A systematic review of mHealth interventions for HIV prevention and treatment among gay, bisexual, and other men who have sex with men

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Abstract

The use of mobile health (mHealth) technologies addressing HIV disparities among gay, bisexual, and other men who have sex with men (GBMSM) has increased. A systematic review of mHealth interventions for HIV prevention and treatment among GBMSM was conducted to summarize the current evidence and provide recommendations for future research. PRISMA guidelines were followed (PROSPERO ID: 148452). Studies identified via PubMed, PsychInfo, or Embase were included that (i) were in English, (ii) were published in a peer-reviewed journal prior to July 1, 2019, (iii) presented primary results, (iv) included only GBMSM, and (v) reported the results of an mHealth intervention (e.g., text message, phone/mobile application [app]) to improve HIV prevention or treatment outcomes. Of 1,636 identified abstracts, 16 published studies met inclusion criteria. Eleven studies were conducted in the United States. One study was a fully powered randomized controlled trial (RCT), seven were single-arm pilots with pre–post assessments, four were pilot RCTs, and four tested public health campaigns with post-assessments. Seven developed study-specific apps, five used text messaging, and four used existing social networking apps. Most (81%) targeted prevention outcomes. Nine cited a specific behavioral theory. All studies found that a mHealth approach was feasible and acceptable. All interventions provided evidence of preliminary efficacy or promising trends on primary outcomes. Although mHealth interventions for HIV prevention and treatment appear feasible and acceptable, most published studies are small pilot trials. Additional research assessing the efficacy and mechanisms of mHealth interventions is needed.

Keywords

GBMSM, MSM, mHealth, HIV, Intervention, Systematic review

INTRODUCTION

Gay, bisexual, and other men who have sex with men (GBMSM) are disproportionately burdened by HIV [1,2]. Global increases in anti-gay legislation hinder human rights protections for GBMSM vulnerable to HIV and the global roll-out of pre-exposure prophylaxis (PrEP) for HIV prevention is slow [3]. HIV-related disparities among GBMSM persist around the world, as high HIV prevalence among GBMSM exists in places as diverse as the Caribbean, Western and Central Europe, Thailand, parts of China, and several countries in Africa [1,2]. In the USA, data

Implications

Practice: Mobile health (mHealth) interventions are an acceptable and potentially effective means to address the HIV prevention and treatment needs of gay, bisexual, and other men who have sex with men.

Policy: Policy makers should consider mHealth HIV prevention and treatment options as an avenue to decrease HIV incidence and increase care among gay, bisexual, and other men who have sex with men.

Research: Future research should assess the efficacy and mechanisms of mHealth interventions for HIV prevention and treatment among gay, bisexual, and other men who have sex with men.

from the Centers for Disease Control and Prevention indicates that 70% of new diagnoses in 2017 were attributable to male–male sexual contact [4]. Further, sizeable proportions of GBMSM fall out of care along the HIV treatment continuum (i.e., linkage to care, adherence to antiretroviral medication [aka antiretroviral therapy (ART)], viral suppression) in the USA and other regions of the globe, including Central and Western Europe, Eastern Europe and Asia, and Africa [5,6]. Accordingly, adult GBMSM are the focus of special prevention efforts, including multiple, tailored HIV prevention interventions [7,8]. However, despite efforts at developing interventions tailored to both the unique health risks and culture of GBMSM, stable rates of HIV infection in this vulnerable population indicate prevention efforts are lagging [2,4,6].

The Internet and the HIV epidemic have long been intertwined among GBMSM, given early Internet adoption among GBMSM to seek sexual partners and find sexual health education [9]. For these reasons, researchers have tried to leverage technology to develop more effective HIV prevention [10–13]. Technologies (e.g., mobile phones, social

media sites) offer platforms with incredible potential to reach and intervene with GBMSM. Technology-based interventions can increase accessibility, convenience, and privacy for vulnerable individuals, like GBMSM, leading to rapidly scalable prevention tools [12]. The international ubiquity of technology use is an added advantage [14–16]. However, the constantly evolving nature of the technology presents unique challenges for developing effective and acceptable technology-delivered interventions [17].

In recent years, mobile-based technologies, such as applications (“apps”) and text messaging, have exploded in popularity as a means of addressing health behaviors. Mobile technology has improved and proliferated within the USA and globally. Among countries with advanced economies (e.g., USA, Netherlands, Japan, Australia), approximately 94% of adults own a mobile phone and 76% own a smartphone [18]. Further, even among countries with emerging economies (e.g., South Africa, Mexico, India), cellphone and smartphone ownership is growing rapidly, with approximately 83% of adults owning a mobile phone and 45% owning a smartphone [18]. As the spread of mobile technologies has increased substantially in the past decade, interest in the potential of technological interventions using mobile technology for health behavior change (mobile health [mHealth]) has correspondingly grown [17–22].

mHealth interventions have been developed for increasing physical activity, monitoring weight management, and medication adherence, among other health behavior concerns [23,24]. These interventions use mobile technology to intervene on behavior in real-time during high-opportunity moments or repeatedly in individuals’ daily lives to increase the likelihood of behavior change. Many of these same mHealth strategies can be applied to behavioral targets in HIV treatment and prevention interventions [25–27].

