alcohol and substance use disorders, and anxiety disorders [7]. Left untreated, PTSD has a chronic, unremitting course that can result in considerable functional impairment and reduced quality of life (e.g., [8]).

Fortunately, effective PTSD treatments exist, including both psychotherapies and medications [9]. Individual, trauma-focused psychotherapy, such as prolonged exposure (PE) therapy, cognitive processing therapy (CPT), and eye movement desensitization and reprocessing (EMDR) are considered first-line treatments as they have the strongest empirical support and been shown to outperform medications in terms of greater and more lasting improvements in PTSD symptoms and lower risk of negative side effects [10, 11]. Unfortunately, availability of these treatments is limited due to a lack of trained mental health care providers in many areas [12]. Moreover, even when these and other effective interventions are available, many of those with PTSD do not access them due to stigma, cost of care, and fear of negative consequences [13, 14].

Digital technology offers novel modalities to deliver interventions for PTSD that can have advantages over and overcome limitations of conventionally delivered (i.e., in person) treatments (i.e., psychotherapy and medications). These include capability to deliver care from a distance, for example through video conferencing, the Internet, and mobile apps. Delivering PTSD care through these modalities could help reduce the intractable mental health treatment gap by offering interventions at scale (some at no- or low-cost) to those who might not have access to services. Digital technology approaches could also be used to improve care delivery as they could be integrated into care to better meet the needs of some patient groups, improve the efficacy of care (e.g., through more powerful treatments, improved patient adherence), and increase efficiency of care (fewer sessions or less provider time). For PTSD in particular, because it is unlike other mental health conditions as a clear cause is known, those who have been exposed to a trauma (e.g., combat, sexual assault, motor vehicle accident, natural disaster) could be provided scalable secondary prevention without delay through digital technology. In addition, as first-line treatments for PTSD are cognitive-behavior therapy (CBT) based (e.g., PE and CPT), they lend themselves well for transfer and scaling up through digital technology applications.

Reviewed here are digital technology–based approaches to delivering PTSD interventions with a focus on those that have received empirical support for their efficacy through randomized controlled trials (RCTs). As such, these include video telehealth, Internet-based interventions (IBIs), virtual reality exposure therapy (VRET), and mobile applications (apps). Each of these delivery modalities is described, including their potential advantages over conventionally delivered care, unique role in PTSD treatment, and evidence for their efficacy, with all studies reviewed here summarized in Table 1. We conclude by highlighting the main findings of this review and their implications for needed future research directions as well as clinical practice.

# Digital technology–based applications for PTSD treatment delivery

## Video telehealth

Video telehealth uses video cameras, monitors, and telecommunication infrastructure (e.g., broadband) to deliver real-time (i.e., synchronous), face-to-face

