IMPLEMENTATION OF HEALTH-RELATED SMARTPHONE APPLICATIONS IN LOW- AND MIDDLE- INCOME COUNTRIES: SCOPING REVIEW AND LEARNINGS FROM THE CHILDSAFE APPLICATION IN MALAYSIA

by
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ABSTRACT

While digital technologies such as smartphone apps have become an increasingly popular way to deliver health interventions, implementation and scale up remains a recognized challenge. Recently, the Johns Hopkins International Injury Research Unit and the Institute for Public Health in Malaysia collaborated in the development of a smartphone app for child injury prevention called ChildSafe that was piloted in Malaysia. The aim of this dissertation was to better understand the implementation of health apps in low- and middle-income countries to identify opportunities and gaps for future research, as well as to strengthen the design, implementation, and dissemination of the ChildSafe app. We had three objectives: 1) to better understand the current state of the peer-reviewed literature on the use and implementation of health apps in low- and middle-income countries; 2) to assess the adoption, fidelity, acceptability, and process of user engagement through the ChildSafe app; and 3) to examine the facilitators and barriers to implementation of the ChildSafe app from the perspective of caregivers of children under five. This dissertation comprises of three manuscript-oriented chapters, each presenting the results from one of these objectives.

The first manuscript, "*Use and Implementation of Health-Related Smartphone Apps in Low- and Middle-Income Countries*" presents the results of a scoping review that identified gaps in the literature on the implementation of health apps in low- and middle-income countries. Building on these learnings, the second manuscript, "*Adoption, Fidelity, and Acceptability of a Smartphone App for Child Injury Prevention*" assessed the implementation of the ChildSafe app from multiple dimensions to generate insight to

strengthen its design, implementation, and dissemination that may be relevant to other similar health apps. Finally, the third manuscript, "*Facilitators and Barriers to Use and Implementation of a Smartphone App for Child Injury Prevention in Malaysia*" applied an established implementation framework to identify facilitators and barriers to use and implementation of the ChildSafe app to contribute to a broader conceptual understanding of the implementation of health apps. Together, these manuscripts make the case for and demonstrate the value of considering implementation from the early stages of digital development through implementation and scale up.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1

INTRODUCTION

SECTION 1: HEALTH APPS IN LOW- AND MIDDLE-INCOME COUNTRIES

Global Emergence of Digital Technologies

Over the past two decades, the world has experienced the introduction and spread of novel digital technologies, including smartphones and the Internet. In 2008, only about 60% of the global population had a mobile phone subscription (1). By 2016, the number of mobile phone subscriptions was greater than the population of the entire world that year and it has remained above ever since (1). Most of these mobile phones are now smartphones that have the added capability to access the Internet and run apps. Globally, the percent of the population with a mobile broadband (Internet) subscription increased from 6.3% in 2008 to 74.2% by 2019 (1). Subscriptions to mobile broadband services are also far greater than that for fixed broadband (74.2% vs. 14.8%), reflecting the increasing value and important role that smartphones are now playing in modern lives, especially in the midst of the coronavirus pandemic (2–4). Further, as technologies evolve and develop, mobile Internet networks are becoming available at faster speeds, supporting more advanced applications through smartphones. In 2019, 92.8% of the population of the world was covered by at least a 3G mobile network and 83.4% by an LTE/WiMAX

(4G) mobile network (1). This widespread availability had been reflected in adoption patterns with almost 52% of individuals around the world reporting using the Internet in 2019, up from just 23.1% in 2008 (1) (Table 1 and Table 2).

Similar trends and patterns have been seen in many Low- and Middle-Income Countries (LMICs) where rapid progress has been achieved. The coverage of mobile phone subscriptions in developing areas reached 100% by 2018 (1). Over 90% of the population living in developing areas were covered by at least a 3G mobile network and over 80% by an LTE/WiMax mobile network in 2019 (1). More than 60% of the population in these countries had a mobile broadband subscription in 2019, an increase from only 1.6% in 2008 (1). As a result, the population living in developing areas that reported using the Internet reached almost 45% by 2019, compared to only 14.6% in 2008 (1). While progress in the global spread of digital technologies has been impressive, advancements in coverage and adoption are still unequal. Gaps remain between High-Income Countries (HICs) and LMICs, across regions, within countries, and among certain population groups (2). Even so, these digital technologies are significantly affecting the health sector and presenting new opportunities for the effective, efficient, and widespread delivery of health interventions (5,6) (Table 1 and Table 2).

Health-Related Smartphone Apps in LMICs

As smartphones and the Internet become more widely available around the world, smartphone apps- small software programs designed for a specific purpose- have become an increasingly popular way to deliver health interventions. According to a report by the

IQVIA Institute, there are now over 318,000 health apps available worldwide that have been downloaded more than 3.35 billion times (6). Health apps are also becoming available in multiple languages besides English, demonstrating the growing interest and potential of health apps among global populations (6). In fact, most countries now have an estimated 210,000 – 250,000 health apps available in their app stores (6). The acceptability and quality of health apps has also improved overtime. In 2017, 55% of apps received a rating of four or more stars out of five compared to only 31% in 2015 (6). However, most health apps are still only developed in English and most languages have only a few health apps available (6). Thus, the use of smartphone apps for health purposes in LMICs remains an emerging area of global health practice and research.

Several global reviews have been conducted that summarize the available literature on digital technologies, including smartphone apps, for many health issues. Global reviews have been conducted on the use of digital health technologies for chronic diseases and cancer (7–18), mental health (19–27), lifestyle and nutrition (28–34), maternal and child health (35–38), infectious diseases (39–42), disabilities and pain (43–45), health service delivery and care (46–49), sexual and reproductive health (50,51) health promotion/education (52), and mHealth (53–57). However, much of the literature identified through these global reviews are from high-income settings and there is little representation from LMICs. LMICs are a distinct setting for implementation of digital health interventions given differences in the coverage of mobile phones and Internet connections, more recent emergence of digital technologies, and different health systems, disease burdens, and technological capacity that exist in these settings.

In recognition of these differences, several reviews of digital health technologies have focused on summarizing the literature from LMICs specifically. These reviews have summarized the literature on digital technologies in LMICs for maternal and child health (58–65), chronic diseases and cancer (66–70), infectious diseases (71–73), mental health (74,75), sexual and reproductive health (76), lifestyle and nutrition (77), health promotion/education (78–81), and mHealth (82–95). Almost all these reviews define digital health technologies broadly and include interventions that use several digital health approaches (ex. SMS text messaging, voice responses systems, web portals, smartphone apps). While in most cases these reviews are focused on a particular health issue, they often include interventions that target different types of users (ex. health workers, patients, caregivers) and multiple health functions (ex. education, self-monitoring, treatment, etc.). Health apps that are developed for populations in LMICs is an emerging area for global health with a body of literature that is expanding rapidly. As such, it will be important to summarize the emerging evidence on health apps in LMICs to identify lessons and gaps for practice and research on the application of this novel digital technology for health. Similar reviews have been done for SMS text messaging, voice response systems, and web portals as their application and body of literature expanded (96–103). However, to the best of our knowledge, this has not yet been done for smartphone apps in LMICs.

Implementation of Health Apps in LMICs

Implementation and scale up of digital health interventions broadly has been a recognized as a particular challenge, including in many LMICs. Many digital health innovations that

are developed and piloted in LMIC settings never reach full implementation and scale resulting in lost investments in development, research, and potential health improvements (104–107). This is in part because of limited consideration for implementation from the onset of the project (104–107). The World Health Organization (WHO) among others have called for a greater focus on understanding the implementation of digital health and mHealth interventions (104–107). Designing digital technologies while considering their implementation has been recognized by the global health community as a best practice for digital health development (104,108). However, it is unclear to what extent implementation has been considered in the development and assessment of health-related apps in LMICs. Implementation research in particular is an emerging area of inquiry that offers a range of systematic approaches and frameworks to better understand how interventions are implemented and why interventions are working or not (109–111). Better understanding of the implementation of digital health and mHealth interventions, especially in LMICs, remains an area for further research.

SECTION 2: CHILD INJURIES IN LOW- AND MIDDLE-INCOME COUNTRIES

Global Burden and Causes of Child Injuries

At the same time, unintentional child injuries have become an important public health problem, especially for LMICs. More than 950,000 children and adolescents less than 18 years old die of injury and violence each year (112). Most (90%) of these injuries are unintentional and almost all (95%) occur in LMICs (112). In addition, millions more

children suffer from non-fatal injuries that may have long-term consequences on the social and economic wellbeing of the household and child (112–114). One study found that approximately 54% of childhood injuries resulted in temporary or permanent disability, 10.8% in hospitalization, and 34.4% in missed work or school to seek treatment (113). Further, many child injuries may never be reported, thus global figures may underestimate the true burden of injuries among children (112,115). Further, it is often the poorest and most disadvantaged children and households that suffer the most from unintentional child injuries.

Injuries due to drowning, fire-related burns, falls, and poisoning are all among the leading causes of death for children and adolescents after the first year of life. Together, these causes account for 34% of global child injury deaths (112). Many of these injuries occur in the home or its immediate surroundings, as this is where children spend most of their time with the potential for multiple risks and hazards (114,116) . One study of unintentional child injuries showed that 55.9% of injuries among children presenting to the emergency department in four low-income countries occurred in the home environment (116). Thus, efforts to address the problem of child injuries will need to address the risks and hazards that exist within the home.

Interventions for Child Injury Prevention

Most child injuries are preventable. Policy, product and environmental modification, supportive home visits, safety devices, education and behavior change, and community-based approaches are all recommended by the WHO for child injury prevention (112).

Further, several systematic reviews have shown the positive effect of child injury prevention interventions (117–125). However, many of these interventions were developed and tested in HICs with limited experience and evidence from LMICs despite the high burden of child injuries that exist in these settings.

Home visits in particular have been identified as a potential strategy for child injury prevention, with several systematic reviews and studies showing their effectiveness in reducing home hazards and child injuries, even in a few middle-income countries (MICs) such as Pakistan and South Africa (119,124,126–129). However, home visits are a resource-intensive and invasive intervention that may not be feasible or acceptable in all LMICs, especially during the coronavirus pandemic when in-person interventions are limited. As a result, the adoption and implementation of child injury prevention measures, such as home visits, is lagging in many LMICs, leaving the problem of child injuries largely unaddressed.

Apps for Child Injury Prevention in LMICs

The emergence and coverage of digital technologies globally and increasing popularity of health apps presents an opportunity to address the persistent problem of child injuries, potentially overcoming some of the barriers to implementation of child injury prevention measures in LMICs. Despite the potential of health apps for child injury prevention in LMICs, few examples currently exist. Two health apps offer first aid guidance for students or adolescents, but do not focus on children under five (130,131). One randomized controlled trial of an app-based intervention to prevent child injuries among

preschoolers in China showed a larger effect on prevention behaviors among the intervention group compared to the control group (132). Another study of a technology-based intervention including an app for child injury prevention for mothers in China is still ongoing (133). However, both interventions focused on the knowledge and behavioral aspects of child injury prevention rather than the potential environmental hazards that may exist in the home. Further evidence is needed on a comprehensive smartphone app for child injury prevention in LMICs.

SECTION 3: MALAYSIA

Overview of Malaysia

Malaysia is an upper MIC of approximately 230,000 square kilometers in Southeast Asia bordering Thailand, Indonesia, and Brunei in the South China Sea (134). Malaysia has achieved impressive economic growth in the past decade, averaging an annual growth rate of 5.4% in its Gross Domestic Product (GDP) between 2010 and 2019 (135). However, this progress has also been accompanied by significant population growth and urbanization, resulting in the increasing density and rapid spread of urban and peri-urban areas. The population of Malaysia has grown at an average pace of 1.4% per year since 2010, reaching a total population of almost 33 million by 2020 (134,136). At the same time, the population in urban areas has increased even more by an average of 2.3% with a corresponding decline of more than 1% in the rural population (136). By 2019, more than 75% of the total population of Malaysia resided in urban areas (136). As a result, the

population density of Malaysia has reached more than 95 people per square kilometer with heavy concentrations around urban areas such as the capital city of Kuala Lumpur, where almost 32% of the total urban population currently resides (136).

Malaysia has made substantial progress in the health of its population towards the Sustainable Development Goals (SDGs), but improvements are still needed, especially in response to emerging health issues. The Maternal Mortality Ratio (MMR) and Under Five Mortality Rate (U5MR) in Malaysia have both decreased since 2000. The MMR was 29 deaths per 100,000 live births in 2017 and the U5MR was 9 per 1,000 live births in 2019 (137,138). Malaysia has also been experiencing a shifting epidemiological profile from one dominated by infectious diseases to one that is seeing increases in non-communicable diseases and injuries (139,140). According to the 2019 Global Burden of Diseases Report, the rate of Disability Adjusted Life Years (DALYs), a measure of the overall burden of disease in a population, attributable to non-communicable diseases and injuries both increased between 2010 and 2019, while that for communicable diseases decreased (139,140). The increase in the rate of DALYs was greatest for injuries that were unintentional (139,140) (Table 3). In addition, the current coronavirus pandemic has had significant impact on the economic and health progress made over the past decades, significantly affecting those who are most vulnerable and from low-income groups (141,142).

Child Injuries in Malaysia

As in other LMICs, Malaysia faces a large burden of child injuries (139,143–145). In 2019, injuries accounted for more than 13% of DALYs and 25% of deaths among children and adolescents less than 19 years old (140). Unintentional injuries were also the second leading cause of DALYs and death after transport injuries, accounting for 35% of DALYs and 30% of deaths (140). Drowning, falls, and foreign bodies were all among the leading causes of DALYs and deaths for children and adolescents in Malaysia (114,140,146). Many of these types of injuries occur in the home environment (114,145) (Table 4).

Child Injury Prevention in Malaysia

As in many LMICs, there has been limited attention and resources dedicated to preventing unintentional injuries among children and adolescents in Malaysia amid other health priorities. Unintentional child injuries are not featured in national strategies and reports for Malaysia for the current period (147). Few interventions and studies have been conducted to introduce or test interventions to address the problem of child injuries in Malaysia (148–150). Thus, more attention is needed to address the burden of child injuries that exists in Malaysia.

SECTION 4: M-CHILD PILOT STUDY

M-Child Pilot Study Introduction

In recognition of the gap for child injury prevention and potential of a smartphone app to offer a potential innovation to address the burden of child injuries in Malaysia, the Johns Hopkins International Injury Research Unit (JH-IIRU) and the Institute for Public Health in Malaysia (IKU) collaborated in the development of a smartphone app called ChildSafe that was piloted in Malaysia in November 2017 – February 2018. The overall aim of the pilot study was to test the initial efficacy, feasibility, and acceptability of the smartphone app for child injury prevention in Malaysia. This dissertation research was embedded within the M-Child Pilot Study.

Study Design and Methods

Mixed methods consisting of both quantitative and qualitative approaches were used for the pilot study. A household survey was conducted at baseline to gather data on participant and household characteristics, home injury hazards, knowledge of child injury prevention, and child injury history. A household survey was also conducted at follow up to assess changes in home injury hazards, knowledge of child injury prevention, and child injury history, as well as acceptability of the app. Self-reported data was collected through the app on home injury hazards and changes to assess reliability of the app and completion of the intervention. In-depth interviews with users of the app were also done to explore user perspectives of the app.

ChildSafe Intervention

ChildSafe is a comprehensive smartphone app for child injury prevention in the home that targets caregivers of children under five as the users. The ChildSafe app targets 43 common child injury hazards in four (4) areas of the home: 1) living and sleeping areas (n=21), 2) bath area (n=7), 3) kitchen and dining room (n=9), and 4) courtyard, rooftop and outdoors (n=6). These child injury hazards are either environmental (n=28) or behavioral (n=15). The design of the app was informed by WHO recommendations for child injury prevention, a review of the literature, prior work on home injury prevention in Malaysia and other LMIC settings, and a consultative process with IKU in Malaysia (112,116,126,151,152).

Users were provided with a brief orientation on how to access and navigate the app by trained data collectors. After users download the app and set up their profile including information on the home environment (ex. number and type of room), caregivers completed a home safety assessment that includes a series of 43 "Yes/No" response questions on the presence or absence of these common child injury hazards in the home. The results of the assessment are then used to inform a tailored tutorial that guides users through changes to address the identified hazards. Users must complete the assessment for each type of room before moving to the tutorial section. The app operates on an Android platform. Users can select to view the app in either English or the Bahasa Malaysia. Caregivers could implement the intervention during a period of two months. The flow of the app is presented in Figure 1 and the home safety assessment is shown in Table 5.

Study Setting

The pilot study of the ChildSafe app took place in Petaling District in Selangor State of Malaysia. This district is located near to the capital city of Kuala Lumpur and is more urban and densely populated. Access to and use of mobile phones and the Internet in Malaysia is high relative to many other LMIC settings. Coverage of mobile phones and mobile broadband subscriptions were both above 100%, almost 100% of the population was covered by a mobile cellular network, and almost 85% reported using the Internet in 2019 (153,154) (Table 6). Android is the most common mobile operating platform in Malaysia (155).

Sampling, Recruitment, Eligibility, and Consent

Caregivers for the pilot study were identified during childcare visits to the health center. Recruitment took place in three phases at two levels. First, we approached the director of the health facility, informed them about the study, and asked whether they agreed for the health facility to participate. If the director consented to participate, they were asked to indicate when the facility was open to childcare visits so recruitment of caregivers could take place. In the second phase of recruitment, health workers introduced the study to caregivers during childcare visits and asked whether the caregiver consented to talk to a member of the research team about the study. If the caregiver agreed, a data collector approached the caregiver in person in a private place at the health facility immediately following the visit and informed them about the study. If the caregiver was interested in participating, the data collector assessed their eligibility. Caregivers were eligible to

participate if they were from a household with a child under five, able to speak English or Malay, not planning to move during the study period and able and willing to give voluntary consent. A total of 361 caregivers participated in the pilot study.

SECTION 5: DISSERTATION RESEARCH

Research Aim and Objectives

This dissertation is entitled "*Implementation of Health-Related Smartphone Applications in Low- and Middle-Income Countries: Scoping Review and Learnings from the ChildSafe Application in Malaysia*". This topic was chosen in recognition of the emergence of digital technologies and popularity of health apps around the world, the potential application of these digital technologies to public health practice and research, and gaps in the experience and evidence of leveraging smartphone apps for health purposes in LMICs. This includes the challenge and limited focus on implementation of health apps and availability of few comprehensive apps for child injury prevention in these settings. The aim of this dissertation research was to better understand the implementation of health-related apps in LMICs to identify opportunities and gaps for future research and strengthen the design, implementation, and dissemination of the ChildSafe app. To this end, we had three research objectives:

1) To better understand the current state of the peer-reviewed literature on the use and implementation of health apps in LMICs;

2) To assess the adoption, fidelity, acceptability, and process of user engagement through the Child Safe app; and
3) To examine the facilitators and barriers to implementation of the ChildSafe app from the perspective of caregivers of children under five with different user status.