Despite increasing interest and emerging HIV-related mHealth intervention research, efforts to document the state of the science of mHealth approaches for GBMSM to prevent and treat HIV are few. Prior reviews are limited in several critical ways. Several focus generally on HIV treatment and prevention, rather than on specific populations at risk (e.g., GBMSM), limiting deeper discussion of how to tailor these types of mHealth interventions to GBMSM [11,25–29]. Additionally, several combine various types of technological interventions (i.e., broadly “eHealth”), such as computer-based, along with mobile technology-delivered, without a specific focus on mHealth [11,25,27,29,30]. Others focus strictly on HIV prevention, without including interventions focused on improving HIV treatment [12,13,30]. Altogether, this creates several key gaps within the literature on mHealth interventions for the purpose of reducing risk of HIV via treatment

or prevention among GBMSM. A review that adequately addresses these issues will identify the advances the field has made thus far, the stage of development of this science, and highlight remaining challenges. Thus, the purpose of the current paper is to systematically review the state of the science of mHealth interventions designed for GBMSM to enhance HIV treatment and prevention behaviors.

METHODS

Search

A systematic review of the literature published prior to July 1, 2019 was conducted across three databases (PubMed, PsychInfo, Embase). Search terms for HIV [AND] Prevention [OR] Treatment, were combined with [AND] search terms for mHealth [AND] Key Populations disproportionately affected by HIV (i.e., persons who inject drugs [OR] sex work [OR] recently incarcerated [OR] GBMSM). These search terms were co-developed, piloted, and refined with a university librarian, then implemented in each of the three databases to identify the relevant published literature across diverse academic disciplines (e.g., medicine, public health, psychology). The review identified a more advanced state of mHealth research with GBMSM compared to the other key populations and our protocol was amended to review mHealth interventions with GBMSM separately. Search protocol details are registered at (PROSPERO, ID: 148452). In brief, results from all three databases were deduplicated. Of the 1,636 total results, 881 unique titles and abstracts were screened, 142 focused on (i) mHealth, (ii) HIV prevention or treatment, and (iii) GBMSM. The review team met weekly to discuss the inclusion and exclusion of each unique title, and consensus was used to clarify any coding discrepancies. This process resulted in 142 articles that were included in a full-text review (Fig. 1).

Eligibility

Articles were included in the current review if they met the following eligibility criteria: (i) published in a peer-reviewed journal before July 1, 2019, (ii) published in English, (iii) reported the primary results of an intervention, (iv) had primary outcomes that were an HIV prevention or treatment behavior (i.e., sexual behavior, injection drug use, PrEP/nPEP adherence, HIV testing, ART adherence, engagement in HIV care), (v) used mHealth to deliver the intervention (i.e., text messaging, mobile-optimized websites, study-developed application, or mobile “app,” preexisting social networking mobile “app”), and (vi) enrolled exclusively cisgender (i.e., assigned male sex at birth and a current male gender identity) GBMSM. We focus on studies of cisgender GBMSM because transgender and non-binary (i.e., gender

Fig 1 | PRISMA flow diagram of identified articles.

identity that is not exclusively masculine or feminine) populations have unique interventions needs and tailoring interventions to those needs is likely to be more effective [31].

Data collection and synthesis

Research assistants were trained in the coding scheme and supervised by research team members (first and second authors). This included weekly code review by the second author and a final code review by the first author to ensure coding agreement. Interrater reliability among coders was established using seven articles (44% of the total included in the review) that were double-coded by research assistants. Interrater reliability was excellent, as evaluated by kappa ($k = .93$). Data codes included study design reflecting the rigor of the intervention and potential risk of bias in published results, study characteristics (e.g., sample size, country), type of mHealth technology used, and HIV prevention and treatment behavioral targets. Results were descriptively summarized and compared by study design.

The Cochrane Risk of Bias Tool for randomized controlled trials (RCTs) [32] was used to assess the methodologic rigor and risk of bias of the four pilot RCTs [33–36] and one fully powered RCT [37].

This tool highlights seven areas of bias, each rated as low, high, or unclear risk of bias. The areas include random sequence generation (selection bias); allocation concealment (selection bias); selective reporting (reporting bias); blinding of participants and personnel (performance bias); blinding of outcome assessors (detection bias); incomplete outcome data (attrition bias); or any other area of bias introduced by the study procedures. We chose not to formally evaluate bias in the single-arm pilot studies [38–44] and the public health campaigns with post-assessment [45–48] because non-randomized intervention studies are inherently biased and would not benefit from bias analysis [49].

RESULTS

Overview of included versus excluded articles

We identified 1,636 articles through database searches (Fig. 1). After removing duplicates, the first and second authors screened an initial group of 881 articles based on the title and abstract. Of those articles, 739 were excluded. Ineligible articles were typically excluded due to not testing interventions. For the remaining 142 articles, eligibility was assessed through a review of the full-text article. We

resolved discrepancies through discussion among the first and second authors. This process resulted in the inclusion of 16 articles. The studies (Table 1) collectively report on the results of interventions with 20,922 participants.

Included studies

The 16 included studies were published in 2012–2019. Fifteen distinct interventions (one study was the pilot version [40] of a fully powered RCT [37] that is also included) were tested. Most of the studies occurred in the USA ($n = 11$, 69%). The remaining five were conducted in China ($n = 2$, 13%), India ($n = 1$, 6%), Spain ($n = 1$, 6%), and Romania ($n = 1$, 6%).

Excluded studies

Of the 126 excluded publications, over half ($n = 68$, 54%) were excluded due to being conference abstracts published in peer-reviewed journals. Other reasons were: not being an intervention study ($n = 20$, 16%); reporting that <100% of the sample were GBMSM ($n = 14$, 11%); not reporting an HIV prevention or treatment outcome ($n = 9$, 7%); not focusing on mHealth ($n = 8$, 6%); presenting secondary data analyses ($n = 5$, 4%); or not being peer-reviewed ($n = 2$, 2%). Of note, due to our strict inclusion criteria, there are several mHealth studies that are not included that target HIV-related health behaviors among other populations (e.g., women, persons who inject drugs) or utilize non-mobile enabled websites (e.g., Keep It Up! [50]).