**Table 1. Meta-analyses and randomized controlled trials of digital technology–delivered interventions for PTSD**

| Intervention delivery | Study design | Author | *N* | Weeks | Intervention details | Efficacy | Notes |
|---|---|---|---|---|---|---|---|
| Video telehealth | Noninferiority RCT | Frueh et al. 2007 | 38 | 14 | CBT (14, weekly, 90-min sessions) delivered by video telehealth vs. in person | No significant differences between conditions at post treatment and 3-month follow-up | Veterans |
| | RCT | Ziemba et al. 2014 | 18 | 10 | CBT (10, weekly, sessions) delivered by video telehealth vs. in person | No significant differences between conditions at post treatment | Veterans |
| | Noninferiority RCT | Morland et al. 2014 | 125 | 6 | Group CPT (12, twice-weekly, 90-min, sessions) delivered by video telehealth vs. in person | Video telehealth not inferior to in person delivery at post-treatment, 3- and 6-month follow-up | Veterans |
| | Noninferiority RCT | Morland et al. 2015 | 126 | 6–12 | CPT (12, once or twice-weekly, 90-min sessions) delivered by video telehealth vs. in person | Video telehealth non-inferior to in person delivery at post-treatment, 3- and 6-month follow-up | Women only, veterans ($n = 21$) and civilians ($n = 105$) |
| | Equivalence RCT | Maieritsch et al. 2016 | 90 | 6–12 | CPT (12, once or twice weekly, 50-min sessions) delivered by video telehealth vs. in person | Trend for equivalence ($p = .094$, n.s.) at post-treatment | Veterans<br>High dropout (43%) compromised power to test for equivalence |
| | Noninferiority RCT | Acierno et al. 2016 | 232 | 8 | BA-TE (8, weekly, 90-min sessions) delivered by HBT vs. in person | HBT not inferior to in person at post-treatment, 3- and 12-month follow-up | Veterans<br>PTSD or subthreshold PTSD |
| | Noninferiority RCT | Acierno et al. 2017 | 150 | 8–12 | PE (8–12, weekly, 90-min sessions) delivered by HBT vs. in person | HBT not inferior to in person at post-treatment, 3- and 6-month follow-up | Veterans |
| | Noninferiority RCT | Liu et al. 2019 | 207 | 12 | CPT (12, weekly, 60 min sessions) video telehealth vs. in person delivery | Video telehealth inferior to in person at post-treatment but not at 6-month follow-up on CAPS. Video telehealth not inferior to in person at either time point on PCL. | Veterans |
| | RCT | Moreland et al. 2019 | 175 | 6–15 | PE (up to 15, weekly, 90-min sessions) delivered by HBT, clinic-to-clinic telehealth, or in-home-in-person | No significant differences among conditions at post-treatment and 6-month follow-up | Veterans |
| Internet-based intervention | MA | Kuester et al. 2016 | 20 RCTs $N = 1778$ | 1–12 | CBT and/or expressive writing vs. passive (e.g., waitlist controls) and active controls | IBIs better than passive controls at post-treatment but not at follow-up. IBIs not better than active controls | Studies included a variety samples and intervention types |
| | MA | Lewis et al. 2019 | 10 RCTs $N = 720$ | 4–14 | CBT vs. passive (e.g., waitlist controls) and active controls | IBIs better than passive controls at post-treatment but not at 3- and 6-mo. follow-up. IBIs not better than active controls | IBIs included DESTRESS, PTSD Coach, Interapy, From Survivor to Thriver, Spring, Warriors Internet Recovery and Education, and others |

**Table 1.** (Continued)

| Intervention delivery | Study design | Author | $N$ | Weeks | Intervention details | Efficacy | Notes |
|---|---|---|---|---|---|---|---|
| Virtual reality exposure therapy | MA | Deng et al. 2019 | 13 RCTs $N = 654$ | 5–12 | VRET vs. waitlist and active controls | VRET better than waitlist controls but not active controls | 10 RCTs with military service members or veterans |
| | MA | Kothgassner et al. 2019 | 9 RCTs $N = 296$ | 8–12 | VRET vs. waitlist and active controls | VRET better than waitlist controls but not active controls | 7 RCTs with military service member or veterans |
| Mobile application | Pilot RCT | Possemato et al. 2016 | 20 | 8 | PTSD Coach with clinician support (4, bi-weekly, 20-min sessions) vs. without | Both conditions significantly improved pre- to post-treatment with CS better than SM ($d = .54$) but ns | Veterans<br>Not powered to test between group differences |
| | Pilot RCT | Miner et al. 2016 | 49 | 4 | PTSD Coach vs. waitlist control | PTSD Coach condition significantly improved, waitlist did not but no between group effect ($d = .25–.33$, n.s.) | Community sample<br>Probable PTSD or subthreshold PTSD |
| | RCT | Kuhn et al. 2017 | 120 | 12 | PTSD Coach vs. waitlist control | PTSD Coach improved more than waitlist | Community sample<br>Probable PTSD or subthreshold PTSD |
| | RCT | Roy et al. 2017 | 144 | 6 | 6 apps with and without daily text messages encouraging use | Both conditions improved with no difference between conditions | Military service members and their family members. Subthreshold PTSD only |