Dissertation Organization

This dissertation consists of an introduction, three manuscript-oriented chapters, and a conclusion. The first chapter is an introduction to the implementation of health-related smartphone apps in LMICs. The second presents a scoping review that aimed to map health apps in LMICs and assess the implementation considerations. The third chapter presents a quantitative assessment of user data to assess characteristics and injury experience associated with the acceptability, adoption, and fidelity of the ChildSafe app, as well as the process of user engagement. The fourth chapter presents a qualitative examination of user perspectives of a smartphone app in an LMIC setting, using the case of the ChildSafe app for child injury prevention in Malaysia. The implications, strengths, weaknesses, and conclusions of this dissertation are summarized in the final chapter.

SECTION 6: CONCEPTUAL AND METHODOLOGICAL FOUNDATIONS

This dissertation draws on several conceptual and methodological foundations in the digital health and implementation research spaces. These conceptual and methodological foundations are described in the next section.

Digital Health and mHealth

The emergence and coverage of novel digital technologies around the world presents a significant opportunity to leverage them to strengthen health systems and the delivery of health interventions. This has led to new concepts in public health practice and research called “digital health” and “mhealth” (mobile health). Digital health is the use of digital technologies including mobile phones, computers, and the Internet, for health purposes (156). Thus, digital health is an umbrella term that encompasses mobile health, health information technology, telehealth and telemedicine, wearable devices, and personalized medicine, among others (156). mHealth, or mobile health, is an area of practice and research under the broader umbrella of digital health and is defined as the use of mobile phones for health purposes (107,157,158).

Classification of Digital Health Interventions

The Classification of Digital Health Interventions was recently released by the WHO to provide a shared approach and framework to categorize the primary function or use of

digital technologies for health purposes (159). Functions are organized by the primary user of the digital technology, which can be the client, healthcare provider, health system and resource managers, or data services (159). For each type of user, broad and specific functions are listed to describe the health use of the digital technology. The identification of the target group and function for the digital technology describes how it is being used to respond to a recognized health system challenge.

The Classification of Digital Health Interventions is useful for this dissertation research in two ways. First, it provides an organizing framework for classifying the health apps that were identified through the scoping review. Since the scooping review includes apps that targeted patients or general populations as the end users, the functions of the identified apps relate to those for clients as shown in Figure 2 below. Based on descriptions in the apps included in the report, apps were classified and organized according to this framework. Second, as the classification framework is meant to provide a shared approach for categorizing digital technologies for health, it is important to specify the target group and function for the ChildSafe app. Again, the target group for the ChildSafe app would be clients (caregivers of children under five) and its functions would include targeted client communication (1.1.2 and 1.1.3) and personal health tracking (1.4.2)

Implementation Research

Implementation research is defined as "the scientific inquiry into questions concerning implementation- the act of carrying an intention into effect, which in health research can

be policies, programmes, or individual practices (collectively called interventions)" (111). Implementation research offers a systematic approach and range of methods and tools that can be used to better understand implementation, including the process of implementing interventions, how and why interventions are being implemented, and what is working or not to inform improvements to strengthen implementation and improve health. Implementation research is an area of inquiry that is recognized for its promise in enabling countries and populations to reach national targets and international health goals (160).

This dissertation research responds to a recognized challenge and research gap in the implementation of digital health and mHealth interventions, specifically smartphone apps, and draws from the field of implementation research in several ways. First, this research aims to better understand implementation of health-related smartphone apps in LMICs by first exploring how implementation is considered in the assessment of health apps in LMICs through a scoping review of the available peer-reviewed literature. In this dissertation, we also explore the implementation of a health-related smartphone app through the case of ChildSafe, an app for child injury prevention for caregivers of children under five in Malaysia. Several implementation research concepts and frameworks are relevant or applied to contextualize or guide these assessments.

Outcomes for Implementation Research

Proctor el al. (2011) recognize several outcomes for implementation research that are distinct from health system and treatment outcomes (161). These outcomes serve three

important functions for assessing implementation: 1) by providing an indication of implementation success, 2) aa proximal measure of the implementation process, and 3) as an intermediate outcome related to health system and treatment outcomes. These implementation outcomes are listed and defined below (Table 7).

Proctor's implementation outcomes are important for this dissertation on the implementation of health-related apps in LMICs in two ways. In our scoping review, we determine the ways and to what extent implementation is being considered in assessments of health-related apps in LMICs. One of the ways that implementation can be considered is by assessing an implementation outcome. Thus, these implementation outcomes provide a framework to identify how implementation is being considered in assessments of health-related smartphone apps. We also consider the acceptability, adoption, and fidelity in our assessment of the ChildSafe app in Malaysia.

Consolidated Framework for Implementation Research

The Consolidated Framework for Implementation Research (CIFR) provides a consolidated menu of constructs that can be used for the systematic assessment of implementation for health interventions (109) (Figure 3). This consolidated framework incorporates and aligns constructs from several relevant implementation theories and frameworks, including Roger's Diffusion of Innovations and Greenhalgh et al.'s Diffusion of Innovations in Service Organizations (110,162). Constructs in the framework are organized according to the broad domains of the intervention, individual, process, and setting (109). The CFIR has been applied in studies assessing a variety of

intervention types and health purposes, but mostly within health organizations (163). Few studies were identified that use the CIFR to assess implementation of a health-related smartphone app. Those that did were typically from the perspective of the health workers, in a health setting, and from HICs (164). Thus, the use of the CIFR for the purpose of this dissertation research represents a novel application that may contribute to the further understanding of the use and application of the model to assess the implementation of health apps.

We used the CIFR to guide our qualitative assessment of the facilitators and barriers to implementation the ChildSafe app among caregivers in Malaysia. The domains and constructs in the framework were adapted to an app targeting patients and general population users (caregivers of children under five). We selected the most relevant constructs to provide insight to strengthen the design, implementation, and dissemination of the app from three domains- the intervention, individuals, and process. Selected constructs under each of these domains are listed with a short description in the table below (Table 8).

Table 1. Mobile Phone and Internet Adoption, World and Developing Areas, 2008-2019

Variable	2008 (Millions)	2008 (%)	2019 (Millions)	2019 (%)
Mobile phone subscriptions				
World	4,030	59.7	8,282	107.8
Developing areas	2,705	49.0	6,600	103.0
Mobile broadband subscriptions				
World	422	6.3	5,702	74.2
Developing areas	86	1.6	4,119	64.3
Fixed broadband subscriptions				
World	411	6.1	1,134	14.8
Developing areas	161	2.9	710	11.1
Population using the Internet				
World	1,570	23.1	3,969	51.4
Developing areas	811	14.6	2,852	44.4

Source: International Telecommunications Union, 2020 (1)

Table 2. Internet Access, World and Developing Areas, 2015-2019

Variable	2015 (Millions)	2015 (%)	2019 (Millions)	2019 (%)
Population covered by at least a 3G mobile network				
World	5,756	78.3	7,128	92.8
Developing areas	4,569	75.0	5,879	91.8
Population covered by at least an LTE/WiMax (4G) mobile network				
World	3,191	43.4	6,405	83.4
Developing areas	2,113	34.7	5,166	80.6

Source: International Telecommunications Union, 2020 (1)

Table 3. Change in DALYs and Deaths, Malaysia, 2010-2019

	Change (2010-2019)					
	DALYs			Death		
Cause	**Number**	**Percent**	**Rate**	**Number**	**Percent**	**Rate**
All Causes						
All causes	1,388,826	0.00%	2,157.86	44,380	0.00%	94.60
Injuries	94,002	-0.87%	35.53	2,122	-1.32%	2.05
Communicable, maternal, neonatal, and nutritional diseases	110,555	-1.69%	-42.81	6,924	-0.65%	13.55
Non-communicable diseases	1,184,270	2.56%	2,165.15	35,334	1.97%	79.00
Injuries						
Injuries	94,002	0.00%	35.53	2,122	0.00%	2.05
Unintentional injuries	33,556	0.71%	29.22	747	0.95%	1.04
Self-harm and interpersonal violence	14,950	0.08%	7.48	325	-0.05%	0.30
Transport injuries	45,495	-0.78%	-1.18	1,050	-0.90%	0.71

Source: 2019 Global Burden of Disease (140)

Table 4. DALYs and Deaths, Adolescents and Children Under 19, Malaysia, 2019

	2019					
	DALY			Deaths		
Cause	**Number**	**Percent**	**Rate**	**Number**	**Percent**	**Rate**
All causes						
All causes	994,631	100.00%	4,773.70	6,392	100.00%	61.34
Injuries	134,727	13.55%	646.62	1,607	25.14%	15.42
Non-communicable diseases	495,135	49.78%	2,376.38	1,955	30.58%	18.76
Communicable, maternal, neonatal, and nutritional diseases	364,769	36.67%	1,750.70	2,830	44.28%	27.16
Injuries						
Injuries	134,727	100.00%	646.62	1,607	100.00%	15.42
Unintentional injuries	47,845	35.51%	229.63	492	30.60%	4.72
Transport injuries	73,635	54.66%	353.41	964	60.00%	9.25
Self-harm and interpersonal violence	13,247	9.83%	63.58	151	9.40%	1.45
Unintentional injuries						
Unintentional injuries	47,845	100.00%	229.63	492	100.00%	4.72
Drowning	17,228	36.01%	82.68	224	45.44%	2.14
Falls	7,886	16.48%	37.85	62	12.63%	0.60
Foreign body	7,107	14.85%	34.11	79	16.05%	0.76
Exposure to mechanical forces	3,393	7.09%	16.29	20	3.98%	0.19
Fire, heat, and hot substances	3,048	6.37%	14.63	27	5.47%	0.26
Poisonings	1,139	2.38%	5.47	13	2.65%	0.13
Adverse effects of medical treatment	1,055	2.20%	5.06	11	2.29%	0.11
Animal contact	1,049	2.19%	5.04	10	2.04%	0.10
Environmental heat and cold exposure	441	0.92%	2.12	1	0.30%	0.01
Exposure to forces of nature	38	0.08%	0.18	0	0.06%	0.00
Other unintentional injuries	5,461	11.41%	26.21	45	9.09%	0.43

Source: 2019 Global Burden of Disease Report (140)

Figure 1. Flow of the ChildSafe App

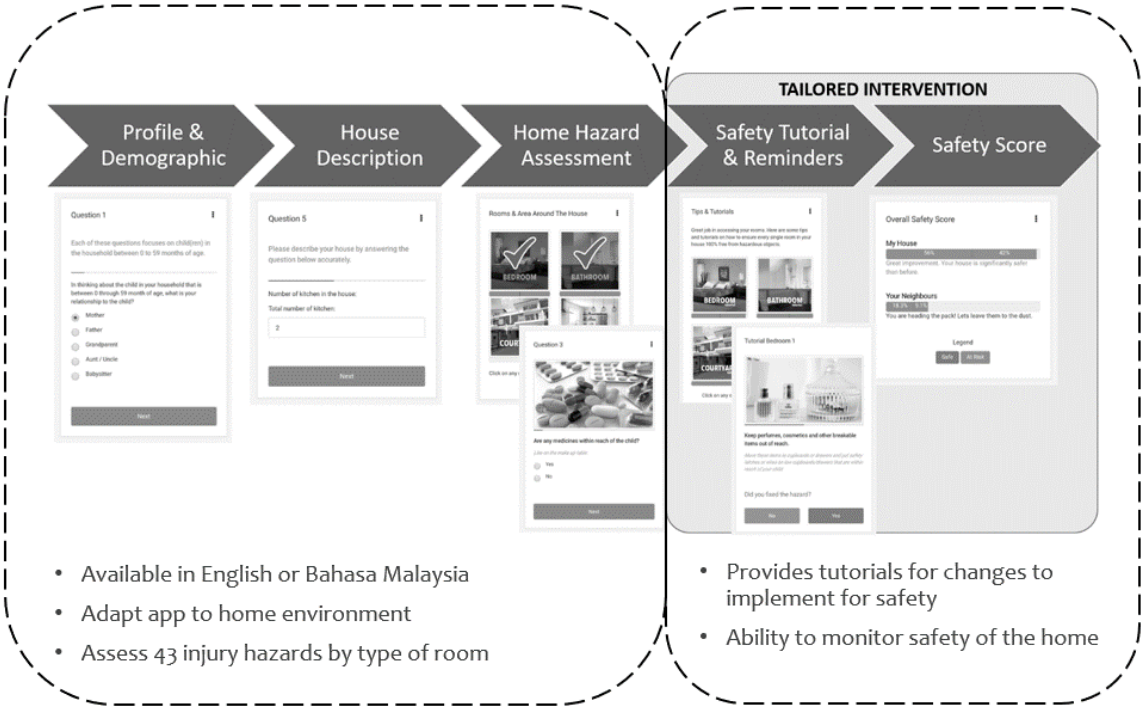


Table 5. Home Safety Assessment for ChildSafe App

N	Variable	Type
	Living & Sleeping Areas	
1	Is there a glass tabletop?	Environmental
2	Are there any breakable objects within reach of the child, particularly on dressing tables?	Behavioral
3	Are any medicines within reach of the child?	Behavioral
4	Are there cosmetics that a child might ingest within reach of the child?	Behavioral
5	Is there any hot or sharp appliance within reach of the child?	Behavioral
6	Are there any small choking hazards within reach of the child?	Behavioral
7	Are any of the child's toys too small (choking hazard), pointed, or sharp?	Environmental
8	Are any houseplants within reach of the child?	Environmental
9	Does the child have access to walker?	Environmental
10	Do you have any cabinets, shelves, or chest of drawers that are unanchored or on a trolley with wheels without locks?	Environmental
11	Are there any loose mats/rugs?	Environmental
12	Are there any electrical outlets into which more than two items are plugged?	Behavioral
13	Are there any frayed or loose cords within reach of the child?	Environmental
14	Are there any electrical cords in the walking area?	Environmental
15	Does the bed/furniture or wall have any sharp corners within reach of the child?	Environmental
16	Does anyone sleep with the child at night?	Behavioral
17	Is there carpeting beneath the surface on which the child sleeps?	Environmental
18	Is there a door with locks on the rooms?	Environmental
19	Do you have curtains and/or blinds?	Environmental
20	Does your home have a smoke detector on every level?	Environmental
21	Does your home have a carbon monoxide detector?	Environmental
	Bath Area	
1	Is there a lock on the inside of the bathroom door within reach of the child?	Environmental
2	Are open buckets of water present?	Behavioral
3	Is there an uncovered large vat/pool of water within the bathroom?	Behavioral
4	Are shampoos/soaps/acid within reach of the child?	Behavioral
5	Is there a water heater (geyser)/pump/machine within reach of the child?	Environmental
6	Is there any anti-slip mat on the floor?	Environmental
7	Is there a lock on the toilet to keep the seat closed?	Environmental
	Kitchen & Dining Room	
1	Is the stove within reach of the child?	Environmental
2	Are matches/lighter/cooking fluids (i.e., paraffin or kerosene) within reach of the child?	Behavioral
3	Are cleaning supplies/chemicals within reach of the child?	Behavioral
4	Are there any knives or sharp objects within reach of the child?	Behavioral
5	Is there any open fire/fireplace within reach of the child?	Environmental
6	Is there a fire extinguisher or bag of sand kept in the kitchen?	Environmental
7	Are cupboards with cooking fluids, cleaning supplies, knives and matches secured or locked?	Environmental
8	Are lighter/cooking fluids kept in non-original or non-labelled containers?	Environmental
9	Are long cloths placed over table where candles, cooking appliances, utensils, or hot foods are placed?	Environmental
	Courtyard, Rooftop & Outdoors	

1	Are any structures with sharp/hard protruding components?	Environmental
2	Are open buckets of water present in the courtyard?	Behavioral
3	If the child plays in the street/road, is the child supervised?	Behavioral
4	If the household has access to water, is there any fence/guardrail/barrier against it?	Environmental
5	Is there any water heater/pump/machine within reach of the child?	Environmental
6	If the household has animals, are they kept in a cage that a child cannot open?	Environmental

Table 6. Access and Adoption of Mobile Phones and the Internet, Malaysia, 2008-2019

Variable	2008 N	2008 %	2019 N	2019 %
Mobile phone subscriptions				
Malaysia	27,713,000	101.75	44,601,400	139.60
Mobile broadband subscriptions				
Malaysia	386,200	1.42	40,430,900	126.55
Population using the Internet				
Malaysia	Not available	55.8	Not available	84.2
Population covered by a mobile cellular network				
Malaysia	Not Available	92	Not available	96.7

Source: International Telecommunications Union (153,154)

Figure 2. Classification of Digital Health Interventions (159)

Table 7. Definitions of Implementation Outcomes

Implementation Outcome	Definition
Acceptability	Perception among implementation stakeholders that a given treatment, service, practice, or innovation is agreeable, palatable, or satisfactory
Adoption	Intention, initial decision, or action to try or employ an innovation or evidence-based practice
Appropriateness	Perceived fit, relevance, or compatibility of the innovation or evidence-based practice for a given practice setting, provider, or consumer; and/or perceived fit of the innovation to address a particular issue or problem
Cost	Cost impact of an implementation effort
Feasibility	Extent to which a new treatment, or an innovation, can be successfully used or carried out within a given agency or setting
Fidelity	Degree to which an intervention was implemented as it was prescribed in the original protocol or as it was intended by the program developers
Penetration	Integration of a practice within a service setting and its subsystems
Sustainability	Extent to which a newly implemented treatment is maintained or institutionalized within a service setting's ongoing, stable operations

Source: Proctor et al. 2011 (161)

Figure 3. Consolidated Framework for Implementation Research (109)

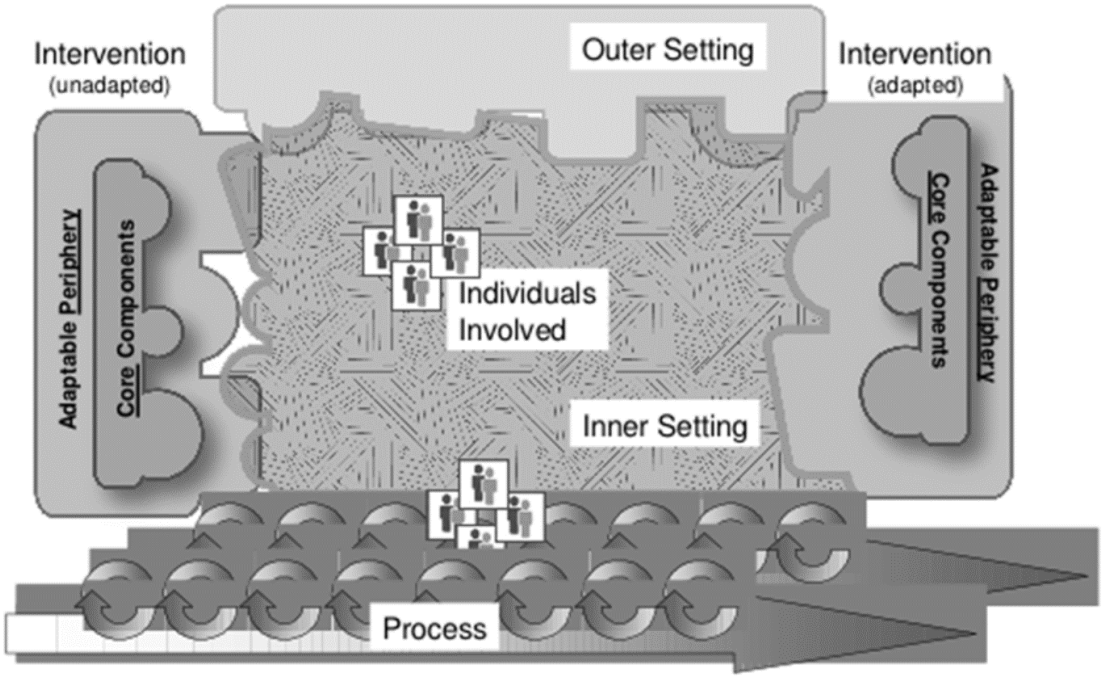


Table 8. Constructs from the Consolidated Framework for Implementation Research

Construct	Short Description
Intervention Characteristics	
Intervention Source	Perception of key stakeholders about whether the intervention is externally or internally developed.
Relative Advantage	Stakeholders' perception of the advantage of implementing the intervention versus an alternative solution.
Adaptability	The degree to which an intervention can be adapted, tailored, refined, or reinvented to meet local needs.
Complexity	Perceived difficulty of implementation, reflected by duration, scope, radicalness, disruptiveness, centrality, and intricacy and number of steps required to implement.
Design Quality & Packaging	Perceived excellence in how the intervention is bundled, presented, and assembled.
Cost	Costs of the intervention and costs associated with implementing the intervention including investment, supply, and opportunity costs.
Individual Characteristics	
Knowledge & Beliefs about the Intervention	Individuals' attitudes toward and value placed on the intervention as well as familiarity with facts, truths, and principles related to the intervention.
Self-efficacy	Individual belief in their own capabilities to execute courses of action to achieve implementation goals.
Individual Stage of Change	Characterization of the phase an individual is in, as he or she progresses toward skilled, enthusiastic, and sustained use of the intervention.
Individual Identification with Organization	A broad construct related to how individuals perceive the organization, and their relationship and degree of commitment with that organization.
Other Personal Attributes	A broad construct to include other personal traits such as tolerance of ambiguity, intellectual ability, motivation, values, competence, capacity, and learning style.
Process	
Planning	The degree to which a scheme or method of behavior and tasks for implementing an intervention are developed in advance, and the quality of those schemes or methods.
Engaging	Attracting and involving appropriate individuals in the implementation and use of the intervention through a combined strategy of social marketing, education, role modeling, training, and other similar activities.
Executing	Carrying out or accomplishing the implementation according to plan.
Reflecting & Evaluating	Quantitative and qualitative feedback about the progress and quality of implementation accompanied with regular personal and team debriefing about progress and experience.

