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The Digital Health Landscape in Addiction and Substance Use Research: Will Digital Health Exacerbate or Mitigate Health Inequities in Vulnerable Populations?

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The Digital Health Landscape in Addiction and Substance Use Research: Will Digital Health Exacerbate or Mitigate Health Inequities in Vulnerable Populations?

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Abstract

Purpose of Review Novel and emerging digital health technologies are increasingly used in substance use and addiction-related self-management and treatment research. The promise of digital health is exciting, yet there are important factors regarding population characteristics to consider prior to using novel technologies with vulnerable populations. This paper reports a review of scientific literature published between 2015 and early 2020 on the use of digital health strategies in research focused on substance use and addiction in vulnerable populations.

Recent Findings Using 13 search terms, three databases were screened for published literature meeting specific inclusion criteria. Common themes expressed across the 32 resulting publications included user acceptability, product reliability, and privacy and security concerns.

Summary Implementation of evidence-based frameworks and guidelines is needed to guide future digital health research in vulnerable populations. Guidance should involve robust evaluations of acceptability, feasibility, and clinically meaningful use of digital health in diverse populations experiencing addiction-related health concerns.

Keywords Digital health · Mobile health · Telemedicine · Underserved in biomedical research · Addiction · Substance use disorder · Research ethics

Introduction

For nearly 60 years, the gradual adoption of telemedicine via information and communication technologies (ICTs) (e.g., tele and videoconferencing, email, wireless tools, phones) has created new opportunities to provide medical information and services to underserved and hard to reach populations(e.-g., racial and ethnic minorities, sexual and gender minorities, economically disadvantaged, rural populations) [1, 2]. The scope of telemedicine expanded with the emergence of novel tools like health information technologies (HIT) that utilize the patient's electronic health record (EHR) to communicate with and about a patient without the need for face to face contact [2, 3••, 4]. ICT-based approaches in health research and healthcare, which include computer-based technologies or "eHealth," and mobile technologies or "mHealth" and "digital health," respectively, quickly became pervasive over the past dozen years as cloud computing capabilities grew and popularity of smartphones increased [4–6]. Given nascent status of this growing field, it is not surprising that the terminology is evolving. While the use of telemedicine, eHealth, mHealth, and digital health might be used interchangeably, for this paper, we use the term "digital health."

As the information technology revolution charges ahead, the health sector is rapidly leveraging the availability of technologies to advance health promotion, diagnosis, and treatment. For example, wearable sensors can be used to

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enumerate physiologic metrics such as an individual's vital signs (electrodermal activity (EDA), heart rate, body temperature) or pertinent attributes of their environment [3••, 4, 7]. Mobile imaging can be used to provide high definition pictures of the individual's anatomy including the sequencing of an individual's germline DNA, RNA, microbiome, and epigenome to illuminate an individual's biology [2, 4]. Continuous glucose and blood pressure monitors via smart watches and smartphone-based imagining tools, including ultrasound, are among the few of many digital health tools developed in the last 5 years serving as virtual health assistants permitting for remote physical examinations [8]. Ubiquitous engagement with social network platforms (Facebook, Twitter, Instagram) allows the opportunity for scientists to observe human behavior and environmental influences that may amplify a health outcome or health behavior as well as deploy applicable interventions [5, 9]. Ecological momentary assessment is a digital strategy where a brief survey is deployed to a participate on their smartphone and used to assess constant states, behaviors, and experiences (biopsychosocial) of an individual in real time with minimal input required from the individual or clinician [5, 10, 11]. As a result, the quantity of data produced by digital health analytics can shine light on important health outcomes [12, 13].

Through the use of digital health approaches, the opportunity to deliver remote healthcare and reduce health inequity among those considered most vulnerable increases [2, 3, 14]. Many research efforts, including those applying digital health, historically lack inclusion of vulnerable populations (underrepresented populations in biomedical research (UBR)) leading to decreased generalizability in research findings and limited application and imprecise interpretations of medical discoveries [14]. Enduring differences in demographic factors such as race, ethnic group, income status, gender identity, age, sexual orientation, disability, sex, geographic location (rural), access to medical care, and health literacy contributes to current day health and healthcare disparities leading to health inequity [6, 14]. For example, across the USA, racial and ethnic minority groups experience inadequate access to quality healthcare, systemic racism, food and house insecurity, and disadvantaged employment and education opportunities, which hamper their potential for optimal health and wellness (e.g., systemic health inequity) [3••]. The scarcity of health equity assessment in public health research hinders the potential to translate clinically meaningful discoveries to UBR populations further exacerbating modern day systemic health inequity [15]. It is crucial to incorporate these individual differences to help guide more accurate prognosis, improve treatments, and assist in the evolving novel individualized therapies [14]. The understanding of how suitable digital health tools are to serve UBR needs is necessary to determine whether digital health serves as a promising solution for addressing health inequity in vulnerable populations [16].

In the last decade, research has shown growing global ownership of mobile phones and tablet devices with 61% of individuals worldwide claiming ownership of a mobile phone [17]. Further, in over 90% of Americans claiming ownership of a mobile phone in the USA, 71% report a low socioeconomic status (less than $30,0000 in US dollars) and 66% report a limited level of education (no more than a high school education) [18, 19]. Moreover, the use of mobile applications and mobile phones to retrieve health information is higher among racial and ethnic minorities compared to white counterparts [3••]. The prevalence of smartphone ownership has fueled the opportunity to enable remote and real-time health education, disease prevention, detection, treatment, and patient monitoring for many populations and may be particularly beneficial to more vulnerable populations due to greater access [20•, 21]. The evolution of digital technologies and the ubiquitous accessibility of the Internet allows for innovative, cost-effective, and unique opportunities to address countless health issues in vulnerable populations including substance use and addiction [20•]. Among the universal advantages are increased access to vulnerable populations, decreased informational barriers, opportunity for patient self-management, interactive contact between healthcare providers and patients, increased participant comfort related to perceived anonymity, and access to cost-effective health interventions [5, 6, 20•, 22•]. Over the past 5 years, a growing number of digital health tools and intervention strategies have been applied to prevention, treatment, and harm reduction interventions [20•]. However, most interventions lack inclusion of vulnerable populations, which contributes to limited generalizability and the meaningful use of the applications for betterment of health of vulnerable communities—further perpetuating health disparities [3••].

Utilization of digital health tools and strategies facilitates real-time intervention deployment and optimal substance use disorder (SUD) treatment. The ability to use digital health tools as mobile devices (smartphones and tablets), wearable devices (smartwatches, adherent patches, and other body worn or ingested sensors), and social media platforms allows for a combination of detection and assessment strategies of substance use and addiction-related behaviors [5, 23]. EMA can be used to gather self-reported data with minimal input from the individual or healthcare practitioner on craving, cues, and substance use while detecting episodes of substance use relapse in real time [23]. For example, physiological characteristics such as an elevated heart rate, increased electrodermal activity and decreased skin temperature, or changes in ECG are among the many patterns that may suggest relapse [23]. Geolocation via mobile apps may also be utilized in combination with the continuous physiological parameters collected to provide contextual basis and signal of substance use [5, 23]. With this, digital health allows for timely intervention from clinicians, which can trigger response to events via text

message or notification to a support group that an event has occurred [23]. Digital health provides the potential to generate machine learning algorithms to determine actionable biometric data and increases the ability to detect substance use and or addiction related outcomes [12, 13, 23].