Methodologic status of the literature

One (6%) study was a fully powered RCT [37]. The majority ($n = 11$, 69%) were pilot studies; four (25%) were pilot RCTs [33–36] and seven (44%) were single-arm pilots with pre–post assessments [38–44]. The remaining four (25%) were public health outreach campaigns with post-assessments [45–48].

The median number of participants across the studies was 111, with a range from 10 [39] to 15,932 participants [48]. The five studies conducted outside of the USA did not report race/ethnicity data [34,36,38,45,48]. The average percentage of the sample comprising people of color enrolled in the U.S. studies was 65%, with a range of 30% [39] to 100% [42,46]. Most studies ($n = 13$, 81%) enrolled only adults (≥ 18 years old) [33,34,36,37,39–42,44–48]. Two (13%) studies included both adolescents and young adults (16 to 24 years old [43], 16 to 29 years old [38]) and one study focused solely on adolescents (14 to 17 years old) [35].

Studies utilized a wide range of recruitment strategies. Most ($n = 7$, 44%) relied exclusively on online methods (e.g., social media advertisements, advertisements on social-sexual networking apps) [33,35,41,45–48]. Five (31%) exclusively used offline methods (e.g., fliers at community-based

organizations, recruitment at clinics) [34,39,42–44]. The remaining four (25%) used both offline and online methods for recruitment [36–38,40].

Studies used a variety of mHealth technologies to facilitate their interventions. Seven (44%) developed a phone app [33,36,38,39,41–43], five (31%) used text messaging [34,35,37,40,44], and four (25%) conducted public health outreach through either advertisements or interactions with participants on preexisting social-sexual phone apps [45–48]. Behavioral theories guide nine (56%) of the interventions [33,35–37,39–43]. Specifically, four (4/9, 44%) used the information-motivation-behavioral skills model [35,36,39,42], one (1/9, 11%) used social cognitive theory [41], and one (1/9, 11%) used a dual processing cognitive-emotional decision-making framework [33]. Three used a combination of theories. Specifically, two (2/9, 22%) combined social support theory, the health belief model, and social cognitive theory [37,40]. The other one (1/9, 11%) combined social cognitive theory, narrative communication theory, and the Fogg behavior model of persuasive technology [43]. Seven (44%) did not cite a specific behavioral theory [34,38,44–48].

Most ($n = 13$, 81%) targeted HIV prevention outcomes [33–41,45–48]. Three (19%) targeted HIV treatment outcomes [42–44]. Among the 13 that targeted prevention outcomes, outcomes included encouragement of HIV testing (8/13, 62%) [33,35,36,41], condom use (7/13, 54%) [33–38,40], PrEP initiation and adherence (3/13, 23%) [33,39,41], and injecting drugs (1/13, 8%) [40]. One study (8%) assessed three outcomes (e.g., condom use, HIV testing, and PrEP) [33]. Two studies (15%) assessed condom use and HIV testing [35,36]. One study (8%) assessed HIV testing and PrEP initiation [41]. One study (8%) assessed condom use and injecting drugs [40]. The remaining ($n = 8$, 62%) focused on only one HIV prevention outcome [34,37–39,45–48]. For the three that targeted treatment outcomes, all (3/3, 100%) targeted ART adherence [42–44].

Results of included prevention interventions ($n = 13$)

Encouragement of HIV testing ($n = 8$)

Of the eight studies that encouraged HIV testing, four (4/8, 50%) were pilot studies [33,35,36,41] and the remaining four (4/8, 50%) conducted public health outreach to encourage testing through either advertisements or interactions with participants on preexisting social-sexual phone apps [45–48]. Of the pilot studies, three (3/8, 38%) were pilot RCTs [33,35,36] and one (1/8, 13%) was a pre–post assessment [41]. Three (3/4, 75%) of the pilot studies developed a phone app [33,36,41]. One pilot study (1/4, 25%) developed a text messaging intervention [35]. All (8/8, 100%) reported that the intervention approaches were feasible and acceptable.

Table 1 | Overview of mHealth interventions for HIV outcomes among gay, bisexual, and other men who have sex with men

Author(s)	Year	Country	N	Age	Type of mHealth	Theoretical model	HIV behavior targets
HIV prevention interventions							
Fully powered RCT							
Reback et al. [37]	2019	USA	286	E = 18–65 M = 41.5 SD = 10.9	Text message	Social Support Theory, Health belief Model, Social Cognitive Theory	Condom use
Pilot RCT							
Bauermeister et al. [33]	2019	USA	180	E = 18–24 M = 21.67 SD = 1.81	App	Dual Processing Cognitive-Emotional Decision-Making Framework	Condom use, PrEP use, HIV testing
Mimiaga et al. [34]	2017	India	100	E ≥ 18 M = 27.7 SD = 9.1	Text message	None reported	Condom use
Ybarra et al. [35]	2017	USA	302	E = 14–18 M = 16.1	Text message	Information, Motivation, and Behavioral Skills Model	Condom use, HIV testing,
Zhu et al. [36]	2019	China	100	E ≥ 18 18–29 = 68% ≥ 30 = 32%	App	Information, Motivation, and Behavioral Skills Model	Condom use, HIV testing
Single arm pilots with pre–post assessment							
Lelutiu-Weinberger et al. [38]	2018	Romania	43	E = 16–29 M = 23.4 SD = 3.6	App	None reported	Condom use, HIV testing
Mitchell et al. [39]	2018	USA	10	E = 18–30 M = 24.1 SD = 2.38	App	Information, Motivation, and Behavioral Skills Model	PrEP adherence
Reback et al. [40]	2012	USA	52	E = 18–65 M = 36.5 SD = 8.9	Text message	Social Support Theory, Health Belief Model, Social Cognitive Theory	Condom use, Injecting drugs
Sullivan et al. [41]	2017	USA	121	E ≥ 18 Median = 28 IQR = 24–34	App	Social Cognitive Theory	PrEP initiation, HIV testing
Public health campaign with post-assessment							
Alarcón Gutiérrez et al. [45]	2018	Spain	2656	E = ≥ 18; median = 32 IQR = 27–39	SSNS	None reported	HIV testing
Huang et al. [46]	2016	USA	122	E ≥ 18	SSNS	None reported	HIV testing
Lampkin et al. [47]	2016	USA	903	E ≥ 18	SSNS	None reported	HIV testing

