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Mobile Technology Use Among Community Health Workers in Sub-Saharan Africa: A Review of the Literature, 2016-2020

By

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Degree to be awarded: Master of Public Health

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An abstract submitted to the
Faculty of the Hubert Department of Global Health
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Master of Public Health
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ABSTRACT

Mobile Technology Use Among Community Health Workers in Sub-Saharan Africa: A Systematic Review

By Margaret Gutierrez

Background: Community Health Worker (CHW) is an umbrella term for citizens who are recruited from the communities where they serve and trained as an extension of the healthcare system, embedded in the narrowest local level. Equipping CHWs with mobile reporting tools, digital training materials and simple mobile technology for conducting tests are some emerging strategies for increased health impact of CHWs.

Objectives: Through a review of literature published since 2016, provide an overview of recent studies of mobile technologies used by CHWs in sub-Saharan Africa to inform suggestions for future technology designs.

Methods: Utilizing PubMed, Web of Science and Embase databases, articles were screened for relevance and, of the 78 articles generated from the search, 49 unique articles underwent full-text review. Five systematic reviews on the topic were consulted to devise the three major themes: technology uses, logistical considerations and study design. Ultimately, 30 articles met the inclusion criteria and were reviewed using MAXQDA.

Results: Inductive analysis led to 13 themes, applied to 30 articles. Applications on mobile phones were the most common type of technology used and quality improvement of CHWs' healthcare delivery was the primary purpose of the various technologies. Acceptability of the technology was commonly analyzed in the literature. The cost of the mobile technology, its likelihood of sustained use and its ability to operate in remote settings were rarely taken into consideration.

Conclusion: A variety of highly specialized mobile technologies add value to CHWs' performance of their different duties, but there is a need for more participatory research that takes into account the holistic, contextual impact and long-term implementation of the technology to improve acceptability and sustained use.

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Thank you to Dr. Kate Winskell for her thought-provoking perspective throughout this process and diligent review of numerous drafts. Thank you Gaëlle Sabben for ensuring that this thesis is pushed to the highest quality possible. Thank you as well to Emory University's Clinical Informationist, John K. Nemeth, for guidance on conducting systematic reviews, utilizing the Woodruff Health Sciences Library resources and Covidence software.

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Abbreviations

CHA	Community Health Assistant
CHW	Community Health Worker
EVD	Ebola Virus Disease
HEW	Health Extension Worker
MCH	Maternal and Child Health
RCT	Randomized Control Trial
WHO	World Health Organization

Introduction

A. Rationale

As defined by Uta Lehmann and David Sanders for the World Health Organization (WHO), Community Health Worker (CHW) is an umbrella term for citizens who are recruited from their communities where they serve as extensions of the healthcare system, embedded in the narrowest local level (Lehmann & Sanders, 2007). Sometimes referred to as "Health Extension Workers" (HEW), "Health Auxiliaries," or "Community Health Volunteers," CHW programs vary widely. From Ethiopia's renowned national HEW program with more than 1 CHW per 500 people, to emerging programs such as Mozambique's, appreciation is growing of the value added by CHWs to healthcare systems (United Nations Agency for International Development, 2017).

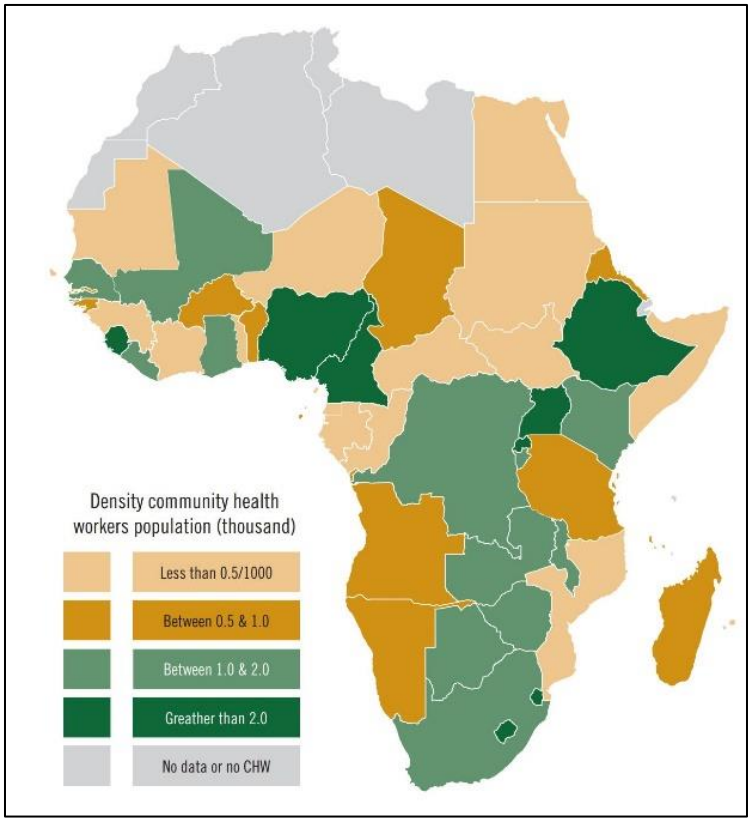
Though the United States has an average of 24.5 physicians per 10,000 people, the WHO estimates that ratio to be as low as 2.5 physicians per 10,000 people in low-income countries (McHenry, Fischer, Chun, & Vreeman, 2019). Based on WHO estimates for human resource needs, it is expected that by 2035, the global shortage of healthcare providers will reach 12.9 million, with the largest gap primarily in sub-Saharan Africa (Gonçalves-Bradley et al., 2020). In 2017, according to the World Bank Group, sub-Saharan Africa averaged only 1 physician per 5,000 people (see Figure 1). African nations, with 3% of the world's healthcare providers, also bear over 24% of the global burden of disease. The United Nations

Figure 1

Physicians per 1,000 people, 2017

Sustainable Development Goals prioritize improved access to primary healthcare, focusing particularly on areas with poor resources and hard to reach communities (Feroz, Jabeen, & Saleem, 2020). As depicted in Figure 2 from the United Nations, CHWs are an increasingly popular strategy for providing healthcare to serve the rural areas in low-resource settings in sub-Saharan Africa, where the majority of populations still reside (McHenry et al., 2019; United Nations Agency for International Development, 2017). CHWs bring preventive, promotive, curative and rehabilitative services closer to communities. They do this by providing maternal and neonatal health education, birth assistance, disease screening and treatment monitoring, among other activities (Feroz et al., 2020; Lehmann & Sanders, 2007). The combination of the limited resources and large rural population makes sub-Saharan Africa a unique setting for utilizing CHWs.

Figure 2
Density of Community Health Workers per Country Population in Sub-Saharan Africa, 2017



Amid scale-up of CHW programs, concerns have emerged regarding the quality of care and productivity of CHWs (McHenry et al., 2019). National CHW programs vary in terms of funding, prioritization of training and available management resources. CHWs also range from informal volunteers who may have completed minimal education to paid, professionally trained

healthcare providers (A. White, Thomas, Ezeanochie, & Bull, 2016). They are a healthcare system's most localized resource, often chosen by their own community to serve their neighbors. CHWs are sometimes the only access that people have directly to the healthcare system (Feroz et al., 2020). This distance from formal facilities can also raise unique challenges.

Mobile technology is an emerging strategy to better manage a high-quality cadre of CHWs (Laktabai et al., 2018). Training, supervision and travel expenses are common challenges faced by CHW programs due to the high number of CHWs living and working in remote locations (Henry et al., 2016). Technology is becoming a cost-effective and widespread method of contacting hard-to-reach areas even in low-income and low-resource countries as bandwidth and mobile connections rapidly increase while the cost of personal mobile phones decreases (Shuaib et al., 2018). By 2016, nearly 100% of the world's inhabited places had mobile signal (A. White et al., 2016). Mobile phones are the most widely-used technology in low- and middle-income countries (Francis et al., 2017). In 2016, about 78% of global mobile phone subscriptions were from developing countries, where more than three quarters of all people subscribed to mobile phones (Thobias & Kiwanuka, 2018). As well, despite significant upfront costs of launching a mobile technology strategy amongst CHWs, emerging research suggests a long-term benefit of replacing paper report books, protocols and guidelines with digitized versions (Coetzee et al., 2018).

Researchers have designed a variety of technologies for CHWs to use ranging from applications on their personal mobile phones to specialized devices for tasks such as digital fingerprint scanning (E. B. White et al., 2018). These strategies address a range of burdens CHWs face in completing their tasks with high quality and efficiency. Though CHWs are often provided with paper protocols, these are typically cumbersome and difficult to rely on for case

management when meeting clients, leading to diagnosis, treatment and reporting errors (Braun et al., 2016). Research on mobile technology tools to address all of these challenges aims to provide CHWs with additional time to visit more clients and provide greater attention and quality to each interaction (Coetzee et al., 2018). Across the spectrum of mobile technologies tested by CHWs, the potential benefits are enormous, including improved data quality, increased supervision and support, strengthened ability to manage cases and provide care and overall financial and administrative efficiency of CHW programs (A. White et al., 2016). This review builds on existing reviews to provide an updated assessment of published studies and of the types and purposes of technology currently in use by CHWs they describe (Gonçalves-Bradley et al., 2020; McHenry et al., 2019; A. White et al., 2016; Winters, Langer, & Geniets, 2018).

B. Problem statement

CHWs are intended to provide faster, personalized care to communities with limited access to health facilities but they often lack the necessary training and resources to provide this care at high standards. What aspects of mobile technology can help improve the quality of care provided in communities by CHWs? The speed at which resources are being developed to assist CHWs through an increasing variety of technological options requires frequently updated evaluation (Gonçalves-Bradley et al., 2020). Most studies currently evaluating CHWs' use of mobile technology are small-scale evaluations (e.g., Braun et al., 2016; Kabakyenga et al., 2016; Shinn et al., 2019). However, scoping reviews conducted even just five years ago are rapidly becoming outdated due to the fast-paced advancement of mobile technology for healthcare. Therefore, an evidence gap grows as more technologies emerge that seek to overcome the challenges CHWs face while serving rural communities.

C. Purpose

This review seeks to provide an update on the rapidly expanding use of mobile technology for CHWs by documenting strengths and weaknesses of mobile technologies used by CHWs as described in literature published since 2016. The guiding research question is "What types and strategies of mobile technology use are described as improving CHWs' performance?" This review compares factors that enable appreciation and sustained use of mobile technology by CHWs and identifies challenges to mobile technology implementation, recommending key considerations for future research in this field.

D. Significance

Though CHWs are intended to provide efficient and cost-effective healthcare support, mobile technology for CHWs requires considerable investment. So, evidence of benefit is necessary before governments invest in mobile technology to improve quality of care provided by CHWs. This review seeks to update existing literature reviews with findings published since 2016 and inform future researchers, implementers and decision makers about which mobile technology strategies may improve CHWs' capabilities and performance.

Literature Review

Community Health Worker Programs in Sub-Saharan Africa

The structure of CHW programs can vary from non-existent to exemplary across sub-Saharan Africa. As defined by the World Health Organization (WHO), a CHW is anyone selected by their community to provide healthcare services, filling the gap between health facilities and the community where they work (Lehmann & Sanders, 2007). With origins of this system tracing as far back as the 1950s in China, community based healthcare services were quickly recognized as an effective strategy to improve rural health outcomes, sparking a spread of CHW programs globally (Lehmann & Sanders, 2007; UNAIDS, 2017).