While digital heath strategies appear promising for addiction- and substance use–related research, specifically in vulnerable populations, the rates of acceptability, feasibility, and reliability for the use of digital health must be considered. This includes identifying the reliability and validity of using digital health tools in addiction and substance use related research, particularly in vulnerable populations [24]. For example, researchers recently discovered smartwatches and other activity sensors provide unreliable heart rate monitoring in populations of color [3••], finding that the photoplethysmography sensors were unable to penetrate through dark skin tones and providing invalid heart rate measures [3••]. The dearth of socio-cultured tailored digital health interventions further propagates health inequities by establishing health benefits to one population and mounting health disparities in another [3••]. Thus, digital health tool developers and the researchers using these tools need to consider these factors, ideally during the product design phase to avoid barriers leading to health inequity in vulnerable populations who may benefit from digital health.

Further, the promising unprecedented scope of sensitive data collection using digital health is a prominent concern of vulnerable populations especially in the area of substance use research [25]. The inability to guarantee data anonymity and participant privacy poses unique ethical challenges for digital health developers and researchers requiring considerations in the design phase to mitigate risk of harm for users [22•, 25]. The realm of participant concerns including perceived legal, social, and economic harms contributes to the challenge of participant acceptability of digital health, particularly in substance use and addiction related interventions [25]. Legal concerns regarding data confidentiality, sharing, and privacy expectation are common concerns expressed by participants, particularly in illicit drug use, which may be of interest in both criminal and civil courts (e.g., family custody disputes) [22•]. Given the possible risks of harm combined with the rapid escalation of digital health research, it is essential to apply ethical frameworks to guide technology design and mitigate possible harms to vulnerable populations, which in turn exacerbate health inequity [26].

A goal of this study was to better understand how digital health is used in substance use and addiction research with a focus on vulnerable populations. To do this, we identified recent literature published on digital health research that focused on substance use and or addiction in vulnerable populations. Through our review of the resulting studies, we were able to assess the characteristics of these studies, including gaps present in the literature as well as potential ethical issues in using digital health strategies in substance use research and the contribution to health inequity in vulnerable populations.

Methods

The scientific literature used to explore these questions was identified via Google Scholar, the NIH RePORTER, and PubMed databases. Each database was reviewed to identify substance use– and or addiction-related publications reporting on the use of health technologies (e.g., mHealth, digital health, eHealth, telemedicine) used in research with populations underrepresented in biomedical research (UBR). For the purpose of this review, UBR, addiction, substance use, and digital health technologies were defined using the terms presented in Table 1 [14, 27–29]. Following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines, the search was performed January 20 through March 2, 2020 and was bracketed by literature published between 2015 and March 2, 2020 [30].

Seven primary search terms were identified to initiate the search, and six secondary search terms were used to expand on the research (see Fig. 1). The first ten results pages returned for each search term per database were reviewed for article titles and abstracts, which potentially met the inclusion criteria and exclusion criteria: (1) focused on a UBR population, (2) focused on an addiction or use of substance, (3) mentioned any type of digital health, and (4) not a review. The inclusion and exclusion criteria were applied at two stages of the review (see Fig. 1) [31]. At stage 1, one author read through the titles and abstracts of the articles resulting from the search strategy. If the titles and abstracts referenced the search terms (see Fig. 1) and the inclusion criteria were met, the article was imported into an Excel file. At stage 2, the same author read through each article in entirety to confirm articles that met the inclusion criteria. Articles were excluded if (1) they met the exclusion criteria of stage one, and (2) the full text was not available. Duplicates and articles that did not meet the inclusion criteria were removed.

Data were extracted from each article to describe: (1) characteristics of the study (including authors, geographic location study conducted, mHealth tools used, funding source, funding institution, year published, publishing journal, type of study, length of follow up and health outcome assessed), (2) characteristics of the target group (including participant characteristics, recruitment methods, participant inclusion/exclusion criteria, sample size, addiction type, UBR category assessed), (3) digital health tools and scales used to measure addiction outcome measure (including mHealth tools and methods used to collect measures, addiction type, types of measures collected using mhealth tools), and (4) study conclusions (including results

Q1 **Table 1** Terms and definitions used as part of the literature review inclusion criteria

Terms	Definitions
Addiction	Chronic dysfunction of the brain system which has the body crave a substance or behavior which is compulsive or obsessive (https://www.healthline.com/health/addiction)
Substance use	The use of drugs or alcohol including substances such as cigarettes, illegal drugs, prescription drugs, inhalants and solvents. (https://www.healthlinkbc.ca/substance-use)
Digital health technologies	Digital tools, technologies, and services that provide flexible, integrated, interoperable and digitally enabled care environments used in the practice of medicine and or public health. (https://www.himss.org/news/himss-defines-digital-health-global-healthcare-industry)
Underrepresented in biomedical research	Populations defined using the terms underrepresented, underserved, and or vulnerable. Populations of the following diversity categories: Blacks/African-Americans Hispanics/Latinos American Indians/Alaska Natives Asian Americans Native Hawaiians and other Pacific Islanders Other race and ethnicity Socioeconomically disadvantaged populations, i.e., annual household income (federal poverty level below 200%) Underserved rural populations Sexual and gender minorities Lack access to care Older adults and children Disability Educational attainment

and study limitations). Measurement domains were established to account for various measures assessed across the literature. We used guidance from the Network of Alcohol and Other Drugs Agencies (NADA) methodology to establish a theme for each measurement domain utilized in Table 2 [32]. Measurement data were categorized in the following domains: acceptability of digital health, attitudes of using digital health in substance use, behavior assessment, behavior and symptom identification, behavior severity and dependence, craving sensation, demographics, digital health accessibility, digital health reliability and validity, depression and anxiety, feasibility of digital health, general health, history/duration of behavior, mental health, medication history/adherence, participant engagement and willingness towards using digital health for treatment, participant engagement with healthcare provider or social group support, participant willingness to share data, psychological distress, privacy and security risk concerns, risk belief of relapse of behavior, self-esteem/self-efficacy/coping mechanisms, social and emotional well-being, and treatment and recovery.

Results

The initial search using the primary and secondary search terms defined in Fig. 1 retrieved a total of 50 articles. Primary search terms retrieved 33 articles, and secondary search terms retrieved 17 articles. After reviewing for duplicates and screening abstracts and full texts, 32 articles met the inclusion criteria. The NIH RePORTER identified most of the articles that met inclusion criteria (12/32, 38%) while PubMed (11/32, 34%) and Google Scholar (9/32, 28%) followed. Eleven of the manuscripts were published by Journal of Medical Internet Research (JMIR) (33%). BioMed Central published 4 studies (12%) while the remaining studies (55%) were dispersed among 15 other journals. The majority of studies were published in 2019 (15/32, 47%) and in 2018 (7/32, 21%), with the remaining published in 2015 and 2017 (8/32, 24%) and 2016 and 2020 (2/32, 6%), respectively.

