

A Systematic Review of the Scope of Study of mHealth Interventions for Wellness and Related Challenges in Pediatric and Young Adult Populations

Sarah J Bond¹, Nathan Parikh¹, Shrey Majmudar¹, Sabrina Pin¹, Christine Wang¹, Lauren Willis¹, Susanne B Haga^{1,2}

¹Duke University, Durham, NC, 27708, USA; ²Duke University School of Medicine, Durham, NC, 27708, USA

Correspondence: Susanne B Haga, Duke University, 101 Science Drive, Box 3382, Durham, NC, 27708, USA, Tel +1 919 684 0325, Fax +1 919 681 8973, Email susanne.haga@duke.edu

Background: Despite the purported advantages and potential efficacy of mHealth interventions to promote wellness in children, adolescents, and young adults, it is not clear what areas have been explored and the challenges reported in the biomedical literature.

Methods: We conducted a scoping review of publications between 2015 and 2019.

Results: We identified 54 papers that met our inclusion criteria. Studies were conducted in 21 countries and ranged in size from six to 9851 participants (median: 184). A total of 41% of studies enrolled adolescents only (n = 19). Of the seven types of mHealth interventions identified, apps were the most common intervention (59%; n = 32) evaluated and 44% of the studies evaluated two or more interventions. The most common topic of the studies reviewed was sexual and reproductive health (24%; n = 13).

Conclusion: Most pediatric mHealth intervention studies are conducted in adolescents in large part, and sexual and reproductive health is the most commonly studied topic. With the easy and widespread accessibility to smartphone technology, the use of mobile apps for wellness interventions will likely continue to expand to other wellness topics.

Keywords: mHealth, wellness, children, adolescents, young adults

Introduction

The explosion of mobile health (mHealth) devices, including smartphones, smartwatches and apps, has enabled widespread usage by a greater segment of the population for a variety of health-related purposes.¹ Each new release and device yields more options and features for monitoring and tracking, reminders, bands or styles, partnerships with other brands (eg, luxury designers or sporting goods), and decreasing costs. mHealth technologies have ushered in the generation of “digital” phenotypes for disease monitoring and early detection.^{2–4} These technologies are being evaluated for a range of clinical purposes, such as disease screening and monitoring as well as health behaviors associated with, recovery, disease management, and compliance with treatment regimens.^{5–8} In parallel, mHealth interventions are being evaluated to promote and sustain healthy behaviors through approaches like daily monitoring, reminders and education to maintain well-being and wellness.^{9–12} Some wearables are approved by the US Food and Drug Administration (FDA) as clinical devices, though accessible through retail stores without a prescription.¹³

Children, adolescents, and young adults have widespread access to digital technologies. A 2018 survey reported that 95% of US teens have access to a smartphone,¹⁴ up from 75% in 2015.¹⁵ A 2019 survey reported that almost half of children by age 11 own or have access to a smartphone.¹⁶ Thus, the introduction of mHealth interventions as educational and self-tracking tools to promote healthy behaviors and choices has garnered much attention, though to a lesser extent than that of adult populations.¹¹ For wellness-related activities, the ability to monitor and track personal activities is

hoped to initiate and sustain healthy behaviors to promote well-being and reduce disease risks. In particular, children and adolescents may greatly benefit from mHealth technologies by learning and adopting healthy behaviors to reduce the onset of health risks, such as obesity and smoking. Establishing healthy behaviors in children and adolescents can build the foundation for lifelong healthy behaviors with substantive returns.¹⁷

However, there remain many questions to address, including which behaviors or topics would benefit from mHealth technologies, which age groups would be most appropriate, and how to sustain long-term use in children and adolescents. While there have been several reviews published on the use of mHealth interventions and children, particularly on physical activity,^{18–20} there has not been a more comprehensive review to date. To identify the range of wellness topics and age groups in which mHealth technologies have been evaluated thus far, we conducted a scoping literature review and present our findings here. We are particularly interested in identifying what types of populations have been studied (concerns about access and diversity) and the challenges encountered by researchers. We anticipate that the findings will provide a better understanding of the topics, age groups, and challenges faced by these studies, and can help identify both gaps in research as well as areas that may benefit from expansion to other age groups or related topics.

Methods

We conducted a scoping review to explore three areas: 1) the scope of mHealth interventions used to improve wellness among healthy children, adolescents, and young adults; 2) the range of wellness topics and corresponding interventions/technologies and age group; and 3) reported challenges with the use of mHealth technologies for wellness in children, adolescents, and young adults. In addition to the absence of a disease state, wellness has been defined as a multi-faceted state of health including emotional, physical, occupational, intellectual, financial, social, environmental, and spiritual parts.^{21–23}

Search Strategy and Selection Criteria

We used the following databases to identify publications on mHealth, wellness, and children, adolescents and young adults: PubMed, Cochrane Central Register of Controlled Trials (CENTRAL) and the Cumulative Index to Nursing and Allied Health Literature (CINAHL) databases. For the PubMed search, we used the following search string with restrictions for age group (all children) and language (English): Wearable[Title/Abstract] OR mobile applications [Title/Abstract] OR mobile phone apps[Title/Abstract] OR text messaging[Title/Abstract] OR apps[Title/Abstract] OR “fitness trackers”[MeSH Terms] OR (“fitness”[All Fields] AND “trackers”[All Fields]) OR “fitness trackers”[All Fields] OR “mobile applications”[MeSH Terms] OR (“mobile”[All Fields] AND “applications”[All Fields]) OR “mobile applications”[All Fields] AND (Clinical Trial[ptyp] AND (“2015/01/01”[PDAT]: “2019/12/31”[PDAT]) AND “humans”[MeSH Terms] AND English[lang]). For CINAHL, we conducted a search with the following search string ((MM “Cellular Phone”) OR (MM “Mobile Applications”) OR (MM “Fitness Trackers”)) and limited it to original research articles, age group (all children), publication date (01/01/2015–12/31/2019), and language (English).