Ethiopia is considered one of the world's leading healthcare systems utilizing CHWs. The program was developed in 2003 to employ "Health Extension Workers" (HEWs) to help Ethiopia achieve universal access to primary healthcare (Wakabi, 2008). Now considered one of the most successful community health systems in the world, Ethiopia boasts a full year of training for all HEWs and a breadth of health topics addressed including sanitation, family planning, health education and disease prevention. As well, within five years of launching, the HEW program trained and employed nearly 25,000 HEWs, resulting in 82% of their target population receiving this increased access to primary healthcare via monthly visits from HEWs (Wakabi, 2008). An impact evaluation of the program just six years after its launch found significant positive health impacts including increased child vaccination rates and improved preventive health behaviors such as sleeping under insecticide-treated bed nets. The study found that these health improvements are strongly correlated with communities where HEWs operated (Admassie, Abebaw, & Woldemichael, 2009).

In their overview of CHWs, Lehmann and his team point out that generalizations about CHWs are difficult because the programs can vary so drastically from one community to the next and over time. However, it is widely accepted that a primary goal of CHWs is to improve access to quality healthcare from a local setting, leading to improved health outcomes. Lehmann et al. also highlight the need for intentional selection, training and support in order to achieve the intended health outcomes. Most importantly, successful CHW programs must be rooted in community needs and context (Lehmann & Sanders, 2007).

One systematic review searches for conditions which improve CHW retention and job satisfaction, such as social support among colleagues (Allana, 2012). The author asserts that many nations globally struggle to equitably distribute access to trained healthcare professionals, but CHWs serve as an affordable local resource for filling these gaps (Allana, 2012). Globally, the study reports that sufficient financial and programmatic investment must be made to support CHWs or their dissatisfaction with work environments will cause CHWs to quit at high rates. Factors most highly associated with high job satisfaction among CHWs include passion for improving their communities' health, opportunities for career development, their status within their communities and financial incentives. Conversely, poor salary or other incentives and insufficient training support are the strongest indicators of dissatisfaction and therefore high attrition of CHWs (Allana, 2012). Allana also emphasizes how properly trained CHWs with access to resources for conducting their work can be linked to improvements in maternal and child health, health education, immunization and case management (Allana, 2012). Ultimately, the recommendations from Allana's review are intended to support not only CHW retention, but improve health outcomes for CHWs' clients and communities.

Similarly, Pallas et al, (2013) study the factors which enable CHW programs to scale up sustainably and effectively in a variety of settings. The study team notes that comparing CHW programs from one context to another is challenging. However, certain aspects of a CHW program are found to be crucial for the growth of CHW programs. Notably, fundamental factors include adequate training, motivation, incentive and management to support not only CHWs but also the communities where they serve (Pallas et al., 2013). Pallas et al. therefore urge researchers and decision-makers to consider context when planning CHW programs. The study's five key recommendations center around a need for community-engaged program design and careful consideration of all levels of implementation, from the individual health needs of a community up through national and global health priorities. These steps will lead to stronger CHW systems and ultimately, improved health outcomes (Pallas et al., 2013).

Mobile Technology in Sub-Saharan African Healthcare

This review studies mobile technology use specifically by CHWs, but mobile technologies are useful at healthcare facilities or at the district health level as well. One study in Kenya evaluates the impact of a mobile electrocardiogram (ECG) for detecting atrial fibrillation (AF), a key risk factor of strokes. Not only is the mobile machine useful in detecting AF, it is also cost effective when shared by a small number of nearby health facilities (Evans, Shirk, Muturi, & Soliman, 2017). The same study asks healthcare providers about their access to mobile phone networks and 100% report the ability to access the internet on personal mobile devices. This speaks to the increasing feasibility of using mobile technology even at the personal healthcare provider level and in otherwise low-resourced settings (Evans et al., 2017).

The Groupe Speciale Mobile (GSM) Association provides an interactive online platform for visualizing mobile network coverage in several countries, including Uganda, the setting for 5 studies from this review. From the map at mobilecoveragemaps.com, we can see that nearly the entire country is capable of utilizing at least 2G phone service (The GSM Association, 2021). Likewise, coverage is widespread in several other countries where studies are conducted from this review including Sierra Leone and Nigeria. However, it is noteworthy that some countries still experience large geographic gaps in mobile coverage, which must be taken into consideration when intending to use mobile technology that requires internet connectivity. For example, The Democratic Republic of the Congo has only very concentrated locations with 2G minimum coverage, primarily near urban areas. Internet connectivity and the typical rates of mobile phone use by CHWs in the location of each study should be considered before attempting to introduce impractical technologies which will not operate if the area suffers from poor network coverage.

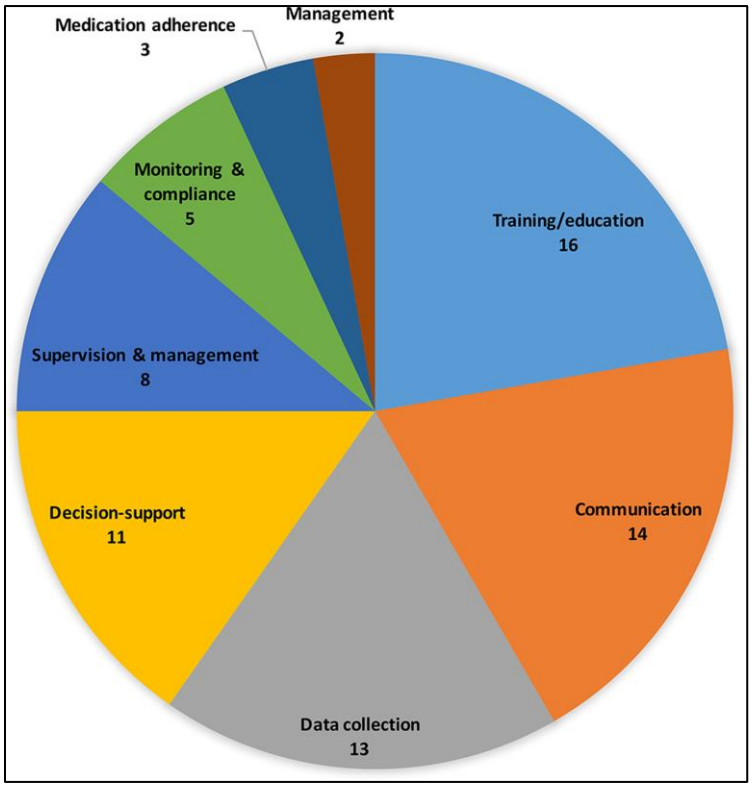
Related Systematic Reviews

Peer-reviewed publications accessible via PubMed about mobile technology use for healthcare in sub-Saharan Africa only date back as far as 2009. However, the volume of publications steadily increases each year since, indicating the growing attention on mobile technologies in healthcare, particularly in sub-Saharan Africa. Past systematic reviews of mobile technology use by CHWs provide a foundation for this review. One review specifically assesses the use of mobile technology for CHW training in low- and middle-income countries. The researchers determine that most existing mobile technologies are not developed using educational pedagogy or theory, therefore inhibiting the full potential of these technologies.

Instead, the authors suggest future collaboration between technology developers and educational theorists to design more productive and supportive training modules via mobile technology for CHWs (Winters et al., 2018).

The same article also categorizes the 16 studies included in their review into eight focal areas: training/education, management, communication, data collection, decision-support, supervision, monitoring and compliance and medication adherence (Winters et al., 2018).Though Winters et al. focuses primarily on training/education modules within mobile technology, the categorization and pie chart show the diversity of mobile technologies used by CHWs, as depicted in Figure 3 (Winters et al., 2018). Notably, of the 16 studies included in this educational review, 14 also focus on improving CHW communication and 13 also feature data collection, or record-keeping and activity reporting for supervisors (Winters et al., 2018).

Figure 3
Overview of mobile technology focal areas



A second systematic review of mobile technology use by CHWs in low-resource settings categorizes the purpose of the technologies into just four focal areas: data collection, communication between CHWs and their patients, communication amongst CHWs and disease

surveillance (A. White et al., 2016). While the review does find that most uses of mobile technology improve healthcare delivery by CHWs, few studies utilize theory-driven evaluation of the actual impact on health outcomes due to the mobile technology. Therefore, the authors recommend future studies of mobile technology incorporate an aspect of evaluation for actual detection of health improvements in the communities served (A. White et al., 2016). Significant limitations noted by White et al. also include internet access or technologies which are unfamiliar to CHWs, which decreased the technology's acceptability. From this finding, the reviewers recommend mobile technology designers and researchers consider the context where the devices will be used before testing acceptability (A. White et al., 2016).

A third systematic review of mobile technology use by CHWs explicitly filters for only studies that did as White et al. recommended; McHenry et al. evaluate only technologies that function without internet access in resource-limited settings globally (McHenry et al., 2019; A. White et al., 2016). Unsurprisingly, existing research in such a specific area and conducted just one year after White et al.'s review, produced only ten studies for evaluation. However, McHenry et al. still determine that mobile technology can improve healthcare delivery by CHWs when culturally adapted to fit the context in which it is used, particularly for resource-poor settings where access to healthcare facilities or specialized healthcare may be limited (McHenry et al., 2019). McHenry's team therefore emphasizes that future mobile technology studies must consider the context in which the technology will be used and adapt to cultural norms as well as resource capabilities. If developed with those who will use the devices, McHenry et al. speculate that technologies will be better accepted by CHWs and their communities, resulting in better health outcomes (McHenry et al., 2019).

Lastly, a fourth systematic review emphasizes the need for future studies which consider the impact of mobile technology use on the health outcomes of the communities served. This review does not limit its technology users to CHWs nor does it include a geographic focus, rather including all healthcare providers at any level of the healthcare system. The results focus primarily on studies from high-income countries utilizing mobile technology. Still, the reviewers recommend increased process evaluations and randomized control trials of mobile technology use by CHWs to better understand both the implementation and causal impact of the technology use on core health indicators (Gonçalves-Bradley et al., 2020).

Taken together, these systematic reviews emphasize the need for community-based, contextualized technologies if we expect to see sustained use by CHWs and a positive impact on local health outcomes (Gonçalves-Bradley et al., 2020; McHenry et al., 2019; A. White et al., 2016; Winters et al., 2018). Ultimately, this review aims to update the findings of these past reviews by bringing together their key recommendations and noting gaps in studies conducted since 2016 where these considerations may warrant future research. This is intended to inform suggestions for future more effective mobile technology designs for use by CHWs.

Methods

This review of mobile technology use by CHWs searched three databases: Embase, PubMed and Web of Science. These were accessed via Emory University. The databases were chosen based on guidance from librarians at the Woodruff Health Sciences Library for anticipated high result yields, popularity and common access.

In Embase, "All Fields" was employed with the recommended search term "'health auxiliary' AND 'mobile technology'". The PubMed search used Medical Subject Headings (MSH), a resource managed by the National Library of Medicine to index health-related keywords for research across several databases (National Library of Medicine, 2020). This study searched using "'Community Health Workers' AND 'mobile technology' AND 'sub-Saharan Africa'". Lastly, the Web of Science search utilized the All Fields criteria by searching "'community health worker' AND 'mobile technology'". All searches limited results to English and publication from 2016 – September 6, 2020 to build on pre-existing systematic reviews (Gonçalves-Bradley et al., 2020; McHenry et al., 2019; A. White et al., 2016; Winters et al., 2018).