With respect to study design, half of the studies were either cross-sectional (12/32, 39%) or feasibility pilots (7/32, 21%) that assessed the feasibility and acceptability of using digital health in vulnerable populations with regimented substance

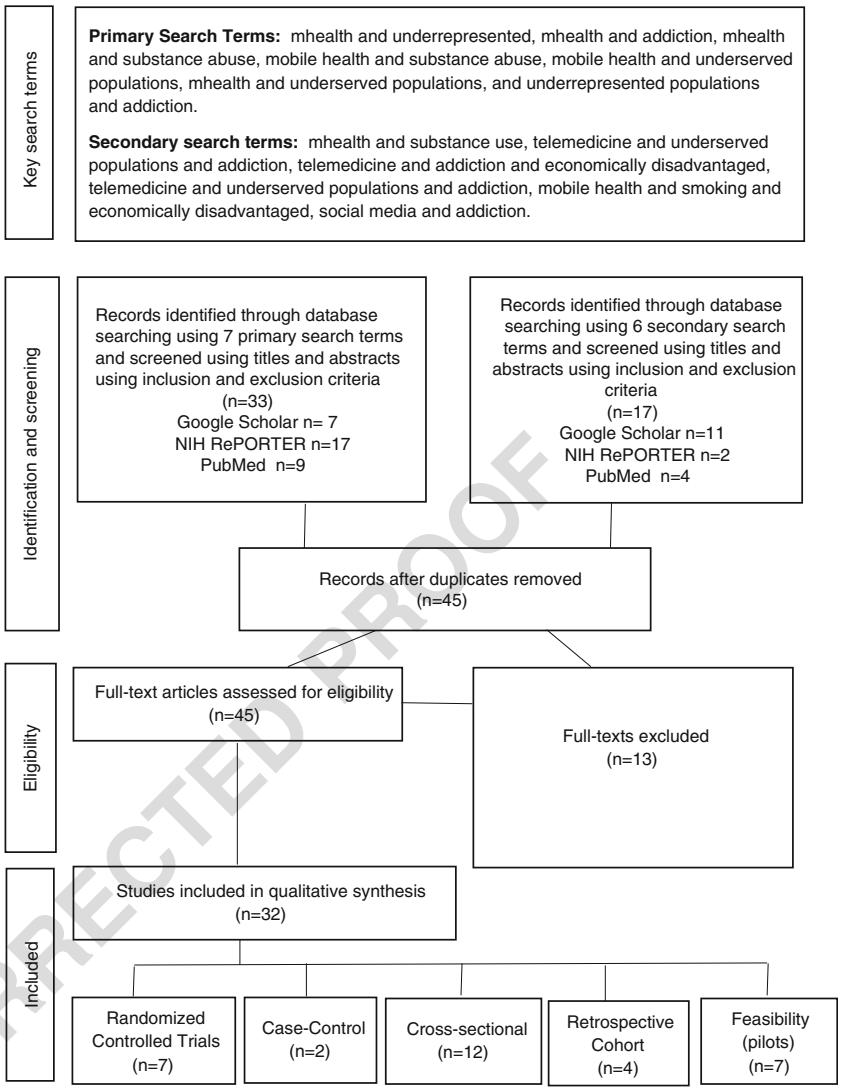

Fig. 1 Process of search term development and selection of data using the Preferred Reporting Items for Systematic Reviews and Meta-Analyses guidelines

use consumption, substance use disorder, or other types of addiction. Seven of the 32 studies were randomized control trials (21%). Fourteen (43%) of the articles assessed multiple types of substance use in one study, while the remaining studies focused on alcohol disorder (5/32, 16%), tobacco use (4/32, 13%), opioid use (3/32, 9%), eating disorders (3/32, 9%), cannabis use (1/33, 3%), and addiction of mobile phone use (1/33, 3%). We observed that many studies used digital health tools such as mobile phone applications (14/32, 42%) while other studies utilized tele-medicine (5/32, 15%), text message (4/32, 12%), Amazon mTurk (2/32, 6%), and social media platforms (1/32, 3%). The remaining six studies used paper- or web-based surveys (6/32, 19%). Given this, most of the research studies in our database utilized diverse study designs to assess various domains of digital health challenging the ability to establish effectiveness of an intervention.

The studies enrolled a wide range of vulnerable populations. Table 3 shows the various categories of vulnerable populations assessed per study. Seven of the studies (21%) focused on the inclusion of populations of racial and ethnic minorities, while five of the studies (15%) focused on the combination of inclusion of multiple categories of vulnerable populations, which included racial and ethnic minorities, populations that are economically disadvantaged, populations of lower educational attainment, and geographically rural populations. Many studies focused on adolescents and children (6/32, 18%) while the remainder of studies focused specifically on sexual and gender minorities (3/32, 9%), vulnerable populations and/or underserved groups (6/32, 18%) (The studies explicitly utilized the terms vulnerable populations and underserved groups to explain the population characteristics.), populations of low educational attainment and economically disadvantaged (3/32, 9%), and medically underserved populations (1/32, 3%). Given the diverse subsets of vulnerable populations and substance use and addiction behaviors assessed, it is challenging to synthesize the effectiveness of the research at a population level due to the absence of evidence-based framework implementation in the study design.

t2.1 **Table 2** Measurement domains and definitions adapted from Network of Alcohol and Other Drugs Agencies (NADA) measurement categories [28] and results

	Measurement domain	Types of measures included in domain	Number and percent of studies utilizing measurement domain
t2.3	Acceptability of digital health	Measures of the acceptability of digital health as a health promotion, screening and management tool	14/32, 44%
t2.4	Attitudes of using digital health in substance use	Measures assessing the attitude of the use of digital health in substance use and addiction-related research	14/32, 44%
t2.5	Behavior severity and dependence	Severity and or dependence of substance use and or addiction	26/32, 81%
t2.6	Behavior and symptom identification	Screening and outcome measures used to identify symptoms of behavior, withdrawal, misuse	25/32, 75%
t2.7	Behavior assessment	Ongoing measures of focused on behavior frequency, dependence, misuse and use.	25/32,78%
t2.8	Craving sensation	Substance use and addiction craving measures	17/32, 53%
t2.9	Demographics	Global measures that include	32/32, 100%
t2.10	Digital health accessibility	Accessibility of the digital health tool	11/32, 34%
t2.11	Digital health reliability and validity	Reliability of the digital health tool or intervention Content validity of how adequately the measures of items reflects objective Construct validity of behavior measures used	12/32, 38%
t2.12	Depression and anxiety	Specific mental health measures related to depression and anxiety that measure symptoms	8/32, 25%
t2.13	Feasibility of digital health	Usability of the digital health tool Feasibility of using the digital health tool Assessment of use of digital health tool	11/32, 34%
t2.14	General health	Global measures of health status (psychological, physical, social)	22/32, 69%
t2.15	History/duration of behavior	General health measures specific to the duration of substance use and or addiction-related behavior	21/32, 66%
t2.16	Mental Health	General mental health measures	7/32, 22%
t2.17	Medication history	General health measures related to current and previous medication adherence	2/32, 6%
t2.18	Participant engagement and willingness towards using digital health for treatment	Global measures that measure participant engagement of use of digital health as health promotion and health management tool	14/32, 43%
t2.19	Participant engagement with healthcare Provider or social group support	General measures of social support and or social functioning via digital health	20/32, 63%
t2.20	Participant willingness to share data.	Measures of participant willingness to share their sensitive data collected by digital health with other stakeholders	11/32, 33%
t2.21	Psychological distress	Specific psychological distress mental health measures that measure symptoms	9/32, 28%
t2.22	Privacy and security risk concerns	Measures of research ethics including the privacy, security and risk concerns of using digital health as health promotion and or health management tools	11/32, 34%
t2.23	Risk belief of relapse of behavior	Severity of substance misuse and or addiction measures related to one's risk belief of relapse	16/32, 48%
t2.24	Self-esteem/self-efficacy/coping mechanisms	Positive mental health measures related to empowerment	17/32, 53%
t2.25	Social and emotional well-being	Positive mental health measures in areas of wellbeing	15/32, 47%
t2.26	Treatment and recovery	Positive mental health measures specific to recovery and rehabilitation	20/32, 63%