(Continued)

Table 1 Continued						
Author(s)	Year	Country	N	Age	Type of mHealth	Theoretical model
Wang et al. [48]	2019	China	15932	E ≥ 18 Median = 27 IQR = 24–31	SSNS	None reported
HIV treatment interventions						
Single arm pilots with pre-post assessment						
Dworkin et al. [42]	2019	USA	43	E = 18–34 Median = 29	App	Information, Motivation, and Behavioral Skills Model of Adherence
Hightow-Weidman et al. [43]	2018	USA	20	E = 16–24 M = 21.8 SD = 1.55	App	Social Cognitive Theory; Narrative Communication Theory; Fogg Behavior Model of Persuasive Technology
Lewis et al. [44]	2013	USA	52	E ≥ 25 M = 38	Text message	None reported
ART adherence						
ART adherence						
ART adherence						

ART Antiretroviral Therapy; E Eligibility; HIV Human Immunodeficiency Virus; IQR Interquartile Range; M Mean; mHealth Mobile Health Technologies; PrEP Pre-Exposure Prophylaxis; SD Standard Deviation; SSNS = Social-Sexual Networking Site.

Among the three pilot RCTs, two (2/3, 66%) found significant increases in HIV testing (i.e., one or more HIV tests during the follow-up period) in the intervention groups compared to the control groups [35,36]. The one pre-post assessment also found a substantial increase in testing during the intervention [41]. The four public health outreach campaigns that used existing social-sexual networking apps had incredible reach and appeared to increase testing among individuals who may not have tested otherwise, but had substantial methodological limitations, including an inability to directly attribute perceived increases in testing to exposure to their particular public health campaigns [45–48].

Condom use (n = 7)

Of the seven studies that targeted condom use, one was a fully powered RCT [37]. The remaining were pilot studies; four (4/7, 57%) pilot RCTs [33–36] and two (2/7, 29%) pre-post assessments [38,40]. One of the pre-post assessments was the pilot study [40] of the fully powered RCT [37]. Most (4/7, 57%) were text messaging interventions. All (7/7, 100%) reported that the intervention approaches were feasible and acceptable.

The fully powered RCT compared two text messaging interventions (one with an interactive feature, one without) to a text message-based control condition. Both intervention conditions had greater and sustained reductions in condomless anal intercourse with both main and anonymous male partners compared to the control condition. Of note, the text message intervention that did not have an interactive feature was slightly more effective compared to the text message intervention with an interactive feature [37]. Among the pilot RCTs, one (1/4, 25%) found a significant decrease in condomless sex in the intervention group compared to the control group [34]. The remaining three found promising, but not statistically significant, trends in condom use (2/4, 50%) [33,36] or no indication of effect (1/4, 25%) [35]. Of the two pre-post assessments, one found significant decreases in condomless sex [40] and the other found a non-significant trend towards decreased condomless sex [38].

PrEP (n = 3)

Of the three studies that encouraged PrEP initiation and adherence, one (1/3, 33%) was a pilot RCT [33] and two (2/3, 66%) were pre-post assessments [39,41]. All three (3/3, 100%) developed a phone app and reported that the app was feasible and acceptable. The pilot RCT found a promising, but not statistically significant, trend indicating that those in the intervention were more likely to have initiated PrEP compared to those in the control [33]. One pre-post study found promising, but not significant, trends in the expected direction for PrEP knowledge and initiation that were attributed by the

participants to use the intervention app [41]. The remaining pre-post assessment was an intervention to increase PrEP adherence among PrEP users. This small study ($n = 10$) found that for individuals who were not already fully adherent, PrEP adherence increased at follow-up [39].

Injecting drugs ($n = 1$)

The one study that assessed injection drug use was a pre-post assessment of a text messaging intervention for GBMSM who use methamphetamines [40]. This study found significantly fewer participants reported injecting methamphetamine at follow-up compared to baseline.

Results of included treatment interventions ($n = 3$)

ART adherence ($n = 3$)

Of the three studies that targeted ART adherence, all three (3/3, 100%) were pre-post assessments. Two (2/3, 66%) developed a phone app [42,43] and one (1/3, 33%) was a text messaging intervention [44]. All three (3/3, 100%) interventions were found to be feasible and acceptable. Both phone app interventions reported increases in ART adherence measures. Specifically, one found improvements in both pill count and self-reported measures of adherence [42] and the other found improvements in self-reported ability to take ART as prescribed [43]. The text messaging intervention showed improvements in self-reported ART adherence, as well as biomarkers of adherence (i.e., viral load and CD4 count) [44].