We reviewed the publication titles and abstracts to screen publications that met our search criteria for mHealth interventions, wellness, and children and young adults. Papers were excluded if they did not report empirical results, such as protocol or design papers, if the study did not focus on healthy children and young people, and if no health technology intervention was used (no technology used at all or the technology used was not a form of mHealth, social media, website, or wearable device). Specifically, studies were excluded if they focused on an affected population (eg, eligibility to participate included disease diagnosis), a population over the age of 25 years of age, a population of caregivers (the intervention was applied to parents or caregivers of children rather than children themselves), or a population of healthcare workers (eg, the technology was used as an intervention for health professionals, not for patients). In addition, qualitative research publications that did not involve an evaluation of a specific mHealth intervention were excluded as we were focused on the scope and challenges encountered in evaluations of mHealth interventions in pediatric populations. Studies were also excluded if their abstracts or full-text versions were not available online, open to all or accessible through the Duke University Library. Two reviewers screened all publications based on these exclusion criteria to identify the set of publications that would be analyzed in-depth.

Data Extraction and Analysis

After finalizing the set of publications to be analyzed, each publication was reviewed by two authors in its entirety and the following study details extracted: country where study was conducted, study purpose/focus, age range of study population, study population size, study design, study population make-up (gender, race/ethnicity), and type of intervention(s). In addition, we extracted reported challenges and limitations related to either the mHealth intervention or study protocol or dataset. Analysis of race/ethnicity make-up was restricted to US-based studies due to differences in categories or non-reporting in non-US studies. Categories and themes were then defined and papers were re-coded accordingly. Age was categorized into one of the three distinct age categories as defined by PubMed's online search filters: children (6–12 years), adolescents (13–18 years), and young adults (19–25 years) or a combination thereof. Three additional categories were created to allow coding of publications with more than one age group: CA (children + adolescents), AY (adolescents + young adults), CAY (children + adolescents + young adults). Each publication was reviewed by a minimum of two authors; discrepancies in coding were resolved through discussion with the entire team. Summary statistics were generated in Excel.

Results

Overview

Our search results are displayed using the Preferred Reporting Items for Systematic Review and MetaAnalyses (PRISMA) flow diagram (Figure 1).²⁴ After duplicates were removed, our search yielded a total of 846 unique papers: 371 from PubMed, 384 from CINAHL, and 91 from the Cochrane database. From these results, we excluded 692 during

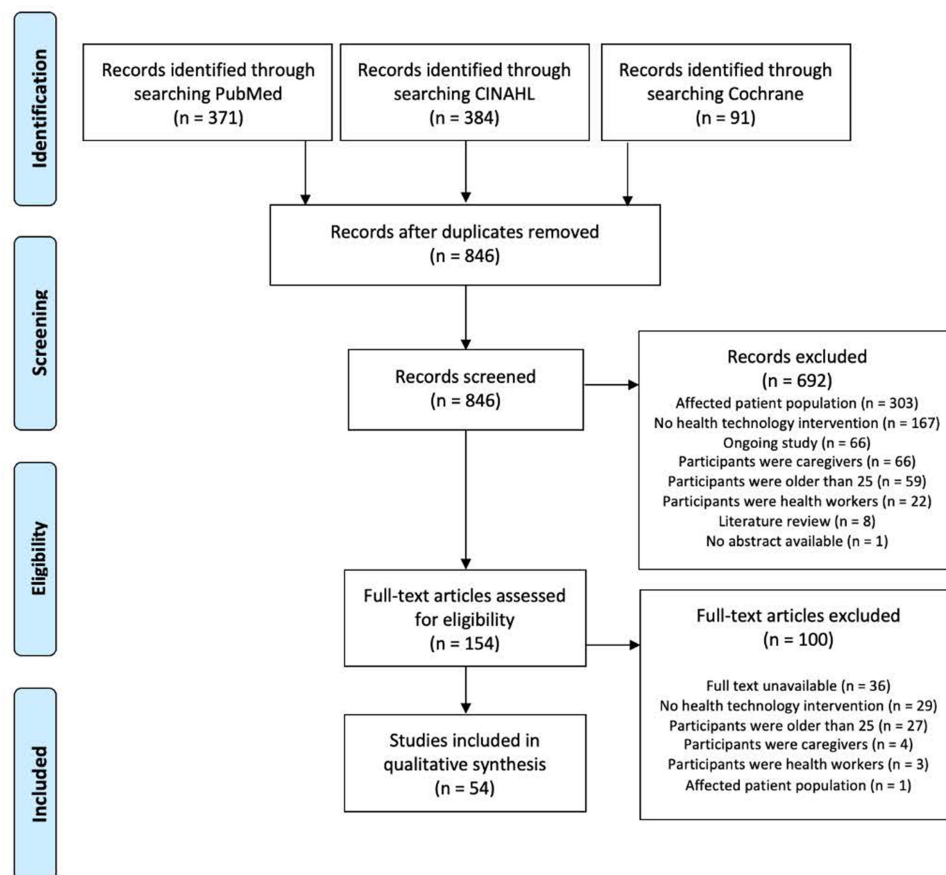


Figure 1 PRISMA flow chart of publication search and screening.