Source: Damschroder et al. 2009 (109)

CHAPTER 2

USE AND IMPLEMENTATION OF HEALTH-RELATED SMARTPHONE APPS IN LOW- AND MIDDLE-INCOME COUNTRIES: A SCOPING REVIEW

SECTION 1: ABSTRACT

Background

There is a growing body of scientific evidence on the use of digital technologies, including smartphone apps, for health purposes. Current reviews to summarize this evidence are dominated by experiences from high-income countries or encompass multiple digital health approaches. Low- and middle-income countries represent a distinct setting for implementation of digital health technologies and smartphone apps are an increasingly popular digital health approach; yet few reviews have been done to summarize the evidence on health apps in these settings. Further, implementation is recognized as a particular challenge for digital health interventions, but it is unclear to what extent it has been considered in assessments of health apps in low- and middle-income countries. To respond to these gaps, we conducted a scoping review to understand the current state of the peer-reviewed literature on the use and implementation of health apps in low- and middle-income countries.

Methods

We conducted a scoping review guided by the methodology of Arksey and O'Malley. We searched PubMed, Embase, and PsycINFO for peer-reviewed studies published between 2008 and 2019. Our search consisted of two broad concepts: 1) low- and middle-income country and 2) smartphone app. Each record was assessed based on eligibility criteria. We extracted a total of 17 data items on the record, geography and context, study characteristics, smartphone app, and implementation considerations.

Results

Our review included 100 records that reported on 89 unique health-related smartphone apps. These apps were developed and assessed in 21 low- and middle-income countries. The largest number of apps were for cancers and chronic diseases and provided education to users. Most studies were pilot studies and included 49 participants or less. Implementation was not considered in the assessment or testing of more than one-thirds of apps and many of these assessments aimed to assess an implementation outcome. Acceptability and feasibility were the two most assessed implementation outcomes.

Conclusion

There is a need for greater consideration of implementation from the early stages of development and implementation of health apps in LMICs and consensus on the operationalization of implementation considerations in the context of a health app.

Key words: Smartphone app; Health app; mHealth; Mobile health; Digital health; Implementation; Low- and Middle-Income Country

SECTION 2: BACKGROUND

In the past two decades, the world has experienced the introduction and spread of novel digital technologies, such as mobile phones and the Internet. In 2016, the number of mobile phone subscriptions was greater than the population of the entire world, and coverage has remained above 100% every year since (1). By 2019, more than 92% of the global population was covered by at least a 3G mobile network and almost 75% had an active mobile broadband subscription (1). This holds true in LMICs where in coverage of mobile phone subscriptions was greater than 100%, almost 92% of the population living in these areas was covered by at least a 3G mobile network, and almost 65% had an active mobile broadband subscription (1). Further, coverage of mobile broadband subscriptions in LMICs were far greater than that for fixed broadband (64.3% vs. 11.1%), demonstrating the important role of mobile phones in these settings.

These digital technologies are significantly affecting the health sector and present new opportunities to leverage them to strengthen health systems and improve health. This has led to new concepts in public health called digital health, which is the use of digital technologies, including mobile phones, for health purposes (156). Digital technologies have become especially important for health as evidenced during the coronavirus pandemic by enabling the remote delivery of health interventions (2–4). Smartphone apps in particular have become an increasingly popular way to deliver health interventions. Apps are small software programs designed for a specific purpose that are downloaded from the Internet through app stores and run on smartphones. According to a report by the IQVIA Institute, there were more than 318,000 health apps available in 2017 that had

been downloaded more than 3.35 billion times (6). On average, countries have between 210,000 and 250,000 health apps available in their apps stores and more apps are becoming available in languages other than English, showing the growing interest in health apps among global populations (6).

There is a rapidly expanding body of scientific evidence on the use of digital technologies for health purposes. Many reviews have been done to summarize the literature on digital health interventions for specific health issues (53–57). However, the literature on digital health is dominated by experiences from HICs. LMICs represent a distinct setting for implementation of digital health interventions given differences in the coverage of mobile phones and the Internet, more recent emergence of digital technologies, and different health systems, diseases burdens, and technological capacity that exist in these settings. While there has been some effort to summarize the literature from LMICs specifically, these reviews typically encompass a variety of digital health approaches (ex. SMS text messaging, voice response systems, web portals) that target different types of users (ex. health workers, patients, caregivers) and multiple health functions (ex. education, self-monitoring, treatment) (82–95). Reviews looking at a single digital health approach have been done for SMS text messaging, voice response systems, and web portals as the literature on these topics grew (96–103). Smartphone apps are a unique digital health approach offering advanced functionality and as the literature on health-related smartphone apps grow, similar efforts to summarize it are needed.

Further, implementation and scale up has been recognized as a particular challenge for digital health interventions, including in LMICs. Many digital health interventions that are piloted in LMICs never reach full implementation and scale, resulting in lost

investments in development, research, and potential health improvements (104–107). This is in part because of limited consideration for implementation from the onset of the project (104–107). The WHO and others have called for a greater focus on understanding implementation of digital health interventions and considering implementation is recognized as a best practice for digital health development (104–108). However, it remains unclear to what extent implementation has been considered in the assessment of health-related apps in LMICs and this is a particular area of interest.

To respond to these gaps in the literature, this review is aimed at understanding the current state of the peer-reviewed literature on the use and implementation of health apps in LMICs. The specific objectives were to: 1) review, map, and summarize the published literature on the use of health apps in LMICs; and 2) examine whether and how implementation of health apps is considered and assessed in LMICs.

SECTION 3: METHODS

We conducted a scoping review guided by the methodology of Arksey and O'Malley (165). Scoping reviews are studies that "aim to map rapidly the key concepts underpinning a research area and the main sources and types of evidence available" (165). According to the authors, scoping reviews may be undertaken for many purposes, including those relevant to this review to: "examine the extent, range, and nature of research activity" and "identify research gaps in the existing literature" (165). Scoping reviews are appropriate when the topic is broader and the state of the evidence is not well

known, unlike systematic reviews that typically focus on well-defined research question and narrow body of evidence. Arksey and O'Malley outline five stages for conducting a scoping review study: 1) identifying the research question, 2) identifying relevant studies; 3) study selection; 4) charting the data; and 5) collating, summarizing, and reporting the results (165). The following sections describe these stages in more detail.

Information Sources

We searched the published literature available in three common public health databases: 1) PubMed; 2) Embase; and 3) PsycINFO. The initial search was conducted in July 2019 and updated in July 2020 to retrieve all articles published up through December 31, 2019. We focused on the published literature because these records represent a body of evidence on health-related smartphone apps that has been peer-reviewed and establish the foundation for further scientific work on this topic.

Eligibility Criteria

The following eligibility criteria was used to screen records for inclusion or exclusion:

Eligibility Criteria:

1. The setting for the record is a LMIC as defined by the World Bank Country and Lending Groups released in 2020 based on data from 2019 (166);
2. The record reports the results of a research study to assess or test an intervention;
3. The intervention being studied includes a smartphone app;

4. The smartphone app targets the general public or patients as the end-user;
5. The intervention aims to directly improve health; and
6. The record is a peer-reviewed publication available in English and was published between 2008 and 2019.

Exclusion Criteria: The record did not meet one or more of the eligibility criteria listed above.

Search

We developed a search strategy based on two broad concepts: 1) LMIC and 2) smartphone app. Given the variety of terms that are used to describe different interventions that leverage smartphone apps- including broad terms like mHealth- as well as the difficulty in identifying smartphone apps that are sometimes referred to by their development name, we felt that the use of these broad concepts enabled us to retrieve a large amount of potentially relevant literature that could then be assessed for eligibility through an extensive process of screening. The full search that was run in PubMed is available in Appendix 2 and was adapted to other databases. We limited the dates of our search to between 2008 and 2019. We used these dates because the first app stores became available in 2008 and apps became accessible to the public at this time. Since data extraction and reporting took place between 2019 and 2020, 2019 was the most current full year that could be included.

Selection of Sources of Evidence

The results of our search were downloaded from each of the databases as CSV or Microsoft Excel© files. The resulting files were then merged in Microsoft Excel© and duplicate records were removed. The remaining records were then screened by two researchers according to pre-established eligibility criteria. First, an initial screening was done using the title and abstract in Microsoft Excel©. Each record was assessed based on each of the eligibility criteria (0: record did not meet eligibility criteria; 1: record met eligibility criteria). When a record did not meet one or more of the eligibility criteria, it was immediately excluded. When a record met all the eligibility criteria, it was retained. When the information in the title and abstract was insufficient to determine inclusion or exclusion, the article was retained until the full text could be reviewed. When the researchers were unsure about whether to include or exclude a record, they consulted with the other during weekly check-ins and a consensus on the record was reached. The full text of included and retained records was then rereviewed to ensure that they met all eligibility criteria. Screening was done between September 2019 and January 2020.

Data Charting Process

The full texts of the included articles were accessed. A data extraction form was developed as a survey using Qualtrics©, an online survey management platform (167). Data extraction was done individually by researchers through the Qualtrics platform. Checks were put in place throughout the survey to ensure the completeness of data extraction. Before completing data extraction on the full set of included records, the form

was tested on a small number of records and improvements were made based on this pilot experience.

Data Items

The data extraction form consisted of five sections namely: 1) Identification; 2) Geography and Context; 3) Study Characteristics; 4) Smartphone App; and 5) Implementation Considerations. We extracted a total of 17 data items from the included records. Details on each of the data items extracted are provided in Table 9.

Definitions

Health Issue: We defined nine (9) categories of health issues as defined below. These categories were not mutually exclusive as several apps addressed several health issues.

1. Cancers and Chronic Diseases: All types of cancers and chronic diseases, including hypertension, diabetes, coronary heart disease, and cardiovascular disease.
2. Child and Adolescent Health: Childhood and adolescent illnesses and care, including adolescent sexual and reproductive health.
3. Health Systems and Delivery: Surgical preparation and management, medication adherence, tele-health, and insurance.
4. HIV and Infectious Diseases: Infectious diseases, including HIV, tuberculosis, and dengue.

5. Injuries and Safety: Injury and safety, including first aid and injury prevention.
6. Maternal Health: Maternal health such as family planning and pregnancy, preeclampsia, gestational diabetes, and breastfeeding.
7. Mental and Behavioral Disorders: Mental and behavioral disorders such as all types of substance use disorders, depression and stress, and bipolar disorders.
8. Mental and Physical Disability: Disability and congenital anomalies, stroke and cognitive impairment, pain and inflammation.
9. Obesity and Lifestyle: Physical inactivity, obesity, and smoking.

App Function: We categorized apps according to the six functions aligned with WHO's Classification of Digital Health Intervention v1.0 (159). Apps could have several purposes and were not mutually exclusive.

1. Education: App provides education and information on a health issue or care (including 1.1 Targeted client communication, 1.2 Untargeted client communication, and 1.6 On-demand information services to clients).
2. Self-monitoring: App is used to do a self-assessment, diagnosis, or monitoring of a health issue (including 1.4 Personal health tracking).
3. Communication: App is used to communicate and link users to health actors, facilities, or systems (including 1.1 Targeted client communication).
4. Treatment: App is used to deliver treatment or therapy to address a health issue.
5. Support: App is used to network users to other patients, caregivers, or users that have similar health concerns or needs to provide support (including 1.3 Client to client communication)

6. Gamification: App is a game that is used to provide prevention, treatment, or management of a health issue.

Data Analysis

The output of the data extraction was downloaded from Qualtrics© as an Microsoft Excel© file and imported to STATA©, a statistical software program (168). Cleaning and coding of the data was done followed by analysis using descriptive statistics. Data was assessed at the level of the record and smartphone app. Data was summarized and presented using numbers, percentages, tables, and figures across health issues and functions.

SECTION 4: RESULTS

Included Records

Our database search identified a total of 6,571 records. After removing 1,479 duplicates, we identified a total of 5,092 unique records. 4,428 articles were screened, and 664 full-text articles were assessed for eligibility. A total of 4,992 records were excluded from the review because they did not meet one or more of our eligibility criteria. Thus, we included a total of 100 records in English that reported the results of a research study published between 2008 and 2019 to assess or test an intervention that aimed to improve health delivered through a smartphone app targeting the general public or patients as the

end-user in a LMIC. The proportion of records included was 2% of the unique identified records. A flow diagram of records is provided in Figure 4.

Excluded Records

Records were excluded if they did not meet one or more of the eligibility criteria. The greatest number of records were excluded because they did not report the results of a study to assess or test an intervention (n=2,503). Examples of such excluded records included protocols, systematic reviews, descriptive studies, or formative studies. 986 records were excluded because the intervention did not include a smartphone app. Examples include records that reported the results of an intervention using another mHealth approach, such as SMS or WhatsApp© text messages. Many records were also excluded because the setting was not a LMIC (n=793). Examples of records that appeared in the search results but took place in a HIC setting include studies that focused on specific groups (African Americans, Latinos) in the United States (US), US veterans who served in Iraq and Afghanistan, refugees from a LMIC who were residing in a HIC, and/or travelers from HICs to LMICs. 544 records were excluded because they did not target the general public or patients as the end-user. For many of these records, health care workers were the targeted end-users of the app, such as doctors, nurses, emergency responders, or community health workers. Some of the smartphone apps that were being assessed (n=140) did not aim to improve health. Examples of such non-health related apps include those that aimed to provide continuing education for health workers, facilitate education for disabled children in schools, or identify and address an invasive species of plants. Only a few records were excluded because they were not available in

English or published between 2008 and 2019 (n=26). Some articles were in other languages, such as Chinese, Russian, and Turkish (n=21), while others appeared the search results from 2019 due to prepublication availability even though they were published in 2020 (n=5).

Smartphone Apps

The 100 included records reported on a total of 89 unique health-related smartphone apps for general public or patient users that were assessed or tested in LMICs. While the results of most apps were reported in one record (n=81, 91%), there were multiple records on eight (8) of the included apps (9%). The greatest number of publications were for smartphone apps called Tumaini (n=3) (169–171), Phone-Based Intervention under Nurse Guidance after Stroke (n=3) (172–174), and Breast Cancer e-Support Program (n=3) (175–177).

Geography and Context

Year of Publication

The first of the records identified by our search was published in 2010. Between 2010 and 2015, there were between zero (0) and three (3) articles published each year on health apps in LMICs. Since 2015, there has been a rapid increase in the number of published articles annually, from one (1) in 2015 to 50 in 2019 alone. The greatest number of

studies were published in 2019, representing 50% of the total included articles in the most recent year. The number of included records by year is presented in Figure 5.

Countries

The 89 apps from the 100 records were developed and assessed in a total of 21 LMICs (Table 10). The greatest number of apps were developed in China, where 20 apps were assessed or tested representing more than 20% of the total identified smartphone apps in LMICS. Many apps were also developed in India (n=13, 15%) and Brazil (n=8, 9%). Together, apps from these three (3) countries (China, India, and Brazil) accounted for almost 50% of the total apps reported. Seven (7; 8%) apps were developed and assessed in multiple countries. Figure 6 shows the distribution of LMIC countries (light grey) where smartphone apps were assessed and tested (dark grey) around the world.

Regions and Income Groups

The apps were developed and accessed across all six (6) WHO regions, with most in the South-East Asia Region (n=24, 27%) (Table 10). Most apps were developed in Upper (n=55; 62%) and Lower (n=25; 28%) MICs. Only two (2) apps were developed in a Low-Income Country (LIC) (Tajikistan, Uganda) (n=2; 2%).

Study Characteristics

Health Issue

The largest number of records were on cancers and chronic diseases (n=31, 31%) followed by mental and physical disability (n=15, 15%), HIV and infectious diseases

(n=12, 12%), maternal health (n=12, 12%), and mental and behavioral disorders (n=11, 11%) (Table 11). Fewer records were on health systems and delivery, child and adolescent health, obesity and lifestyle, or injuries and safety.

Design and Methods

Most studies were pilot studies (n=22, 22%), although many were randomized trials (n=20, 20%) or used mixed methods (n=22, 22%) to assess the app (Table 11). Quantitative methods were also frequently used (n=19, 19%), but quasi-experimental and qualitative methods were less common. Figure 7 shows the design and methods of studies by health issue.