All generated article citations were downloaded into Endnote citation software, then uploaded into a new project in the Covidence systematic review program. At this time, duplicate articles were identified and removed. Article title and abstract screening identified articles that did not meet the following inclusion criteria:

- Focus setting was sub-Saharan Africa, as defined by The World Bank (The World Bank Group, 2020)
- Primary user of the mobile technology was CHWs

- Full-text article was available
- The research was an original intervention (rather than a systematic review)

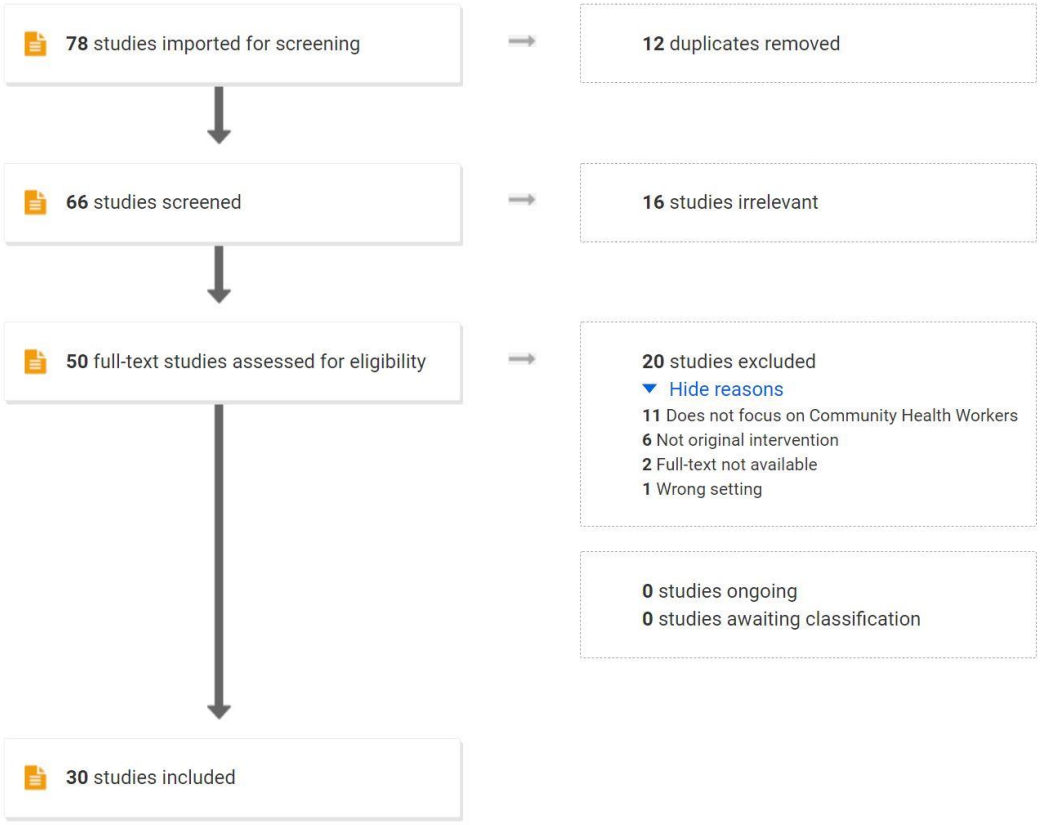
Articles that did not meet these criteria were immediately eliminated from the review. The database search generated 78 articles of which 12 were duplicates, making 66 total unique publications. After title and abstract review, 17 articles were eliminated. Of the 17 excluded, ten articles did not focus on sub-Saharan Africa, six articles did not assess CHWs utilizing the mobile technology themselves and one article was not a full-text publication but rather a conference abstract.

Prior to full-text review, four systematic reviews were consulted which presented findings related to CHWs and mobile technology from previous years (Gonçalves-Bradley et al., 2020; McHenry et al., 2019; A. White et al., 2016; Winters et al., 2018). The articles evaluated by these systematic reviews were screened for inclusion in this review of recent literature as well. This identified only one new article not already included in this review. This was likely because this study aims to add an updated evaluation of new mobile technologies utilized by CHWs, building on existing research, due to the rapid growth in this field. Therefore, many sources reviewed by past systematic reviews were published prior to this search period. As well, several of the systematic reviews analyzed interventions across countries outside sub-Saharan Africa. Because healthcare needs, CHW systems and mobile technology capabilities vary significantly in other regions, such as Europe, they have been excluded from this review, but should be analyzed in future research.

Full-text PDF review provided a final evaluation of inclusion based on the same criteria for the remaining 50 articles. Of these, 20 were excluded because they did not focus on sub-Saharan Africa, 11 did not focus on CHWs as the users of the mobile technology, two were not

full-text reports and five were not original interventions but rather systematic reviews. The Preferred Reporting Items for Systematic Review and Meta-Analysis (PRISMA) tool was used to visualize the screening process via the Covidence program and is displayed in figure 4.

Figure 4
PRISMA Chart



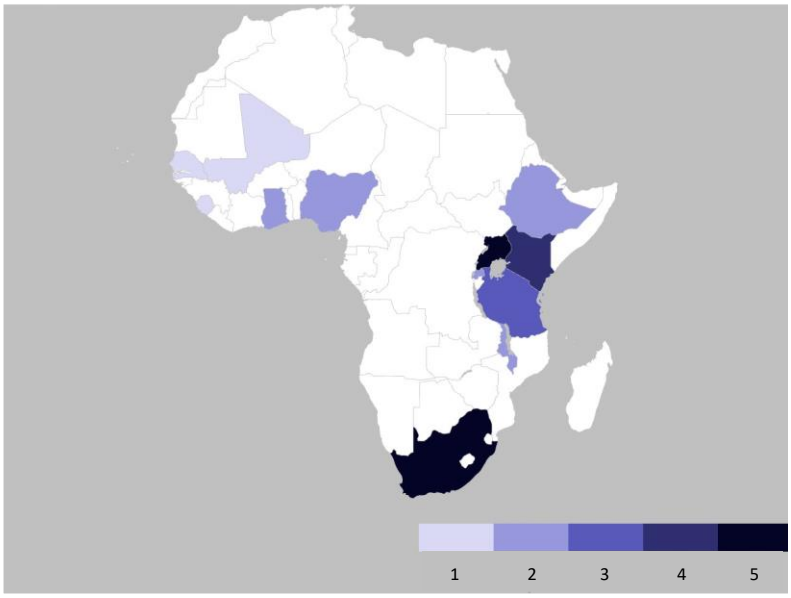
The remaining 30 articles were analyzed qualitatively in MAXQDA 2020 software for evidence around three categories: study design, logistical considerations and uses of mobile technology by CHWs (VERBI Software, 2020). The review of five older systematic reviews of mobile technology use by CHWs informed the initial derivation of the three categories of interest and ideas for the themes within each category (Gonçalves-Bradley et al., 2020; Lee, Cho, & Kim, 2017; McHenry et al., 2019; A. White et al., 2016; Winters et al., 2018). From these three categories, an initial list of themes was developed including "training before testing" within the

study design category, “remote-setting capability” within the logistical considerations category, and “educational” within the technology uses category. However, full-text review of the articles ultimately determined the final codebook via inductive analysis. With the three overarching themes in mind, all articles undergoing full-text review were coded within each category, such as “comparison group” if the study design included the use of a comparison group or “communication” if the use of that mobile technology intended to improve communication between the CHWs and their clients, peers or supervisors. Co-occurrences were examined between codes to assess where certain codes were more common and overlapped. Frequencies were computed for each code and co-occurrence. These themes allowed for comparison across the various technologies, taking context and intended purpose into consideration.

This review of recent literature did not involve research with human subjects. Therefore, the study did not undergo any formal institutional review board approval process.

Results

Figure 5
Geographic Distribution of Studies Reviewed



The final review included 30 studies conducted in 13 countries, as depicted by the map in figure 5. As shown, five studies each were conducted in South Africa and Uganda, the maximum for any country (e.g. Adam et al., 2019; Chang et al., 2017; Ramukumba & Hägglund, 2019). Kenya was also a common study site with four studies conducted there (Henry et al., 2016; Laktabai et al., 2018; Shinn et al., 2019; Vedanthan et al., 2019). Only one study was conducted in Mali (Whidden et al., 2018), Senegal (MacDonald & Diallo, 2019), Sierra Leone (Vallières, McAuliffe, van Bavel, Wall, & Trye, 2016) and the Democratic Republic of the Congo (Diese et al., 2018). Study durations ranged from one day to an outlier study which extended over ten years (Willcox et al., 2019). The vast majority of studies were conducted over six to twelve months, during which time CHWs utilized the mobile technology in their daily tasks screening their community for diseases, such as pneumonia in Uganda and helping pregnant women prepare for childbirth in Senegal (MacDonald & Diallo, 2019; O'Donovan et al., 2018).

Of the 30 studies reviewed, data collection relied mostly on mixed methods (15 studies) while 11 studies collected exclusively quantitative data and 4 studies focused on qualitative interviews, focus group discussions or both. The size of the studies varied considerably with some studies involving 2 CHWs (Shinn et al., 2019) while others tested their technology on as

many as 327 CHWs (Vallières et al., 2016). However, this exact number was difficult to ascertain for some studies, due to grouping interviews or surveys across *all* participants including CHWs but also community members and supervisors. Additionally, some studies measured study "participants" as the number of clients served by CHWs and never specified how many CHWs were involved in the intervention to reach that number of community members. It was therefore also difficult to calculate an average number of CHWs participating in the studies. Based on estimated CHW participants, the uncertain average is 76 CHWs in each study. A breakdown of these study aspects is presented in Figure 6.