The literature review identified 24 common measurement domains, which include measures of health outcomes and technology evaluation measures used across the studies for data collection and analysis (Table 2). Among the common measurement domains assessed were behavior severity and or dependence (26/32, 81%), behavior assessment (25/32, 78%), behavior and symptom identification (25/32, 75%), general health (22/32, 69%), history and duration of behavior (21/32, 66%, treatment and recovery (20/32, 63%), participant engagement and willingness towards using digital health for treatment (20/32, 63%), craving sensation (17/32, 53%),risk belief of relapse of behavior (16/32, 48%), acceptability of digital health (14/32, 44%), and attitudes of digital health use in substance use interventions (14/32, 44%) (Table 2). Given this, most

t3.1 **Table 3** Brief description of digital health studies included in this review

t3.2 Author/year	Behavior	Tools used	UBR categories included in sample	Significant findings	Limitations
t3.3 Anderson et al. (2015)	Anorexia nervosa	Telemedicine: video chat and counseling	Adolescents	Family-based intervention using telemedicine may be effective in meeting demands of adolescents and families living in rural locations.	Small sample size and the results are not generalizable.
t3.4 Bagot et al. (2019)	Cannabis use	Mobile app	Adolescents	Integrating content, language, interfaces, delivery systems, and rewards with which adolescents who use cannabis are familiar, engage with on a day-to-day basis, and identify as relevant, may increase treatment engagement and retention for adolescents in substance use treatment.	The results are not generalizable. There are a low number of race and ethnic minorities in sample and did not query adolescents about alternative platforms for intervention other than an app delivered via phone and not query about access to the app.
t3.5 Bonar et al. (2019)	Substance use and risky sexual behavior	Text message, semi-structured interviews, and survey	Race and ethnic minorities African-American Gender	Perceived benefits (e.g., altruism) were experienced more than risks in using text messages for substance use treatment in patients 18–25 years of age.	Small sample size, longer follow-up required, self-report, measures lacked psychometric properties.
t3.6 Brown et al. (2019)	Cocaine use	Survey to assess attitudes towards use of digital health for substance use treatment.	Vulnerable, underserved	Text message reminders preferred for reasons of privacy, accessibility, and economizing phone minutes for treatment for patients with HIV.	The results are not generalizable. The study had a small sample size and focused on populations 40–60 years of age.
t3.7 Cordova et al. (2015)	Substance use	Digital interview to assess healthcare provider trust worthiness in digital health in substance use interventions.	Adolescents, gender, African-American, vulnerable populations	Five themes emerged from populations: Acceptability of the mHealth app to adolescents in primary care, inclusion of a risk assessment to improve clinician-adolescent HIV/STI and drug use communication, incorporation of culturally specific HIV/STI and drug use content, incorporation of interactive aspects in the app to engage youth, and perspectives on the appearance of the app.	Cross-sectional and represents the clinician's perspective.
t3.8 Curtis et al. (2019)	Substance use	Survey—Facebook platform—SHE RECOVERS group	Female, transgender, non-binary	The use of social media group platforms may be a vital tool for expanding recovery supports for those lacking in access and availability because of geography,	The results are not generalizable.

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t3.9 **Table 3** (continued)

	Author/year	Behavior	Tools used	UBR categories included in sample	Significant findings	Limitations
					social determinants, or other barriers.	
t3.9	Curtis et al. (2019)	Substance use	Survey—social media use for substance use treatment	Adolescents. Generation Z	Cross-platform solutions capable of transcending generational preferences are necessary and one-size-fits-all digital interventions should be avoided.	The results are not generalizable. There is a gap in collection data between generations, each generation collected in separate part of the USA.
t3.10	Genz et al. (2015)	Substance use- injecting drugs	Survey to assess patterns of mobile phone ownership, internet use, and willingness to provide health information	Medically underserved, African-American, vulnerable populations	Utilization of information and communication technology among this cohort of people who inject drugs was reported at a lower level than what has been estimated for the general US population.	Cross-sectional and self-report.
t3.11	Glass et al. (2017)	Alcohol use	A-CHESS mobile app	African-American	Mobile app may significantly improve reduction of substance use during at risk days.	Self-report. Measures collected did not use validated instruments, and not assess a broad range of services such as inpatient treatment.
t3.12	Guille et al. (2020)	Opioid use	Tele-medicine post-partum follow up	Pregnant women	Potential use of digital health in pregnant women who suffer from substance use disorder.	Participants followed up for only 2-month post- partum.
t3.13	Harder, Musau, Musyimi, Ndetei, and Mutiso (2019)	Alcohol use	Motivational interviewing via mobile app	Rural Kenyan	Mobile phone-based motivational interviewing may be an effective treatment for alcohol use problems among adults visiting primary care in Kenya. Providing mobile motivational interviewing may help clinicians in rural areas to reach patients needing treatment for alcohol use problems.	The results are not generalizable.
t3.14	Haug et al. (2017)	Substance use	Mobile phone based training program i.e. Ready4Life with text message	Adolescents	The feasibility and potential benefits to deliver mobile health intervention among participants with substance abuse disorder.	Restricted to adolescents without regular cigarette use, only 50% of students completed follow up biasing evaluation of program and the results of efficacy.
t3.15	Hochstatter et al. (2019)	Opioid use	Weekly electronic surveys via A-CHESS mobile app	Economically disadvantaged and low education attainment	A-CHESS allows for implementation of multiple services in addiction treatment while collecting data related to substance use.	The results are not generalizable. Lack validity and reliability of HCV care measures.

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t3.16 **Table 3** (continued)

	Author/year	Behavior	Tools used	UBR categories included in sample	Significant findings	Limitations
t3.17	Hooper, Carpenter, and Salmon (2019)	Tobacco use.	Telemedicine—web coach, web-entry tobacco cessation program	African-American, Hispanic/Latino, Asian, Alaska Native, economically disadvantaged, low education attainment	Digital inequalities exist in web-based tobacco cessation services. Findings have implications for the development and implementation of digital tobacco interventions for racial/ethnic minority communities.	1-year snapshot in 2015 so causality cannot be inferred. Rapid changes in technology, access, and comfort using digital applications.
t3.18	Johnson et al. (2019)	Hookah smoking	Amazon mTurk—tailored messaging	Economically disadvantaged, low education attainment, gender	Tailored messages effective in younger populations who smoke hookah.	Cross-sectional study design. Lack data regarding effectiveness for long-term engagement.
t3.19	Liang, Han, Du, Zhao, and Hser (2017)	Substance use	S-Health mobile app, text message and surveys	Low education attainment, China	Pilot demonstrated the feasibility and potential benefits to deliver mobile health intervention among participants with substance use disorder.	The results are not generalizable. Follow up was only for 1 month. Possibility of behaviors not being tracked in real-time.
t3.20	Mares et al. (2016)	Substance use	SEVA mobile app	Economically disadvantaged Underinsured Race and ethnicity Individuals who attend Federal Health Qualified Centers	Implementation of SEVA showed sustained positive use of app in Federally Qualified Health Center populations.	Self-report. Represent clinicians experience and perceptions.
t3.21	McKay et al. (2018)	Alcohol use	A-CHESS and TMC mobile app	African-American Hispanic/Latino	Possible benefits for mobile automated recovery support.	Cannot determine which of the mobile apps allowed for treatment effects. Counselor turnover follow up period not long enough.
t3.22	Pretlow, Stock, Roeger, Allison (2019)	Binge eating	Mobile app	Adolescents	Significant decrease in zBMI and overall maintenance of weight loss with using a mobile app.	The results are not generalizable and unvalidated participant questionnaires and scales.
t3.23	Quanbeck et al. (2018)	Substance use	SEVA mobile app	Economically disadvantaged Underinsured Race and ethnicity Individuals who attend Federal Health Qualified Centers	Possible benefits for mobile automated treatment and recovery support.	Selection bias, self-report, could not retrieve race and ethnic group data for substance use disorder, not reproducible.
t3.24	Rupinder, Legha, Moore, Ling, Novins, and Shore (2019)	Alcohol use	Tele-medicine: telepsychiatry	Alaska Native	Telepsychiatry help assess many factors causing post-traumatic stress disorder and allowed participants to remain engaged longer and more likely to complete treatment.	The results are not generalizable.
		Substance use		Hispanic/Latino		