Sample Size

The median number of participants analyzed by the study was 58. The largest number of studies included 49 participants or less (n=41, 41%), followed by studies with between 50 and 99 participants (n=26, 26%) and between 100 and 299 (n=15, 15%) (Table 11). Studies with between 300 and 499 and more than 500 participants were less common. Figure 8 shows the sample size of studies by health issue.

Smartphone Apps

Health Issue

The largest number of apps addressed cancers and chronic diseases (n=27; 30%) (Table 12). These were followed by apps for mental and physical disability (n=12; 13%). Other apps targeted maternal health (n=11; 12%) and mental and behavioral disorders (n=10;

11%). A smaller number of apps were for health systems and delivery, HIV and infectious diseases, child and adolescent health, obesity and lifestyle, and injuries and safety.

Phase

The greatest number of apps were developed as a tool for prevention of a health issue (n=43, 48%), followed by apps used for management (40; 45%) (Table 12). Apps for treatment were slightly less common, with 33 in total representing 37% of apps. Figure 9 shows the number and phase of apps by health issue.

Function

The greatest number of apps provided education on a health issue to users (n=56, 63%) and enabled users to complete self-monitoring (n=55, 62%) (Table 12). Many apps were also used for communication and linkages with the health actors or facilities (n=40, 45%). Treatment or therapy was provided through some apps (n=21, 24%), while others provided support and networking (n=14, 16%). Only a few apps used gamification (n=8, 9%). The number and function of the app by health issue are shown in Figure 10.

Collaborators

Almost all apps were developed in collaboration with a university (n=81, 91%) (Table 12). Almost half were also developed in collaboration with a health facility (n=38, 43%). The government collaborated in the development of only 12 (13% of) apps. Private organizations, civil society organizations, international partners, and schools collaborated in the development of a small number of apps. Figure 11 shows the collaborators by health issue.

Implementation

Implementation Considerations

Implementation was not considered in the assessment or testing of more than one-third of apps (n=35; 39%) (Table 13). Most studies that considered implementation included a specific implementation objective (n=45; 83%). Many of these studies on apps assessed an implementation outcome (n=29, 54%). Assessments of only a few apps focused on the implementation process (n=15, 28%) or were guided by an implementation framework (n=13, 24%).

Health Issue

Implementation was considered for between 29% and 100% of apps on a specific health issue (Table 13). Assessments for all apps for HIV and infectious diseases (n=8, 100%) and almost all apps for mental and behavioral disorders (n=8, 80%) considered implementation. Implementation of apps for obesity and lifestyle (n=2, 29%) as well as health systems and delivery (n=3, 33%) were less commonly assessed. Figure 12 shows how implementation was considered for each health issue.

App Function

Between 57% and 66% of apps for a specific function considered implementation. Implementation was considered for more apps providing education (n=37; 66%) and communication (n=26; 65%) (Table 13). Apps that provided support considered implementation less frequently (n=8, 57%). Figure 13 shows how implementation was considered for each app function.

Implementation Outcomes

Acceptability (n=25, 86%) and feasibility (n=14, 48%) were the two most assessed implementation outcomes (Table 13). Appropriateness, adoption, and fidelity were the only other implementation outcomes assessed. The results for acceptability and feasibility are further described below.

Acceptability

Acceptability was accessed using a diversity of definitions and methods that are presented along with the results (Table 14). Definitions applied to assess acceptability included simple measures and perceptions of satisfaction or preferences, pre-defined criteria to achieve acceptability, and broad conceptualizations that assessed acceptability from multiple perspectives (ex. intention to use, ease of use, privacy, convenience, etc.). Acceptability was typically used to assess the app design or content, although in a few cases, the app was designed with the intention of increasing acceptability of a service (ex. TFPA's 'healthy lifestyles' app) (178). Acceptability for most apps was assessed using quantitative data collection, such as surveys and app/server data (n=18; 72%). Qualitative data collection, including co-design workshops, user testing sessions, interviews, and observations, was used to assess acceptability of 11 apps (44%). Acceptability of four (4) apps was assessed using both quantitative and qualitative approaches (16%). Acceptability was typically assessed by the patient or population that were the users of the app (n=96%), but health workers were sometimes engaged instead (n=6; 24%). Some apps assessed acceptability from both perspectives (n=5; 20%).

Of the 25 apps that assessed acceptability, 18 (72%) were found to be acceptable and 7 (28%) had inconclusive or unclear results (i.e. determined to be not acceptable, had aspects that were acceptable and others that were not, some users thought it was acceptable and others did not) (Table 14). Acceptable apps were mostly for prevention (n=7; 86%) or management of a health issue (n=11; 85%). Most acceptable apps addressed cancers and chronic diseases (n=8; 89%) and were for education (n=12; 75%), communication (n=10; 77%), and self-monitoring (n=12; 67%). Acceptable apps were also found for HIV and infectious diseases, maternal health, health systems and delivery, mental and physical disability, gamification, and treatment. Apps were found to be less acceptable for treatment (n=6; 60%), mental health (n=4; 80%), and support (n=2; 67%). Apps on prevention, treatment, child and adolescent health, cancers and chronic diseases, mental and physical disability, communication, education, self-monitoring, and treatment function also had inconclusive results regarding acceptability.

Feasibility

Studies used a diversity of definitions and methods to measure feasibility and determine results (Table 15). Most used quantitative methods from surveys, app/server data, and project documentation to assess feasibility (n=8; 57%). Qualitative methods, including in-depth interviews, focus group discussions, and observations, were used to assess feasibility of a smaller number of apps (n=6; 43%). Studies on 12 (86%) apps assessed feasibility from the perspective of users and five (36%) from the perspective of health workers. Three (21%) assessed feasibility from both perspectives.

Less than half of studies (n=6; 43%) that assessed feasibility found that the app or intervention was feasible, while results from more than half were inconclusive or unclear

(i.e. determined to be not feasible, had aspects that were feasible and others that were not) (n=8; 57%) (Table 15). Most apps were found feasible for management (n=3; 50%), cancers and chronic diseases (n=2; 67%), mental and physical disability (n=2; 67%), and communication (n=5; 50%). Apps were also found to be feasible for all phases of health, HIV and infectious diseases, maternal health, injuries and occupational health, education, self-monitoring, and treatment function. Most apps were found to have inconclusive results on the feasibility for treatment phase (n=6; 86%), mental health (n=5; 100%), treatment function (n=6; 67%), education (n=5; 63%), and self-monitoring (n=5; 56%). Apps for prevention, management, child and adolescent health, cancers and chronic diseases, mental and physical disability, communication, and support also had inconclusive results on feasibility.

Implementation Framework

Eight (8) different implementation frameworks were used to assess the apps (Table 13). The Technology Acceptance Model (n=4, 31%) and Mobile App Rating Scale (n=2, 15%) were the most common implementation frameworks used (179,180).

SECTION 5: DISCUSSION

This scoping review mapped the existing peer-reviewed literature on health-related smartphone apps for general public users or patients in LMICs to reveal several learnings, opportunities, and gaps for future research and practice. In this review, we identify the existence of a small but rapidly growing body of literature on health-related smartphone

apps in LMICs as a distinct digital health approach. This growing body of scientific literature provides opportunities to summarize and learn about experiences leveraging smartphone apps for health purposes across issues, functions, and LMIC contexts.

We reveal the geographical scope and range of health issues and functions in the peer-reviewed literature on health-related smartphone apps. As other work has also suggested, this demonstrates the increasing popularity of health-related smartphone apps for general public users or patients in LMICs (6). We also identified concentrations of literature on health-related smartphone apps in the Southeast Asia region, MICs, and China, Brazil, and India. Most of the literature also focused on cancers/chronic diseases, mental/physical disability, education, self-monitoring, prevention, and management. The results of studies that assessed acceptability also demonstrated that the use of apps for these purposes and functions was also acceptable. These concentrations of health apps offer opportunities to summarize the experiences and assess the value and contribution of health apps for these contexts, health issues, and functions. This is an area for ongoing research.

We also note gaps in the available literature on health apps in low-income settings, as well as for injuries and safety, child and adolescent health, and HIV and infectious diseases. As smartphones and mobile Internet networks become more saturated and technical capacities expand, there may be new opportunities to leverage smartphone apps for health purposes in other low-income settings (1). The gaps in the literature on injuries and safety, child and adolescent health, HIV and infectious diseases are also noteworthy given the burden of injuries and infectious diseases that exist in LMIC settings (139,181). Despite the small number, apps were also found to be an acceptable way to deliver many

interventions for HIV and infectious diseases and maternal health. With the growing popularity of health apps among global populations, apps offer many functions and potential opportunities to deliver interventions that align with health needs. This is especially important given the current coronavirus pandemic that has emphasized the important role of Internet and digital technologies to support health and service delivery when in-person interventions may be limited (2–4). More research is need on how health-related smartphone apps can support health goals and service delivery in these areas.

Our scoping review also showed gaps in the assessment of implementation of health-related smartphone apps in LMICs. Many apps that were introduced in LMICs were through small-scale studies, notably pilot and mixed methods studies with a smaller number of participants. We also found that implementation was not considered for more than one-third of apps that have been introduced in these settings, with varying levels based on the targeted health issue or app function. Of the apps for which implementation was considered, most assessed acceptability and feasibility of the app to be delivered in the setting, with varying levels of success. Very few considered other implementation outcomes or issues, including the implementation process. Further, recognized approaches to assess implementation, such as standard definitions of implementation outcomes or implementation frameworks were rarely applied, making linkages to the implementation research literature or summarizing experiences across studies and apps difficult to accomplish (161). Implementation in particular has been identified as a challenging area for digital health and mHealth interventions broadly, with few innovations and pilot projects moving to full implementation and scale (104,106). Implementation research is a defined area of inquiry that offers a systematic approach to

assessing implementation to understand how and why interventions are working and how implementation can be strengthened (111). More work is needed to understand the implementation and scale up of health-related apps using recognized approaches and methods from implementation research to contribute to a common understanding.

Limitations

There are several limitations to this scoping review. First, we included only the peer-review literature in English from three common public health databases. By doing so, our review did not include information on apps that were never evaluated or only published in the grey literature outside of scientific studies, or that were published in a language other than English. There are likely many health apps that have been developed and implemented in LMICs that have not been published in the peer-reviewed literature. There was also some challenge in identifying and distinguishing health-related apps from other mHealth approaches. Many descriptions of health-related apps were not always clear and comprehensive. Further, our review did not seek to assess the effectiveness of smartphone apps for improving health or the quality of evidence from the included studies. Our review was also limited to studies published prior to 2020. Given the increasing popularity of health-related apps in recent years, there is a need to continue to map and reexamine the use of health-related apps as the situation in LMICs evolves.

Conclusion

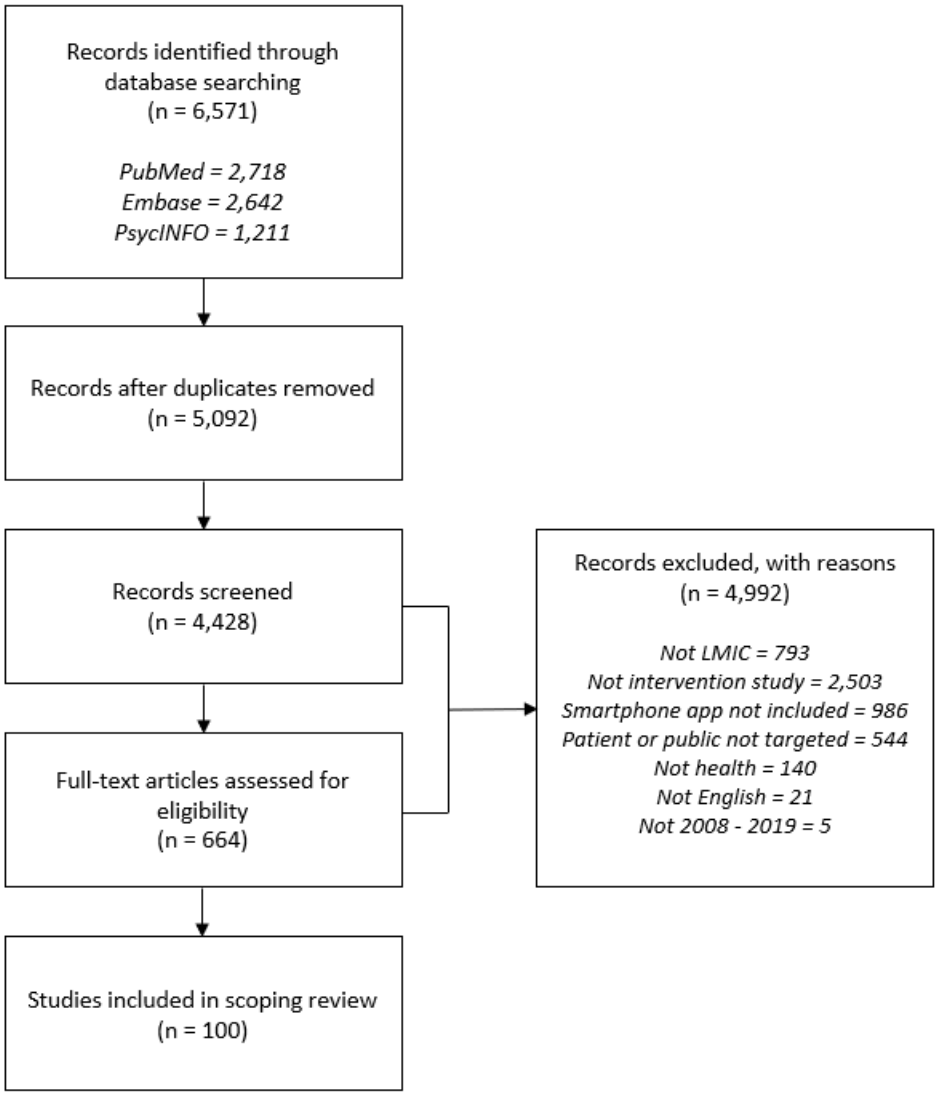
Health-related smartphone apps for general public users and patients are becoming increasingly popular for many purposes to address different health issues. There are significant gaps in the published, peer-reviewed literature on the use and implementation of health-related apps that present opportunities for future research and practice, and a need to apply systematic approaches to assessing implementation to contribute to a shared understanding.

Table 9. Data Items for Extraction

N	Variable	Definition	Type	Response
Identification				
1	First Author	The first author of the included published record	Open	Blank
2	Title of Record	The title of the included published record	Open	Blank
3	App Name	The name of the smartphone app, intervention, or study	Open	Blank
Geography and Context				
4	Year of Publication	The year in which the record was published	Structured	2008, 2009, 2010, 2011, 2012, 2013, 2014, 2015, 2016, 2017, 2018, 2019
5	Country	The country where the app was assessed or tested	Open	Blank
6	World Health Organization Region	Region for the country where the app was assessed or tested based on classification by the WHO (182)	Structured	African Region, Eastern Mediterranean Region, European Region, Region of the Americas, South-East Asia Region, Western Pacific Region
7	World Bank Income Group	Income group for the country where the app was assessed or tested based on the World Bank's 2020 country classifications (166)	Structured	Upper Middle Income, Lower Middle Income, Low Income
Study Characteristics				
8	Design and Methods	The study design or methods as identified by the study	Structured	Pilot study, Randomized trial, Quasi-experimental, Mixed methods, Quantitative, Qualitative
9	Sample Size	The number of participants analyzed in the study	Structured	49 or less, Between 50-99, Between 100-299, Between 300-499, 500 or more
Health-Related Smartphone Apps				
10	Health Issue	The health issue that the study aimed to address	Structured	Cancers and Chronic Diseases, Child and Adolescent Health, Health Systems and Delivery, HIV and Infectious Diseases, Injuries and Safety, Maternal Health, Mental and Behavioral Disorders, Mental and Physical Disability, Obesity and Lifestyle (See Definitions section)
11	Phase	The phase of health that the app aimed to address	Structured	Prevention; Treatment; Management
12	Function	The function of the app in addressing the health issue aligned with WHO's Classification of Digital	Structured	Education, Self-monitoring, Communication, Treatment, Support, Gamification (See Definitions section)

		Health Interventions v1.0 (159)		
13	Collaborators	The types of organizations listed as collaborators	Structured	University, Health Facility, Government, Private Sector, Civil Society Organizations, International Partners, School
Implementation Considerations				
14	Implementation	Whether implementation of the app was considered	Structured	Yes, No
15	Implementation Consideration	How implementation of the app was considered in the study	Structured	Implementation Objective, Implementation Outcome, Implementation Framework, Implementation Process
16	Implementation Outcome	Type of implementation outcome assessed for the app according to Proctor's Implementation Outcomes Framework (161)	Structured	Acceptability, Adoption, Appropriateness, Costs, Feasibility, Fidelity, Penetration, Sustainability
17	Implementation Framework	The implementation framework applied to assess the app	Open	Blank