Figure 6
Table of Study Characteristics

Study Authors	Primary Objectives	Study Methods	# of CHWs in Intervention
Adam, M. et al	Exclusive breastfeeding rates	Cluster randomized-control trial (RCT), mixed methods	84
Boyce, S. P. et al	Adherence to CHW management guidelines	Quasi-experimental, mixed methods	250
Braun, R. et al	Acceptability and benefits of mobile technology for family planning services	Mixed methods	25
Chandani, Y. et al	CHW demand-driven resupply efficiency	Mixed methods	Unclear. Approximately 120
Chang, L. W. et al	Access and quality of HIV care and resources	Cluster RCT, quantitative	Unclear Approximately 10-40
Coetzee, B. et at	Acceptability and feasibility of CHWs using tablets	Qualitative	24
Diese, M. et al	Perceptions of mobile phone use for MCH surveillance	Cross-sectional, mixed methods	Unclear. Up to 190
Dusabe-Richards, J. N. et al	Feasibility of CHWs using mobile devices for core duties	Mixed methods, primarily qualitative	Unclear. Up to 57
Eksteen, S. et al	Ability of CHWs to conduct hearing and vision screening	Quantitative	4
Ettinger, K. M. et al	Usefulness of mHealth app for patient assessment	Human-centered design, mixed methods	10

Francis, F. et al	Applicability of phone-based app for reporting fever cases and managing malaria	Prospective longitudinal, quantitative	Unclear. Likely 8
Hackett, K. M. et al	Perceptions of mobile technology use for MCH	Qualitative	64
Henry, J. V. et al	Perceptions of mobile technology use for communication	Mixed methods, descriptive	25
Kabakyenga, J. et al	Effect of mobile technology use onCHWs' case management	Observational, mixed methods	96
Laktabai, J. et al	Quality improvement of CHWs testing for malaria	Mixed methods	100
LeFevre, A. E. et al	Effectiveness of mobile technology to deliver health messages and reminders	Naturalist design, descriptive, mixed methods	Unclear
MacDonald, M. E. et al	Uptake of CommCare app	Ethnographic, mixed methods	13
Mangwi Ayiasi, R. et al	Effect of mobile technology on MCH home visits	RCT, quantitative	48
O'Donovan, J. et al	Pneumonia surveillance using mobile technology	Pilot RCT, mixed methods	63
Out, A. et al	Knowledge and attitudes of health workers on Ebola Virus Disease	Cross-sectional, quantitative	94
Ramukumbam M. M. et al	Perceptions of mobile technology use by CHWs	Exploratory case study, qualitative	46
Shinn, J. R. et al	Hearing screening	Cross-sectional, quantitative	2
Shuaib, F. M. B. et al	Acute Flaccid Paralysis surveillance via app	quantitative	Unclear. Up to 204
Sonderman, K. A. et al	Surgical site infection post-cesarean section surveillance	Prospective RCT, quantitative	Unclear
Thomsen, C. F. et al	Perceptions of mobile technology use for childbirth	Qualitative	36
Vallières, F. et al	Mobile technology effect on CHW job satisfaction, motivation and supervision	Randomized longitudinal cohort, quantitative	327
Vedanthan, R. et al	Hypertension case management	Cluster randomized trial, quantitative	Unclear
Whidden, C. et al	Mobile technology for CHW supervision and feedback	RCT, mixed methods	72
White, E. B. et al	Feasibility of mobile technology for tuberculosis contact investigation	Parallel-convergent RCT, mixed methods	15
Willcox, M. et al	Cost-effectiveness of scaling mobile technology for MCH	Economic forecasting, longitudinal cohort, quantitative	Unclear

Two devices were highly specialized: a Deki Reader for rapid malaria tests and a digital fingerprint scanner (Laktabai et al., 2018; E. B. White et al., 2018). However, 90% of the technologies reviewed were some form of application for mobile phones or tablets (or "apps"). These were apps on smartphones that CHWs could quickly familiarize themselves with using. Typically, the app was easy to learn and prompted CHWs to watch educational videos or guided them through entering and reporting data, conducting a patient consultation or screening for particular conditions via digital forms (e.g. Boyce, Nyangara, & Kamunyori, 2019; Braun et al., 2016; Ettinger, Pharaoh, Buckman, Conradie, & Karlen, 2016). However, some studies reported poor technology design and CHWs complained of an inability to easily learn how to use the app or fulfill its purpose. For example, a study in South Africa using videos to supplement home visits discovered that CHWs actually *lost* confidence in their skills when asked to use this app because they feared embarrassment if the technology failed or they did not know how to troubleshoot issues (Coetzee et al., 2018).

Smartphones are increasingly affordable around the world, but no study discussed CHWs using their own device capable of running the new technology. The studies in this review also did not predict or detail an anticipated budget for their app or device to be used by health ministries. Instead, the devices were always provided to CHWs for the duration of the study and replaced if lost, stolen or broken. For full details of study duration, location and technology used, see Appendix A.

Study topics also varied, but the primary interest was supporting maternal and child health (MCH). Some technologies targeted education by providing video tools or consultation guides for CHWs to better support pregnant women and new mothers (e.g. Coetzee et al., 2018). Others enabled stronger communication during childbirth emergencies via phone calls to

supervisors for guidance or to local clinics to send help (Dusabe-Richards et al., 2016). The second most commonly addressed health issue was malaria. Uses included improved surveillance and reporting as well as direct rapid testing (e.g. Francis et al., 2017). Other health issues included impaired hearing (Shinn et al., 2019), pneumonia (O'Donovan et al., 2018), hypertension (Vedanthan et al., 2019), Ebola virus disease (Otu, Ebenso, Okuzu, & Osifo-Dawodu, 2016) and acute flaccid paralysis symptoms to detect suspected polio (Shuaib et al., 2018).

About one quarter of studies primarily sought to improve the quality of care CHWs provide, communication with supervisors or reporting. One study did this by creating WhatsApp chat groups mixing CHWs and supervisors (Henry et al., 2016). Others set up systems for immediate feedback. These quality improvement strategies included pre-programmed devices, such as the malaria rapid test reader, consultation with supervisors over the phone or frequently-updated reports which allowed for rapid feedback (Whidden et al., 2018; E. B. White et al., 2018). More than half of the quality-improvement studies facilitated more streamlined and rapid digital reports which improved linkage to care for hypertension, polio, malaria and HIV (e.g. Shuaib et al., 2018; Vedanthan et al., 2019).

To better understand the various technologies, the articles were coded based on the purpose of each technology, details for implementing the devices and the design of each study. Table 2 outlines the thirteen sub-themes that emerged during inductive analysis of the final thirty articles included in the review. These codes were labeled according to theme whereby the green category is technology uses, the yellow category is logistical considerations and the purple category is study design.

Table 1: Study themes, organized by category			
Theme	**Sub-Theme**	**Definition**	**# of articles coded**
Technology Uses	**Administrative**	Mobile technology that enables CHWs to conduct administrative tasks	19
	Educational	Mobile technology described as providing any form of educational materials utilized by CHWs to inform themselves and/or clients, including job training	9
	Quality Improvement	Instances when mobile technology is designed to foster improved CHW skills and/or services including decision-making	23
	Communication	Presenting types of mobile technology that facilitates improved communication for CHWs either with their clients, supervisors, health facilities and/or each other	15
Logistical Considerations	**Scalability**	Discussing factors influencing the scale-up of a particular form of mobile technology by more CHWs	3
	Sustainability	Acknowledging intended use of the mobile technology beyond the study duration, without involvement of the study team, or for the duration of the study period, and possible challenges related to sustained use	4
	Acceptability	Reference to CHWs' opinions of the mobile technology's acceptability and perceptions of integrating its use into their work, including mobile technology's impact on the role of the CHW and their work, such as changes in confidence or the perception of their role among the community	22
	Cost	Discussion of financial factors related to CHWs' use of mobile technology within the study and beyond the study itself	8
	Remote setting capabilities	Mention of the mobile technology's ability to operate in remote settings, namely those without consistent internet access and/or ease of charging devices	10
	Data privacy	Consideration of the security and privacy of data collected and/or stored by mobile technology and	10

		perspectives relating to data privacy either by CHWs, patients or other stakeholders	
Study Design	**Comparison group**	Reference to the inclusion of a comparison group in the study design	13
	Sufficient use	Discussion of the study participants' consistent, reliable use of the mobile technology during the study period or lack thereof and the effects of this factor on the data collected	8
	Training before testing	Reference to training for CHWs before testing the mobile technology and discussion of the sufficiency and content of that training or lack thereof	18

Most Common Sub-Themes Across All Categories

Every article was coded with at least two different sub-themes and three articles received the highest number, with eight sub-themes each (Chandani et al., 2017; Dusabe-Richards et al., 2016; Shinn et al., 2019). The quantity of sub-themes applied to one article did not necessarily suggest superior mobile technology type, study rigor or implementation style. For example, one study developed mobile technology intended specifically for teaching CHWs about Ebola virus disease (Otu et al., 2016), while more than half of the studies intentionally aimed to provide a variety of resources to CHWs. Relatedly, if a mobile technology did not store any sensitive data, then data privacy was not of concern to that particular study (e.g. Henry et al., 2016), hence the data privacy sub-theme was not applied. Any particularly high or low frequency of any specific sub-themes is discussed with regards to the relevance of those studies to the codebook designed for this review.

With the introduction of various mobile technologies, the quality of work performed by CHWs nearly always improved with digitized solutions for previously time-consuming tasks, such as reporting. The most common sub-theme used to code articles was quality improvement

resulting from the use of the mobile technology. Nearly every research team included a component to measure the impact of the new technology on the performance, skills, behavior or operating procedures of the CHWs. Along with the use of administrative technologies, interventions that sought quality improvement typically included an aspect of increased time efficiency or bundled tasks that previously required CHWs to complete or submit paper forms, travel to health centers for trainings or meetings, travel to clients' homes or conduct lengthy examinations of clients while consulting a paper guide (e.g.Boyce et al., 2019).

Quality improvement also related to the skills CHWs possessed. Though coded as a distinct sub-theme, educational mobile technologies co-occurred frequently with quality improvement activities. Some educational mobile technologies aimed to increase the number of skills and health topics CHWs could address within their communities, equipping them with video tutorials or step-by-step procedures to evaluate clients on new health issues (Shuaib et al., 2018). For example, the AVADAR mobile phone app, tested in Nigeria, played a video reminder once per week depicting a child with symptoms of acute flaccid paralysis to ensure CHWs could recognize possible cases of polio and auto-report any sightings after watching the video (Shuaib et al., 2018). Education via mobile technology was often tested as a replacement for expensive, time-consuming in-person workshops (e.g. O'Donovan et al., 2018). Results from these studies showed promise of offering greater efficiency in training, particularly when video tools were incorporated to provide visual learning (Coetzee et al., 2018). Eight of the nine studies reported increased knowledge by CHWs (e.g. Adam et al., 2019; Otu et al., 2016; Thomsen et al., 2019). However, one study in Uganda seeking to train CHWs to detect pneumonia cases found no difference between detection rates of CHWs with tablet videos versus the control arm without videos. However, even without an impact on educational attainment, the CHWs reported high

acceptability of the tablet and videos within their work. It is possible the video content itself needed revision, because qualitative analysis showed acceptable delivery methods but no improvement in health outcomes (O'Donovan et al., 2018). In summary, improved educational tools via mobile technologies nearly always enabled quality improvement.

Acceptability of use was also frequently assessed in the evaluation of a mobile technology. This included perspectives not only from CHWs using the technology but also clients whose personal data was sometimes recorded and reported via these unfamiliar devices. Studies showed the highest acceptability of mobile technologies when the devices included security measures such as password protection or encryption (e.g. Braun et al., 2016; Eksteen et al., 2019). Supervisors appreciated more easily contacting their teams of CHWs and management could better track routine reporting and feedback from CHWs (e.g. Ramukumba & Hägglund, 2019). Typically, the introduction of a mobile technology job aid was well perceived by CHWs, accompanied by a boost in their confidence performing their tasks and providing services (e.g. Hackett, Kazemi, & Sellen, 2018).

Infrequent Sub-themes

Though mobile phone use is increasingly common across sub-Saharan Africa, internet connectivity is not always available, particularly in the rural areas where CHWs typically work. However, in more than half of the articles when operability in remote settings was discussed, it was in reference to internet connectivity as a major challenge which demanded unexpected problem-solving during the study (Dusabe-Richards et al., 2016). One team provided each of their CHWs with solar chargers where electricity for charging the devices was rare (O'Donovan et al., 2018). Several others designed storage strategies for the mobile phone or tablet application to save records until internet connectivity was available, at which time all data would be

uploaded (Adam et al., 2019; Francis et al., 2017; Shinn et al., 2019; Sonderman et al., 2018). This decreased the challenge of internet connectivity but did not eliminate it. Three studies focused on educational videos that could be played offline while visiting clients (Adam et al., 2019). Only two of the thirty technologies reviewed were fully operational offline (Braun et al., 2016; O'Donovan et al., 2018).