Notes: Adapted from Liberati A, Altman DG, Tetzlaff J, et al. The PRISMA statement for reporting systematic reviews and meta-analyses of studies that evaluate health care interventions: explanation and elaboration. *PLOS Medicine*. 2009;6(7):e1000100. doi:10.1371/journal.pmed.1000100.²⁴ © 2009 Liberati et al. Creative Commons Attribution License.

the title/abstract screening because they did not fit our criteria. The five most common reasons for exclusion were that the study focused on an affected patient population ($n = 303$), no health technology intervention was used in the study ($n = 167$), the publication was the study protocol, and no data had been collected ($n = 66$), the participants were caregivers of children and young people ($n = 66$), and the participants were older than 25 years ($n = 59$). After reviewing the title and abstract, we accessed the full text of the remaining 154 studies to confirm that they met our study criteria. During this step, we excluded 100 additional studies primarily because the full text was unavailable ($n = 36$), no health technology intervention was used in the study ($n = 29$), and participants were older than 25 years ($n = 27$). A total of 54 studies were included in our final analysis (Table 1). The major datapoints abstracted from the publications are shown in Figure 2.

Study Design

Fifty-seven percent ($n = 31$) of studies conducted randomized controlled trials and 22% ($n = 12$) conducted cluster-randomized controlled trials (eg, schools, classes, or geographic regions/neighborhoods). Fifteen percent ($n = 8$) were observational or cohort studies, and the remaining papers were longitudinal studies, cross-over studies, and cluster (non-randomized) controlled trials.

Study Location

We reviewed where (by country) the studies were conducted and identified a total of 21 countries. The largest proportion of studies were conducted in the United States, accounting for 32% ($n = 18$) of total studies. The remainder of the studies were conducted in Europe (14), Australia and New Zealand (10), Africa (3), Canada (2), the United Kingdom (2), and one study each in Korea, Thailand, Tajikistan, Brazil, and Turkey.

Study Population Characteristics

We analyzed the study population size and diversity with respect to gender, race/ethnicity, and age group. Of the 54 total papers analyzed, there were a total of 26,817 participants enrolled. Study population sizes ranged from 6 participants to 9851 participants, with a median of 184 participants (mean: 497; SD: 1342). Almost all studies reported their gender breakdown (93%, $n = 50$) with the plurality of studies having a near 50–50 male-female ratio (38%, $n = 19$). Fourteen studies had >60% female enrollment, while eight studies had <40% female enrollment.

Overall, 48% ($n = 26$) of publications reported racial/ethnic diversity of their study populations, most predominantly by the U.S.-based studies (83%; $n = 15$). Among the U.S.-based studies reporting race, 40% ($n = 6$) of studies enrolled exclusively or predominantly a non-White population (defined as <20% White participants), while seven studies had >50% White participants.

We assigned publications into one of the three distinct age categories: children (6–12 years), adolescents (13–18 years), and young adults (19–25 years), or a combination thereof. Of the 54 studies, 15% ($n = 8$) enrolled solely children, 35% enrolled adolescents ($n = 19$), and 24% ($n = 13$) enrolled young adults (Figure 3). Twenty-six percent of studies ($n = 14$) enrolled multiple age groups with the largest combined age groups being adolescents and young adults (AY) (18%; $n = 10$). One study enrolled all three age groups (CAY).

Types of mHealth Interventions

We categorized the mHealth interventions into eight categories: (1) mobile apps, (2) text messages, (3) wearables, (4) website, (5) emails, (6) social media, (7) videos, and (8) virtual reality (Figure 4). Mobile apps were the most common intervention, evaluated in 59% ($n = 32$) of studies, followed by text message intervention studies (41%; $n = 22$). Virtual reality was the least common intervention with only one study assessing the use of virtual reality images as a distractive pain intervention. Fifty-six percent ($n = 30$) of the studies included only one intervention and 44% ($n = 24$) included two or more interventions. For the US-based studies, five of the 18 studies provided a device for participants to use to complete the study – two wearable studies and 3 app-based studies. Only one study specifically stated that provision of the device (smartphone) was part of the remuneration and thus, could be kept by the participants;⁵⁰ it was unclear if participants of other studies were able to keep the device.

We examined a specific type of mHealth intervention evaluated by age group (Table 2). Adolescents were the most common age group to be enrolled in text message intervention studies, participating in 59% of all studies evaluating text

Table I List of 54 Publications Identified in the Search That Met the Criteria for Analysis and Key Datapoints

Study Focus	Reference	Country	Age of Study Participants	Study Size	Type of Intervention
Alcohol Use	Hides et al. (2018) ²⁵	Australia	AY	197	Mobile App, Text Messages
Alcohol Use	Haug et al. (2017) ²⁶	Switzerland	Adolescents	1041	Text Messages, Website
Alcohol Use	Paz Castro et al. (2017) ²⁷	Switzerland	Adolescents	1041	Text Messages, Website
Diet/Nutrition or Weight	Trude et al. (2018) ²⁸	USA	CA	509	Text Messages, Social Media
Diet/Nutrition or Weight	Lubans et al. (2016) ²⁹	Australia	Adolescents	361	Mobile App, Wearables
Diet/Nutrition or Weight	Sarcona et al. (2017) ³⁰	USA	Young adults	401	Mobile App
Diet/Nutrition or Weight	De Cock et al. (2018) ³¹	Belgium	Adolescents	988	Mobile App
Diet/Nutrition or Weight	Wilksch et al. (2018) ³²	Australia and New Zealand	Young adults	608	Website, Emails
Diet/Nutrition or Weight	Carfora et al. (2017) ³³	Italy	Young adults	124	Text Messages, Mobile App, Emails
Diet/Nutrition or Weight	Pedersen et al. (2016) ³⁴	Denmark	CA	1488	Text Messages
Diet/Nutrition or Weight	Heikkila et al. (2019) ³⁵	Finland	Young adults	79	Mobile App
Diet/Nutrition or Weight	Lyzwinski et al. (2019) ³⁶	Australia	Young adults	90	Mobile App
General Health	Utario et al. (2018) ³⁷	Indonesia	Children	120	Mobile App
General Health	Rodgers et al. (2018) ³⁸	USA	Adolescents	274	Mobile App, Website, Emails
General Health	Ashton et al. (2017) ³⁹	New Zealand	Young adults	50	Website, Wearables, Social Media, Mobile App
General Health	Karaman et al. (2019) ⁴⁰	Turkey	Young adults	172	Mobile App, Virtual Reality
General Health	Brinker et al. (2016) ⁴¹	Germany	Adolescents	9851	Mobile App
General Health	Fassnacht et al. (2015) ⁴²	Portugal	Children	49	Text Messages, Wearables
General Health	Marchetti et al. (2018) ⁴³	Brazil	Adolescents	291	Mobile App, Videos
Mental Health	Bidargaddi et al. (2017) ⁴⁴	Australia	AY	387	Website, Text Messages, Mobile App, Emails
Mental Health	Huberty et al. (2019) ⁴⁵	USA	Young adults	88	Mobile App, Text Messages
Mental Health	Whittaker et al. (2017) ⁴⁶	New Zealand	Adolescent	855	Text Messages, Website
Mental Health	Puolakanaho et al. (2019) ⁴⁷	Finland	Adolescent	249	Website, Mobile App, Text Messages
Mental Health	Mackrill et al. (2019) ⁴⁸	Denmark	Adolescent	6	Mobile App