Figure 4. Flow Diagram of Records



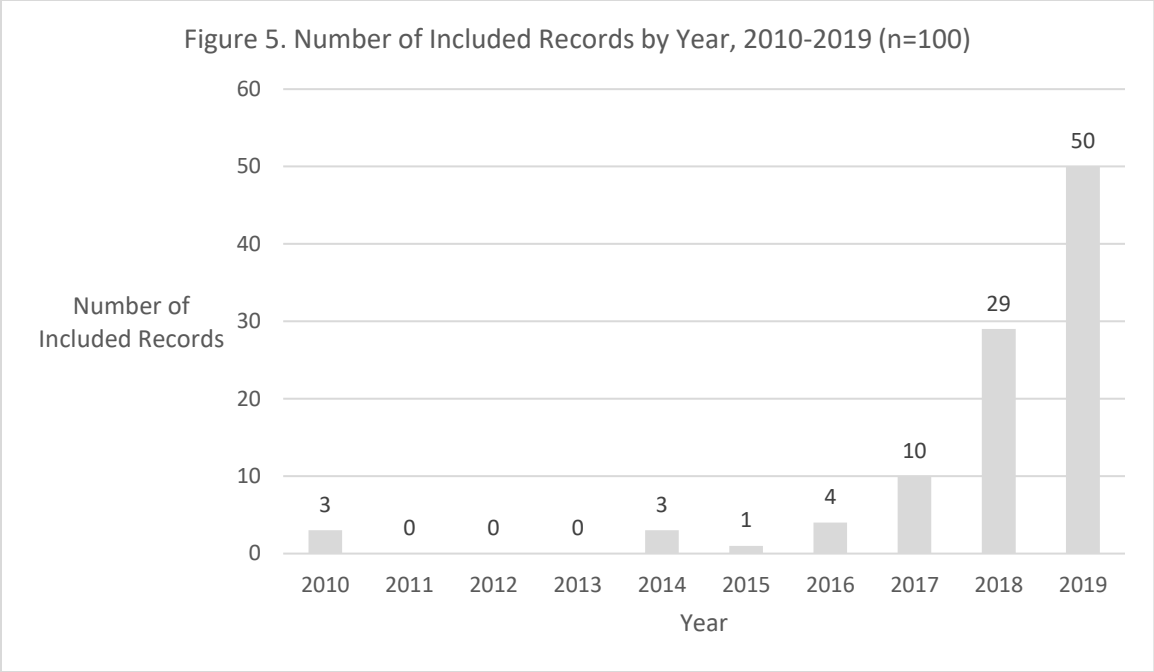
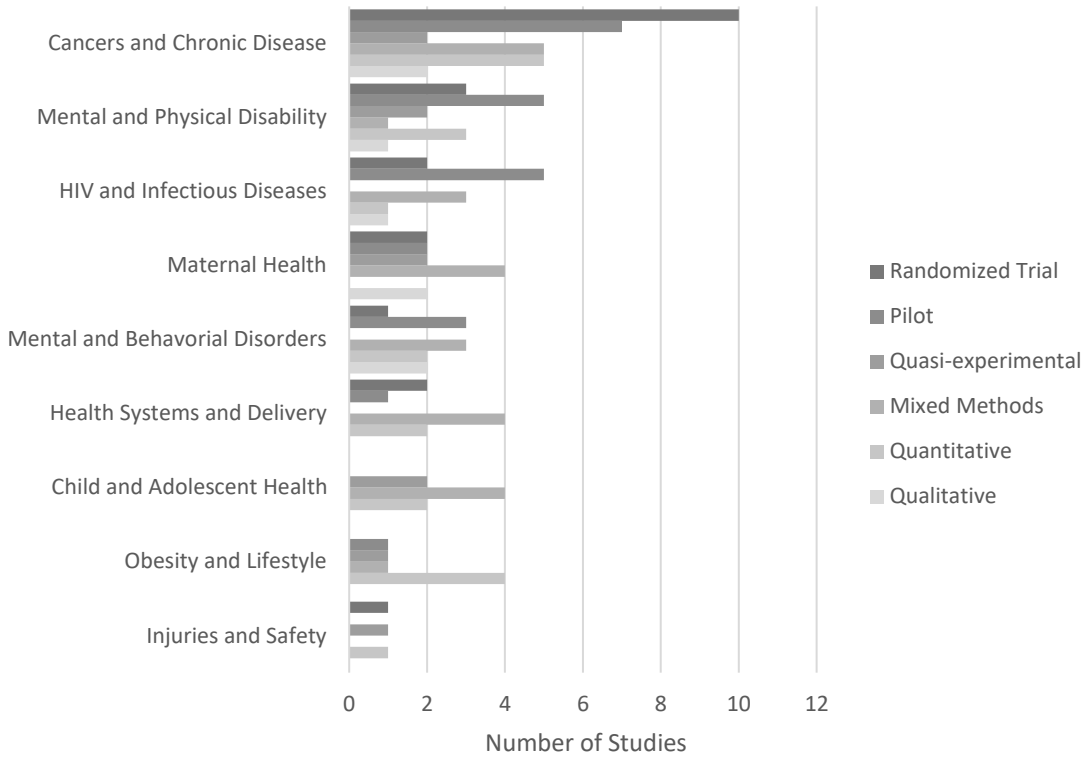


Figure 6. Map of Health-Related Smartphone Apps in LMICs

Table 10. Number of Apps by WHO Region and World Bank Income Group (n=89)		
	N	**%**
World Health Organization Region		
South-East Asia Region	24	27
Western Pacific Region	22	25
African Region	12	13
Region of the Americas	12	13
Eastern Mediterranean Region	10	11
European Region	2	2
Multiple Countries	7	8
World Bank Income Group		
Upper Middle Income	55	62
Lower Middle Income	25	28
Low Income	2	2
Multiple Countries	7	8
Country		
China	20	22
India	13	15
Brazil	8	9
Indonesia	6	7
Iran	5	6
South Africa	4	4
Ghana	3	3
Kenya	3	3
Pakistan	3	3
Thailand	3	3
Malaysia	2	2
Mexico	2	2
Sri Lanka	2	2
Colombia	1	1
Dominican Republic	1	1
Iraq	1	1
Lebanon	1	1
Nigeria	1	1
Tajikistan	1	1
Turkey	1	1
Uganda	1	1
Multiple Countries	7	8

Figure 7. Design and Methods of Study by Health Issue (n=100)



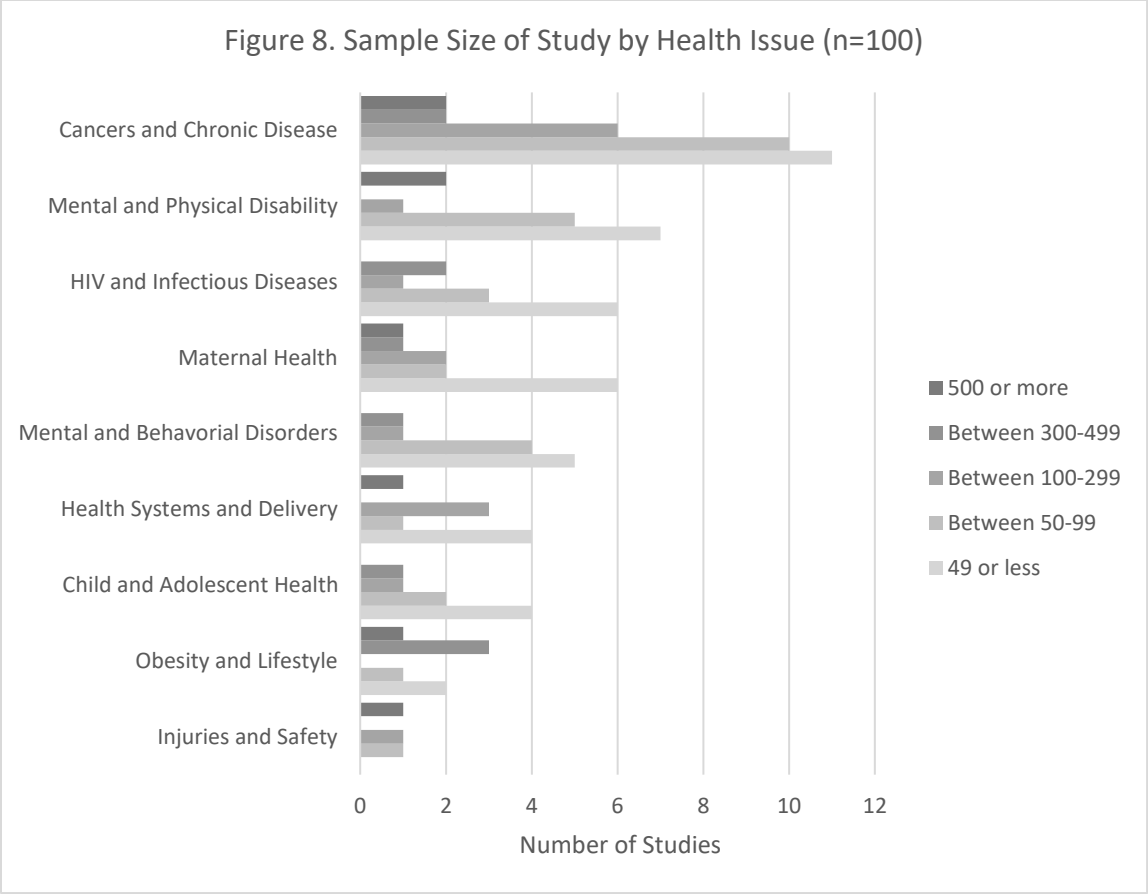


Figure 8. Sample Size of Study by Health Issue (n=100)
Cancers and Chronic Disease
Mental and Physical Disability
HIV and Infectious Diseases
Maternal Health
Mental and Behavorial Disorders
Health Systems and Delivery
Child and Adolescent Health
Obesity and Lifestyle
Injuries and Safety
0
2
4
6
8
10
12
Number of Studies
500 or more
Between 300-499
Between 100-299
Between 50-99
49 or less

Table 11. Study Characteristics (n=100)		
	N	**%**
Health Issue		
Cancers and Chronic Disease	31	31
Mental and Physical Disability	15	15
HIV and Infectious Diseases	12	12
Maternal Health	12	12
Mental and Behavioral Disorders	11	11
Health Systems and Delivery	9	9
Child and Adolescent Health	8	8
Obesity and Lifestyle	7	7
Injuries and Safety	3	3
Design and Methods		
Pilot	22	22
Mixed Methods	22	22
Randomized Trial	20	20
Quantitative	19	19
Quasi-Experimental	10	10
Qualitative	7	7
Sample Size		
49 or less	41	41
Between 50 and 99	26	26
Between 100 and 299	15	15
Between 300 and 499	9	9
500 or more	9	9

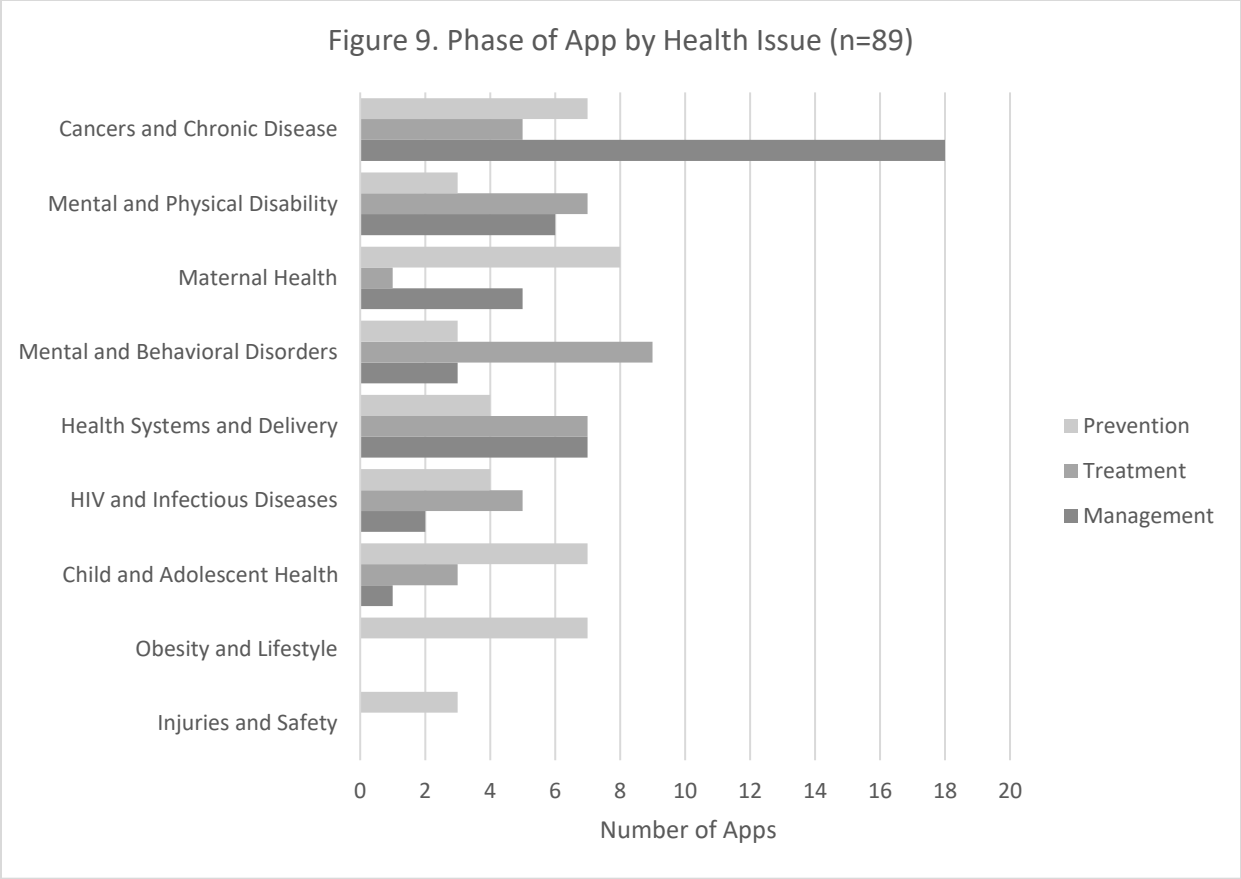


Figure 9. Phase of App by Health Issue (n=89)
Cancers and Chronic Disease
Mental and Physical Disability
Maternal Health
Mental and Behavioral Disorders
Health Systems and Delivery
HIV and Infectious Diseases
Child and Adolescent Health
Obesity and Lifestyle
Injuries and Safety
0
2
4
6
8
10
12
14
16
18
20
Number of Apps
Prevention
Treatment
Management

Figure 10. Function of App by Health Issue (n=89)

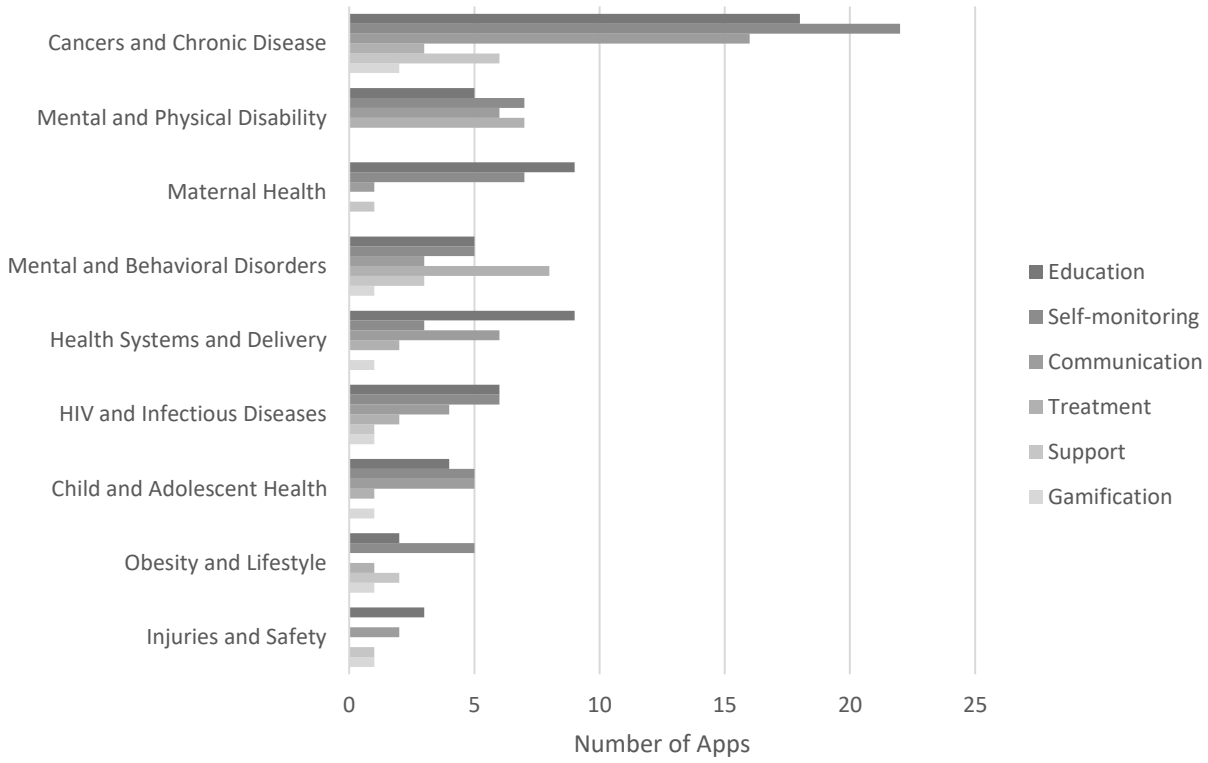


Figure 11. Collaborators of App by Health Issue (n=89)

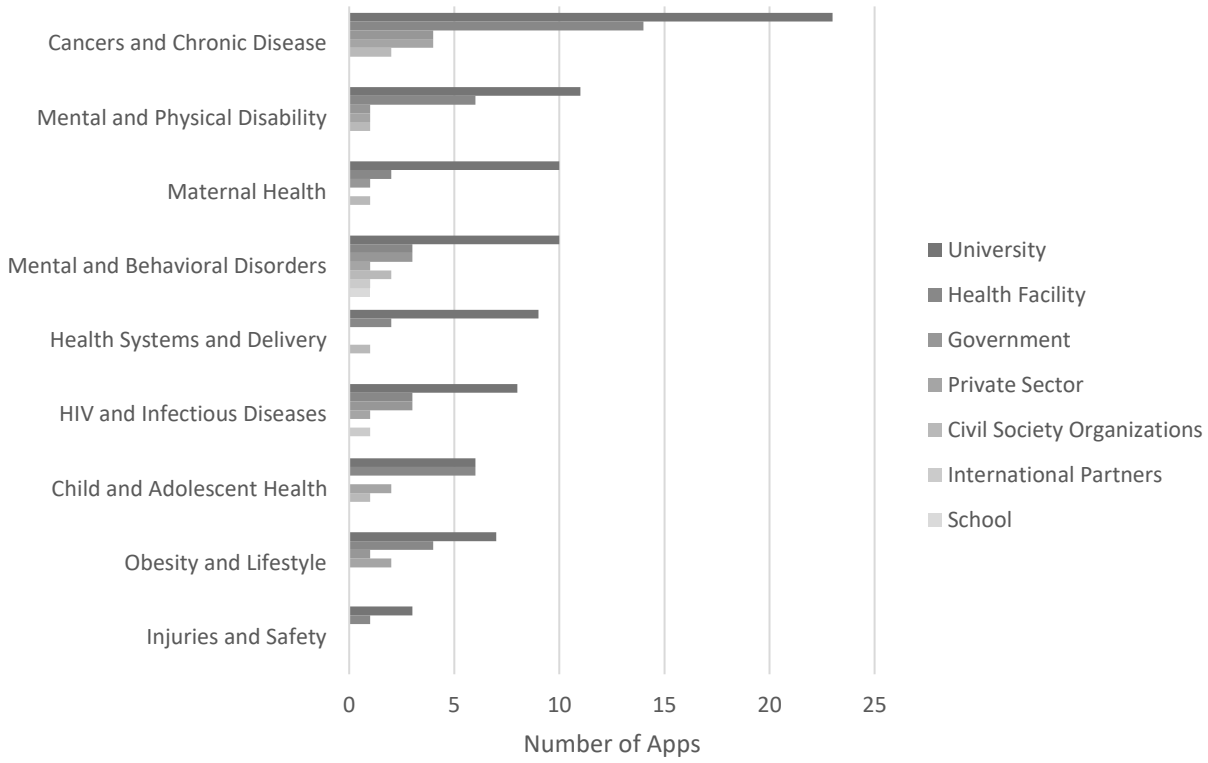


Table 12. Health-Related Smartphone Apps (n=89)		
	N	**%**
Health Issue		
Cancers and Chronic Disease	27	30
Mental and Physical Disability	12	13
Maternal Health	11	12
Mental and Behavioral Disorders	10	11
Health Systems and Delivery	9	10
HIV and Infectious Diseases	8	9
Child and Adolescent Health	8	9
Obesity and Lifestyle	7	8
Injuries and Safety	3	3
Phase		
Prevention	43	48
Treatment	33	37
Management	40	45
Purpose		
Education	56	63
Self-monitoring	55	62
Communication	40	45
Treatment	21	24
Support	14	16
Gamification	8	9
Collaborators		
University	81	91
Health Facility	38	43
Government	12	13
Private Sector	10	11
Civil Society Organizations	7	8
International Partners	2	2
School	1	1