*BA-TE*, behavioral activation–therapeutic exposure; *CAPS*, Clinician Administered PTSD Scale; *CBT*, cognitive behavior therapy; *CPT*, cognitive processing therapy; *HBT*, home-based telehealth; *MA*, meta-analysis; *n.s.*, not significant; *PCL*, PTSD Checklist; *PE*, prolonged exposure; *RCT*, randomized controlled trial treatment, including both psychotherapy and medication management. As such, the clinician and patient can be remote but are able to see and hear each other approximating in-person care. Advances in and widescale availability of electronic hardware (i.e., personal computers, tablets, and smartphones) and broadband service along with HIPAA-compliant video teleconferencing programs are facilitating the rapid increase in use of video telehealth. Given the expense of telehealth equipment and unknown risks, early applications typically involved a "hub and spoke" model, where providers at a larger, urban medical facility delivered specialty care to patients at smaller, more rural, remote clinics. Today, with increased availability of telehealth technology as well as studies demonstrating its safety, applications now include clinic to the patient's home (i.e., home-based telehealth, HBT) and "anywhere to anywhere" care (e.g., from the provider's home to a patient's workplace).

Video telehealth delivery of PTSD interventions offers advantages over conventionally delivered care. Foremost among these is its ability to provide access to specialty care (e.g., first-line EBTs for PTSD) to individuals in areas where such care is not otherwise available (e.g., rural or underserved areas). As such, it can reduce the burden on patients including having to travel long distances for care. HBT delivery improves on this, while also making treatment available and more acceptable for those who limit time outside their home (e.g., due to physical impairment or PTSD avoidant symptoms) or who would not seek clinic-based care due to stigma (see Morland et al., current issue for a more detailed review of this topic).

We identified nine RCTs that have examined video telehealth for PTSD, six of which tested clinic-to-clinic applications, two tested HBT delivery, and one tested both clinic-to-clinic and HBT delivery. Regarding clinic-to-clinic, a 14-weeek RCT ($N = 38$) with military veterans with PTSD compared video-delivered ($n = 17$) with in-person ($n = 21$) CBT (14, weekly, 90-min sessions) [15]. At post-treatment and 3-month follow-up, video telehealth was not inferior to in person on PTSD (PTSD Checklist; PCL) and depression symptoms (Beck Depression Inventory; BDI); however, both groups showed little improvement.

Similarly, a 10–15-week RCT with Operation Enduring Freedom/Operation Iraqi Freedom (OEF/OIF) veterans with PTSD ($N = 18$) compared video telehealth ($n = 7$) with in-person ($n = 6$) individual CBT (based on Beck's model) delivered in weekly sessions [16]. Although not powered to test for non-inferiority, at post-treatment, improvement in PTSD (Clinician Administered PTSD Scale; CAPS) did not appear different between video telehealth and in-person delivery (23- vs. 22-point reduction, respectively). Similar positive, equivalent outcomes were evidenced for depression (Montgomery–Asberg Depression Rating Scale; MADRS) and anxiety symptoms (Anxiety Rating Scale; HAM-A), as well as mental health quality of life (SF-36 v2).

A 6-weeek non-inferiority design RCT with rural military veterans with PTSD ($N = 125$) compared video telehealth ($n = 61$) with in-person ($n = 64$) group CPT (12, twice-weekly, 90-min sessions) [17]. At post-treatment and 3- and 6-month follow-up, video telehealth was not inferior to in person CPT on PTSD symptoms (CAPS) with both conditions showing significant, sustained improvement in PTSD symptoms.

A 6–12-week non-inferiority design RCT ($N = 126$) with women trauma survivors with PTSD compared video telehealth ($n = 63$) with in-person ($n =$

63) individual CPT (12, once- or twice-weekly, 90-min sessions) [18]. At post-treatment and 3- and 6-month follow-up, video telehealth was not inferior to in-person on PTSD symptoms (CAPS) with both conditions showing significant, sustained improvement in PTSD symptoms.