(Continued)

Table 1 (Continued).

Study Focus	Reference	Country	Age of Study Participants	Study Size	Type of Intervention
Mental Health	Rosmalen-Nooijens et al. (2017) ⁴⁹	Netherlands	AY	57	Website
Miscellaneous	Creaser et al. (2015) ⁵⁰	USA	Adolescents	274	Mobile App
Miscellaneous	Price et al. (2018) ⁵¹	United Kingdom	Children	886	Wearables
Miscellaneous	Moon et al. (2017) ⁵²	Korea	Children	45	Mobile App, Website
Miscellaneous	Huber et al. (2018) ⁵⁴	Australia	Children	96	Mobile App, Videos
Miscellaneous	Taylor et al. (2019) ⁵⁵	USA	CAY	197	Mobile App
Physical Activity	Schaefer et al. (2016) ⁵⁶	USA	Children	24	Wearables
Physical Activity	Heino et al. (2018) ⁵³	Finland	Young adults	375	Text Messages
Physical Activity	Pope et al. (2019) ⁵⁷	USA	Young adults	38	Wearables, Social Media
Physical Activity	Patten et al. (2017) ⁵⁸	Canada	Children	20	Mobile App, Wearables
Physical Activity	Direito et al. (2015) ⁵⁹	New Zealand	Adolescents	86	Mobile App, Wearables
Physical Activity	Gabbiadini et al. (2018) ⁶⁰	Italy	Young adults	78	Mobile App
Physical Activity	Wattanapisit et al. (2018) ⁶¹	Thailand	Young adults	26	Mobile App
Physical Activity	Brannon et al. (2018) ⁶²	USA	Adolescents	10	Text Messages, Wearables, Mobile App
Physical Activity	Kerner et al. (2019) ⁶³	United Kingdom	Adolescent	62	Wearables
Physical Activity	Kennedy et al. (2018) ⁶⁴	Australia	Adolescents	607	Mobile App
Physical Activity	Silva et al. (2015) ⁶⁵	Portugal	Children	139	Text Messages, Wearables
Sexual/Reproductive Health	McCarthy et al. (2018) ⁶⁶	Tajikistan	AY	573	Mobile App
Sexual/Reproductive Health	Sabben et al. (2019) ⁶⁷	Kenya	CA	30	Mobile App
Sexual/Reproductive Health	Rokicki and Fink (2017) ⁶⁸	Ghana	AY	498	Text Messages
Sexual/Reproductive Health	Akinola et al. (2019) ⁶⁹	USA	AY	110	Mobile App
Sexual/Reproductive Health	Rokicki et al. (2017) ⁷⁰	Ghana	AY	756	Text Messages
Sexual/Reproductive Health	Jacobson et al. (2018) ⁷¹	USA	AY	25	Mobile App, Emails
Sexual/Reproductive Health	Ybarra et al. (2017) ⁷²	USA	Adolescents	283	Text Messages
Sexual/Reproductive Health	Bull et al. (2017) ⁷³	USA	Adolescents	852	Text Messages

(Continued)

Table 1 (Continued).

Study Focus	Reference	Country	Age of Study Participants	Study Size	Type of Intervention
Sexual/Reproductive Health	Trent et al. (2015) ⁷⁴	USA	AY	100	Text Messages
Sexual/Reproductive Health	Bull et al. (2016) ⁷⁵	USA	Adolescents	852	Text Messages
Sexual/Reproductive Health	Ybarra et al. (2018) ⁷⁶	USA	Adolescent	302	Text Messages
Sexual/Reproductive Health	Buchanan et al. (2017) ⁷⁷	USA	AY	67	Text Messages
Sexual/Reproductive Health	Cordova et al. (2018) ⁷⁸	USA	Young adults	30	Mobile App

messaging. Mobile apps were the most common intervention evaluated in children. Adolescents and young adults were most often enrolled in studies including a mobile app intervention.