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t3.26 **Table 3** (continued)

	Author/year	Behavior	Tools used	UBR categories included in sample	Significant findings	Limitations
t3.25	Ryan-Pettes, Lange, and Magnuson (2018)		Survey—digital health–based support		Mobile phones are feasible and desired to deliver treatments that provide support to caregivers of teens discharged from substance use treatment.	Cross-sectional. The results are not generalizable.
t3.26	Shrestha, Karkib, and C openhaverb (2017)	Substance use	Paper survey—assess interest in using digital health in drug treatment settings	Sexual orientation, vulnerable	Demonstrated high-risk people who use drugs are interested in using mHealth based tools as an HIV prevention approach within a common type of drug treatment	Self-reported data and results may be subject to social desirability bias, cross-sectional studies limit ability to infer causal relationship, measure used to assess NCI, i.e., BINI has yet to be validated against a comprehensive neuropsychological testing battery, and results are not generalizable.
t3.27	Sillice et al. (2018)	Mobile phone use addiction.	Amazon mTurk-survey	African-American Hispanic/Latino	There are differences in perspectives and attitudes on user preferences on digital health.	Limited prediction of acceptance of digital health approaches.
t3.28	Spears et al. (2019)	Tobacco use	iQuit Mindfully mobile text message	Race and ethnic minorities and economically disadvantaged	Text messages and social support may serve as beneficial coping strategies.	Small sample size and cannot determine feasibility.
t3.29	Tofighi et al. (2019)	Substance use	Survey to assess digital health use, privacy concerns and barriers.	African-American Homelessness Economically disadvantaged	The use of digital health for treatment and rehab in homeless and low income populations with HIV or Hepatitis C may be feasible.	Small sample size, not generalizable, non-validated surveys used, lack of participant use assessment, feasibility, and clinical impact.
t3.30	Vidmar et al. (2018)	Addictive eating	EMPOWER mobile app	Adolescents Hispanic/Latino African-American Female.	100% app retention from participants and potential lowering cost in treatment using digital health apps for eating addiction	Small sample size, no randomization allowing for the selection of motivated patients. Study not designed to test efficacy.
t3.31	Vidrine et al. (2018)	Tobacco use	Nicotine replacement therapy, text message, phone counseling	Economically disadvantaged, African-American, Hispanic/Latino, Female, education attainment.	Text messaging alone may not increase cessation rates for socioeconomically disadvantaged smokers. Text messaging plus proactive counseling may be an efficacious option	Error in intervention group assignments.
t3.32	Weintraub et al. (2018)	Opioid use	MAT video-teleconferencing	Rural, Underserved	Treatment with buprenorphine can be delivered effective with telemedicine to patients with opioid use disorder in rural drug treatment program.	Lack comparison groups, demonstrated issues with sustainability, inability to systematically determine who withdrew from program, and high

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t3.33 **Table 3** (continued)

Author/year	Behavior	Tools used	UBR categories included in sample	Significant findings	Limitations
					percentage of sample state opioid abstinence.
t3.33 Yang et al. (2015)	Alcohol use and HIV related behaviors	Mobile App- EMA	African-American Men who have sex with men.	Demonstrated feasibility and acceptability of use of EMA methods for collecting data on alcohol use and promote substance use reduction in specified population.	Small sample size and study under powdered.
t3.34 Yoo, Shah, Chinh, Ming-Yuan, and Gustafson (2019)	Alcohol use	A-CHESS mobile app and discussion group message	African-American, low education attainment, economically disadvantaged.	Receiving emotional support via app from healthcare providers improved coping self-efficacy protecting patients from harmful effects of emotional distress on risking drinking.	Did not examine different types of social support. Solely focused on discussion board formatted discussion.
t3.35 Zhang et al. (2019)	Substance use	Mobile app	Chinese Singaporean Malay Low education attainment	The results demonstrate feasibility and accessibility of recruiting participants to undertake attention bias modification interventions via mobile app. Improvements in app are needed.	The results are not generalizable.

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studies focused on overall behavioral assessment and treatment and demonstrated potential feasible treatment tools. For example, the Addiction Comprehensive Health Enhancement Support System App (ACHESS) demonstrated a positive effect on alcoholism treatment utilizing features such as GPS technology to track locations where an individual usually is at high risk of alcohol consumption and automate support text messages to prevent relapse [33]. Moreover, smartphone-based support groups via ACHESS have served as resourceful tools for alcoholism treatment in Hispanic/Latino, African-American, and lower SES populations reducing social cues allowing individuals to feel comfortable in discussing stigmatized topics [33–35]. Further, many studies utilized a type of mobile phone application with EMA capabilities and text message treatment via mobile phone or telemedicine ($n = 5$, 16%). For example, EMA via a mobile app was utilized to assess alcohol use in African-American men who have sex with men with HIV and found favorable results of self-reported acceptability and feasibility of the tool [36]. Moreover, web-based and smartphone text message–based smoking cessation programs such as Web Coach provide evidence-based strategies for tobacco cessation tailoring treatments on an individual scale in racial and ethnic minorities of lower SES [37, 38]. Additionally, the web- and text-based messaging interventions between patients of various UBR populations and healthcare providers demonstrated potential benefits in support for quitting tobacco smoking, alcohol use, cannabis use, cocaine use, other illicit drug use, and addiction [21, 25, 37–39].

Acceptability of the use of digital health was a common domain assessed ($n = 11$, 32%). The definition of acceptability of digital health depended on the stakeholder and health behavior and or outcome. In one case, researchers used a 10-point scale to measure acceptability of text messaging for treatment and found that 76% of the racial/ethnic diverse smokers from a lower socio-economic background rated the use that approach favorably. The iQuit Mindfully text messaging program for smoking cessation treatment reported a 22% smoking cessation rate at end of treatment and 19% at 1-month follow-up [40]. Similarly, SEVA (a Sanskrit word meaning "self-caring") [41], a digital health system assisting with substance use among patients from federally qualified health centers, showed an program adoption rate between 53 and 60% over a 12-month period resulting in a 44% reduction in risky drinking days and 34% reduction in illicit drug-use days [41]. Overall, the results demonstrate potential adoption of digital health in vulnerable populations in areas of substance use and addiction research.

Discussion

The literature reviewed for this research focused on the design and impact of digital health tools in substance use and addiction in vulnerable populations between 2015 and early 2020. Using the combination of three databases and 13 search terms, our literature search resulted in 32 research studies that focused on a variety of substances and or addictions in various categories of vulnerable populations. The breadth of search terms selected arose from popular terms used to describe digital health, vulnerable populations, addiction, and substance use. Although additional search terms may exist, the search terms utilized provided sufficient evidence of research published over the past 5 years of digital health applied to substance use and/or addiction in vulnerable populations. Results of this review reveal a growing interest in leveraging digital health in substance use– and addiction-related research.

Studies using a cross-sectional design dominated the research evaluated ($n = 12$, 38%) and provided insights regarding the acceptability, feasibility, and reliability of digital health applied to substance use– and addiction-related research [24, 41–50, 51•]. Randomized controlled trials ($n = 7$, 22%) [33–35, 37, 39, 52, 53] and feasibility pilot trials ($n = 7$, 22%) [36, 40, 54–58] followed highlighting a subset of trends among digital health used in research among diverse categories of vulnerable populations. The need for population-based research is required to assess potential barriers influenced by demographic characteristics prior to assessing the effectiveness of implementing a technology into the community [51•]. Throughout the literature, digital health demonstrated increased access to health research and services to vulnerable populations by removing barriers of geography and perceived stigma associated with addiction and or substance use treatment and recovery [59].