Another common challenge when managing a cadre of CHWs spread across vast, often remote areas, is communication. Of concern to half of the studies, creative approaches sought to improve CHWs' communications. Eight studies enabled either text or phone call communication between CHWs and their supervisors and six of these showed improvement in CHW performance as well as high acceptability of the apps or devices (e.g. Braun et al., 2016; Kabakyenga et al., 2016; Mangwi Ayiasi, Kolsteren, Batwala, Criel, & Orach, 2016). CHWs could more easily receive technical assistance over the phone, share learning opportunities via WhatsApp with CHWs across Nairobi (Henry et al., 2016), alert the local health facility in Uganda that a referred client was on their way (Mangwi Ayiasi et al., 2016) or improve supply chain efficiency in Rwanda (Chandani et al., 2017). Four studies sought to improve reporting work tasks to supervisors and one even created a performance dashboard visible to supervisors and CHWs with quality, timeliness and quantity of care visits reported (Ettinger et al., 2016; Kabakyenga et al., 2016; Ramukumba & Hägglund, 2019; Whidden et al., 2018). In more than half of all studies reviewed, mobile technologies were primarily intended to improve communications in some manner. Only one of the 15 communications studies reported no impact on communications (Vallières et al., 2016). However, only ten studies reported finding an improvement in communications (e.g. Chandani et al., 2017; Henry et al., 2016) and the remaining four had inconclusive impacts on improved communication.

Study Design Sub-Themes

In assessing the study design, "comparison group" was used when a designated set of CHWs who did not have access to the technology being tested were included in the study. This study design facilitated better understanding of the impact the technology may have had on the health outcomes of interest or the work of the CHW. Only four studies maintained a comparison group operating under the usual standard of care. For example, one study evaluated whether follow-up phone calls after cesarean-section deliveries using tablets helped identify and refer infections in Rwanda whereas the control group had no mechanism for reminders or the ability to call clients (Sonderman et al., 2018). Another study included a comparison arm but CHWs trained in the same sessions alongside the intervention arm, simply without the added benefit of the mobile technology (e.g. Adam et al., 2019). One third of the articles with a comparison group specified that allocation was conducted randomly. As CHWs work embedded in their communities, random allocation into control and intervention arms was typically done at the district, village or sub-county level to ensure CHWs of the same areas were allocated to the same study group, preventing possible cross-over contamination. One unique study utilized trained otolaryngology residents as the comparison group. The researchers assessed the technical expertise and health diagnosis outcomes achievable by CHWs conducting the same hearing tests, compared to the highly-specialized otolaryngology residents (Shinn et al., 2019). However, two-thirds of the studies in this review did not include any form of comparison group in their study design.

Findings about CHWs inconsistently or unreliably using mobile technologies were coded as "sufficient use". This typically related to shortcomings in the technologies' hardware and/or software design, durability including battery life, understanding and experience of use by CHWs,

cost of airtime and/or charging, vulnerability to loss and theft, time required for use and availability of an internet connection (Boyce et al., 2019; Braun et al., 2016; Thomsen et al., 2019; E. B. White et al., 2018). Only two articles discussed the rate of technology use by CHWs as "high usage", therefore meeting benchmarks set by the research teams about the number of times the device was used. One study was about frequency of communications within a WhatsApp group of CHWs and supervisors in Kenya while the other monitored SMS reporting of suspected Acute Flaccid Paralysis in Nigeria (Dusabe-Richards et al., 2016; Shuaib et al., 2018). This frequent technology use enabled the research teams to better evaluate the technologies' possible impact. One article observed a mixed rate of utilization, with some CHWs relying on the mobile technology for educational videos about family planning, diet and vaccination in Ethiopia far more often than others. The researchers attributed this to the diversity of household visits the CHWs conducted and therefore the variable relevance of the device to some CHWs who conducted fewer relevant visits during the study period (Thomsen et al., 2019). The vast majority of articles did not discuss the amount of time CHWs spent using the devices at all.

The third and final sub-theme that emerged under "study design" was "training before testing". This sub-theme was used in more than half of all studies in reference to mobile technology training with the specified device or application for CHWs before they were observed or tested using the mobile technology as well as discussing the sufficiency of that training. Topics covered in the trainings included how to operate the particular mobile technology, how to troubleshoot errors and background information on particular health topics (Adam et al., 2019; Coetzee et al., 2018; Eksteen et al., 2019; Francis et al., 2017; LeFevre et al., 2017; E. B. White et al., 2018). Only four articles utilized practical assessments and

questionnaires to ensure adequate thoroughness of their training. Few studies included a component of observed mobile technology use before actual testing via role play or observed client visits. In consultation with specialists in the field, Shinn's study team required CHWs to use the mobile device for hearing screenings to the standards approved by otolaryngologists, sometimes conducting up to 14 observed trial screenings, before conducting solo hearing screenings (Shinn et al., 2019). Training was not always optimal. Two studies acknowledged weaknesses in the training and feedback from CHWs requesting further training.

Post-Hoc Sub-themes

Sub-codes were utilized to indicate whether a sub-theme was only coded within the discussion section of the article, typically as recommendations the authors made with the benefit of hindsight. These sub-codes, indicated by "[SUB-THEME] discussion only", were a crucial addendum. Hindsight acknowledgement of a particular issue, such as the burdensome cost of the technology or the inability to operate without a stable internet connection, meant that the issue was significant enough to warrant discussion by the researchers even though the issue was not addressed in their initial study design. For example, training CHWs properly before testing the technology was the most common theme not mentioned until the discussion section, as was the case in five studies (e.g. Coetzee et al., 2018; Diese et al., 2018). This indicates that planning for sufficient training should be a component of future mobile technology studies. The ability to scale up the technology and, more often, address the barriers to doing so, were also rarely mentioned until the discussion section. Lastly, cost of the technology was not mentioned until the discussion section of four studies, often noting that cost-effectiveness should be featured in future studies (Eksteen et al., 2019; Shuaib et al., 2018). The uses of a technology were never

mentioned exclusively in the discussion section. However, study design and logistical considerations were particularly prevalent in the explanation of study limitations.

Discussion

As seen from the thirty studies in this review, approaches to mobile technology for CHWs can vary widely. Important considerations used by these studies can inform the development and implementation of stronger mobile technology in the future. The studies in this review employ mobile technology for a variety of purposes including improved communications, new education methods for CHWs and strengthened quality-of-care provided by CHWs. These studies also acknowledge many important logistical hurdles that future studies can now plan ahead for, such as limited internet connectivity, patients' concerns regarding data privacy and the cost of technologies. Most commonly evaluated, the acceptability of different technologies by both CHWs and their communities clearly has a strong impact on the frequency and ability to use the devices and apps. This review gathers all of these factors to examine characteristics of technologies addressed in published studies including their purposes and features to make suggestions about where mobile technologies for CHWs continue to need improvement.

Certain priorities for researchers and practitioners, as well as CHWs, are evident when considering the co-occurrence of *acceptability* with other codes. Nearly all studies include some measure of the CHWs' acceptance of the new mobile technologies. Highly accepted mobile technology enables CHWs to feel at ease communicating with each other and supervisors, confident managing their cases and facilitate delivery of high-quality care (e.g. Kabakyenga et al., 2016). These factors not only improve CHWs' ability to provide high-quality health services via improved communication, it also boosts their approval of the mobile technology as a job tool (e.g. Chandani et al., 2017; Hackett et al., 2018). Therefore, communication and quality improvement approaches are clear priorities in the studies reviewed.

Data confidentiality is of great concern in any public health intervention and is particularly relevant when considering rural, locally-based health information stored on CHWs' mobile technology. CHW and particularly community concern about data privacy and device security has been noted as one of the primary barriers to the adoption of mobile technology by healthcare providers of all kinds in sub-Saharan Africa (Gonçalves-Bradley et al., 2020). Similarly, older systematic reviews recommend including data security measures in future mobile technology designs for use by CHWs (Gonçalves-Bradley et al., 2020; A. White et al., 2016). However, twenty articles in this study do not address this and the lack of security measures on the devices even becomes a barrier towards use in some skeptical communities where patients express discomfort having their medical information entered into the mobile devices and even falsely believe the devices video record their interactions with CHWs (Coetzee et al., 2018). Fewer than one third of studies addressed data privacy by either encrypting or deidentifying patient data or by password-protecting the mobile device (e.g. Eksteen et al., 2019). Of the ten studies that did acknowledge data security, seven only referred to the studies' patient information (e.g. Chang et al., 2017). This leaves the devices vulnerable, potentially making data accessible in the very communities of the participants, which could erode trust in the mobile technology and even in the CHW and healthcare system if the information is leaked beyond the CHW. To address this, three studies specify that password protection was set up on the devices or that all data is sent to a cloud-based server and therefore inaccessible from the CHWs' devices (Braun et al., 2016; Chang et al., 2017; Eksteen et al., 2019). Any future mobile technology used by CHWs that collects data or is even perceived to collect personal data, should have privacy settings. This will increase community and CHW acceptance of the mobile technology, thereby improving implementation.

The studies in this review do not directly measure the characteristics of mobile technology or factors relating to its implementation which lead to high acceptability by CHWs and their communities, sustained use, feasible scale-up prospects and other helpful aspects that make a mobile technology more or less successful or useful. Rather, primary aims are to evaluate impacts on certain health behaviors or outcomes such as improve newborn feeding practices or increase adherence to tuberculosis medication by patients. This indicates a research gap in evidence of the actual mobile technology use by CHWs None of the studies in this review discussed conducting a Strengths Aspirations Opportunities and Results (SOAR) assessments (Expert Program Management). This valuable method helps understand the context in which the technologies are used, such as whether or not internet is widely available. Due to this gap in evidence, I recommend future studies focus specifically on the factors enabling or hindering use of mobile technology by CHWs, rather than only the health outcomes that follow thereafter. This includes studies measuring what amount and style of training is required for proper use, evaluating the cost for CHWs and their employers to utilize mobile technology and more human-centered design studies, such as Ettinger's research in South Africa, ensuring acceptable technology design (Ettinger et al., 2016). Understanding the effectiveness of the technology for particular health outcomes has the potential to be even more valuable if we can understand *how* that health outcome was achieved and the ways in which technology contributed.

Sustainability of use over time is hardly evaluated by any of the studies included. Only one study addresses the long-term use of mobile technologies over ten years in Ghana (Willcox et al., 2019). One other study shows how continued frustrations or embarrassment if the device does not work during one patient encounter can lead to decreased willingness to use the device over time. The study notes that 87% of CHWs utilize the device in the first quarter of the

evaluation, yet only 51% of CHWs use the device by the final quarter (E. B. White et al., 2018). In addition, technology is known to degrade and is sensitive to breaking or malfunction. Only one study acknowledged a need for implementers to plan accordingly for replacing devices or compensating CHWs adequately for data, text-messaging, calling time or charging in order to consistently have access to the technology. This could become a significant cost for CHW management, which the study quantifies for the context in Ghana (Willcox et al., 2019). One factor shown to impact sustained use of technologies over time is proper training provided to CHWs. However, none of the studies provide a clear recommendation for appropriate amount or frequency of training to ensure consistent and continued use of the technologies studied. The length of training depends on the design of the technology. Studies that include a component of refresher trainings and/or observing CHWs' successful technology use before completing the training show more success with CHW adoption and proper use of the technologies (e.g. Mangwi Ayiasi et al., 2016). Perceived usefulness of the technology by CHWs for daily tasks, reasonable costs and adequate training all impact the likelihood of sustained technology use after the study ends. Ultimately, mobile technologies for CHWs should be designed with the idea that the technology can feasibly be adopted by local healthcare systems, including addressing issues of cost and durability of the devices.