Study Purpose/Focus

We identified seven categories for the study focus or purpose (eg, behavior and health measure): 1) sexual/reproductive health; 2) diet/nutrition or weight; 3) activity; 4) general health; 5) mental health; 6) alcohol use, and 7) miscellaneous (Figure 5). A few studies evaluated mHealth interventions relevant to multiple purposes; for those publications, we categorized them with the topic that aligned best with the primary purpose of the study. Out of the 54 total studies reviewed, the most common purpose was sexual/reproductive health (24%; $n = 13$). Twenty percent of the studies focused on physical activity ($n = 11$) and seventeen percent focused on diet/nutrition or weight ($n = 9$). Thirteen percent ($n = 7$) of studies focused on general health. The remainder of the studies were coded as “miscellaneous” ($n = 6$) as they did not focus on any particular wellness/disease type or those that assessed specific features (eg, gaming) but were not

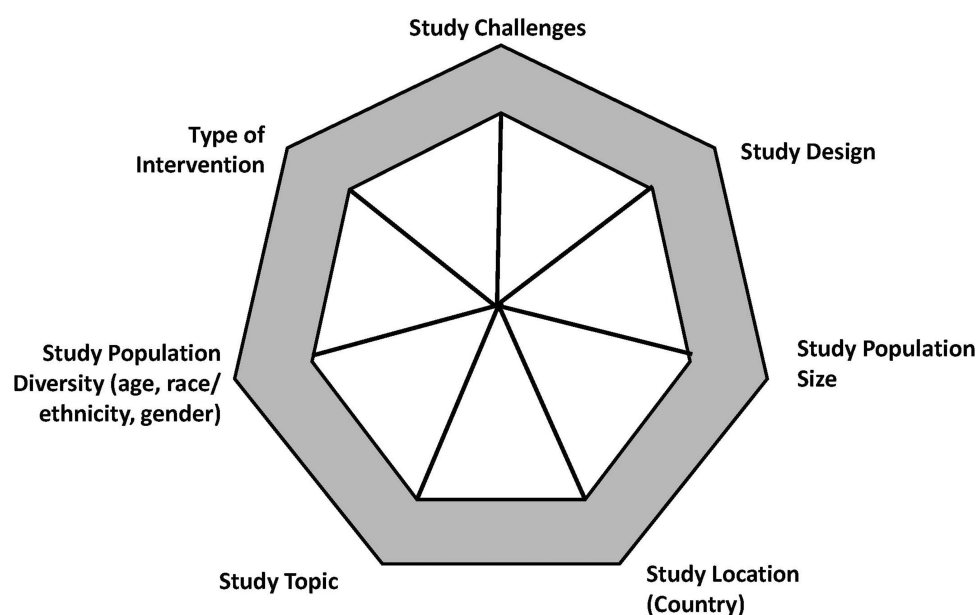


Figure 2 The seven key datapoints abstracted from the 54 publications reviewed.

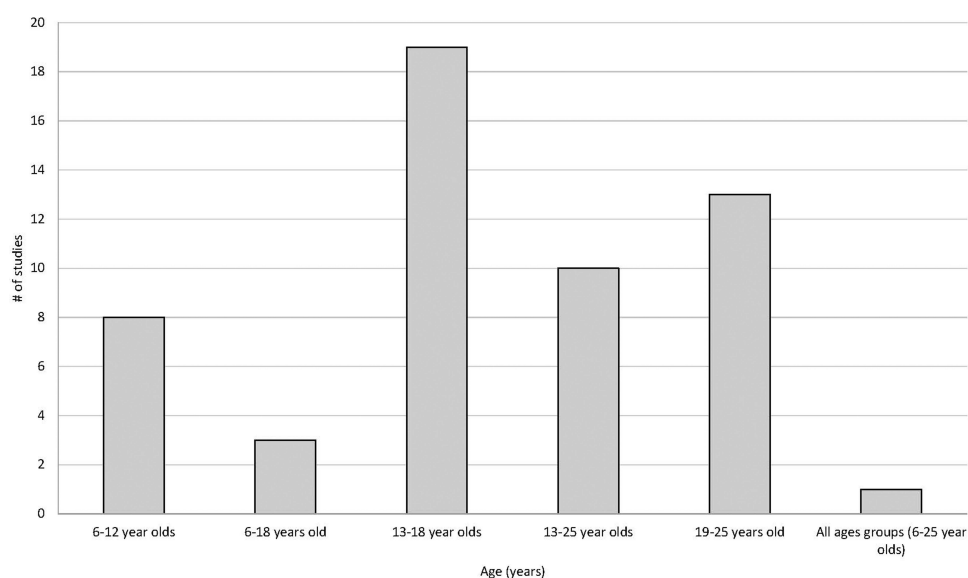


Figure 3 Breakdown by age of study populations. The age categories were children (6–12 years), adolescents (13–18 years), and young adults (19–25 years).
Abbreviations: AY, young adults; CAY, children and young adults.

associated with a wellness/health focus (topics such as novice teen driving, self-reported compliance of daily diary-keeping, and effects of screen media on children's executive function).

With respect to type of mHealth intervention, Table 3 shows the interventions evaluated by study focus. Further analysis of each study topic is described in the sections below (excluding the miscellaneous category for a total of 48 studies).

Sexual/Reproductive Health

The most common purpose among the publications reviewed was sexual and reproductive health ($n = 13$). Specifically, studies focused on reducing the incidence of sexually transmitted infections and increasing contraception use. Two-thirds ($n = 9$) of the sexual/reproductive health studies were conducted in the US. Five of the nine U.S.-based studies enrolled a majority of non-White participants with one study focused exclusively on African-American and Latina girls. In addition to the bias towards minority participants, most were single-sex studies (six were female-only and two male-only).