A 6–12-week equivalency design RCT ($N = 90$) with military veterans with PTSD compared video telehealth ($n = 45$) with in person ($n = 45$) CPT (12, once- or twice-weekly, 50-min sessions) [19]. At post-treatment, outcomes for video telehealth appeared equivalent to in-person delivery on both the CAPS ($p = .094$) and PCL ($p = .079$), but high dropout resulted in too small of a sample to test for equivalence. For both modalities, PTSD (CAPS and PCL) and depression symptoms (BDI-II) improved significantly from pre- to posttreatment.

A 12-week non-inferiority design RCT ($N = 207$) with military veterans with PTSD compared video telehealth ($n = 103$) with in-person ($n = 104$) CPT (12, weekly, 60-min sessions) [20]. Video telehealth was inferior to in-person at post-treatment but not at 6-month follow-up based on the CAPS. However, self-reported symptoms of PTSD (PCL) and depression (Patient Health Questionnaire-9; PHQ-9) demonstrated non-inferiority at both time points. In addition, both delivery modalities showed significant and sustained improvements in PTSD and depression symptoms.

Given the success of clinic-to-clinic trials and current widescale availability of video conferencing technology, researchers have begun testing HBT. An 8-week non-inferiority design RCT ($N = 232$) with military veterans with significant PTSD symptoms (including both full and subthreshold PTSD) compared evidence-based psychotherapies for PTSD and major depression (i.e., in vivo and imaginal exposure therapy, behavioral activation) delivered by HBT ($n = 111$) or in person ($n = 121$) [21]. Eight, 90-min sessions were delivered weekly. At post-treatment and 3- and 12-month follow-up, HBT was not inferior to in-person on PTSD (PCL) and depression symptoms (BDI-II), and both conditions show significant sustained improvements in symptoms.

A second HBT study used a 12-week non-inferiority design RCT ($N = 132$) with military veterans with PTSD symptoms comparing home-based telehealth ($n = 64$) to in-person ($n = 68$) delivered PE over 10–12, weekly, 90-min sessions [22]. At post-treatment and 3- and 6-month follow-up, home-based telehealth was not inferior to in-person on PTSD symptoms (PCL); however, for depression symptoms (BDI) at post-treatment and 3-month follow-up it was inferior, but at 6 months it was not. Across conditions, PTSD symptom demonstrated large ($d$s > 1.0) and sustained improvements.

Finally, a third HBT RCT used variable-length PE (6–15 weekly, 90-min sessions dependent on treatment response) with military veterans with PTSD comparing three conditions: HBT ($n = 58$), clinic-to-clinic telehealth ($n = 59$), and in-home-in-person ($n = 58$) in which the therapist delivered PE in person to the patient at their home [23]. At post-treatment and 6-month follow-up, no statistically significant differences were evidenced in PTSD symptom (CAPS) improvement among conditions with all showing strong treatment effects (i.e., $d$s = 0.96–1.08). For depression symptoms (BDI) at post-treatment and 6-month follow-up, outcomes for HBT were not significantly different compared with the other conditions; however, at both time points, in-home-in-person was significantly better than clinic-to-clinic.

In summary, the RCTs reviewed here provide strong evidence that when EBT for PTSD is delivered by video telehealth it is as effective as when it is delivered in person. This appears to be the case regardless of whether video telehealth involves individual or group treatment or is delivered from clinic-to-clinic or clinic-to-home. Moreover, like conventional delivery, the benefits on comorbid symptoms of depression appear to transfer to video telehealth delivery. However, all of samples of the RCTs reviewed except for one [18] were exclusively of military veterans.