In comparison to recommendations from related, older systematic reviews, the studies in this review are missing some notable topics. For one, evidence is lacking for the ability to scale-up many of the mobile technology strategies evaluated, particularly in regards to cost, despite three systematic reviews recommending this consideration (Gonçalves-Bradley et al., 2020; McHenry et al., 2019; A. White et al., 2016). When lost, stolen and broken devices are simply replaced by the study team, we lose the ability to measure whether constantly supplying the

particular technology will be feasible long-term without support from the study team (Shiferaw, Workneh, Yirgu, Dinant, & Spigt, 2018). Beyond funding challenges, there is also very limited review of local Ministry of Health or other infrastructure support for using these mobile technologies among an entire cadre of CHWs. No study proposes how a healthcare system would obtain their mobile technology for more CHWs or maintain use after initial roll-out. Prioritizing ease of use and perceived usefulness are key recommendations by Gonçalves-Bradley (2020), and these appear to improve in more recent studies, becoming key aspects of many studies included in this review. However, several key considerations still need evaluation, including long-term cost of mobile technologies and systematic support.

This review of recent literature has certain limitations. The first is the inclusion criteria that publications must be in English, likely resulting in the exclusion of valuable sources. Additionally, access to publications via Emory University databases means that some platforms for publications were not screened for relevant sources. Possibly due to the COVID-19 pandemic, no articles were published in 2020 that fit the inclusion criteria. This is likely because so much research was paused during the COVID-19 pandemic and priorities have shifted towards COVID-19 related studies. Additionally, there is no standardized method for comparing the sources or style of evidence provided by the different studies. This review attempted to synthesize the available findings to inform future research on mobile technology use based on factors of importance identified from past systematic reviews. Though sometimes considered ideal components of research for strong evidence, study context, objectives and limitations mean that randomization and blinding are not always possible, necessary or even relevant. Therefore, no judgement was made of the evidence provided by the included studies. Rather, findings were presented with consideration of the study's implementation characteristics, such as training, and

purpose in relation to each mobile technology. This review and future reviews like it could benefit from a multi-person team of reviewers. This review was conducted individually and therefore, all inclusion and exclusion decisions, as well as theme identification, were made independently.

Public Health Implications & Recommendations

Ultimately, this review highlights key gaps in current knowledge and the need for further research into technology use by CHWs. Before designing new mobile technologies for CHWs, it would be beneficial to conduct further research on existing interventions. For example, we must quantify the costs incurred by governments adopting existing technologies and the return on investment for CHW job satisfaction, abilities and resulting health improvements in their communities. More information should be collected as well regarding the long-term adoption of various technologies and their sustained use by CHWs, or lack thereof, as well as long-term impacts of their use both on CHWs' performance and health outcomes for patients. In parallel, human-centered design and participatory research must be used to inform the development of new technologies, in consultation with CHWs, their clients and their managers to more effectively identify the most important areas where mobile technology can assist. Very few studies included in this review collected iterative user feedback throughout the development of their mobile technology and only one study purposefully studied the local research context and culture before implementation (LeFevre et al., 2017). Those that did prioritize feedback from CHWs showed markedly higher rates of acceptance and appreciation for the technology, enabling improved performance (Adam et al., 2019).

The importance of CHWs is rooted in their community ties. The underserved areas where CHWs work almost always face dire health disparities. Therefore, the attention these studies pay to improving the health of these communities is crucial and must be built upon with further research. This effort towards a more context-driven approach to health can be strengthened by

community-based methods. Seeking input from the CHWs and their clients would enable future mobile technology designs that meet the needs of the communities.

Conclusion

Mobile technology is becoming ever more widespread and accessible, even in the world's most remote communities. These remote societies often face unique and significant challenges to accessing healthcare, which makes them a priority location for CHWs to work and bring health services a step beyond brick-and-mortar health facilities. A wide variety of researchers are turning their attention to these CHWs in an attempt to facilitate higher quality work in such challenging conditions, often far from formal health facilities and primary care providers, with limited supplies and difficulty traveling to trainings. With insight gleaned from the thirty studies included in this review, the hope is that health-focused mobile technology use by CHWs can continue to boost the effectiveness and skill of CHWs globally and improve health outcomes.

This review presents the documented strengths and weaknesses of studies on various mobile technologies as well as the design and implementation of the technologies across sub-Saharan Africa for use by CHWs. The aim is to inform stronger future mobile technology programs for CHWs. The apps and devices considered in this review present promising approaches to enhance communication, provide access to educational or digital data management and reporting tools, and improve quality of care. The technologies presented have the potential to improve the detection and treatment of an array of health issues. This means CHWs can have more impact but it also means that comparing these technologies is difficult due to the range of priorities and contexts. A highly-specialized hearing tool for screening children in very remote areas is inherently very different from a study of WhatsApp chat groups for CHW cohorts and their supervisors in low-income neighborhoods of cities (Henry et al., 2016; Shinn et al., 2019). Despite these different priorities, the studies in this review share an ambition to develop useful tools for improving community health and all show potential for some form of progress. Key

themes across the studies in this review such as acceptability, training before testing and data privacy indicate that future studies must engage CHWs for input in designing the technologies. Context is critical if the devices or apps are to be optimally used by CHWs in a sustainable manner. Researchers may build on lessons learned from these studies to design more feasible, acceptable and effective future technologies for CHWs.

References

Adam, M., Tomlinson, M., Le Roux, I., LeFevre, A. E., McMahon, S. A., Johnston, J., . . . Bärnighausen, T. (2019). The Philani MOVIE study: a cluster-randomized controlled trial of a mobile video entertainment-education intervention to promote exclusive breastfeeding in South Africa. *BMC Health Serv Res, 19*(1), 211. doi:10.1186/s12913-019-4000-x

Admassie, A., Abebaw, D., & Woldemichael, A. D. (2009). Impact evaluation of the Ethiopian Health Services Extension Programme. *Journal of Development Effectiveness, 1*(4), 430-449. doi:10.1080/19439340903375724

Allana, S. (2012). Community Health Workers at a Cross-Roads: Systematic review of programmatic indicators including job satisfaction, attrition, training, quality of care, and program outcomes.

Boyce, S. P., Nyangara, F., & Kamunyori, J. (2019). A mixed-methods quasi-experimental evaluation of a mobile health application and quality of care in the integrated community case management program in Malawi. *J Glob Health, 9*(1), 010811. doi:10.7189/jogh.09.010811

Braun, R., Lasway, C., Agarwal, S., L'Engle, K., Layer, E., Silas, L., . . . Kudrati, M. (2016). An evaluation of a family planning mobile job aid for community health workers in Tanzania. *Contraception, 94*(1), 27-33. doi:10.1016/j.contraception.2016.03.016

Chandani, Y., Duffy, M., Lamphere, B., Noel, M., Heaton, A., & Andersson, S. (2017). Quality improvement practices to institutionalize supply chain best practices for iCCM: Evidence from Rwanda and Malawi. *Research in social & administrative pharmacy : RSAP, 13*(6), 1095-1109. doi:10.1016/j.sapharm.2016.07.003

Chang, L. W., Mbabali, I., Kong, X., Hutton, H., Amico, K. R., Kennedy, C. E., . . . Nakigozi, G. (2017). Impact of a community health worker HIV treatment and prevention intervention in an HIV hotspot fishing community in Rakai, Uganda (mLAKE): study protocol for a randomized controlled trial. *Trials, 18*(1), 494. doi:10.1186/s13063-017-2243-6

Coetzee, B., Kohrman, H., Tomlinson, M., Mbewu, N., Le Roux, I., & Adam, M. (2018). Community health workers' experiences of using video teaching tools during home visits-A pilot study. *Health Soc Care Community, 26*(2), 167-175. doi:10.1111/hsc.12488

Diese, M., Kalonji, A., Izale, B., Villeneuve, S., Kintaudi, N. M., Clarysse, G., . . . Ntambue, A. M. (2018). Community-based maternal, newborn, and child health surveillance: perceptions and attitudes of local stakeholders towards using mobile phone by village health volunteers in the Kenge Health Zone, Democratic Republic of Congo. *BMC Public Health, 18*(1), 316. doi:10.1186/s12889-018-5186-2

Dusabe-Richards, J. N., Tesfaye, H. T., Mekonnen, J., Kea, A., Theobald, S., & Datiko, D. G. (2016). Women health extension workers: Capacities, opportunities and challenges to use eHealth to strengthen equitable health systems in Southern Ethiopia. *Can J Public Health, 107*(4-5), e355-e361. doi:10.17269/cjph.107.5569

Eksteen, S., Launer, S., Kuper, H., Eikelboom, R. H., Bastawrous, A., & Swanepoel, W. (2019). Hearing and vision screening for preschool children using mobile technology, South Africa. *Bull World Health Organ, 97*(10), 672-680. doi:10.2471/blt.18.227876

Ettinger, K. M., Pharaoh, H., Buckman, R. Y., Conradie, H., & Karlen, W. (2016). Building quality mHealth for low resource settings. *J Med Eng Technol, 40*(7-8), 431-443. doi:10.1080/03091902.2016.1213906

Evans, G. F., Shirk, A., Muturi, P., & Soliman, E. Z. (2017). Feasibility of Using Moble ECG Recording Technology to Detect Atrial Fibrilation in Low-Resource Settings. *Global Heart, 4*, 285-289.