Figure 12. Implementation Considerations by Health Issue (n=89)

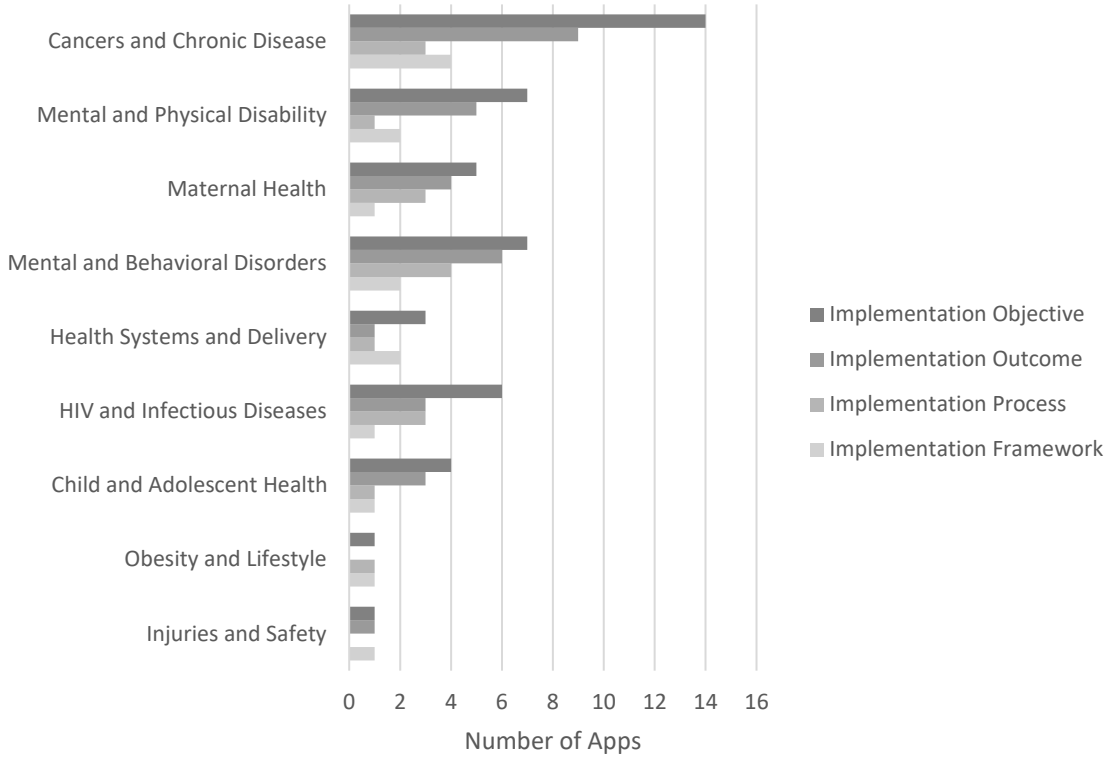


Figure 13. Implementation Considerations by App Function (n=89)

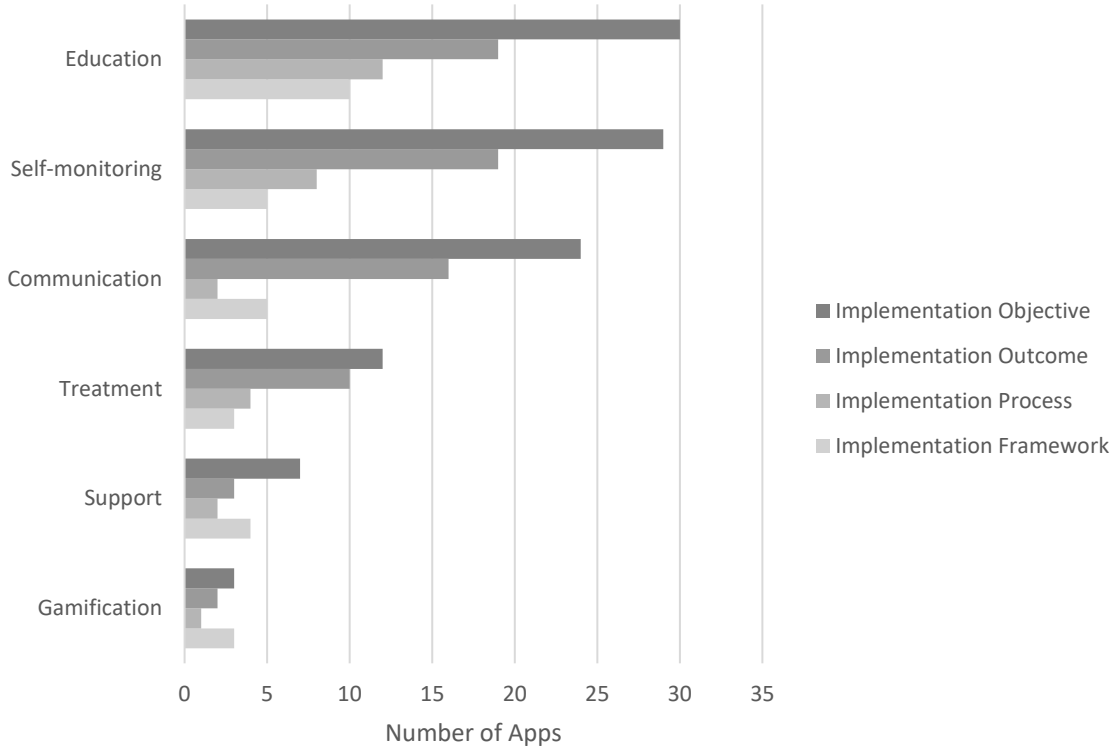


Table 13. Implementation Considerations		
	N	**%**
Implementation (n=89)		
Considered	54	61
Not Considered	35	39
Implementation Considered by Health Issue (n=89)		
Cancers and Chronic Disease	17	63
Mental and Physical Disability	7	58
Mental and Behavioral Disorders	8	80
Maternal Health	7	64
Health Systems and Delivery	3	33
HIV and Infectious Diseases	8	100
Child and Adolescent Health	6	75
Obesity and Lifestyle	2	29
Injuries and Safety	2	67
Implementation Considered by Purpose (n=89)		
Education	37	66
Self-monitoring	34	62
Communication	26	65
Treatment	13	62
Support	8	57
Gamification	5	63
Implementation Considerations (n=54)		
Implementation Objective	45	83
Implementation Outcome	29	54
Implementation Process	15	28
Implementation Framework	13	24
Implementation Outcome (n=29)		
Acceptability	25	86
Feasibility	14	48
Appropriateness	2	7
Adoption	1	3
Fidelity	1	3
Implementation Framework (n=13)		
Technology Acceptance Model (179)	4	31
Mobile App Rating Scale (180)	2	15
System Usability Scale Questionnaire for the Assessment of Mobile Apps (183)	2	15
Accelerated Creation to Sustainment (184)	1	8
Critical Success Factors (185)	1	8
Framework for the Rationale Analysis of Mobile Education Model(186)	1	8
Health Information Technology Usability Evaluation Model (186)	1	8
Users Success Rate (187)	1	8

Table 14. Acceptability Methods and Study Results

App	Definitions	Methods	Participants	Results	Interpretation
Interactive Mobile Application for Contraceptive Choice (188)	Acceptability (tool features, technological acceptability, preferences over the content, and content satisfaction)	In-depth interviews	25 women; 17 providers	App perceived to be a confidential decision aid, but recommended features to improve interaction and need for additional information	Acceptable
Step-by-Step (189)	Acceptability (Acceptance of having psychological problems, acceptance of the concept of psychological help itself, and acceptance of an app-based offer)	Key informant interviews; Focus Group Discussion	128 Syrian refugees	44% (n=16) key informants and 50% of focus groups identified acceptability as a barrier	Unclear
MoomMae (190)	Acceptability (Usability (satisfaction) and usefulness (intention to use))	Survey; In-Depth Interviews	21 women	Users found the app acceptable with a mean satisfaction score of 4.33, intended to continue using the app following the trial period (mean 4.62) and plan to introduce the app to other mothers (mean 4.81)	Acceptable
CKD mHealth app (191)	Satisfaction	In-Depth Interviews; Observation	8 users	Good user satisfaction; Differences between young and elderly when using the app; Issues with understanding some of the content	Acceptable
NeMo (192)	Acceptability (ease of use and learnability; trust	In-depth Interviews; Observation;	32 women; 12 CHWs	Ease of use score of 4.34, learnability	Unclear

	in technology and intent to use, intent to act, perception of band embodiments, perception of app embodiments; Phone-sharing model)	Focus Group Discussions		score of 3.56, trust score of 4.66; intention to use system score of 4.72; 29/32 (91%) would take their baby to health care facility if told was sick; preferences for band and app; Phone-sharing model was not acceptable to CHWs	
9zest Stroke Rehab App (193)	Satisfaction	Survey	20 stroke survivors	60% of participants reported excellent satisfaction and 30% reported very good; all reported that they would use the service in the future	Acceptable
El Buen Consejo Movil (194)	Acceptability of app usage and app (content, technology, interaction with others, privacy, confidentiality), acceptability for patients	In-Depth interviews; Survey	18 participants; 21 clinical staff	Most had smartphones, all reported interest in mobile application therapy due to its convenience, privacy, and affordability. Most found intervention relevant, comprehensible, and culturally appropriate	Unclear
Pain Guard (195)	Acceptance (Satisfaction)	Survey	31 cancer patients	23 (74%) indicated that they were satisfied, 5 (16%) that they were somewhat satisfied	Acceptable
ProFibro (196)	Satisfaction	In-depth interview; Observation	10 patients with fibromyalgia	Participants considered the experience was pleasant, easy to use and understand, content was	Unclear

				relevant, but improvements needed	
OrtogApp (197)	Acceptability (usability and user satisfaction in terms of type and intensity of emotion)	Survey	30 patients in the perioperative stage	73.3% (n=22) of users scores higher than 68 on usability instrument; Satisfaction index was 82.9%; age, education and use were not correlated with satisfaction	Acceptable
vDOT (198)	Acceptability (mobile phone and internet access, ease of use, convenience, privacy, experiences, challenges, concerns)	Survey	22 patients	91% described app as easy to use, all reported being able to record videos without difficulty, 95% uploaded without difficulty, and 91% found text message reminders helpful, 91% felt it was more convenient and preferable, 82% more private. Challenges with patient level barriers (psychosocial factors, mental health), poor connectivity and cellphone related challenges	Acceptable
DIAR (199)	Acceptability (satisfaction, continuation, acceptable, easy to use)	Survey	6 patients	All patients were satisfied with the intervention and agreed service should be continued; 90% found system acceptable and easy to use for diabetes management	Acceptable

Gather m-Health (200)	Acceptability (satisfaction, acceptability, impact on practice, impact on patients)	Survey	44 patients	80% of participants satisfied or very satisfied with all aspects of app, highest satisfaction (95%) from ability to view own data; All providers found it to be acceptable and helpful; very positive impact on patient satisfaction and clinic's diabetes management	Acceptable
Google Fit (201)	Acceptability (>70% of participants rate the smartphone as easy to use defined as rating of 70 or higher in the 10-centimeter VAS)	Survey	40 patients	34 rated the smartphone app as easy to use	Acceptable
OneTouch Reveal (202)	Acceptance (value of functions and features of meter and app and for supporting patients)	Survey	355 health care providers from seven countries including India (n=54) and Algeria (n=50)	High acceptance of meter and app across dimensions	Acceptable
POD Adventures (203)	Acceptability (developmental, cultural, contextual)	Focus Group Discussions; Co-Design Workshops; User-testing sessions	118 adolescents; 8 service providers	Identify features to optimize with regards to media preferences, literacy, gamification, in-game support, human support; group delivery	Unclear
Home-based cardiac tele-rehabilitation (204)	Acceptance (importance of five basic components of cardiac rehabilitation; accept or refuse to participate; main reasons	Survey	150 patients	Only 13% has heard of cardiac rehabilitation; 89 (60%) participants accepted to participate and 61 (40%) refused; Age,	Unclear

	participants accept or refuse)			sex, education, income, distance to hospital, exercise time, location, mobile phone usage associated with participation; determinants of participation included age, income, education, and exercise time; Main reasons for accepting were it makes life safer and more independent, Main reasons for refusal was cumbersome operation	
Mobile phone-based ecological momentary assessment app (205)	Acceptability (preference)	Survey	75 patients	46% (37/70) of participants preferred face-to-face interviews rather than mHealth app	Unclear
TFPA's 'healthy lifestyles' app (178)	Acceptability (of at least one method of effective contraception at 4 months, individual methods)	Survey	472 users	Increase in acceptability of effective contraception between baseline and follow up from 2% to 65%, individual methods from 1% to 49-58%; Some evidence that intervention was greater among women compared to men	Acceptable
CONEMO (206,207)	Acceptance (satisfaction)	App/server data; surveys; In-depth interviews	51 patients; 29 patients	Intervention generally positive with all mean ratings above 3.5; Satisfaction was high	Acceptable

Mo-Buzz (208,209)	Acceptance (receptive to the app)	Survey	513 members of public	93.8% (n=481) said would use the app when it was launched	Acceptable
CycleBeads (210,211)	Satisfaction (recommend to friend)	Survey	185 Kenyan women; 18,591 users	70% reported that they were satisfied with method and app; 60% would definitely recommend and 22% would probably recommend	Acceptable
PINGS (172–174)	Acceptability (receptivity)	Focus Group Discussions	24 stroke survivors and caregivers; 7 clinical and research team	Intervention highly accepted and helped fill gaps in access to care	Acceptable
Tumaini (169–171)	Acceptability (appeal, relevance, value, usability, understandability)	Survey; Focus Group Discussions	30 adolescents; 22 parents	App scored well with participants on all indicators of acceptability; parents receptive to this study and future study	Acceptable
iBeni (212)	Acceptability (ease of use, functionality, design, usefulness, satisfaction)	Survey	11 seniors	91% (10/11) positive ease of use, 100% positive perceived usefulness and attitude towards use of technology, and satisfaction; 82% (9//1) positive intention to use	Acceptable

Table 15. Feasibility Methods & Study Results

App	Definition	Methods	Participants	Results	Interpretation
Interactive Mobile Application for Contraceptive Choice (188)	Feasibility (Ease of use, ability to understand content, clarify and adequacy of information provided, appropriateness of length of time required, and need for clarification or semantics)	In-depth interviews	25 women; 17 providers	App was perceived to be self-explanatory, easy to use and understand, and included necessary content. There was disagreement between women and providers on length of time to complete the tool and counseling. Tool was appealing but concerns over appropriateness for all women and literacy.	Feasible
NeMo (192)	Feasibility of a CHW-lead training and sensitization initiative	Focus Group Discussions	12 CHWs	Importance of sensitizing the community	Unclear
9zest Stroke Rehab App (193)	Feasibility (fidelity checklist including internet connectivity issues and app functionality)	Survey	20 stroke survivors	Issues with internet connectivity and stability of streaming	Feasible
El Buen Consejo Movil (194)	Feasibility (recruitment, adherence and retention, clinical relevance, staff engagement)	In-Depth interviews	18 participants; 21 clinical staff	Perceived app as clinically relevant; Completion rate was 17%; Most common reasons for lack of completion were time, technical difficulties, login issues, security features, misaligned incentives	Unclear

vDOT (198)	Feasibility (Adherence, verifiable fraction)	App/server data, Project documentation	25 patients	Median adherence at 74% and median verifiable fraction was 86%	Feasible
Google Fit (201)	Feasibility (>75% of participants recorded steps for >75% of planned chemotherapy days)	App/server data	40 patients	37 recorded steps for >75% of days	Feasible
POD Adventures (203)	Feasibility of intervention delivery	Focus Group Discussions; Co-Design Workshops; User-testing sessions	118 adolescents; 8 service providers	Identify features to optimize feasibility of delivery with regards to in-game support, human support, managing risk, group delivery	Unclear
Mobile phone-based EMA app (205)	Feasibility (agreement between EMA, urine test, LET assessment	App/Server Data; Project Documentation	50 participants	% agreement between EMA and LET ranged from 66.7 – 85.8%, EMA and urine from 51.2 – 71.5% demonstrating poor agreement	Unclear
CONEMO (206,207)	Feasibility (perceptions of the viability to scale up the nurse-supported intervention within similar health care centers and be implemented by staff nurses; feasibility of intervention for potential RCT-completion of sessions)	In-depth interviews	6 nurses	Lack of time to perform the related activities, activities necessary to be included as part of monthly schedule and paid work hours; barrier was job insecurity; Access to sessions decreased overtime and app worked adequately despite	Unclear

				connectivity issues	
PINGS (172–174)	Feasibility (satisfaction; retention rate)	Project documentation	60 stroke patients	Participants expressed excellent satisfaction ratings; Retention at 9 months was over 90% in both arms; challenges included network connectivity, login to app, low literacy levels, inability to operate device	Feasible
First Aid Guideline (130)	Feasibility (operating system, content conformity, appearance, language)	Survey	120 students	81.67% of students found the application very feasible and 18.33% found it feasible	Feasible
S-Health (213)	Feasibility (usability, easy to understand, comfortable, recall, willing, ease of use, preferences)	Survey	71 participants	Participants in the intervention group agreed on many ratings, but there was no difference from the control group	Unclear
CareCradle (214)	Feasibility (usability, proportion of videos that could be reviewed, number of audio calls completed)	App/Server Data; Project Documentation	24 parents	The average number of videos sent was 23 (47.9%), 80% of audio calls were completed	Unclear
AT-Info-Map (215,216)	Feasibility (usefulness, challenges, benefits, accuracy, completeness)	Focus Group Discussions	72 participants	Participants were enthusiastic about app, but technical issues caused major challenges	Unclear

CHAPTER 3

ADOPTION, FIDELITY, AND ACCEPTABILITY OF A SMARTPHONE APP FOR CHILD INJURY PREVENTION:

LEARNINGS FROM THE PILOT STUDY OF CHILDSAFE IN MALAYSIA

SECTION 1: ABSTRACT

Background

Almost all child deaths due to injuries occur in low- and middle-income countries and can be prevented, but the problem remains largely unaddressed. Apps have become a popular way to deliver health interventions, but there is limited understanding of their implementation, especially in low- and middle-income countries. We developed and piloted a smartphone app for child injury prevention in Malaysia. The aim of this study was to assess the adoption, fidelity, acceptability, and process of user engagement through the app.

Methods

Quantitative methods of data collection and analysis were used consisting of household surveys at baseline and follow-up and self-reported user data through the app's server. Descriptive statistics and exploratory analysis were done, followed by simple logistic regression to test for associations on acceptability and adoption and Wilcoxon Rank Sun

tests to test for differences in fidelity of the app. We also explored the process of user engagement by quantifying user completion and dropout throughout the assessment.