The use of digital health strategies introduces ethical, legal/regulatory, and social implications (ELSI) in both research and clinical practice and, particularly, in the area of substance use and addiction. The ELSI associated with the studies in our database included acceptability within the targeted populations, the validity and reliability of the measurement tools, participant privacy, data management (e.g., collection, storage and sharing protocols), potential legal liability, and mandated reporting requirements. As these issues influence the integrity of the research and subsequent knowledge gained, it is a positive finding that the studies included in our review attended to barriers and facilitators to adoption, usability, efficacy, privacy, and other factors that affect the risk to benefit calculus.

Participant privacy concerns and willingness to share data are consistent themes expressed across literature retrieved [24, 25, 43–47, 51•, 52, 60, 61]. A barrier to adoption was voiced by healthcare practitioners using SEVA who expressed legal and liability concerns due to making clinical decisions via mobile platform in lieu of administering directly to the patient during an in person visit [44]. Protecting participant privacy and data confidentiality is more challenging in digital health and can interfere with clinician and patient acceptability and subsequent adoption. For example, adolescents in the

community-engaged HIV/STI and drug abuse prevention primary care program worried about the confidentiality of their information collected during qualitative interviews [45].

The clinical application of digital health technology and the liability of using digital health in treatment, recovery, and self-monitoring settings are common concerns among clinicians [22•, 44]. The reliability of digital health tools, measures, and scales used challenges the acceptability of adoption of digital health [35, 45]. Generally speaking, little evidence exists regarding the reliability and validity of digital health tools and measures, and this is true within addiction and substance use digital health research. The measurement domains utilized to measure outcomes across studies were inconsistent, contributing to low confidence in healthcare providers that digital health strategies are a trustworthy solution. Given the number of digital health tools that lack validation and empirical evidence on safety and efficacy, clinicians fear an increased risk of potential harm to patients particularly when suggesting digital solutions to support self-management [22•, 44–46]. For example, certain features such as alerts on mobile applications may inadvertently induce a craving [22•]. Digital health tools are not always clinically validated to determine the precision of the tool [62]. To further complicate matters, validation is defined differently across stakeholders (e.g., app developer, scientists) [62]. Factors such as verification of sensor performance, analytical validation of the performance of the algorithm, and clinical validation of acceptable meaningful and accurate measures in the specified populations and context of use need to be considered when validating a digital health tool [62, 63]. Further, the concern to use digital health tools for clinical purposes to communicate results and serve as treatment and or self-management in lieu of inpatient visits for high risk populations raises liability and related legal concerns [22•, 44, 46]. Factors such as the risk of a tool inaccurately reporting symptoms or not reporting suicide ideation in a timely manner and/or providing a treatment plan without physically seeing the patient and relying on the patient to self-report are but a few examples of important considerations [22•, 46].

Digital health presents unprecedented opportunities to vastly scale self-monitoring, but there is a massive gap of inclusion of inter-method reliability and validity assessment of the tools and scales utilized, particularly in substance use– and addiction-related treatment and self-monitoring limiting the ability to determine the generalizability of the results. Of the studies that met the inclusion criteria, 41% claimed that their results were not generalizable [24, 39, 46, 48–50, 51•, 52–54, 57, 58, 60]. These studies lacked the inclusion of evidence-based frameworks and guidelines necessary to establish the reliability of measures needed to provide clinical evidence of efficacy, safety, and effectiveness of the use of digital health tools prior to the implementation in a clinical and non-clinical setting in diverse populations. Further, the inconsistency in the taxonomy of measurement domains limits the ability to conclude generalizable findings. For example, studies claim to measure acceptability of digital health but define acceptability in various ways. It is essential to establish standard taxonomy for measurement domains to consistently and accurately measure factors such as behavior change technique within established constructs. Establishing digital health frameworks that clarify underlying mechanisms linking research and intervention design features, effective psychotherapeutic approaches and clinical outcomes are needed to establish clinical evidence of efficacy of use of digital health [23]. With this, digital health can be tailored to demographic trends in diverse populations and allow for personalization of interventions and use of tools.

While researchers are adopting digital health technologies in substance use and addiction-related research, minimal empirical data exists to guide the assessment of risks and benefits among vulnerable populations who participate research. Given the sensitivity and granularity of digital health data, it is critical for researchers to gather these insights at an individual and community level prior to implementing digital health focused on stigmatizing health concerns like substance use and addiction, especially in populations historically underrepresented [45]. Efforts to create decision-support tools to assist the digital health community are forming. One example is the Digital Health Checklist that guides the researcher in evaluating the ethical dimensions of respect for persons, beneficence, and justice as a foundation and, more specifically, issues that may be associated with privacy, data management, usability, access, and the risks to benefit evaluation [64]. Having tools to help researchers and clinicians make informed decisions about the health technologies are critical and should be sensitive to issues that may be unique to a specific population (e.g., older adults, men who have sex with men).

While our review was rigorous and comprehensive, several limitations were identified in research evaluated within the scope of our review. The search terms utilized may have limited the findings included in our review and the measurement domains assessed were grouped in common themes developed by the author while using NADA guidelines of how scales were grouped. This introduces selection bias and literature may be grouped differently by other researchers. Most studies lacked the assessment of effectiveness of the intervention and research. Moreover, the literature was cross-sectional of nature and relied on self-report leading to potential recall bias. Further, the short duration of interventions limited the ability to accurately determine potential causal relationships and sustained use of digital health. The lack of generalizable results across nearly half of studies evaluated is particularly alarming. Clearly, rigorous evidence-based research is needed prior to promoting digital health as healthcare solution generally speaking and, in particular, with vulnerable populations with mental health and other stigmatizing conditions.

Conclusions

This review serves as an essential step in the assessment of current user trends, experiences, and perceptions of digital health providing a foundation to inform future research and digital health development. Digital health holds the potential to address health inequity in UBR populations, but there are several factors that need to be considered prior to deploying digital health as solution in health promotion, diagnosis and treatment. The analysis of demographic trends provides an opportunity to assess preferred digital health features among populations experiencing addiction and or substance use. With the term UBR being arbitrary, it is important to consider origins of health disparities and the social determinants of health when designing digital health tools and interventions. These psychosocial factors serve as the foundation of majority of health inequities and are crucial for predicting health behavior and outcomes [3••]. Given the numerous types of data that can be collected on individuals, there is a need for patient-centered, digital interventions, particularly in stigmatized populations, to ensure meaningful use of the tools. With this, stakeholders need to consider a human-centered design approach and engaging diverse populations during the early development phase of digital health tools prior to promoting as modernized solutions to achieve health equity [3••].

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Compliance with Ethical Standards

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

Human Subjects This article does not contain any studies with human or animal subjects performed by any of the authors.