Expert Program Management. SOAR Analysis. Retrieved from https://expertprogrammanagement.com/2019/11/soar-analysis/

Feroz, A., Jabeen, R., & Saleem, S. (2020). Using mobile phones to improve community health workers performance in low-and-middle-income countries. *BMC Public Health, 20*(1), 49. doi:10.1186/s12889-020-8173-3

Francis, F., Ishengoma, D. S., Mmbando, B. P., Rutta, A. S. M., Malecela, M. N., Mayala, B., . . . Michael, E. (2017). Deployment and use of mobile phone technology for real-time reporting of fever cases and malaria treatment failure in areas of declining malaria transmission in Muheza district north-eastern Tanzania. *Malar J, 16*(1), 308. doi:10.1186/s12936-017-1956-z

Gonçalves-Bradley, D. C., J Maria, A. R., Ricci-Cabello, I., Villanueva, G., Fønhus, M. S., Glenton, C., . . . Shepperd, S. (2020). Mobile technologies to support healthcare provider to healthcare provider communication and management of care. *Cochrane Database of Systematic Reviews, 2020*(8). doi:10.1002/14651858.CD012927.pub2

Hackett, K. M., Kazemi, M., & Sellen, D. W. (2018). Keeping secrets in the cloud: Mobile phones, data security and privacy within the context of pregnancy and childbirth in Tanzania. *Soc Sci Med, 211*, 190-197. doi:10.1016/j.socscimed.2018.06.014

Henry, J. V., Winters, N., Lakati, A., Oliver, M., Geniets, A., Mbae, S. M., & Wanjiru, H. (2016). Enhancing the Supervision of Community Health Workers With WhatsApp Mobile Messaging: Qualitative Findings From 2 Low-Resource Settings in Kenya. *Glob Health Sci Pract, 4*(2), 311-325. doi:10.9745/ghsp-d-15-00386

Kabakyenga, J., Barigye, C., Brenner, J., Maling, S., Buchner, D., Nettle-Aquirre, A., . . . MacLeod, S. (2016). A demonstration of mobile phone deployment to support the treatment of acutely ill children under five in Bushenyi district, Uganda. *Afr Health Sci, 16*(1), 89-96. doi:10.4314/ahs.v16i1.12

Laktabai, J., Platt, A., Menya, D., Turner, E. L., Aswa, D., Kinoti, S., & O'Meara, W. P. (2018). A mobile health technology platform for quality assurance and quality improvement of malaria diagnosis by community health workers. *PLoS One, 13*(2), e0191968. doi:10.1371/journal.pone.0191968

Lee, S., Cho, Y. M., & Kim, S. Y. (2017). Mapping mHealth (mobile health) and mobile penetrations in sub-Saharan Africa for strategic regional collaboration in mHealth scale-up: an application of exploratory spatial data analysis. *Global Health, 13*(1), 63. doi:10.1186/s12992-017-0286-9

LeFevre, A. E., Mohan, D., Hutchful, D., Jennings, L., Mehl, G., Labrique, A., . . . Moorthy, A. (2017). Mobile Technology for Community Health in Ghana: what happens when technical functionality threatens the effectiveness of digital health programs? *BMC Med Inform Decis Mak, 17*(1), 27. doi:10.1186/s12911-017-0421-9

Lehmann, U., & Sanders, D. (2007). *Community Health Workers: what do we know about them?* : World Health Organization

MacDonald, M. E., & Diallo, G. S. (2019). Socio-cultural contextual factors that contribute to the uptake of a mobile health intervention to enhance maternal health care in rural Senegal. *Reprod Health, 16*(1), 141. doi:10.1186/s12978-019-0800-z

Mangwi Ayiasi, R., Kolsteren, P., Batwala, V., Criel, B., & Orach, C. G. (2016). Effect of Village Health Team Home Visits and Mobile Phone Consultations on Maternal and Newborn Care Practices in Masindi and Kiryandongo, Uganda: A Community-Intervention Trial. *PLoS One, 11*(4), e0153051. doi:10.1371/journal.pone.0153051

McHenry, M. S., Fischer, L. J., Chun, Y., & Vreeman, R. C. (2019). A systematic review of portable electronic technology for health education in resource-limited settings. *Glob Health Promot, 26*(2), 70-81. doi:10.1177/1757975917715035

National Library of Medicine. (2020). Medical Subject Headings. Retrieved from https://www.nlm.nih.gov/mesh/meshhome.html

O'Donovan, J., Kabali, K., Taylor, C., Chukhina, M., Kading, J. C., Fuld, J., & O'Neil, E. (2018). The use of low-cost Android tablets to train community health workers in Mukono, Uganda, in the recognition, treatment and prevention of pneumonia in children under five: a pilot randomised controlled trial. *Hum Resour Health, 16*(1), 49. doi:10.1186/s12960-018-0315-7

Otu, A., Ebenso, B., Okuzu, O., & Osifo-Dawodu, E. (2016). Using a mHealth tutorial application to change knowledge and attitude of frontline health workers to Ebola virus disease in Nigeria: a before-and-after study. *Hum Resour Health, 14*, 5. doi:10.1186/s12960-016-0100-4

Pallas, S. W., Minhas, D., Perez-Escamilla, R., Taylor, L., Curry, L., & Bradley, E. (2013). Community Health Wrorkers in Low- and Middle-Income Countries: What Do We Know About Scaling Up and Sustainability? *Am J Public Health, 103*(7).

Ramukumba, M. M., & Hägglund, M. (2019). "I feel like a nurse and my clients learn more": mHealth, Capacity Building and Empowerment in Community Based Care. *Stud Health Technol Inform, 265*, 195-200. doi:10.3233/shti190163

Shiferaw, S., Workneh, A., Yirgu, R., Dinant, G. J., & Spigt, M. (2018). Designing mHealth for maternity services in primary health facilities in a low-income setting - lessons from a partially successful implementation. *BMC Med Inform Decis Mak, 18*(1), 96. doi:10.1186/s12911-018-0704-9

Shinn, J. R., Zuniga, M. G., Macharia, I., Reppart, J., Netterville, J. L., & Jayawardena, A. D. L. (2019). Community health workers obtain similar results using cell-phone based hearing screening tools compared to otolaryngologists in low resourced settings. *Int J Pediatr Otorhinolaryngol, 127*, 109670. doi:10.1016/j.ijporl.2019.109670

Shuaib, F. M. B., Musa, P. F., Gashu, S. T., Onoka, C., Ahmed, S. A., Bagana, M., . . . Mkanda, P. (2018). AVADAR (Auto-Visual AFP Detection and Reporting): demonstration of a novel SMS-based smartphone application to improve acute flaccid paralysis (AFP) surveillance in Nigeria. *BMC Public Health, 18*(Suppl 4), 1305. doi:10.1186/s12889-018-6187-x

Sonderman, K. A., Nkurunziza, T., Kateera, F., Gruendl, M., Koch, R., Gaju, E., . . . Hedt-Gauthier, B. L. (2018). Using mobile health technology and community health workers to identify and refer caesarean-related surgical site infections in rural Rwanda: a randomised controlled trial protocol. *BMJ Open, 8*(5), e022214. doi:10.1136/bmjopen-2018-022214

The GSM Association. (2021). Uganda. *Mobile Coverage Maps.* Retrieved from https://www.mobilecoveragemaps.com/

The World Bank Group. (2020). Sub-Saharan Africa. *Data.* Retrieved from https://data.worldbank.org/country/ZG

Thobias, J., & Kiwanuka, A. (2018). Design and implementation of an m-health data model for improving health information access for reproductive and child health services in low resource settings using a participatory action research approach. *BMC Med Inform Decis Mak, 18*(1), 45. doi:10.1186/s12911-018-0622-x

Thomsen, C. F., Barrie, A. M. F., Boas, I. M., Lund, S., Sørensen, B. L., Oljira, F. G., & Tersbøl, B. P. (2019). Health workers' experiences with the Safe Delivery App in West Wollega Zone, Ethiopia: a qualitative study. *Reprod Health, 16*(1), 50. doi:10.1186/s12978-019-0725-6

UNAIDS. (2017). China's Community Health Services Are a Model For The World. Retrieved from https://www.unaids.org/en/resources/presscentre/featurestories/2017/august/20170821_community-health

United Nations Agency for International Development. (2017). *2 Million African Community Health Workers*. Retrieved from https://www.unaids.org/en/resources/documents/2017/African2mCHW

Vallières, F., McAuliffe, E., van Bavel, B., Wall, P. J., & Trye, A. (2016). There's No App for That: Assessing the Impact of mHealth on the Supervision, Motivation, Engagement, and Satisfaction of Community Health Workers in Sierra Leone. *Annals of Global Health, 82*(5), 936-949. doi:10.1016/j.aogh.2016.07.002

Vedanthan, R., Kamano, J. H., DeLong, A. K., Naanyu, V., Binanay, C. A., Bloomfield, G. S., . . . Fuster, V. (2019). Community Health Workers Improve Linkage to Hypertension Care in Western Kenya. *J Am Coll Cardiol, 74*(15), 1897-1906. doi:10.1016/j.jacc.2019.08.003

VERBI Software. (2020). MAXQDA 2020 [computer software]. Berlin, Germany: VERBI Software. Retrieved from maxqda.com

Wakabi, W. (2008). Extension Workers Drive Ethiopia's Primary Health Care. *The Lancet, 372*. Retrieved from https://www.thelancet.com/action/showPdf?pii=S0140-6736%2808%2961381-1

Whidden, C., Kayentao, K., Liu, J. X., Lee, S., Keita, Y., Diakité, D., . . . Johnson, A. D. (2018). Improving Community Health Worker performance by using a personalised feedback dashboard for supervision: a randomised controlled trial. *J Glob Health, 8*(2), 020418. doi:10.7189/jogh.08.020418

White, A., Thomas, D. S. K., Ezeanochie, N., & Bull, S. (2016). Health Worker mHealth Utilization A Systematic Review. *Cin-Computers Informatics Nursing, 34*(5), 206-214. Retrieved from <Go to ISI>://WOS:000376462300003

https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4860109/pdf/nihms753233.pdf

White, E. B., Meyer, A. J., Ggita, J. M., Babirye, D., Mark, D., Ayakaka, I., . . . Davis, J. L. (2018). Feasibility, Acceptability, and Adoption of Digital Fingerprinting During Contact Investigation for Tuberculosis in Kampala, Uganda: A Parallel-Convergent Mixed-Methods Analysis. *J Med Internet Res, 20*(11), e11541. doi:10.2196/11541

Willcox, M., Moorthy, A., Mohan, D., Romano, K., Hutchful, D., Mehl, G., . . . LeFevre, A. (2019). Mobile Technology for Community Health in Ghana: Is Maternal Messaging and Provider Use of Technology Cost-Effective in Improving Maternal and Child Health Outcomes at Scale? *J Med Internet Res, 21*(2), e11268. doi:10.2196/11268

Winters, N., Langer, L., & Geniets, A. (2018). Scoping review assessing the evidence used to support the adoption of mobile health (mHealth) technologies for the education and

training of community health workers (CHWs) in low-income and middle-income countries. *BMJ Open*, *8*(7), 10. doi:10.1136/bmjopen-2017-019827

Figures

1. The World Bank Group. *Physicians (per 1,000 people) – Sub-Saharan Africa*. 2020. https://data.worldbank.org/indicator/SH.MED.PHYS.ZS?locations=ZG&view=map
2. United Nations Agency for International Development. (2017). *2 Million African Community Health Workers*. Retrieved from https://www.unaids.org/en/resources/documents/2017/African2mCHW
3. Winters, N., Langer, L., & Geniets, A. (2018) Scoping review assessing the evidence used to support the adoption of mobile health (mHealth) technologies for the education and training of community health workers (CHWs) in low-income and middle-income countries. *BMJ Open*, *8*(7), 10. doi:10.1136/bmjopen-2017-019827
4. Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) Chart. Created using Covidence software.
5. Geographic Distribution of Studies. Created using Microsoft Excel.
6. Table of Study Characteristics. Created using Microsoft Word.