Summary of methodologic rigor and risk of bias of included RCTs

The majority of RCTs were categorized as low risk of selection bias due to using adequate methods to generate a randomized sequence (4/5, 80%) [33–36] and proper concealment of allocations prior to assignment (4/5, 80%) [33–36]. The remaining study did not provide enough information to determine selection bias or proper allocation concealment [37]. All (5/5, 100%) were evaluated as having a high risk of performance bias due to inadequate methods for blinding the participants to intervention allocation and unclear risk of detection bias due to none providing descriptions of outcome assessor blinding or assessment procedures [33–37]. All (5/5, 100%) were determined to be low risk of reporting bias due to selective outcome reporting and unclear risk of any other possible biases that should be accounted for [33–37]. Finally, most of the studies appeared to be low risk (3/5, 60%) [34–36] for attrition bias due to the amount, nature, or handling of incomplete outcome data, whereas the remaining two (2/5, 40%) [33,37] did not provide enough information to determine their risk of attrition bias.

DISCUSSION

We conducted a systematic review of mHealth HIV prevention and treatment interventions for GBMSM. The first report of results from an mHealth intervention exclusively for GBMSM was in 2012 [40], and since that time the results of 15 additional GBMSM-tailored interventions have been reported [33–39,41–48]. Given that GBMSM continue to be disproportionately affected by HIV in the USA and globally [1,2,4], in combination with the finding that only one efficacy trial of a GBMSM-focused mHealth intervention has been reported [37], suggests that this area of study is still in its infancy. There is substantial room for growth both in the variation of GBMSM mHealth interventions that should be developed and tested, as well as the reach of interventions in regions where GBMSM disproportionately bear the burden of HIV and where sex between men is highly stigmatized [51,52]. This review found that one-third of the studies were conducted in non-USA countries, and none were conducted in African countries with a high rate of HIV among GBMSM [3].

Opportunities to develop and test mHealth interventions for GBMSM will require greater investment in large-scale trials that are powered to detect group differences. Mirroring other reviews of HIV-related eHealth interventions, the current review found only one fully powered efficacy trial of a GBMSM-tailored mHealth interventions [37], far outnumbered by the number of published pilot studies and public health campaigns. Due to resource constraints, pilot studies, including those reviewed here, are often limited by both the extent of the follow-up period and the use of self-reported outcomes, rather than objective biological outcomes. This finding reflects the burgeoning nature of the field, which over time will mature.

Perhaps more challenging is that this imbalance in the number of pilot versus efficacy trials may reflect a deeper disconnect between scientific rigor and optimizing the development and refinement process for mHealth technologies. Despite more recent advances in study designs (e.g., adaptive study designs [53]), the RCT has long been considered the “gold standard” to assess intervention outcomes [54]. Conducting a large-scale RCT often takes years to complete and requires that the intervention is delivered with a high level of fidelity that does not allow for changes to the intervention during the study period. In contrast, apps and other mHealth technologies outside of research contexts are in a constant state of development and testing, allowing businesses to be responsive to user needs and desires. Developing and testing effective mHealth interventions for GBMSM will continue to require a high level of rigor, however, designs that also allow for refinement and testing within a trial may be needed to accelerate the timeline from conception to scale

up. Mohr and colleagues proposed the Continuous Evaluation of Evolving Behavioral Intervention Technologies (CEEBIT) framework that allows for refinement of mHealth interventions while retaining a high level of scientific rigor [55]. This and yet-to-be-developed frameworks should be considered in order to meet the demand for tailored HIV-related mHealth prevention and treatment services among GBMSM in the USA and globally.

Despite these challenges, HIV-related mHealth interventions to date show a high level of promise to meet the needs of GBMSM. All interventions reviewed here were shown to be feasible and acceptable across multiple formats (i.e., mobile apps, text messaging, public health outreach) and outcomes (i.e., HIV testing, condom use, PrEP, injecting drugs, and ART adherence). Prior reviews of eHealth interventions for HIV also show high levels of feasibility and acceptability across populations and technologies [56–58]. As such, the science of mHealth interventions for GBMSM may be advanced by agreeing upon core features that have been demonstrated to be acceptable to GBMSM (e.g., reminders and notifications), and focus efforts instead on novel features that have not been assessed for their acceptability or those where consensus has not been reached. In this way, resources are not unnecessarily spent on demonstrating acceptability for intervention components that have already been shown to be acceptable and feasible.

Our analyses of the scientific rigor and risk of bias showed some variability across domains assessed (e.g., 60% of studies assessed showed a low risk of attrition bias, while 100% of studies assessed showed a high risk of performance bias and a low risk of reporting bias). This variability is likely not specific to mHealth interventions, rather is present in behavioral intervention RCT studies more broadly. For example, executing rigorous randomization procedures in behavioral interventions studies is relatively straightforward, and mHealth intervention studies easily take advantage of computer-based randomization programs that can automatically allocate participants to study condition. In contrast, it is less clear how to adequately blind participants to behavioral intervention study condition, and if and how blinding occurred are often under described or not described at all. Of note is the relatively low level of attrition reported across studies. This may reflect the relatively short follow-up periods in most pilot trials or may reflect high levels of engagement in mHealth studies among GBMSM. Questions related to participant retention will start to be answered as the results of efficacy trials of ongoing mHealth interventions for GBMSM (e.g., [59]) are reported.