References

Papers of particular interest, published recently, have been highlighted as:

- • Of importance
- •• Of major importance

1. Raŝković D, Milenković A, De Groen PC, Jovanov E. From telemedicine to ubiquitous M-Health. Biomedical Information Technology. 2008:479–96.
2. LeRouge C, Garfield MJ. Crossing the telemedicine chasm: have the U.S. barriers to widespread adoption of telemedicine been significantly reduced? Int J Environ Res Public Health. 2013;10(12):6472–84.
3.•• Brewer LPC, Fortuna KL, Jones C, Walker R, Hayes SN, Patten CA, et al. Back to the future: achieving health equity through health informatics and digital health. JMIR mHealth uHealth. 2020;8(1):e14512 **The Brewer et al. (2020) manucript provided crucial context regarding health inequity experienced from a community-based approach lens which is essential in all research.**
4. Topol EJ, Steinhubl SR, Torkamani A. Digital medical tools and sensors. JAMA. 2015;313(4):353–4.
5. Carreiro S, Chai PR, Carey J, Lai J, Smelson D, Boyer EW. mHealth for the detection and intervention in adolescent and young adult substance use disorder. Curr Addict Reports. 2018;5(2):110–9.
6. Lai J, Chapman B, Carreiro S, Costigan A, Rodriguez Perez K, Gonzalez G, et al. A pilot study of a telemedicine-based substance use disorder evaluation to enhance access to treatment following near-fatal opioid overdose. Proc 53rd Hawaii Int Conf Syst Sci. 2020.
7. Pilemalm S, Timpka T. Third generation participatory design in health informatics-making user participation applicable to large-scale information system projects. J Biomed Inform. 2008;41(2):327–39.
8. Topol E. The patient will see you now: the future of medicine is in your hands. New York: Basic Books; 2015.
9. Nebeker C, Dunseath SE, Linares-Orozco R. A retrospective analysis of NIH-funded digital health research using social media platforms. Digit Heal. 2020;6(January).
10. Stone AA, Shiffman S. Ecological momentary assessment (EMA) in behavioral medicine. Ann Behav Med. 1994;16(3):199–202. https://doi.org/10.1093/abm/16.3.199.
11. Burke L, Shiffman S, Music E, Styn M, Kriska A, Smailagic A, et al. Ecological momentary assessment in behavioral research: addressing technological and human participant challenges. J Med Internet Res. 2017;19(3).
12. Mohr D, Zhang M, Schueller S. Personal sensing: understanding mental health using ubiquitous sensors and machine learning. Annu Rev Clin Psychol. 2017;13:23–47. https://doi.org/10.1146/annurev-clinpsy-032816-044949.
13. Bui A, Van Horn J. Envisioning the future of 'big data' biomedicine. J Biomed Inform. 2017;69:115–7. https://doi.org/10.1016/j.jbi.2017.03.017.
14. All T, Investigators P, All T, Obama PB, Initiative PM, Institutes N, et al. Special report: the "all of us" research program. 2019.
15. Bailey ZD, Krieger N, Agénor M, Graves J, Linos N, Bassett MT. Structural racism and health inequities in the USA: evidence and interventions. Lancet. 2017;389(10077):1453–63. https://doi.org/10.1016/S0140-6736(17)30569-X.
16. Stowell E, Lyson MC, Saksono H, Wurth RC, Jimison H, Pavel M, et al. Designing and evaluating mHealth interventions for vulnerable populations: A systematic review. Conf Hum Factors Comput Syst - Proc. 2018:1–17.
17. BankMyCell. No Title [Internet]. UNE 2020 mobile user statistics: discover the number of phones in the world & smartphone penetration by country or region 2020. https://www.bankmycell.com/blog/how-many-phones-are-in-the-world. Q2
18. Center PR. No Title [Internet]. 2019 [cited 2020 Nov 4]. https://www.pewresearch.org/internet/fact-sheet/mobile/.
19. Anderson BYM. Monica Anderson. Pew Res Cent. 2015;(June):1–26 http://www.pewinternet.org/2015/10/29/technology-device-ownership-2015/.
20.• Blankers M, Mujcic A. E-health and m-health: using new technologies to respond to drug problems. Eur Monit Cent Drugs Drug Addict. 2017:1–20 www.bct-taxonomy.com. **The Blankers et al. (2017) manuscripts provided insights on which evidence-based tools are currently utilized in substance use interventions. This provided a foundation of knowledge for the author of what evidence-based tools are out there and where gaps in the literature exists regarding the inclusion of vulnerable populations.**
21. Haug S, Paz Castro R, Meyer C, Filler A, Kowatsch T, Schaub MP. A mobile phone-based life skills training program for substance use

prevention among adolescents: pre-post study on the acceptance and potential effectiveness of the program, Ready4life. JMIR mHealth uHealth. 2017;5(10):e143.

22.• Capon H, Hall W, Fry C, Carter A. Realising the technological promise of smartphones in addiction research and treatment: an ethical review. Int J Drug Policy. 2016;36:47–57. https://doi.org/10.1016/j.drugpo.2016.05.013 **The Capon et al. (2016) provided perspective on ethical layers needed to be considered in a digital health study design focused on substance use and addiction. This allowed the authors to assess the literature collected from a ethical and legal perspective.**

23. Tofighi B, Chemi C, Ruiz-Valcarcel J, Hein P, Hu L. Smartphone apps targeting alcohol and illicit substance use: systematic search in in commercial app stores and critical content analysis. J Med Internet Res. 2019;21(4).

24. Bagot K, Hodgdon E, Sidhu N, Patrick K, Kelly M, Lu Y, et al. End user–informed mobile health intervention development for adolescent cannabis use disorder: qualitative study. J Med Internet Res. 2019;21(10):1–13.

25. Bonar E, Koocher G, Benoit M, Collins L, Cranford J, Walton M. *Ethics Behav*. 2018;28(3):218–34. https://doi.org/10.1080/10508422.2017.1293541f.

26. Nebeker C, Murray K, Holub C, Haughton J, Arredondo EM. Acceptance of mobile health in communities underrepresented in biomedical research: barriers and ethical considerations for scientists. JMIR mHealth uHealth. 2017;5(6):e87.

27. Tyler TJL and M. What is addiction? [Internet]. 2016 [cited 2020 Nov 4]. Available from: https://www.healthline.com/health/addiction.

28. Snowdon A. HIMSS defines digital health for the global healthcare industry [Internet]. 2020 [cited 2020 Nov 4]. Available from: https://www.himss.org/news/himss-defines-digital-health-global-healthcare-industry.

29. British Columbia Health Link. Substance use [Internet]. 2019 [cited 2020 Nov 4]. Available from: https://www.healthlinkbc.ca/substance-use.

30. PRISMA transparent reporting of systematic reviews and meta-analyses [Internet]. 2015. Available from: http://www.prisma-statement.org/PRISMAStatement/.

31. Møller A, Bissenbakker KH, Arreskov AB, Brodersen J. Specific measures of quality of life in patients with multimorbidity in primary healthcare: a systematic review on patient-reported outcome measures' adequacy of measurement. Patient Relat Outcome Meas. 2020;11:1–10.

32. Information MH, Project M. A review of screening, assessment and outcome measures for drug and alcohol settings. 2009.

33. McKay JR, Gustafson DH, Ivey M, McTavish F, Pe-Romashko K, Curtis B, et al. Effects of automated smartphone mobile recovery support and telephone continuing care in the treatment of alcohol use disorder: study protocol for a randomized controlled trial. Trials. 2018;19(1):1–15.

34. Glass J, McKay J, Gustafson D, Kornfiled R, Rathouz P, McTavish F, et al. Treatment seeking as a mechanism of change in a randomized controlled trial of a mobile health intervention to support recovery from alcohol use disorders. J Subst Abus Treat. 2017;77:57–66. https://doi.org/10.1016/j.jsat.2017.03.011.

35. Yoo W, Shah DV, Chih MY, Gustafson DH. A smartphone-based support group for alcoholism: effects of giving and receiving emotional support on coping self-efficacy and risky drinking. Health Informatics J. 2019:146045821988840.

36. Yang C, Linas B, Kirk G, Bollinger R, Chang L, Chander G, et al. Feasibility and acceptability of smartphone-based ecological momentary assessment of alcohol use among African American men who have sex with men in Baltimore. JMIR mHealth uHealth. 2015;3(2):e67.