## Internet-based interventions

Internet-based interventions (IBIs) for PTSD involve computer programs that are capable of remotely providing cognitive training, psychoeducation, interactive exercises (such as creating trauma narratives), and support. IBIs vary in format (e.g., with and without peer or clinician support), length (generally 4 to 12 weeks), and target outcomes (e.g., reductions in PTSD symptoms, improvement in attentional or informational processes), but generally require individuals to participate using a personal computer. Many IBIs follow a course-based format that encourages users to complete a sequence of modules (often weekly), each of which typically involves text-, audio-, or video-based psychoeducation, written assignments, and specific coping-skills training exercises [24], nearly all derived from EBTs [9]. Other types of IBIs use cognitive and attentional training designed to improve working memory and PTSD symptoms [25]. Typically, IBIs involve some clinician support to screen potential users, provide orientation to the program, ensure safety during use, monitor progress, or provide feedback. Amount of support varies widely across IBIs, as interventions are intended for different stages of care (e.g., not connected to care, before starting treatment, as an adjunct to treatment, or post-treatment) and for different levels of scale (e.g., individual practice, clinic, health system, or public health efforts).

Like other digital technologies for PTSD, IBIs offer advantages for those who are unlikely to access conventionally delivered services and those who might benefit from having care supplemented by technology-based approaches. With approximately 80% of US households having a personal computer, and 68% having a tablet device that would be capable of accessing many IBIs [26], IBIs have tremendous potential to reach those in need.

Efficacy of IBIs for improving PTSD symptoms has been evaluated by several recent meta-analyses. In the first published meta-analysis, Kuester et al. [27••] identified 20 RCTs of IBIs for PTSD: 5 RCTs of expressive-writing and 15 RCTs of CBT. Results across 973 treatment and 805 control participants showed moderate to large effects of CBT-focused IBIs on PTSD symptoms ($k = 7$, $g = 0.72$, 95% CI = [.57–.76], $p < .001$) compared with passive control conditions (i.e., waitlist) but not compared with active control conditions (i.e., psychoeducation, writing). One intervention, "Interapy," had undergone multiple RCTs, and effects were large for reducing PTSD symptoms, and arousal and avoidance in particular ($g$s = 0.81–.84, $p$s < .001). The lack of available RCTs did not afford sufficient power for moderator analyses, and few studies included long-term follow-up evaluations. Additionally, the 20 RCTs included varied substantially in target populations (e.g., breast cancer survivors, parents grieving the loss of a pregnancy, veterans) and in methods (e.g., peer support groups, weekly writing sessions, psychoeducation, coping-skills training).

A more recent meta-analysis [28] focused exclusively on IBIs that used interactive, CBT interventions and identified 10 RCTs (only 3 of which overlapped with Kuester et al. 2016 [27••]) of 720 participants. Results were similar to Kuester et al. 2016 [27••] showing significant effects of IBIs for reducing PTSD symptoms post-intervention ($g = 0.60$, 95% CI = [.24–.97]) but not at 3- and 6-month follow-up. Results also suggested significant effects of IBIs for improving depression symptoms, anxiety symptoms, and overall quality of life at both post-intervention and at follow-up. Moderator analyses found stronger effects for interventions that were trauma-focused ($g = 1.04$, 95% CI = 0.51 to 1.57] or therapist-guided ($g = 0.86$, 95% CI = 0.47 to 1.25). Several RCTs compared a CBT-focused intervention with a non-CBT intervention, and there did not appear to be a difference between these intervention types.

In a separate meta-analysis of the same RCTs used by Lewis et al. [28], Simon et al. [29] evaluated drop-out from IBIs and systematically reviewed measures of treatment acceptability, treatment satisfaction, and therapeutic alliance. Although the RCTs used a wide variety of measures, they generally demonstrated moderate-to-high levels of treatment acceptability and fairly strong alliance with clinical providers. Rates of dropout also varied, ranging from 8.7 to 62.5%. Dropout was significantly higher in treatment than control conditions (RR = 1.39, 95% CI = 1.03–1.88), suggesting that additional work is needed to better understand how to promote retention and motivation of those who engage with IBIs. However, it should be noted that dropout rates are comparably high and also demonstrate considerable variability in IBIs for other psychological disorders (31% [30••]) and in face-to-face interventions for PTSD (averaging 18% [31]).