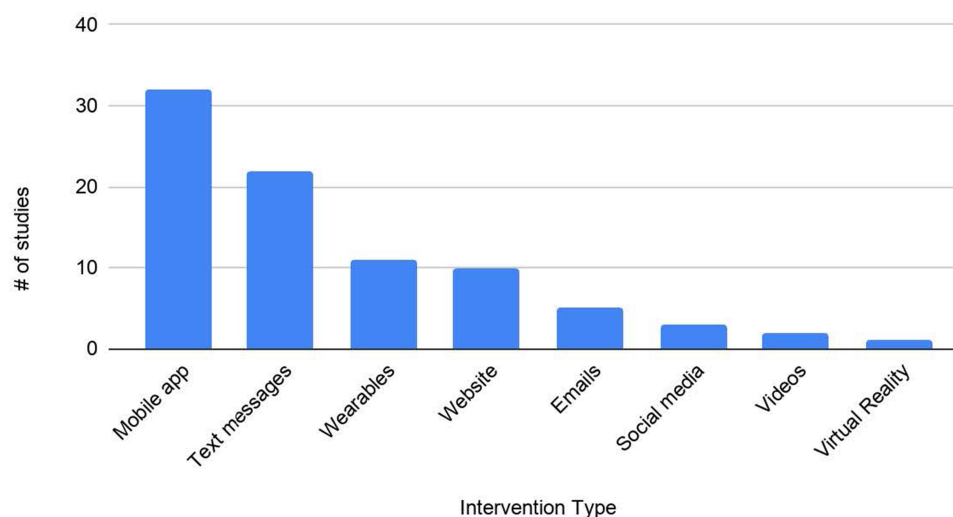


Figure 4 Breakdown of types of interventions.

Table 2 Use of Interventions by Age Category

Age Group/ Intervention	Mobile App Intervention	Text Message Intervention	Wearable Intervention	Website Intervention	Email Intervention	Social Media Intervention	Video Intervention	VR Intervention
Children (only)	6	4	1	2	2	0	1	0
Adolescent (only)	9	7	7	5	1	3	1	0
Young adults (only)	12	4	0	1	1	0	0	
CA	2	1	1	0	0	0	0	0
AY	2	6	2	2	1	0	0	0
CAY	1	0	0	0	0	0	0	0
SUM	32	22	11	10	5	3	2	1

Notes: Children (6–12 years); adolescents (13–18 years); young adults (19–25 years); CA (children + adolescents); AY (adolescents + young adults); CAY (children + adolescents + young adults).

The majority of studies ($n = 7$) enrolled both adolescents and young adults, with five studies exclusively targeting adolescents, and one exclusively for young adults. The median study population size was 283 (range: 25–852). Four types of interventions were used, with text messages being the most common intervention (61%; $n = 8$), followed by mobile apps (38%; $n = 5$), email combined with mobile apps (8%; $n = 1$), and wearables (8%; $n = 1$).

Diet/Nutrition and Weight

The second most prevalent study purpose was diet/nutrition or weight, comprising 17% ($n = 9$) of the publications. Three studies were conducted in Australia, two in the US, and one each in New Zealand, Finland, Denmark, Belgium, and Italy. Of the U.S.-based studies, one focused primarily on African Americans. With respect to age, four studies enrolled only adolescents and five enrolled only young adults. The median study population size was 401 (range: 79–1488). Studies only enrolled young adults and adolescents. With respect to gender, five of the nine publications reported a majority of female participants (two studies did not report gender breakdown). One paper focused exclusively on females and another exclusively on adolescent boys. The most common intervention used in the nine studies was mobile apps (56%; $n = 5$), followed by text messages (44%; $n = 4$). Two studies used wearables and two other studies used email. Four studies evaluated two or more mHealth interventions.

Physical Activity

Tied with diet/nutrition and weight, there were 11 studies on physical activity, focused primarily on increasing physical activity. The studies enrolled participants across the three age groups, with three studies focused on children, four focused each on adolescents and young adults. There were no single-sex studies, though females comprised the majority of the study population in six studies. The median study population size was 62 (range: 10–607). With respect to race/ethnicity, only one study was conducted in the US and reported a 90% White enrollment. Other studies were conducted in Canada, Australia, New Zealand, Italy, Portugal, the United Kingdom, and Thailand. Six studies used mobile apps and six studies evaluated a combination of interventions (eg, mobile app plus wearable and text messages plus wearable). Wearables were evaluated in seven (64%) studies and apps were evaluated in six (54%) studies on physical activity; in comparison, wearables were only evaluated in 20% of the studies overall.

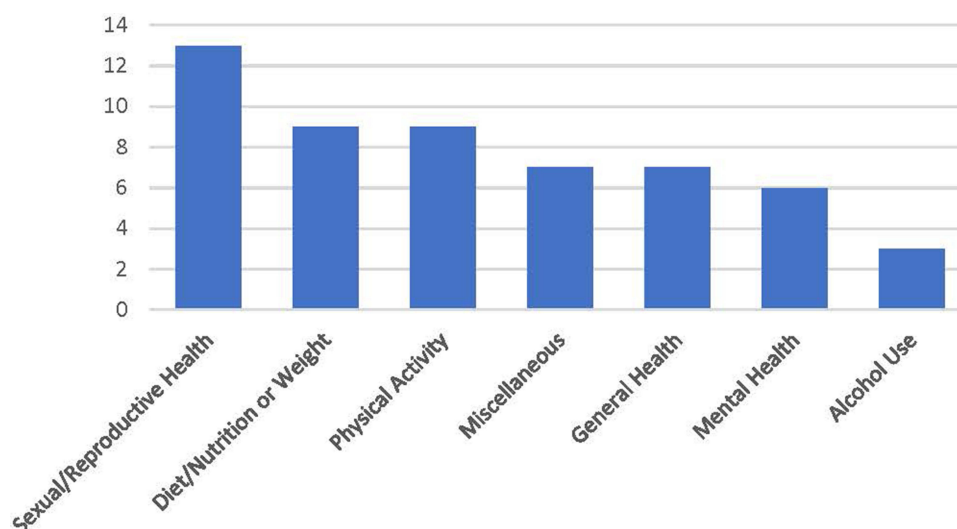


Figure 5 Breakdown by study focus.