Appendix A Study Characteristics

Authors	Title	Publication Year	Study duration	Country	Technology Used	Codes applied
Adam, M. Tomlinson, M. Le Roux, I. LeFevre, A. E. McMahon, S. A. Johnston, J. Kirton, A. Mbewu, N. Strydom, S. L. Prober, C. Bärnighausen, T.	The Philani MOVIE study: a cluster-randomized controlled trial of a mobile video entertainment-education intervention to promote exclusive breastfeeding in South Africa	2019	10 months	South Africa	short videos via mobile phones	comparison group, educational, remote setting capability, scalability, training before testing
Boyce, S. P. Nyangara, F. Kamunyori, J.	A mixed-methods quasi-experimental evaluation of a mobile health application and quality of care in the integrated community case management program in Malawi	2019	first 4 patient visits	Malawi	mobile phone app	acceptability, comparison group, quality improvement, sufficient use
Braun, R. Lasway, C. Agarwal, S. L'Engle, K. Layer, E. Silas, L. Mwakibete, A. Kudrati, M.	An evaluation of a family planning mobile job aid for community health workers in Tanzania	2016	6 months	Tanzania	mobile phone app	acceptability, administrative, communication, data privacy, quality improvement, remote setting capability, sufficient use
Chandani, Y. Duffy, M. Lamphere, B. Noel, M. Heaton, A. Andersson, S.	Quality improvement practices to institutionalize supply chain best practices for iCCM: Evidence from Rwanda and Malawi	2017	4 years	Rwanda, Malawi	Logistics Indicator Assessment Tool and cStock information system via mobile phones	acceptability, administrative, communication, quality improvement, scalability, sufficient use, sustainability, training before testing

Chang, L. W. Mbabali, I. Kong, X. Hutton, H. Amico, K. R. Kennedy, C. E. Nalugoda, F. Serwadda, D. Bollinger, R. C. Quinn, T. C. Reynolds, S. J. Gray, R. Wawer, M. Nakigozi, G.	Impact of a community health worker HIV treatment and prevention intervention in an HIV hotspot fishing community in Rakai, Uganda (mLAKE): study protocol for a randomized controlled trial	2017	3 years	Uganda	mobile phone app	acceptability, comparison group, data privacy, quality improvement, training before testing
Coetzee, B. Kohrman, H. Tomlinson, M. Mbewu, N. Le Roux, I. Adam, M.	Community health workers' experiences of using video teaching tools during home visits-A pilot study	2018	6 months	South Africa	tablet app	acceptability, administrative, data privacy, educational, quality improvement, training before testing
Diese, M. Kalonji, A. Izale, B. Villeneuve, S. Kintaudi, N. M. Clarysse, G. Ngongo, N. Ntambue, A. M.	Community-based maternal, newborn, and child health surveillance: perceptions and attitudes of local stakeholders towards using mobile phone by village health volunteers in the Kenge Health Zone, Democratic Republic of Congo	2018	unclear	Democratic Republic of Congo	mobile phone	acceptability, quality improvement, training before testing
Dusabe-Richards, J. N. Tesfaye, H. T. Mekonnen, J. Kea, A. Theobald, S. Datiko, D. G.	Women health extension workers: Capacities, opportunities and challenges to use eHealth to strengthen equitable health systems in Southern Ethiopia	2016	unclear	Ethiopia	mobile phone	acceptability, administrative, communication, comparison group, cost, remote setting capability, sufficient use, training before testing

Eksteen, S. Launer, S. Kuper, H. Eikelboom, R. H. Bastawrous, A. Swanepoel, W.	Hearing and Vision Screening for Preschool Children Using Mobile Technology, South Africa	2019	16 months	South Africa	HearScreen mobile phone app	administrative, communication, cost, data privacy, training before testing
Ettinger, K. M. Pharaoh, H. Buckman, R. Y. Conradie, H. Karlen, W.	Building quality mHealth for low resource settings	2016	prototype and design stages (time unclear)	South Africa	mobile phone app	acceptability, administrative, data privacy, quality improvement
Francis, F. Ishengoma, D. S. Mmbando, B. P. Rutta, A. S. M. Malecela, M. N. Mayala, B. Lemnge, M. M. Michael, E.	Deployment and use of mobile phone technology for real-time reporting of fever cases and malaria treatment failure in areas of declining malaria transmission in Muheza district north-eastern Tanzania	2017	1 year	Tanzania	Community-based Disease Surveillance and Treatment of Malaria (ComDSTM) system for mobile phones	Administrative, cost, remote setting capability, training before testing
Hackett, K. M. Kazemi, M. Sellen, D. W.	Keeping secrets in the cloud: Mobile phones, data security and privacy within the context of pregnancy and childbirth in Tanzania	2018	9 months	Tanzania	mobile phone app (SP+)	acceptability, administrative, data privacy, quality improvement, training before testing
Henry, J. V. Winters, N. Lakati, A. Oliver, M. Geniets, A. Mbae, S. M. Wanjiru, H.	Enhancing the Supervision of Community Health Workers With WhatsApp Mobile Messaging: Qualitative Findings From 2 Low-Resource Settings in Kenya	2016	6 months	Kenya	WhatsApp social media messaging app for mobile phones	acceptability, communication, cost, quality improvement

Kabakyenga, J. Barigye, C. Brenner, J. Maling, S. Buchner, D. Nettle-Aquirre, A. Singhal, N. Kyomuhangi, T. Tumusiime, D. Finch, J. MacLeod, S.	A demonstration of mobile phone deployment to support the treatment of acutely ill children under five in Bushenyi district, Uganda	2016	7 months	Uganda	mobile phone app	acceptability, administrative, communication, comparison group, quality improvement, training before testing
Laktabai, J. Platt, A. Menya, D. Turner, E. L. Aswa, D. Kinoti, S. O'Meara, W. P.	A mobile health technology platform for quality assurance and quality improvement of malaria diagnosis by community health workers	2018	first 10 patients tested	Kenya	Deki Reader mobile device	acceptability, administrative, communication, quality improvement, remote setting capability, sufficient use
LeFevre, A. E. Mohan, D. Hutchful, D. Jennings, L. Mehl, G. Labrique, A. Romano, K. Moorthy, A.	Mobile Technology for Community Health in Ghana: what happens when technical functionality threatens the effectiveness of digital health programs?	2017	3 years	Ghana	mobile phone app	administrative, communication, sustainability, training before testing
MacDonald, M. E. Diallo, G. S.	Socio-cultural contextual factors that contribute to the uptake of a mobile health intervention to enhance maternal health care in rural Senegal	2019	2 years	Senegal	mobile phone app	acceptability, administrative, communication, educational, quality improvement, training before testing
Mangwi Ayiasi, R. Kolsteren, P. Batwala, V. Criel, B. Orach, C. G.	Effect of Village Health Team Home Visits and Mobile Phone Consultations on Maternal and Newborn Care Practices in Masindi and Kiryandongo, Uganda: A Community-Intervention Trial	2016	1.5 years	Uganda	mobile phones	acceptability, communication, comparison group, cost, quality improvement, training before testing

O'Donovan, J. Kabali, K. Taylor, C. Chukhina, M. Kading, J. C. Fuld, J. O'Neil, E.	The use of low-cost Android tablets to train community health workers in Mukono, Uganda, in the recognition, treatment and prevention of pneumonia in children under five: a pilot randomised controlled trial	2018	1 month	Uganda	Android tablets	acceptability, comparison group, cost, educational, remote setting capability, training before testing
Otu, A. Ebenso, B. Okuzu, O. Osifo-Dawodu, E.	Using a mHealth tutorial application to change knowledge and attitude of frontline health workers to Ebola virus disease in Nigeria: a before-and-after study	2016	2 weeks	Nigeria	tablet application	educational, quality improvement
Ramukumba, M. M. Hägglund, M.	"I feel like a nurse and my clients learn more": mHealth, Capacity Building and Empowerment in Community Based Care	2019	unclear	South Africa	mobile phone app	acceptability, administrative, communication, data privacy, educational, quality improvement
Shinn, J. R. Zuniga, M. G. Macharia, I. Reppart, J. Netterville, J. L. Jayawardena, A. D. L.	Community health workers obtain similar results using cell-phone based hearing screening tools compared to otolaryngologists in low resourced settings	2019	4 days	Kenya	HearX Group's "HearScreen" audiometer program for mobile phones	administrative, communication, comparison group, data privacy, quality improvement, remote setting capability, sustainability, training before testing

Shuaib, F. M. B. Musa, P. F. Gashu, S. T. Onoka, C. Ahmed, S. A. Bagana, M. Galway, M. Braka, F. Muluh, T. J. Banda, R. Akpan, G. Tunji, A. Idris, U. K. Olusoga, A. Briand, P. Obiako, N. Nebechukwu, T. Mkanda, P.	AVADAR (Auto-Visual AFP Detection and Reporting): demonstration of a novel SMS-based smartphone application to improve acute flaccid paralysis (AFP) surveillance in Nigeria	2018	8 weeks	Nigeria	mobile phone app utilizing SMS	administrative, communication, educational, quality improvement, sufficient use
Sonderman, K. A. Nkurunziza, T. Kateera, F. Gruendl, M. Koch, R. Gaju, E. Habiyakare, C. Matousek, A. Nahimana, E. Ntakiyiruta, G. Riviello, R. Hedt-Gauthier, B. L.	Using mobile health technology and community health workers to identify and refer caesarean-related surgical site infections in rural Rwanda: a randomised controlled trial protocol	2018	1 year	Rwanda	tablet application (REDCap)	comparison group, data privacy, quality improvement, remote setting capability
Thomsen, C. F. Barrie, A. M. F. Boas, I. M. Lund, S. Sørensen, B. L. Oljira, F. G. Tersbøl, B. P.	Health workers' experiences with the Safe Delivery App in West Wollega Zone, Ethiopia: a qualitative study	2019	unclear	Ethiopia	"Safe Delivery App" (SDA) mobile phone app	acceptability, comparison group, cost, educational, quality improvement, sufficient use, training before testing
Vallières, F. McAuliffe, E. van Bavel, B. Wall, P. J. Trye, A.	There's No App for That: Assessing the Impact of mHealth on the Supervision, Motivation, Engagement, and	2016	18 months	Sierra Leone	mobile phone app	acceptability, administrative, communication, comparison group

	Satisfaction of Community Health Workers in Sierra Leone					
Vedanthan, R. Kamano, J. H. DeLong, A. K. Naanyu, V. Binanay, C. A. Bloomfield, G. S. Chrysanthopoulou, S. A. Finkelstein, E. A. Hogan, J. W. Horowitz, C. R. Inui, T. S. Menya, D. Orango, V. Velazquez, E. J. Were, M. C. Kimaiyo, S. Fuster, V.	Community Health Workers Improve Linkage to Hypertension Care in Western Kenya	2019	unclear	Kenya	mobile phone app	administrative, comparison group, quality improvement
Whidden, C. Kayentao, K. Liu, J. X. Lee, S. Keita, Y. Diakité, D. Keita, A. Diarra, S. Edwards, J. Yembrick, A. Holeman, I. Samaké, S. Plea, B. Coumaré, M. Johnson, A. D.	Improving Community Health Worker performance by using a personalised feedback dashboard for supervision: a randomised controlled trial	2018	9 months	Mali	"CHW Performance Dashboard" tool	acceptability, communication, comparison group, quality improvement

White, E. B. Meyer, A. J. Ggita, J. M. Babirye, D. Mark, D. Ayakaka, I. Haberer, J. E. Katamba, A. Armstrong-Hough, M. Davis, J. L.	Feasibility, Acceptability, and Adoption of Digital Fingerprinting During Contact Investigation for Tuberculosis in Kampala, Uganda: A Parallel-Convergent Mixed-Methods Analysis	2018	unclear	Uganda	multispectral fingerprint scanners and embedded matching software	acceptability, administrative, data privacy, quality improvement, remote setting capability, sufficient use, training before testing
Willcox, M. Moorthy, A. Mohan, D. Romano, K. Hutchful, D. Mehl, G. Labrique, A. LeFevre, A.	Mobile Technology for Community Health in Ghana: Is Maternal Messaging and Provider Use of Technology Cost-Effective in Improving Maternal and Child Health Outcomes at Scale?	2019	10 years	Ghana	Mobile phone app MOTECH's "Client Data Application"	acceptability, administrative, communication, cost, scalability