In summary, based on the studies reviewed, IBIs for PTSD showed moderate to strong effects particularly when compared with passive control conditions but not when compared with active controls. Despite a large effect size, however, it is not clear if benefits are durable, possibly due to few studies (i.e., 3) that have included follow-up assessments. Inclusion of therapist support with IBIs is shown to improve outcomes. Broader effects of IBIs were found on improvement in depression and anxiety symptoms as well as quality of life both short and long term. Finally, much like conventionally delivered treatments [9], IBIs that are trauma-focused showed stronger effects.

## Virtual reality

VR therapy involves having patients enter computer-generated, interactive, immersive, three-dimensional simulated environments which include sights and sounds but also can include other sensory stimuli such as vibrations and smells. The most common application of VR therapy for PTSD involves exposure therapy (i.e., VRET) to facilitate the imaginal and in vivo exposure exercises of PE. With the recent increased availability of inexpensive, consumer VR hardware (goggles) along with powerful computers with high-speed graphic cards, VR environments are more life-like and interactive than ever and its delivery has become more feasible.

VRET may have advantages over conventionally delivered PTSD care. As VRET includes multi-sensory stimuli it could enhance emotional engagement in and processing of trauma-related memories and stimuli, the mechanisms through which PE is theorized to work. This could be particularly helpful for those who fail traditional exposure therapy or who cannot adequately access traumatic material (e.g., due to emotional numbing symptoms of PTSD) for emotional processing to occur [32••]. VRET could also provide failsafe environments for patients to develop mastery over triggering situations under the guidance of a therapist who can pace the exposure before the patient confronts such situations in the real world.

Two recent meta-analyses have summarized findings of RCTs evaluating VRETs. A meta-analysis of 13 RCTs with 654 participants investigated the efficacy of VRET and sought to identify treatment moderators [32••]. Across studies, VRET was delivered over 5–12 weeks with most studies (i.e., 10) utilizing mostly male military service member or veteran samples. At post-treatment, VRET was more efficacious at reducing PTSD symptoms (CAPS & PCL-M) than waitlist control conditions ($g = 0.567$, $p < .01$) but not better than active treatment conditions ($g = 0.017$, $p = .939$). Effects of VRET were shown to be maintained at 3- and 6-month follow-up. A similar pattern of findings was evidenced for depression symptoms, with VRET being better than waitlist control but not active control conditions. Lastly, more sessions of VRET related to greater benefits.

The other recent meta-analysis included 9 RCTs of VRET (8 shared with Deng et al., 2019 [32••]) with 296 participants; most samples (i.e., 7) again were comprised of mostly male military service members or veterans [33••]. A similar pattern of findings emerged with VRET being found to be better than waitlist control conditions on both PTSD ($g = 0.62$, $p = .017$) and depression symptoms ($g = 0.50$, $p = .008$) but not better than active treatment conditions (PTSD: $g = 0.25$, $p = .356$; depression: $g = 0.24$, $p = .340$). However, VRET was not found to be better when compared with either control condition for anxiety symptoms.

In summary, these meta-analyses clearly demonstrate that VRET is an effective treatment for PTSD as well as depression symptoms, with benefits being maintained for up to 6 months post-treatment. These meta-analyses also highlight that existing RCTs are limited by small, mostly male, service member and veteran samples, possibly reducing the generalizability of these findings to women and other trauma populations.

## Mobile apps

Mobile apps are software programs that run on mobile devices, including smartphones and tablets. In 2019, 81% of adult in the US owned a smartphone [34] and both major smartphone platforms (i.e., Apple and Android) have stores for easy distribution of apps. In fact, an estimated ten thousand mental health-related apps are available in the App Store and Google Play [35]. These include apps intended to deliver PTSD psychoeducation and tools for self-management of symptoms (e.g., PTSD Coach [36]). Such apps offer advantages over conventionally delivered PTSD care, including increased availability to evidence-based interventions, reduced cost of care, convenient and anonymous use, and in the moment interventions.

Mobile apps are also available for use by patients who are in EBTs for PTSD (e.g., PE Coach, CPT Coach) possibly improving treatment engagement and homework adherence resulting in improved outcomes. Although no apps for PTSD treatments have been evaluated, there is emerging evidence that integrating mobile interventions into psychotherapy can improve outcomes ($d = .57$) [37].