This review has several important limitations that should be considered. Although every effort was made to identify and review all relevant mHealth interventions for GBMSM, likely some published intervention studies were missed. Relatedly, we did not include published eHealth interventions that

were not specifically formatted for mHealth technologies. Thus, we excluded studies that used other technologies to deliver intervention and were shown to be efficacious (e.g., [50]). Because of this rapidly changing field, we also excluded some mHealth interventions for GBMSM that were published after July 1, 2019 (e.g., [60]), suggesting the need to continually monitor and update published literature in this area. mHealth intervention studies for transgender and gender non-binary individuals were also excluded. It is possible that some studies reviewed here may have not adequately assessed gender identity and include transgender men in their sample. Future reviews of HIV-related mHealth interventions for transgender persons is important to advance understanding in this area. Finally, we focused on mHealth interventions that delivered content directly to GBMSM participants. Other important intervention approaches to meet the HIV prevention and treatment needs of GBMSM include increasing provider knowledge of, and competency in, working with GBMSM and addressing structural factors (e.g., legal protections) that limit the availability and impact of interventions for this group.

With these limitations in mind, the results of this review provide important areas for future research. First, demonstrating that mHealth interventions for GBMSM are not only feasible and acceptable, but also efficacious through demonstrating that they improve objective HIV prevention and treatment outcomes is critical. The ability for mHealth interventions to be widely disseminated and easily accessible has been touted as major advantages of technology-based interventions [25,61], but these advantages have not been realized in part because such interventions often lack evidence to justify scale up. Most of the studies reviewed here are pilot trials with self-reported outcomes. Second, the fact that there are relatively few published mHealth interventions for GBMSM, it is difficult to assess what components are most impactful or the conditions where different mHealth intervention approaches are most successful. Conducting such analyses is important since the results may be counterintuitive. For example, in the only efficacy trial found in this review, Reback and colleagues found that one-way, non-interactive text messages were more effective than interactive text messages [37], which has important implications for future programming. A more thorough reporting of study procedures of mHealth intervention studies for GBMSM is also needed to understand areas to improve scientific rigor and potential sources of bias in these studies. These are substantial challenges facing the field of mHealth interventions for GBMSM, but the published studies reviewed here suggest a promising future for such interventions. Advancing research and practice in this emerging area will require thoughtful coordination and effort to actualize the promise of mHealth interventions for GBMSM.

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Compliance with Ethical Standards

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

Human Rights: This article does not contain any studies with human participants performed by any of the authors.

Informed Consent: This study does not involve human participants and informed consent was therefore not required.

Welfare of Animals: This article does not contain any studies with animals performed by any of the authors.