Results

We analyzed the adoption, fidelity, and process of 327 participants. 65 participants were complete users and 183 participants were discontinuing users of the app. Users completed on average 76.52% of the assessment. Several factors were found to be associated with user adoption and fidelity, including the relationship to child, gender, separate rooms in the house, main caregiver during the day, and baseline safety score. Most users dropped out of the app following the living area and bedroom assessment. 158 participants rated the acceptability of the app and most gave the app a rating of four out of five. Factors associated with acceptability of the app included gender, education, accommodation type, and separate rooms in the house.

Conclusion

We found that an app for child injury prevention may be an acceptable option to deliver child injury prevention information, but there were challenges with its adoption, fidelity, and process of the intervention that need to be improved to achieve optimal effectiveness. Mothers were an important user group for an app for child injury prevention for caregivers.

Key Words: Implementation; Smartphone app; Health app; Malaysia; Childhood injuries; Child injury prevention; Digital health; Mobile health; mHealth; Low- and Middle-Income Country

SECTION 2: BACKGROUND

More than 950,000 children and adolescents less than 18 years old die of injury and violence each year (112). Almost all these injuries are unintentional (90%) and occur in LMICs (95%) (112). Most injuries to children happen in the home environment and are preventable. Policy, product and environmental modification, supportive home visits, safety devices, education and behavior change, and community-based approaches have all been proven-effective and are recommended by WHO for child injury prevention (112,117–123). Yet, many of these interventions were developed and adopted in HIC and represent limited experience and evidence from LMICs. Home visits in particular have been successfully tested in a few MIC settings; however, they are also a resource-intensive and invasive intervention that may not be feasible at scale, especially during the current coronavirus pandemic when in-person interventions are restricted (2–4). As a result, the adoption of child injury prevention measures in LMICs is lagging, leaving the problem largely unaddressed.

At the same time, the world has experienced the introduction and near coverage of many digital technologies, including smartphones and the Internet, even in many LMICs. Access to 3G mobile networks reached almost 92% of the population living in developing areas and about 65% of the population in these areas had an active mobile broadband subscription in 2019 (1). Adoption of mobile broadband subscriptions in these settings far exceeded that of fixed broadband, demonstrating the important role of smartphones for this population. This coverage of smartphones and the Internet provides an opportunity to leverage these technologies for health purposes.

Smartphones that have the capability to access the Internet and run apps, which are small software programs designed for a specific purpose. Smartphone apps have become increasingly popular for health and wellness but are targeted towards populations in HICs. In 2017, a report by the IQVIA Institute identified more than 318,000 health apps that have been downloaded more than 3.35 billion times (6). The report also estimated that most countries have an average of between 210,000 – 250,000 health apps available in their app stores (6). More apps are becoming available in languages other than English, suggesting a growing interest in health apps among global populations such as those in LMICs (6). Several health apps have been developed and tested for populations living in LMICs, including a comprehensive smartphone app for child injury prevention in China (132,217)

Further, many digital technologies that are piloted in LMIC settings never reach full implementation and scale, in part because of little consideration for implementation resulting in lost investments in development, research, and opportunities to improve health. Considering implementation during the development of digital health interventions has been recognized as a best practice. A recent scoping review of the scientific literature found that implementation was not considered for many health apps in LMICs and when it was, it usually done as part of small pilot studies to assess the initial feasibility or acceptability of the app. Adoption, fidelity, and the process of user engagement were not typically assessed for most health apps in LMICs. Thus, a comprehensive understanding of the implementation of health apps in LMICs presents a significant gap in the literature, especially as health systems begin to rely on more digital technologies like smartphone apps for remote service delivery.

To respond to this gap, the aim of this study was to assess the adoption, fidelity, acceptability, and process of user engagement of an app for child injury prevention in Malaysia. Child injuries are a common cause of death and disability in this setting (143,146). While one study found that home visits could be effective at reducing child injury hazards in the home, the intervention was not scaled up because of the high human and financial costs (151). In addition, the coronavirus pandemic means that in-person interventions may be limited. Most Malaysians have smartphones and mobile broadband subscriptions and Internet use is high (153). This provided an opportunity to leverage these digital technologies for child injury prevention and we developed an app for child injury prevention that was piloted in Malaysia from November 2017 – February 2018. The app's design, research strategy, and results will be reported elsewhere.

SECTION 3: METHODS

Data on the home safety assessment was self-reported through user data on the app's server, as well as collected by trained data collectors through household surveys at baseline and follow up to assess reliability and changes in home injury hazards. The household survey at baseline was also used to gather information on the participant and household characteristics, knowledge of child injury prevention, and child injury history. The follow up survey was used to assess changes in knowledge of child injury prevention and child injury history, as well as acceptability of the app.

Intervention

ChildSafe is a comprehensive smartphone app for childhood injury prevention in the home consisting of a home safety assessment and tailored tutorial targeted at caregivers of children under five. The app targeted 43 common child injury hazards in four (4) areas of the home: 1) living and sleeping area (n=21), 2) bath area (n=7), 3) kitchen and dining room (n=9), and 4) courtyard, rooftop, and outdoors (n=6). The home safety assessment consists of a series of "Yes/No" response questions on the presence of absence of these common child injury hazards. The results of the home safety assessment are used to inform a tailored tutorial that is delivered through the app with changes that can be done to address the identified hazards. The app operates on an Android platform in both English and Bahasa Malaysia. The home safety assessment was designed and informed by WHO recommendations for child injury prevention, a consultative process with the Ministry of Health in Malaysia, a literature review, and prior studies on child injury prevention in Malaysia and other LMICs (112,116,126,151,152). The design approach and technical specifications for the app will be described elsewhere.

Setting

The app was pilot tested in Petaling district near to the capital city of Kuala Lumpur in Selangor State, Malaysia. Coverage of mobile broadband subscriptions and Internet use are high in this setting. In 2019, the coverage of mobile broadband subscriptions was 126.55 per 100 inhabitants and 84.2% of the population reported using the Internet (153,154). Most smartphones in Malaysia operate on an Android platform (155).

Participants

Participants in the pilot study were caregivers of children under five years old, including parents and guardians. Caregivers were eligible to participate if the household has at least one child under five years old, the caregiver owned an Android smartphone, he or she was able to read English or Malay, the family was not planning to move from the area in the next three months, and he or she was available and willing to give informed consent to participate in the study. There was only one participant per household and the household was the unit of analysis for this study.

Sampling Approach and Size

Caregivers of children under five were recruited through childcare visits at selected health facilities. Health facilities were identified and selected in collaboration with the Ministry of Health in Malaysia and Selangor State Health Department, and the directors were approached for consent and recruitment. Health workers at participating facilities then approached caregivers of children under five during childcare visits and asked whether the caregiver consented to talk to a member of the research team about the study. If the caregiver agreed, they were approached by a data collector after their childcare visit who informed them about the study. Interested caregivers were then assessed for eligibility. Eligible caregivers were then invited to participate. Recruitment for the pilot study took place during a three-month period from October to December 2017.

Data Collection

Data was collected for this analysis using household surveys at baseline and follow up along with user data from the app's server. A household visit was arranged with eligible participants who agreed to participate at a convenient time during the baseline period for two months from November and December 2017. At this baseline household visit, trained data collectors from IKU downloaded the app onto the participants phone, facilitated the user to create a profile, provided a brief orientation to the components of the app, and completed a household survey using a tablet that included an independent home safety assessment. Follow up visits were arranged approximately two months after baseline between January and February 2018 to conduct another independent home safety assessment and gather information on the acceptability of the app. During the two months between baseline and follow up, participating caregivers were able to use the app to access the home safety assessment and tailored tutorial. This self-reported user data was uploaded to the app's server for analysis. Table 16 describes the variables for this analysis, including the questions, responses, and coding.

Calculations

Baseline Safety Score

A baseline safety score was generated for each household. The responses to the home hazard assessment collected by the trained data collector at baseline were assessed for safety. Safe responses were given a score of one (1), while unsafe responses indicating the presence of a home hazard were scored zero (0). The score across all potential home

safety hazards was summed and divided by the total (n=43) to generate a percent. The mean was determined by adding the baseline safety scores of all households and dividing by the total number of households (n=327). Finally, the baseline safety scores were dichotomized for analysis by determining whether the score was above (0) or below (1) average based on the mean.

Baseline Knowledge Score

A baseline knowledge score was also calculated for each household using the knowledge assessment questions delivered during the baseline survey. Correct responses were given a score of one (1) and incorrect responses were given a score of zero (0). The score was then summed and divided by the total number of questions (n=6). A mean was determined by summing the scores and dividing by the total number of households (n=327). The baseline knowledge score was then dichotomized for analysis by identifying scores that were above (0) or below (1) average based on the mean.

Outcomes

Adoption: Complete and Non-Users

Adoption is defined as "the intention, initial decision, or action to try or employ an innovation or evidence-based practice" (161). We categorized user status into three (3) groups using the assessment questions that were completed by participants using the app. Participants were considered non-users when they downloaded the app at baseline but did not use it to access the assessment. Participants who used the app to access the assessment but did not complete it to reach the tutorial (intervention) were considered semi-users. Those who used the app, completed the assessment, and reached the tutorial

(intervention) were considered complete users. We considered users to have adopted the app when they completed the assessment and reached the tutorial (complete users). Users who did not adopt the app were those who did not access the assessment (non-users). Thus, we compared complete and semi-users to assess adoption. Semi-users were considered as in the process of adopting the app and were not assessed for adoption.

Fidelity: Percent Assessment Completion

Fidelity is defined as "the degree to which an intervention was implemented as it was prescribed in the original protocol or as it was intended by the program developers" (161). We used the percent completion of the assessment by users from the data uploaded to the app server to measure fidelity. Percent assessment completion was calculated for complete and semi-users (n=144) based on the number of assessment questions completed by the users of the app. Completion of each assessment question was determined by giving a score of one (1) for a response and zero (0) for no response, indicating drop out. The total number of responses was summed across the assessment and divided by the total to generate a percent (n=43). Non-users did not access the assessment thus were not considered in assessments of fidelity.

Acceptability: Five-Star Rating

Acceptability is defined as "the perception among implementation stakeholders that a given treatment, service, practice, or innovation is agreeable, palatable, or satisfactory" (161). Users were asked to rate their acceptability of the app during the follow-up survey by answering: On a scale from one (1) to five (5), how would you rate your experience with ChildSafe? One (1) was considered not good and five (5) was excellent. A rating

above four (4) is considered to be of acceptable quality for apps (6). Thus, we considered a five-star rating acceptable and any rating below to be not acceptable. Non-users and those who did not complete follow up did not answer the question on acceptability of the app and could not be assessed.

Data Analysis

Data from the app and tablet were downloaded from the server and imported to STATA©, a statistical programming software, for analysis (168). Data from the two sources (household survey and server data) were cleaned and merged to create one dataset that was coded as presented in Table 16. Then, calculations were done to generate the baseline safety score, baseline knowledge score, and the percent assessment completion. Descriptive statistics were used for participant and household characteristics, baseline injury experience, user status, percent assessment completion, and participant acceptability rating of the app. This was followed by exploratory analysis of characteristics and baseline injury experience on adoption and acceptability using Chi^2 tests. Simple logistic regression was done to test for associations on adoption and acceptability of the app. We used Wilcoxon Rank Sum tests to test for differences in fidelity of the app. The process of user engagement through the app was explored by assessing the completion and drop out of users by each room and assessment question. Data cleaning, analysis, and presentation was done by AM.

Ethics

Ethics approval to conduct the study was obtained from the IRB at JHSPH and the Medical Research and Ethics Committee at the Ministry of Health in Malaysia. Informed consent was obtained from participants prior to conducting the household survey.

SECTION 4: RESULTS

Participants and Households

In total, 376 caregivers were approached, met all eligibility criteria, and consented to participate in the study. 361 (96.01%) caregivers downloaded the app and completed the household survey at baseline. 34 (9.42%) participants could not be analyzed because they had missing entries on the baseline household survey. 169 (51.68%) of these participants were lost to follow up in assessing acceptability of the app at the follow up household survey. Thus, we analyzed the adoption, fidelity, and process of 327 (90.58%) participants for this study and acceptability of 158 (48.31%) participants at follow up. A flow diagram is presented in Figure 14.

Characteristics and Baseline Injury Experience

Most participants were the mother of the child (n=223, 68.20%), female (n=232, 70.95%), aged 30 years or more (n=278, 85.02%), and did not have an undergraduate degree (n=177, 54.13%) (Table 17). Most households included five or more members

(n=235, 71.87%) and had only one child under five (n=182, 55.66%). For most households, the child or children were over three years old (n=186, 56.88%). Most houses were double or triple stories (n=246, 73.23%), with four or more rooms (n=249, 76.15%), and were owned by the family (n=246, 75.23%). In most households, the main caregiver during the day was someone other than the mother (n=166, 50.76%) and both parents worked outside the home (n=173, 52.91%). Most households had a below average safety score (n=172, 52.60%), while most participants had an above average knowledge score (n=219, 66.97%). Most had not experienced a child injury in the past three months (n=266, 81.35%).

User Status

Participants were categorized as non-users, semi-users, or complete users (n=327). More than half of participants were non-users (n=183; 55.96%) (Table 18). The remaining 144 (44.04%) participants were users of the app. Only 65 (20% of) participants competed the app and reached the intervention. The rest of participants were semi-users who stopped using the app at some point during the assessment (n=79, 24.16%).

Adoption

Characteristics and Baseline Injury Experience Among Complete and Non-Users

To assess adoption, we examined participant and household characteristics and baseline injury experience among complete and non-users (n=248). We compared complete and

non-users to determine if there was a relationship between characteristics and baseline injury experience and adoption of the app. We found that there was a statistically significant relationship between adoption of the app and the relationship to the child, gender, number of separate rooms in the house, and baseline injury score (Table 19). A greater percentage of mothers were complete users than non-users, while a greater percentage of fathers, grandparents, aunt/uncles, and other caregivers were non-users (p=0.038). Similarly, a greater percentage of females were complete users and males were non-users (p=0.029). A greater percentage of non-users had houses with three or less rooms compared to complete users who had houses with four or more rooms (p=0.017). More complete users also had a below-average safety score at baseline, while more non-users had an above-average safety score (p=0.039). For the other characteristics or baseline injury experience variables, there was no statistically significant difference between complete and non-users.

Characteristics and Baseline Injury Experience on the Odds of Being a Complete User

We tested the association between participant and household characteristics and baseline injury experience on the odds of being a complete user, indicating adoption of the app. The relationship to child, gender, number of separate rooms in the house, main caregiver during the day, and baseline safety score were all found to be statistically significantly associated with the odds of being a complete user (Table 20). Mothers and females were more likely to be complete users. The odds of being a complete user was two times greater among mothers compared to fathers and other caregivers (OR 2.00; 95% CI: 1.03 – 3.90, p: 0.033), and more than two times greater for females compared to males (OR: 2.15; 95% CI: 1.07 – 4.33, p: 0.024). If the main caregiver of the child during the day was

the mother, the odds of being a complete user was almost two times higher (OR 1.77; 95% CI: 1.00 – 3.14, p: 0.050). Participants with a below average safety score at baseline were also almost two times more likely to be a complete user (OR 1.85; 95% CI: 1.03 – 3.34, p: 0.038). Participants with houses with four or more rooms were also more than two times more likely to be complete users (OR 2.61: 95% CI: 1.16 – 5.95, p: 0.013). For the other characteristics and baseline injury experience variables, the odds of being a complete user were not statistically significant.

Fidelity

Percent Assessment Completion Among Users

Based on the inputs from the house description, users were able to access a tailored assessment that examined the presence of 43 potential injury hazards in the home by number and type of room. We calculated the percent completion of the assessment among users of the app (n=144). Overall, users completed the assessment of an average of 76.52% (95% CI: 72.38 – 80.65) of potential injury hazards (Table 21). Users completed the assessment of the most potential injury hazards in the living and bedroom (92.36%, 95% CI: 87.97 – 96.75), but completed the assessment of fewer potential injury hazards in the bathroom and kitchen. The smallest percentage of potential injury hazards were assessed in the courtyard (52.78%, 95% CI: 44.53 – 61.03).

Mean Percent Assessment Completion by Characteristic and Baseline Injury Experience

We assessed the relationship between participant and household characteristics, baseline injury experience, and mean percent assessment completion to assess fidelity of the app. There was a statistically significant difference between the mean percent assessment completion and the main caregiver during the day and baseline safety score (Table 22). Households in which the main caregiver during the day was mothers had a mean percent assessment completion of 80.84% (95% CI: 75.55 – 86.14) compared to 71.54% (95% CI: 65.12 – 77.96) among fathers and other caregivers (p: 0.046). Users with a below average safety score at baseline also progressed further through the assessment and these results were highly significant. Users with a below average safety score at baseline had a mean percent assessment completion of 83.36% (95% CI: 78.34 – 88.38) compared to 68.42% (95% CI: 62.03 – 74.82) among users with an above average safety score at baseline (p: <0.001). There was no statistically significant difference in mean percent assessment completion for other characteristics or baseline injury experience variables.

Acceptability

User Acceptability Rating of the App

We asked users at follow up to rate their experience with the app on a scale from one (1) to five (5), with one being not good and five being excellent (N=158). The mean rate of the app was 3.95 out of five (95% CI: 3.82 – 4.07). The greatest number of participants gave the app a rate of four (4) (n=82, 51.90%), followed by ratings of five (5) (n=37,

23.42%) and three (3) (n=35, 22.15%). Only two (1.27%) participants each rated the app either a one (1) or a two (2) (1.27%) (Table 23).

Characteristics and Baseline Injury Experience on User Acceptability of the App

We assessed participant and household characteristics and baseline injury experience on user's acceptability of the app, defined as giving the app a rating of five out of five (n=158). Gender, education, accommodation type, and separate rooms in the house were all associated with acceptability of the app (Table 24). Females were almost three times more likely to give the app a rating of five out of five compared to males (OR: 2.84; 95% CI: 0.93 – 8.67, p-value: 0.044). Users with an undergraduate degree or more were also 69% less likely to give the app a rating of five (OR: 0.31; 95% CI: 0.14 – 0.68, p-value: 0.003). Users with double or triple story level houses were 62% less likely to rate the app five (OR: 0.38; 95% CI: 0.17 – 0.82, p-value: 0.015) and those with four or more rooms were 65% less likely (OR: 0.35; 95% CI: 0.15 – 0.78, p-value: 0.012). There was no statistically significant difference in the likelihood of giving the app a rating of five for the other characteristics or baseline injury experience.

Process

Assessment Completion and Drop Out Among Users

We explored the completion and drop out of the assessment for each type of room and question among complete and semi-users (n=144). The greatest number of users stopped using the app during the assessment of the living area and bedroom (n=11, 7.64%), while some users stopped using the app while assessing the kitchen (n=4, 2.78%) (Table 25,

Figure 15). No users stopped using the app while assessing the bathroom or courtyard area. The greatest number of users stopped using the app after completing the living area and bedroom assessment and before reaching the first assessment question on the bathroom (n=47, 32.64%). Others stopped using the app after the kitchen assessment and before the first question on the courtyard (n=6. 4.17%). Some users stopped the assessment when they reached the questions that assessed whether there was carpeting beneath the surface on which the child sleeps (n=4, 2.78%) or a smoke detector on every level (n=3, 2.08%). For the rest of the questions, all users completed them or only one user dropped out (n=1, 0.69%).