We identified four RCTs that have examined mobile-app-delivered PTSD interventions, three of which evaluated the same app, PTSD Coach, which is intended as a self-help intervention that includes PTSD psychoeducation and symptom monitoring and management tools. These include a 1-month pilot RCT ($N = 49$) with community trauma survivors with elevated PTSD (subthreshold and probable PTSD based on the PCL-C ≥ 25) that compared PTSD Coach ($n = 25$) with a waitlist control ($n = 24$) [38]. At post-treatment, between group effect size estimates were small ($d$s = .25 and .33, intent to treat and per protocol, respectively) and not significant. However, PTSD Coach participants had a significant reduction in PTSD symptoms ($p = .04$), whereas waitlist control participants did not ($p = .09$) and while not significantly different, a numerically higher percentage in PTSD Coach participants had a clinically significant improvement than waitlist participants (i.e., 39.1% vs. 19.0%).

An 8-week pilot feasibility RCT ($N = 20$) with veterans with PTSD compared self-guided PTSD Coach ($n = 10$) with clinician-supported PTSD Coach ($n = 10$), which involved four 30-min sessions with a primary care mental health provider intended to support participants' use of the app [39]. Both conditions showed improvement in PTSD symptoms (PCL) but no difference in improvement between conditions. However, the between-group effect size ($d = .54$) and percentage of those showing clinically significant change in PTSD symptoms (37.5% vs 70%) while not significant favored the clinician-supported condition.

A 12-week RCT ($N = 120$) among community trauma survivors with probable PTSD (based on a PCL-C cut score of ≥ 40) compared PTSD Coach ($n = 62$) with a waitlist control ($n = 58$) [40•]. At post-treatment, PTSD Coach participants showed greater improvement in PTSD symptoms (PCL), depression symptoms (Patient Health Questionnaire-8; PHQ-8), and psychosocial functioning (Brief Inventory of Psychosocial Functioning; B-IPF) than waitlist participants, with improvements being maintained at 3-month follow-up. However, while PTSD Coach participants improved more than waitlist participants, group outcomes were not significantly different at post-treatment.

Finally, a 6-week RCT ($N = 144$) with military service members and their family members who had subthreshold PTSD symptoms but not full PTSD (i.e., PCL 28 to 49) tested an app-based intervention [41]. All participants received information about six free apps they could download and use to learn about PTSD and practice helpful coping (e.g., social engagement, stress reduction). Half of the participants were randomized to a resilience enhancement intervention consisting of a 60-min session that provided a CBT-based rationale for app use that introduced psychoeducation, coping skills, relaxation techniques, and engagement in social activities. Following this, participants received daily text messages encouraging use of the apps. The other half were randomized to a control condition which included a 30-min introduction session promoting safety and sharing of resources in case symptoms worsened. This group also received daily text messages but with positive aphorisms instead of those encouraging use of apps. At post-treatment, both conditions significantly improved on PTSD symptoms (PCL) with no difference between conditions and improvement was maintained at 3-, 6-, and 12-month follow-up. A similar pattern emerged for depression (PHQ-9) and anxiety (Generalized Anxiety Disorder 7-Item, GAD-7) symptoms; however, depression symptom improvement was not maintained at 6 months and anxiety symptoms improvement was not maintained at 12 months.

In summary, mobile app delivery of PTSD interventions as stand-alone or guided-self-help appears promising for reducing PTSD and depression symptoms, but only a few RCTs were available for review and their findings are limited by small samples. In addition, while Possemato et al. [39] pilot tested use of PTSD Coach in primary care, no RCTs were identified that have examined the potential added benefit of using mobile apps as adjuncts to EBTs for PTSD.