References

- Beyrer C, Sullivan P, Sanchez J, et al. The increase in global HIV epidemics in MSM. *AIDS*. 2013;27(17):2665–2678.
- Beyrer C, Baral SD, van Griensven F, et al. Global epidemiology of HIV infection in men who have sex with men. *Lancet*. 2012;380(9839):367–377.
- Beyrer C, Baral SD, Collins C, et al. The global response to HIV in men who have sex with men. *Lancet*. 2016;388(10040):198–206.
- Centers for Disease Control and Prevention. *HIV Surveillance Report*, 2017. Vol. 29. Atlanta, GA: Centers for Disease Control and Prevention; 2018. Available at <http://www.cdc.gov/hiv/library/reports/hiv-surveillance.html>. Accessibility verified December 17, 2018.
- National Center for HIV/AIDS, Viral Hepatitis, STD, and TB Prevention. *Selected National HIV Prevention and Care Outcomes in the United States*. Atlanta, GA: Centers for Disease Control and Prevention; 2018. Available at <https://www.cdc.gov/hiv/pdf/library/factsheets/cdc-hiv-national-hiv-care-outcomes.pdf>. Accessibility verified July 18, 2019.
- Joint United Nations Programme on HIV/AIDS. *Ending AIDS: Progress Towards the 90-90-90 Targets*. Geneva, Switzerland: UNAIDS; 2017. Available from: https://www.unaids.org/sites/default/files/media_asset/Global_AIDS_update_2017_en.pdf. Accessibility verified July 30, 2019.
- Herbst JH, Sherba RT, Crepaz N, et al.; HIV/AIDS Prevention Research Synthesis Team. A meta-analytic review of HIV behavioral interventions for reducing sexual risk behavior of men who have sex with men. *J Acquir Immune Defic Syndr*. 2005;39(2):228–241.
- Johnson WD, Hedges LV, Ramirez G, et al. HIV prevention research for men who have sex with men: a systematic review and meta-analysis. *J Acquir Immune Defic Syndr*. 2002;30(suppl 1):S118–S129.
- Grov C, Breslow AS, Newcomb ME, Rosenberger JG, Bauermeister JA. Gay and bisexual men's use of the internet: research from the 1990s through 2013. *J Sex Res*. 2014;51(4):390–409.
- Mitchell JW. The use of technology to advance HIV prevention for couples. *Curr HIV/AIDS Rep*. 2015;12(4):516–522.
- Noar SM, Black HG, Pierce LB. Efficacy of computer technology-based HIV prevention interventions: a meta-analysis. *AIDS*. 2009;23(1):107–115.
- Sullivan PS, Jones J, Kishore N, Stephenson R. The roles of technology in primary HIV prevention for men who have sex with men. *Curr HIV/AIDS Rep*. 2015;12(4):481–488.
- Sullivan PS, Grey JA, Simon Rosser BR. Emerging technologies for HIV prevention for MSM: what we have learned, and ways forward. *J Acquir Immune Defic Syndr*. 1999 2013;63(suppl 1):S102–S107.
- Garrett R, Smith J, Young SD. A review of social media technologies across the global HIV care continuum. *Curr Opin Psychol*. 2016;9:56–66.
- Sullivan PS, Carballo-Diéguez A, Coates T, et al. Successes and challenges of HIV prevention in men who have sex with men. *Lancet*. 2012;380(9839):388–399.
- Swendeman D, Rotheram-Borus MJ. Innovation in sexually transmitted disease and HIV prevention: internet and mobile phone delivery vehicles for global diffusion. *Curr Opin Psychiatry*. 2010;23(2):139–144.
- Fiordelli M, Diviani N, Schulz PJ. Mapping mHealth research: a decade of evolution. *J Med Internet Res*. 2013;15(5):e95.
- Taylor K, Silver L. *Smartphone Ownership is Growing Rapidly Around the World, But Not Always Equally*. Washington, DC: Pew Research Center; 2019. Available at <https://pewresearch-org-preprod.go-vip.co/pewglobal/2019/02/05/smartphone-ownership-is-growing-rapidly-around-the-world-but-not-always-equally/>. Accessibility verified July 29, 2019.
- WHO Global Observatory for eHealth. *mHealth: New Horizons for Health Through Mobile Technologies: Second Global Survey on eHealth*. Geneva, Switzerland: World Health Organization; 2011. Available at <https://apps.who.int/iris/handle/10665/44607>. Accessibility verified July 18, 2019.
- Bert F, Giacometti M, Gualano MR, Siliquini R. Smartphones and health promotion: a review of the evidence. *J Med Syst*. 2014;38(1):9995.
- Conroy DE, Yang CH, Maher JP. Behavior change techniques in top-ranked mobile apps for physical activity. *Am J Prev Med*. 2014;46(6):649–652.
- Zhao J, Freeman B, Li M. Can mobile phone apps influence people's health behavior change? An evidence review. *J Med Internet Res*. 2016;18(11):e287.
- Khaylis A, Yiaslas T, Bergstrom J, Gore-Felton C. A review of efficacious technology-based weight-loss interventions: five key components. *Telemed J E Health*. 2010;16(9):931–938.
- Anglada-Martinez H, Riu-Viladoms G, Martin-Conde M, Rovira-Illamola M, Sotoca-Mombona JM, Codina-Jane C. Does mHealth increase adherence to medication? Results of a systematic review. *Int J Clin Pract*. 2015;69(1):9–32.
- Simoni JM, Kutner BA, Horvath KJ. Opportunities and challenges of digital technology for HIV treatment and prevention. *Curr HIV/AIDS Rep*. 2015;12(4):437–440.
- Catalani C, Philbrick W, Fraser H, Michael P, Israelski DM. mHealth for HIV treatment & prevention: a systematic review of the literature. *Open AIDS J*. 2013;7:17–41.
- Muessig KE, Nekkanti M, Bauermeister J, Bull S, Hightow-Weidman LB. A systematic review of recent smartphone, internet and web 2.0 interventions to address the HIV continuum of care. *Curr HIV/AIDS Rep*. 2015;12(1):173–190.
- Schnall R, Travers J, Rojas M, Carballo-Diéguez A. eHealth interventions for HIV prevention in high-risk men who have sex with men: a systematic review. *J Med Internet Res*. 2014;16(5):e134.
- Henny KD, Wilkes AL, McDonald CM, Denson DJ, Neumann MS. A rapid review of eHealth interventions addressing the continuum of HIV care (2007–2017). *AIDS Behav*. 2018;22(1):43–63.
- Nguyen LH, Tran BX, Rocha LEC, et al. A systematic review of eHealth interventions addressing HIV/STI prevention among men who have sex with men. *AIDS Behav*. 2019;23(9):2253–2272.
- Poteat T, Malik M, Scheim A, Elliott A. HIV prevention among transgender populations: knowledge gaps and evidence for action. *Curr HIV/AIDS Rep*. 2017;14(4):141–152.
- Higgins JP, Altman DG, Gøtzsche PC, et al.; Cochrane Bias Methods Group; Cochrane Statistical Methods Group. The cochrane collaboration's tool for assessing risk of bias in randomised trials. *BMJ*. 2011;343:d5928.
- Bauermeister JA, Tingler RC, Demers M, et al. Acceptability and preliminary efficacy of an online HIV prevention intervention for single young men who have sex with men seeking partners online: the myDEX project. *AIDS Behav*. 2019;23(11):3064–3077.
- Mimiaga MJ, Thomas B, Biello K, et al. A pilot randomized controlled trial of an integrated in-person and mobile phone delivered counseling and text messaging intervention to reduce HIV transmission risk among male sex workers in Chennai, India. *AIDS Behav*. 2017;21(11):3172–3181.
- Ybarra ML, Prescott TL, Phillips GL, Bull SS, Parsons JT, Mustanski B. Pilot RCT results of an mHealth HIV prevention program for sexual minority male adolescents. *Pediatrics*. 2017;140:e20162999.
- Zhu X, Zhang W, Operario D, et al. Effects of a mobile health intervention to promote HIV self-testing with MSM in china: a randomized controlled trial. *AIDS Behav*. 2019;23(11):3129–3139.
- Reback CJ, Fletcher JB, Swendeman DA, Metzner M. Theory-based text-messaging to reduce methamphetamine use and HIV sexual risk behaviors among men who have sex with men: automated unidirectional delivery outperforms bidirectional peer interactive delivery. *AIDS Behav*. 2019;23(1):37–47.
- Lelutiu-Weinberger C, Manu M, Ionescu F, et al. An mHealth intervention to improve young gay and bisexual men's sexual, behavioral, and mental health in a structurally stigmatizing national context. *JMIR Mhealth Uhealth*. 2018;6(11):e183.
- Mitchell JT, LeGrand S, Hightow-Weidman LB, et al. Smartphone-based contingency management intervention to improve pre-exposure prophylaxis adherence: pilot trial. *JMIR Mhealth Uhealth*. 2018;6(9):e10456.
- Reback CJ, Grant DL, Fletcher JB, et al. Text messaging reduces HIV risk behaviors among methamphetamine-using men who have sex with men. *AIDS Behav*. 2012;16(7):1993–2002.
- Sullivan PS, Driggers R, Stekler JD, et al. Usability and acceptability of a mobile comprehensive HIV prevention app for men who have sex with men: a pilot study. *JMIR Mhealth Uhealth*. 2017;5(3):e26.
- Dworkin MS, Lee S, Chakraborty A, et al. Acceptability, feasibility, and preliminary efficacy of a theory-based relational embodied conversational agent mobile phone intervention to promote HIV medication