General Health

Thirteen percent ($n = 7$) of studies reviewed focused on general health. Each of these studies was conducted in a different country: US, Brazil, Germany, Australia, Portugal, Indonesia, New Zealand, and Turkey. Half of the studies ($n = 4$) focused on young adults exclusively, while the remainder focused on adolescents ($n = 2$) or children ($n = 2$). For the interventions, six of the seven studies evaluated a mobile app (3 studies in combination with other interventions including wearables, a website, text messages, social media, emails, and/or virtual reality).

The median study population size was 172 participants (range: 49–9851). With respect to race/ethnicity for the U.S.-based study, 56% of participants were White.

Mental Health

Six (11%) of the reviewed studies focused on interventions for mental health. Specifically, these studies assessed the use of mHealth applications to improve mindfulness and wellness, and reduce the risk of depression. Each of these studies was conducted in a different country: US, Australia, New Zealand, the Netherlands, Finland, and Denmark. With respect to age, three studies enrolled solely adolescents, one study enrolled solely young adults, and two enrolled both adolescents and young adults. The median study population size was 171 participants (range: 6–855). There was no predominant mHealth intervention evaluated – equally divided between text messaging ($n = 4$), mobile apps ($n = 4$), and websites ($n = 4$). Four studies evaluated more than one mHealth intervention, one study evaluated only a mobile app and the other a website. A minority of participants (28%) were White and 15% Hispanic in the only U.S.-based study.

Alcohol Use

The remaining three publications of the 54 reviewed focused on alcohol use. Two of the three studies were conducted in Switzerland and one in Australia. With respect to age, two studies only enrolled adolescents and the other study enrolled both young adults and adolescents. For all studies, text messaging was evaluated in combination with a second intervention (a website in two studies and a mobile app in the other study). The median study population size was 1041 participants (range: 197–1355). One study enrolled predominantly female participants (78%), while the other studies were gender-balanced.

Challenges with mHealth Interventions and Study Limitations

Studies reported multiple challenges or limitations related to the mHealth intervention. We categorized the reported challenges related to the mHealth intervention into three categories: (1) self-monitoring and/or self-reporting; 2) device-related; and 3) application-related bugs, issues, or insufficiencies. Self-monitoring and/or self-reporting results was the

Table 3 Number of Studies by Topic and mHealth Intervention (Top Table) and by Topic and Age Category (Bottom Table)

Intervention/Study Topic	Sexual/Reproductive Health	Diet/Nutrition or Weight	Physical Activity	General Health	Mental Health	Alcohol Use	Total
Text Messages	8	3	3	1	4	0	19
Mobile Apps	5	6	6	6	4	1	27
Wearables	1	1	7	2	0	0	11
Social Media	0	1	1	1	0	0	3
Website	0	1	0	2	4	2	9
Emails	1	2	0	1	1	0	5
Videos	0	0	0	1	0	0	1
Virtual Reality	0	0	0	1	0	0	1
TOTAL	15	14	17	15	13	3	—
Ages/Study Topic	Sexual/Reproductive Health	Diet/Nutrition or Weight	Physical Activity	General Health	Mental Health	Alcohol Use	Total
Young Adults	0	5	4	2	1	0	12
Young Adults and Adolescents	7	0	0	0	2	1	10
Adolescents	4	2	4	3	3	2	18
Children and Adolescents	1	2	0	0	0	0	3
Children	0	0	3	2	0	0	5
TOTAL	13	9	11	7	6	3	—

Note: the total number of studies is greater than the number of reviewed studies due to the use of multiple interventions for some studies.

most common challenge, reported in 30% ($n = 16$) of articles. Of the 16 studies that reported this challenge, 42% ($n = 10$) involved studies evaluating a mobile app. A total of 31% ($n = 5$) reported this challenge in studies conducted on young adults only and 44% ($n = 4$) on adolescents only. Device-related issues and application-related bugs, issues, or insufficiencies were reported in six and eight studies, respectively.

Limitations related to the study design or implementation were divided into nine categories: 1) lack of diversity in the study population; 2) insufficient sample size; 3) experimental versus control limitations; 4) short follow-up or intervention period; 5) randomization and stratification issues; 6) participant attrition and/or lack of compliance; 7) survey/questionnaire limitations; 8) missing or insufficient data; 9) could not isolate intervention. The most common limitation was the lack of diversity in study populations, which was reported in 28% ($n = 15$) of publications. This limitation was particularly common in studies regarding sexual/reproductive health wherein 54% ($n = 7$) of publications reported this challenge. Participant attrition and/or lack of compliance was reported in 13 studies, followed by small study sample size ($n = 11$), and experimental vs control limitations ($n = 10$).

Overall, the highest number of issues was reported by diet/nutrition and weight studies (2.8 issues/study), closely followed by physical activity studies (2.4 issues/study). Further analysis demonstrated differences in reported study challenges by study purpose. In the mental health studies, the most frequently mentioned challenge was a participant attrition and/or lack of compliance, reported in five of the six studies. In physical activity studies, the major reported issue was limited sample size (64%; $n = 7$), followed by participant attrition (36%; $n = 4$). In diet and nutrition-related

studies, the major challenges reported were self-monitoring/reporting and participant attrition and/or lack of compliance (44%; $n = 4$ each). For studies on sexual health and reproduction, the most commonly reported challenge and lack of diversity (54%; $n = 7$), followed by self-monitoring and/or self-reporting challenges (31%; $n = 4$).

In human subject studies for non-adult participants (defined as under the age of 18 years in the U.S.), obtaining consent may present another challenge. We did not abstract information about consent from all studies given the mix of US and non-US studies and the differing policies regarding human subjects protection that may impact the conduct of research. In the U.S.-based studies, a total of 16 of the 18 studies conducted disclosed that they had obtained approval by an institutional review board. Of the 12 studies that included a description of the consent process, three approaches were used: child assent and parental consent; parental consent; and parental consent waived.