## Conclusions

In general, this review of RCTs of digital technology–based applications to deliver PTSD interventions supports their efficacy. More specifically, RCTs of video telehealth demonstrate that PTSD therapy delivered by this modality is as good as that delivered in person, both in the short and long term, for individual or group treatment, and for clinic-to-clinic or clinic-to-home delivery. However, this conclusion is based on a literature that is almost exclusively of studies using military veteran samples. Likewise, evidence for IBIs supports their efficacy, with better outcomes for IBIs that include therapist support and are trauma-focused. However, long-term efficacy has not yet been established. There is strong support for the immediate and lasting benefit of VRET, but findings are limited by studies with small samples mostly of military service members and veterans. Lastly, the evidence for mobile apps is promising but inconclusive given the lack of full-scale RCTs to date and no studies testing the efficacy of mobile apps as adjuncts to EBTs for PTSD. In addition to demonstrating positive PTSD symptom outcomes, PTSD interventions delivered through these modalities consistently show broader effects on comorbid depressive symptoms and psychosocial functioning and/or quality of life.

Given the noted limitations of the literature reviewed, future research directions are clear. These include future studies with more diverse samples, particularly for those of video telehealth and VRET where the extant literature is almost entirely reliant on mostly male military and veteran samples. Future research is also needed that includes follow-up periods beyond 6 months to assess if intervention gains are maintained over the long term. Future research should also evaluate how well these efficacy findings translate to outcomes of less-controlled effectiveness trials and real-world applications through pragmatic trails, as well as post-implementation program evaluation efforts.

Clinicians wanting to offer PTSD interventions using digital technology must consider several factors before doing so. Foremost among these is deciding which digital technology application to use. While video telehealth applications are widely available, beyond military and veteran healthcare settings, tested VRET programs are not. Likewise, there is limited availability of tested IBIs with only a few currently open to the public (i.e., the PTSD Course [24] [available in Australia], VetsPrevail [42], and Interapy [43] [available in the Netherlands]). For mobile apps, the only app that has be subjected to RCTs, PTSD Coach [36], is available at no cost in both major app marketplaces (i.e., Google Play and the App Store).

In addition to finding an evidence-based application, patients must have the technology knowledge and skills to competently participate. Given society's increasing reliance on technology, interfaces have become much simpler and more intuitive to use so most patients should now be able to use technology in care, especially technology they are already routinely using (e.g., the Internet, mobile apps, video teleconferencing). Regardless, clinicians should assess their patients' use of and comfort with technology (e.g., have they ever downloaded and used a smartphone app for health-related purposes?) and this information should inform orientation to the technology that will be used in care. It should be noted that while some groups lead (e.g., younger adults) or lag (e.g., older adults) in adoption of technology, clinicians must be careful not to assume that individuals in such groups will or will not prefer and benefit from using technology in care. Finally, as no technology is perfectly reliable, problem solving and backup plans for known and unforeseen issues that might arise should also be discussed. For example, if a video call is dropped and cannot be quickly reestablished due to limited bandwidth, an easy backup solution is connecting by landline phone.

Finally, clinicians also must navigate the salient ethical issues of using digital technology. These include obtaining informed consent from patients regarding the purpose of the technology intervention, any risks or benefits of it, and alternatives to using the technology intervention. Clinicians must also ensure the confidentiality of patient information and data that they collect and store. If protected health information is being shared electronically (e.g., by email, through video teleconferencing) with the clinician, it is vital that it be done in a HIPAA-compliant manner. Lastly, as technology-based interventions allow for asynchronous, remote care, expectations should be set for if or when the clinician will respond to patient electronic data and plans should be in place for managing patient safety issues should they arise (e.g., having contact information for local emergency resources where the patient resides).

With the emerging evidence of PTSD interventions delivered by digital technology, additional treatment options are increasingly becoming available that promise to improve accessibility, affordability, and acceptable of care. As their use becomes more widespread, these intervention modalities could help to reduce the tremendous unmet need for PTSD care in the population.

## Compliance with ethical standards

**Conflict of interest**
Eric Kuhn declares that he has no conflict of interest. Jason Owen declares that he has no conflict of interest.

**Human and animal rights and informed consent**
This article does not contain any studies with human or animal subjects performed by the either author.

**Disclaimer**
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- •• Of major importance

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