- adherence in young HIV-positive African American MSM. *AIDS Educ Prev*. 2019;31(1):17–37.
43. Hightow-Weidman L, Muessig K, Knudtson K, et al. A gamified smartphone app to support engagement in care and medication adherence for HIV-positive young men who have sex with men (AllyQuest): development and pilot study. *JMIR Public Health Surveill*. 2018;4(2):e34.
44. Lewis MA, Uhrig JD, Bann CM, et al. Tailored text messaging intervention for HIV adherence: a proof-of-concept study. *Health Psychol*. 2013;32(3):248–253.
45. Alarcón Gutiérrez M, Fernández Quevedo M, Martín Valle S, et al. Acceptability and effectiveness of using mobile applications to promote HIV and other STI testing among men who have sex with men in Barcelona, Spain. *Sex Transm Infect*. 2018;94(6):443–448.
46. Huang E, Marlin RW, Young SD, Medline A, Klausner JD. Using grindr, a smartphone social-networking application, to increase HIV self-testing among black and latino men who have sex with men in Los Angeles, 2014. *AIDS Educ Prev*. 2016;28(4):341–350.
47. Lampkin D, Crawley A, Lopez TP, Mejia CM, Yuen W, Levy V. Reaching suburban men who have sex with men for STD and HIV services through online social networking outreach: a public health approach. *J Acquir Immune Defic Syndr*. 2016;72(1):73–78.
48. Wang L, Podson D, Chen Z, et al. Using social media to increase HIV testing among men who have sex with men - Beijing, China, 2013–2017. *MMWR Morb Mortal Wkly Rep*. 2019;68(21):478–482.
49. Deeks JJ, Dinnes J, D'Amico R, et al.; International Stroke Trial Collaborative Group; European Carotid Surgery Trial Collaborative Group. Evaluating non-randomised intervention studies. *Health Technol Assess*. 2003;7(27):iii–x, 1.
50. Mustanski B, Parsons JT, Sullivan PS, Madkins K, Rosenberg E, Swann G. Biomedical and behavioral outcomes of keep it up!: an eHealth HIV prevention program RCT. *Am J Prev Med*. 2018;55(2):151–158.
51. Santos GM, Makofane K, Arreola S, Do T, Ayala G. Reductions in access to HIV prevention and care services are associated with arrest and convictions in a global survey of men who have sex with men. *Sex Transm Infect*. 2017;93(1):62–64.
52. Wanyenze RK, Musinguzi G, Matovu JK, et al. “If you tell people that you had sex with a fellow man, it is hard to be helped and treated”: barriers and opportunities for increasing access to HIV services among men who have sex with men in Uganda. *PLoS One*. 2016;11(1):e0147714.
53. Almirall D, Nahum-Shani I, Sherwood NE, Murphy SA. Introduction to SMART designs for the development of adaptive interventions: with application to weight loss research. *Transl Behav Med*. 2014;4(3):260–274.
54. Simon SD. Is the randomized clinical trial the gold standard of research? *J Androl*. 2001;22(6):938–943.
55. Mohr DC, Cheung K, Schueller SM, Hendricks Brown C, Duan N. Continuous evaluation of evolving behavioral intervention technologies. *Am J Prev Med*. 2013;45(4):517–523.
56. Horvath KJ, Lammert S, LeGrand S, Muessig KE, Bauermeister JA. Using technology to assess and intervene with illicit drug-using persons at risk for HIV. *Curr Opin HIV AIDS*. 2017;12(5):458–466.
57. LeGrand S, Muessig KE, Horvath KJ, Rosengren AL, Hightow-Weidman LB. Using technology to support HIV self-testing among MSM. *Curr Opin HIV AIDS*. 2017;12(5):425–431.
58. Muessig KE, LeGrand S, Horvath KJ, Bauermeister JA, Hightow-Weidman LB. Recent mobile health interventions to support medication adherence among HIV-positive MSM. *Curr Opin HIV AIDS*. 2017;12(5):432–441.
59. Horvath KJ, Amico KR, Erickson D, et al. Thrive with me: protocol for a randomized controlled trial to test a peer support intervention to improve antiretroviral therapy adherence among men who have sex with men. *JMIR Res Protoc*. 2018;7(5):e10182.
60. Horvath KJ, Lammert S, MacLehose RF, Danh T, Baker JV, Carrico AW. A pilot study of a mobile app to support HIV antiretroviral therapy adherence among men who have sex with men who use stimulants. *AIDS Behav*. 2019;23(11):3184–3198.
61. Pequegnat W, Rosser BR, Bowen AM, et al. Conducting Internet-based HIV/STD prevention survey research: considerations in design and evaluation. *AIDS Behav*. 2007;11(4):505–521.