37. Vidrine DJ, Frank-Pearce SG, Vidrine JI, Tahay PD, Marani SK, Chen S, et al. Efficacy of mobile phone-delivered smoking cessation interventions for socioeconomically disadvantaged individuals: a randomized clinical trial. JAMA Intern Med. 2019;179(2):167–74.

38. Hooper MW, Carpenter KM, Salmon EE. Web-based tobacco cessation interventions and digital inequality across US racial/ethnic groups. Ethn Dis. 2019;29(3):495–504.

39. Liang D, Han H, Du J, Zhao M, Hser YI. A pilot study of a smartphone application supporting recovery from drug addiction. J Subst Abuse Treat. 2018;88:51–8. https://doi.org/10.1016/j.jsat.2018.02.006.

40. Spears CA, Abroms LC, Glass CR, Hedeker D, Eriksen MP, Cottrell-Daniels C, et al. JMIR Mhealth Uhealth. 2019;7(6) https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6613894/.

41. Quanbeck A, Gustafson DH, Marsch LA, Chih MY, Kornfield R, McTavish F, et al. Implementing a mobile health system to integrate the treatment of addiction into primary care: a hybrid implementation-effectiveness study. J Med Internet Res. 2018;20(1).

42. Johnson AC, Lipkus I, Tercyak KP, Luta G, Rehberg K, Phan L, et al. Development and pretesting of risk-based mobile multimedia message content for young adult hookah use. Heal Educ Behav. 2019;46(2_suppl):97–105.

43. Sillice MA, Dunsiger S, Jennings E, Lantini R, Bock BC. Differences in mobile phone affinity between demographic groups: implications for mobile phone delivered interventions and programs. mHealth. 2018;4(August):39.

44. Mares ML, Gustafson DH, Glass JE, Quanbeck A, McDowell H, McTavish F, et al. Implementing an mHealth system for substance use disorders in primary care: a mixed methods study of clinicians' initial expectations and first year experiences. BMC Med Inform Decis Mak. 2016;16(1):1–12. https://doi.org/10.1186/s12911-016-0365-5.

45. Cordova D, Bauermeister JA, Fessler K, Delva J, Nelson A, Nurenberg R, et al. A community-engaged approach to developing an mHealth HIV/STI and drug abuse preventive intervention for primary care: a qualitative study. JMIR mHealth uHealth. 2015;3(4):e106.

46. Brown S-E, Krishnan A, Ranjit YS, Marcus R, Altice FL. Assessing mobile health feasibility and acceptability among HIV-infected cocaine users and their healthcare providers: guidance for implementing an intervention. mHealth. 2020;6(September):4–4.

47. Curtis B, Bergman B, Brown A, McDaniel J, Harper K, Eisenhart E, et al. Characterizing participation and perceived engagement benefits in an integrated digital Behavioral health recovery community for women: a cross-sectional survey. JMIR Ment Heal. 2019;6(8):e13352.

48. Curtis BL, Ashford RD, Magnuson KI, Ryan-Pettes SR. Comparison of smartphone ownership, social media use, and willingness to use digital interventions between generation Z and millennials in the treatment of substance use: cross-sectional questionnaire study. J Med Internet Res. 2019;21(4).

49. Shrestha R, Huedo-Medina TB, Altice FL, Krishnan A, Copenhaver M. Examining the acceptability of mHealth technology in HIV prevention among high-risk drug users in treatment. AIDS Behav. 2017;21(11):3100–10.

50. Ryan-Pettes SR, Lange LL, Magnuson KI. Mobile phone access and preference for technology-assisted aftercare among low-income caregivers of teens enrolled in outpatient substance use treatment: questionnaire study. JMIR mHealth uHealth. 2019;7(9):1–14.

51.• Tofighi B, Leonard N, Greco P, Hadavand A, Acosta MC, Lee JD. Technology use patterns among patients enrolled in inpatient detoxification treatment. J Addict Med. 2019;13(4):279–86 **The Tofighi et al. (2019) manuscript provided insights on diverse**

platforms utilized to assess substance use and abuse. This served as a great source assessing participant perspectives on use of digital health and barriers that may effect the adoption of the tool.

52. Hochstatter KR, Gustafson DH Sr, Landucci G et al. AMHI to IHCOAPWOUDP for a RCTJRP 2019;8(8):e12620. P 2019 A 1. doi:https://doi.org/10.2196/1262. A mobile health intervention to improve hepatitis C outcomes among people with opioid use disorder: protocol for a randomized controlled trial. JMIR. 2019; 8(8).
53. Harder VS, Musau AM, Musyimi CW, Ndetei DM, Mutiso VN. A randomized clinical trial of mobile phone motivational interviewing for alcohol use problems in Kenya. Addiction. 2019.
54. Zhang M, Ying J, Amron SB, Mahreen Z, Song G, Fung DSS, et al. A smartphone attention bias app for individuals with addictive disorders: feasibility and acceptability study. J Med Internet Res. 2019;21(9).
55. Pretlow RA, Stock CM, Roeger L, Allison S. Treatment of the sensory and motor components of urges to eat (eating addiction?): a mobile-health pilot study for obesity in young people. Eat Weight Disord [Internet]. 2020; Available from: https://doi.org/10.1007/s40519-019-00836-z.
56. Guille C, Simpson AN, Douglas E, Boyars L, Cristaldi K, McElligott J, et al. Treatment of opioid use disorder in pregnant women via telemedicine: a nonrandomized controlled trial. JAMA Netw Open. 2020;3(1):e1920177.
57. Anderson KE, Byrne CE, Crosby RD, Le Grange D. Utilizing Telehealth to deliver family-based treatment for adolescent anorexia nervosa. Int J Eat Disord. 2017;50(10):1235–8.
58. Vidmar AP, Pretlow R, Borzutzky C, Wee CP, Fox DS, Fink C, et al. An addiction model-based mobile health weight loss intervention in adolescents with obesity. Pediatr Obes. 2019;14(2):1–9.
59. Molfenter T, Boyle M, Holloway D, Zwick J. Trends in telemedicine use in addiction treatment. Addict Sci Clin Pract [Internet]. 2015;10(1):1–9.
60. Reginald Fils-Aime J, Grelotti DJ, Thérosme T, Kaiser BN, Raviola G, Alcindor Y, et al. A mobile clinic approach to the delivery of community-based mental health services in rural Haiti. PLoS One. 2018;13(6):1–15.
61. Weintraub E, Greenblatt AD, Chang J, Himelhoch S, Welsh C. Expanding access to buprenorphine treatment in rural areas with the use of telemedicine. Am J Addict. 2018;27(8):612–7.
62. Coravos A, Doerr M, Goldsack J, Manta C, Shervey M, Woods B, et al. Modernizing and designing evaluation frameworks for connected sensor technologies in medicine. NPJ Digit Med. 2020;3(1): 1–10. https://doi.org/10.1038/s41746-020-0237-3.
63. Goldsack JC, Coravos A, Bakker JP, Bent B, Dowling AV, Fitzer-Attas C, et al. Verification, analytical validation, and clinical validation (V3): the foundation of determining fit-for-purpose for biometric monitoring technologies (BioMeTs). NPJ Digit Med. 2020;3:55.
64. Nebeker C, Bartlett Ellis RJ, Torous J. Development of a decision-making checklist tool to support technology selection in digital health research. Transl Behav Med. 2019.

AUTHOR QUERIES

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Q1. Please check if all tables are presented/captured correctly.
Q2. If applicable, please provide the access dates of references [17, 18, 19, 27, 28, 29, 30 and 40].