Discussion

mHealth technologies may be an effective tool in the promotion, initiation and sustainability of healthy behaviors in children, adolescents, and young adults. Although each age group may present different challenges and health concerns, the growing widespread use of digital technologies at early ages presents an opportunity to introduce mHealth as both an educational and monitoring tool to motivate healthy behaviors. Furthermore, the opportunity to embed gamification and rewards, connecting and sharing with peers, and other age-appropriate features that can be personalized further in mHealth technologies may be quite advantageous compared to traditional approaches for improving healthy behaviors, health education and monitoring.

In our review, we identified a global group of researchers evaluating mHealth technologies spanning 21 countries across all three age groups, with an understandable bias towards adolescents and young adults due to their maturity and ability to use the devices with minimal adult supervision and support. The US had the highest proportion of publications, followed by Europe. Notably, there were no publications from many low- and middle-income countries, a trend also documented by other reviewers,⁷⁹ although others have found the use of mHealth interventions to be increased in low and middle-income countries.⁸⁰ However, the exploration of mHealth-based interventions has been increasing for adult conditions in some countries such as Ethiopia.⁸¹ Cost, access to devices, and connectivity may limit the widespread use of mHealth applications for children and young adults.⁸² Availability of apps across common smartphone platforms (eg Apple, Android, and both) may improve accessibility and equity of access for owners of different phone types, particularly given the cost differences between platforms and some developers advocate for cross-platforms to improve access.⁸³ However, some data suggest that cross-platform availability does not exist for some health apps; one study reported only a third of apps analyzed were available as Apple and Android versions, but half were only available through Apple.⁸⁴

The most common focus of mHealth studies was on sexual and reproductive health – most of which centered around youth contraception or HIV. L'Engle et al⁷⁹ identified even more studies (35) in their review of mobile phone-based interventions and sexual and reproductive health but also included interventions such as vaccine reminders, which we did not. Among the diet/nutrition and weight or (physical) activity studies, many specifically focused either on food/caloric intake (eg, snacking) or obesity. Schoeppe et al reported 25 apps that had been developed and evaluated for diet and physical activity in children and adolescents.⁸⁵

Matching the appropriate mHealth technology with the health goal and age group is critical to the success of the intervention. Of the seven mHealth interventions identified in the 54 studies, apps were the most common intervention evaluated, appearing in 61% of studies, though biased to young adults and adolescent study populations. For some topics, like physical activity, apps were the predominant type of intervention evaluated. Apps are an appealing intervention as they have widespread outreach, do not require in-person interaction, and can function as educational, motivational or a combination thereof;⁸⁶ gamification may be a particularly attractive feature in apps for young populations.⁸⁷ Despite their popularity with adults, wearables were evaluated in only 20% of studies overall though evidence has been reported that use of wearables is feasible in younger children.⁸⁸ Wearables were least studied in children (1/11) and most studied in adolescents (9/11 studies). In addition, for children and adolescents, a single intervention may be insufficient to achieve the desired wellness goals with 44% of studies evaluating two or more interventions. Compared to wearables, mobile apps can be customized to their targeted age group and include features such as gamification to incentivize sustained use.⁸⁷ However, the use of combined interventions is often reported to present challenges in determining the predominant intervention.

One-third of the U.S.-based studies reviewed exclusively or almost exclusively enrolled non-White populations (<10%) and all but one of the remaining had diverse participation (one study had enrollment of >90% White participants). In some cases, a mHealth intervention was designed for a specific target population such as the African American and Latina females.⁶⁹ With respect to gender, about 40% of studies reported almost equal enrollment of males/females and in a quarter of the studies, more than 60% of participants were females. Female enrollment was particularly high in studies focused on mental health with all but one study enrolling more than 60% female participants.

We found that many studies listed self-reporting as a major study challenge, as anticipated for studies with young populations. This challenge was noted in 71% of young adult populations, likely due to the higher use of data collection methods, such as surveys in this age group compared to younger children. In addition to low completion rates, recall bias has also been reported as another challenge in young study populations.⁸⁹ Compliance is another issue often reported, consistent with older reports of inconsistent or low use of wearables in children.^{19,20,90} Reminders may be helpful to increase regular use of devices.^{91–93} The racial make-up of the study populations was inconsistent, with five US-based studies enrolling a majority non-White population, and seven studies recruiting 50% or more White participants (three studies enrolled >70% White participants).

Some limitations of our findings should be noted. We opted to exclude publications that gathered data from caregivers or affected populations, which may have skewed the number of articles that focused on younger children. In addition, the exclusion of non-English language may have resulted in a lower count of publications in other countries. Long-term longitudinal studies may have followed participants enrolled as children or adolescents into adulthood and potentially biased findings reported here. The review is limited to 2015–2019 and thus does not reflect more recent work; an analysis of the next 5-year period could characterize the growth of the field and direction of the field for mHealth interventions in children and young adults.

In summary, during this early stage of mHealth intervention research, we found that a wide range of studies have been conducted around the world, though mostly concentrated in the US, in children, adolescents, and young adults. Of the seven areas of wellness identified, mental health had the highest number of studies. With the higher maturity level and age-specific issues, adolescents and young adults were the primary focus on mHealth interventions, and mobile apps were the most common type of intervention evaluated to date. While cost and access to devices may be limiting factors in expanding research in children and young adults, the more specific challenges regarding the utilization of mHealth reflect user interest, appeal and sustainability. We anticipate that the scope of topics and number of studies will expand as the impact of these interventions is demonstrated and more features and tools are developed to engage younger users for longer periods of time and potentially habituate regular use.

Disclosure

The authors report no conflicts of interest in this work.

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