SECTION 5: DISCUSSION

We examined the relationships between participant and household characteristics, baseline injury experience, and acceptability, adoption, and fidelity of the app, as well as the process of user engagement through the app. We found that the app for child injury prevention was acceptable to most users, but there were challenges with its adoption and fidelity. We also identified several participant and household characteristics that were associated with differences in the acceptability, adoption, and fidelity of the app. Finally, we identified where users were completing or dropping out in the app process.

Our analysis showed that an app for caregivers may be an acceptable way to deliver child injury prevention information in LMICs. Home visits are recommended for this purpose; however, they are often not feasible or scalable in LMICs because of their resource-

intensive and invasive nature, especially during the coronavirus pandemic when in-person interventions are limited (112,122,124,126–129). Most users of ChildSafe gave the app a rating of four or higher out of five, which is high relative to many other health apps (6). To the best of our knowledge, no other studies have assessed the acceptability of an app for child injury prevention targeting caregivers in an LMIC setting. Apps have been found to be an acceptable way to deliver health education and information for other health purposes in LMICs, including family planning (188,211), HIV (170), mental health (203), and smoking (218). More research is needed on the acceptability of apps for child injury prevention and other health purposes, across multiple LMIC settings.

Our results also indicate that a smartphone app for child injury prevention may be an option to deliver child injury prevention information, especially for certain users. We found that participants with below average safety scores and a greater number of rooms in the house (with potentially more risks for child injuries) were more likely to be complete users and progress further through the app, indicating that users with the greatest need were completing more of the app. A randomized controlled trial on a comprehensive app for child injury prevention among caregivers in China found that the intervention resulted in a larger reduction in risky behaviors compared to the control group (132). Another study of an app for child injury prevention, also in China, is still ongoing (133). Future research on the effectiveness of health apps for child injury prevention across multiple LMIC settings as well as consideration of the effectiveness among different users is needed.

We also found that mothers were an important user group for an app for child injury prevention targeting caregivers. Mothers were more likely to be complete users and

progress further through the app when they were the main caregiver of the child. Females (mostly mothers) also found the app to be more acceptable. Another study on an app for child injury prevention specifically targeted mothers for dissemination, but the results have not yet been reported (133). However, mothers have been successfully targeted for apps for other child health issues (192,219). Thus, mothers may be an important group to target for dissemination and early adoption of child health apps and represent a strategic entry point for diffusion to other caregivers (110). Further consideration should be given whether and how an app can be used to foster engagement for different users around child health issues and how the content in the app can be adapted to different user types, including fathers, older siblings, and children. Other studies of health apps have used novel built-in algorithms or machine learning to enable this adaptability (170,171,203).

Our findings emphasize the importance of user experience when developing, testing, and implementing health-related smartphone apps. For example, we found that users progressed further in the assessment of certain rooms, indicating user's safety concerns for specific areas of the home. We also found that many users dropped out while completing the assessment of the living area and bedroom that had the greatest number of assessment questions, suggesting potential user fatigue. We also found that most users dropped out of the assessment during the transition from one room to the next. These transitions may present design aspects that facilitate user dropout. Some users did not answer certain assessment questions, perhaps because of challenges with understanding or relevance. Users with double or triple story houses or with four or more rooms also found the app to be less acceptable, likely because of the higher burden of completing the app. Consideration of the user experience is an underlying pillar of user-centered design

approaches that have been employed in the development of several health-related apps in LMICs (177,189,191,203,220,221). However, our work also showed the importance of the user experience beyond the design phase and the need for ongoing, iterative development through its implementation.

Finally, this study revealed the complexity of assessing the implementation of health apps. We demonstrate that there are multiple outcomes that can be used to assess the implementation of health apps (acceptability, adoption, fidelity, process). As such, our analysis moves beyond an aggregated assessment of user acceptability to provide a better understanding of the user experience among users with different characteristics and using multiple implementation outcomes (161). These implementation outcomes have not been used commonly in assessments of health apps and we demonstrated the operationalization of these outcomes for an app context. However, there is need for further exploration of implementation within an app context and consensus on the operationalization of implementation outcomes for this purpose. This finding echoes calls by other public health researchers to move beyond acceptability, feasibility, and adoption when assessing the implementation of digital health interventions such as health apps (222,223).

Limitations

Our study has several limitations. First, we experienced many participants who were lost to follow up in assessing the acceptability of the app. This loss to follow up may have meant that the acceptability findings may represent those users who felt that the app was

more acceptable and thus remained in the study or those who had more extreme reactions towards the app and were more motivated to share. There were also many users who were considered semi-users of the app. These semi-users may have had different characteristics and injury experiences than both non-users or complete users. In considering adoption and fidelity of the app, it was unclear how to handle these semi-users. Since adoption implies a binary decision to adopt or not adopt, these semi-users were not included in assessments of adoption. On the other hand, since fidelity assesses completion of the app, these semi-users were in the process of completing the app and thus were included in these assessments. This means that while the overall enrollment in the study was more than 300, many assessments were based on a smaller number of participants. Due to this smaller sample size, our study may not have been powered to correctly identify factors that were associated with acceptability, adoption, and fidelity of the app. In addition, the concentration of participants and households with certain characteristics and only a few among other categories meant that meaningful differences could not always be identified without reducing the number of categories. This reduction may have masked important differences that existed within sub-categories and remains an area for ongoing consideration.

Conclusion

A smartphone app may be an acceptable option to deliver child injury prevention information, but we experienced challenges with the adoption, fidelity, and process of the intervention that need to be improved to achieve optimal effectiveness. Mothers were an important user group for the app that can be targeted for dissemination and early adoption to facilitate diffusion to other caregivers.

Table 16. Variables

Variable	Question	Responses	Coding
Participant Characteristics			
Relationship to Child	In thinking about the child in your household that is between 0 through 59 months of age, what is your relationship to that child?	Father Mother Grandparent Aunt/Uncle Other	Father, Grandparent, Aunt/Uncle, Other: 0 Mother: 1
Gender	Gender of respondent	Male Female	Male: 0 Female: 1
Age	Age of respondent	Blank Number	29 years or less: 0 30 years or more: 1
Education	What is the highest academic achievement you have completed?	No education/Did not complete primary school UPSR PMR SPM STPM/Matriculation/A-level/Diploma Undergraduate degree or more	STPM or less: 0 Undergraduate degree or more: 1
Household Characteristics			
Household Size	In which categories do your household members fall?	Adults (Above 18 years old) Children (Under 5 years of age) Children (Between 5 and 10 years of age) Children (Between 11 and 18 years of age)	4 members or less: 0 5 members or more: 1
Number of Children Under Five	Children (Under 5 years of age)	Children (Under 5 years of age)	Single Child Under Five: 0 Multiple Children Under Five: 1
Age of Children Under Five	Which age groups do the children in the household fall under?	Children 0-12 months of age Children 13-24 months of age Children 25-36 months of age Children 37-48 months of age Children 49-59 months of age	3 or fewer years old: 0 Between 3 and 5 years old: 1
Accommodation Type	Type of accommodation:	Single-story terrace/bungalow Double-story terrace/bungalow/townhouse Three-story terrace/bungalow/townhouse Flat/Apartment/Condominium	Apartment/Condominium/Single Level House: 0 Double/Triple Level House: 1

Separate Rooms in House	Number of separate rooms in the house	Blank Number	3 rooms or less: 0 4 rooms or more: 1
House Ownership	House ownership	Own House Rented	Own House: 0 Rented: 1
Main Caregiver During Day	During the day, who is the main caregiver of your child at home?	Father Mother Grandparents Older Siblings Aunt/Uncle Friends Other	Father, Grandparents, Older Siblings, Aunt/Uncle, Friends, Other: 0 Mother: 1
Dual Occupation Family	What is the occupation of the father/mother?	Unemployed/Stays at Home Works Outside of the Home	One or neither parent work outside the home: 0 Both parents work outside the home: 1
Baseline Injury Experience			
Baseline Safety Score	1-44 Assessment Questions Assessed by the Data Collector During the Survey Conducted at Baseline	Refer to Calculations section below	Above Average: 0 Below Average: 1
Baseline Knowledge Score	1-6 Knowledge Assessment Questions	Refer to Calculations section below	Above Average: 0 Below Average: 1
Baseline Injuries	In thinking about your child that is between 0 through 59 months of age, has your child(ren) had an unintentional injury in the past 3 months?	No Yes	No previous Injury: 0 Previous Injury: 1
Outcomes			
Adoption	1-44 Assessment Questions Assessed by the Participant Using the App	Refer to Calculations section below	Non-User: 0 Complete User: 1 Semi-User
Fidelity	1-44 Assessment Questions Assessed by the	Refer to Calculations section below	0 – 100%

	Participant Using the App		
Acceptability	On a scale from 1 (not good) to 5 (excellent), how would you rate your experience with ChildSafe?	Blank Number	1-4 rate: 0 5 rate: 1

Figure 14. Flow Diagram

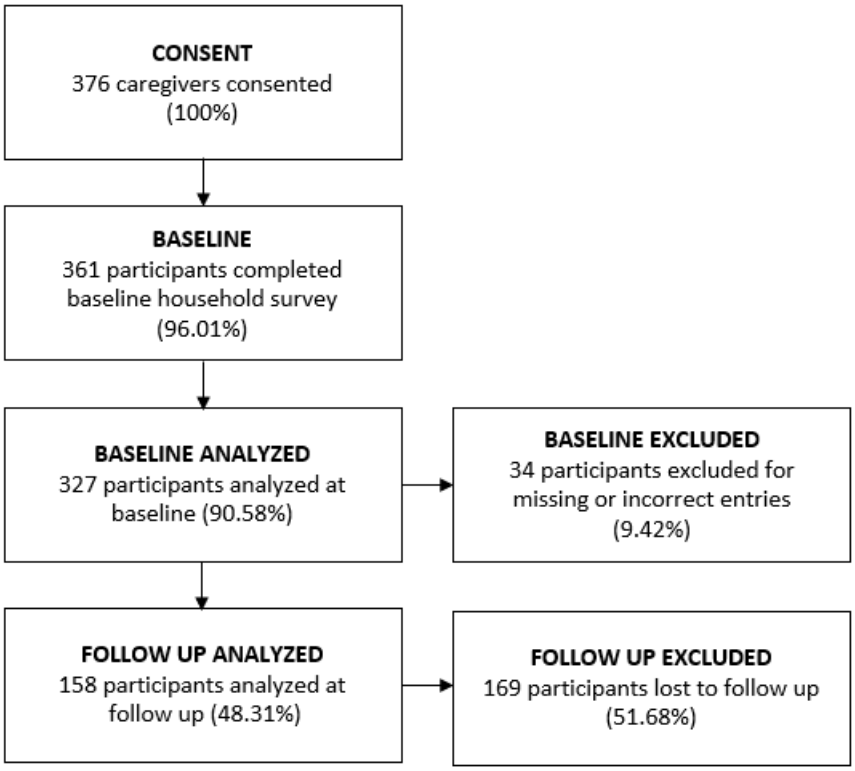


Table 17. Participant and Household Characteristics (n=327)

Variable	N	%
Participant Characteristics		
Relationship to Child		
Mother	223	68.20
Father, Grandparent, Aunt/Uncle, Other	104	31.80
Gender		
Female	232	70.95
Male	95	29.05
Age		
29 years or less	49	14.98
30 years or more	278	85.02
Education		
STPM/Matriculation/A-level/Diploma or less	177	54.13
Undergraduate degree or more	150	45.87
Household Characteristics		
Household Size		
4 members or less	92	28.13
5 members or more	235	71.87
Number of Children Under Five		
Single Child Under Five	182	55.66
Multiple Children Under Five	145	44.34
Age of Children Under Five		
3 or fewer years old	141	43.12
Between 3 and 5 years old	186	56.88
Accommodation Type		
Apartment/Condominium/Single Level House	81	24.77
Double/Triple Level House	246	75.23
Separate Rooms in House		
3 rooms or less	78	23.85
4 rooms or more	249	76.15
House Ownership		
Own House	246	75.23
Rented	81	24.77
Main Caregiver During Day		
Father, Grandparents, Older Siblings, Aunt/Uncle, Friends, Other	166	50.76
Mother	161	49.24
Dual Occupation Family		
One or neither parent work outside the home	154	47.09
Both parents work outside the home	173	52.91
Baseline Injury Experience		
Baseline Safety Score		
Above Average	155	47.40
Below Average	172	52.60
Baseline Knowledge Score		
Above Average	219	66.97
Below Average	108	33.03
Baseline Injuries		
No Previous Injury	266	81.35
Previous Injury	61	18.65

Table 18. User Status of Participants (n=327)

Variable	N	%
User Status	327	100
Complete User	65	19.88
Semi-User	79	24.16
Non-User	183	55.96

Table 19. Characteristics and Baseline Injury Experience by Complete and Non-Users (n=248)

	Complete User (n=65)		Non-User (n=183)		
Variable	**N**	**%**	**N**	**%**	**P>Chi²***
Participant Characteristics					
Relationship to Child					
Father, Grandparent, Aunt/Uncle, Other	14	21.54	65	35.52	
Mother	51	78.46	118	64.48	**0.038**
Gender					
Male	12	18.46	60	32.79	
Female	53	81.54	123	67.21	**0.029**
Age					
29 years or less	13	20.00	23	12.57	
30 years or more	160	87.43	52	80.00	0.144
Education					
STPM/Matriculation/A-level/Diploma or less	31	47.69	105	57.38	
Undergraduate degree or more	34	52.31	78	42.62	0.178
Household Characteristics					
Household Size					
4 members or less	15	23.08	54	29.51	
5 members or more	50	76.92	129	70.49	0.320
Number of Children Under Five					
Single Child Under Five	39	60.00	101	55.19	
Multiple Children Under Five	26	40.00	82	44.81	0.502
Age of Children Under Five					
3 or fewer years old	28	43.08	72	39.34	
Between 3 and 5 years old	37	56.92	111	60.66	0.598
Accommodation Type					
Apartment/Condominium/Single Level House	12	18.46	48	26.23	
Double/Triple Level House	53	81.54	135	73.77	0.209
Separate Rooms in House					
3 rooms or less	8	12.31	49	26.78	
4 rooms or more	57	87.69	134	73.22	**0.017**
House Ownership					
Own House	54	83.08	135	73.77	
Rented	11	16.92	48	26.23	0.130
Main Caregiver During Day					
Father, Grandparents, Older Siblings, Aunt/Uncle, Friends, Other	26	40.00	99	54.10	0.051
Mother	39	60.00	84	45.90	
Dual Occupation Family					
One or neither parent work outside the home	103	56.28	29	44.62	
Both parents work outside the home	36	55.38	80	43.72	0.105
Baseline Injury Experience					
Baseline Safety Score					
Above Average	22	33.85	89	48.63	
Below Average	43	66.15	94	51.37	**0.039**
Baseline Knowledge Score					

Above Average	43	66.15	127	69.40	
Below Average	22	33.85	56	30.60	0.628
Baseline Injuries					
No Previous Injury	55	84.62	153	83.61	
Previous Injury	10	15.38	30	16.39	0.849

*__Bold__ indicates statistical significance

Table 20. Simple Logistic Regression on the Odds of Being a Complete User (n=248)

Variable	Crude OR	Lower 95% CI	Higher 95% CI	P>Chi^2*
Participant Characteristics				
Relationship to Child				
Mother	2.00	1.03	3.90	**0.033**
Father, Grandparent, Aunt/Uncle, Other	REF			
Gender				
Female	2.15	1.07	4.33	**0.024**
Male	REF			
Age				
30 years or more	0.58	0.27	1.22	0.155
29 years or less	REF			
Education				
Undergraduate degree or more	1.48	0.84	2.61	0.179
STPM/Matriculation/A-level/Diploma or less	REF			
Household Characteristics				
Household Size				
5 members or more	1.40	0.72	2.70	0.314
4 members or less	REF			
Number of Children Under Five				
Multiple Children Under Five	0.82	0.46	1.46	0.501
Single Child Under Five	REF			
Age of Children Under Five				
Between 3 and 5 years old	0.86	0.48	1.52	0.599
3 or fewer years old	REF			
Accommodation Type				
Double/Triple Level House	1.57	0.77	3.19	0.200
Apartment/Condominium/Single Level House	REF			
Separate Rooms in House				
4 rooms or more	2.61	1.16	5.85	**0.013**
3 rooms or less	REF			
House Ownership				
Rented	0.57	0.28	1.19	0.120
Own House	REF			
Main Caregiver During Day				
Mother	1.77	1.00	3.14	**0.050**
Father, Grandparents, Older Siblings, Aunt/Uncle, Friends, Other	REF			
Dual Occupation Family				
Both parents work outside the home	0.63	0.35	1.11	0.106
One or neither parent work outside the home	REF			
Baseline Injury Experience				
Baseline Safety Score				
Below Average Score	1.85	1.03	3.34	**0.038**
Above Average Score	REF			
Baseline Knowledge Score				
Below Average Score	1.16	0.64	2.12	0.630
Above Average Score	REF			
Baseline Injuries				

Previous Injury	0.93	0.43	2.02	0.849
No Previous Injury	REF			

*__Bold__ indicates statistical significance

Table 21. Percent Assessment Completion Among Users (N=144)		
Variable	**Mean**	**95% CI**
Percent Assessment Completion, Overall	76.52	72.38 – 80.65
Percent Assessment Completion, By Room		
Living Area and Bedroom	92.36	87.97 – 96.75
Bathroom	59.72	51.62 – 67.83
Kitchen	56.94	48.76 – 65.13
Courtyard	52.78	44.53 – 61.03

Table 22. Mean Percent Assessment Completion by Characteristic and Baseline Injury Experience (n=144)

Variable	Mean	Lower 95% CI	Higher 95% CI	p>z*
Participant Characteristics				
Relationship to Child				
Mother	77.68	72.84	82.53	0.259
Father, Grandparent, Aunt/Uncle, Other	73.37	65.14	81.59	
Gender				
Female	77.88	73.15	82.61	0.179
Male	72.27	63.49	81.06	
Age				
29 years or less	81.29	71.96	90.63	
30 years or more	75.46	70.81	80.11	0.395
Education				
STPM/Matriculation/A-level/Diploma or less	77.59	71.80	83.38	
Undergraduate degree or more	75.44	69.40	81.48	0.882
Household Characteristics				
Household Size				
4 members or less	73.62	65.30	81.95	
5 members or more	77.55	72.72	82.38	0.449
Number of Children Under Five				
Single Child Under Five	79.35	74.08	84.61	
Multiple Children Under Five	72.87	66.21	79.53	0.137
Age of Children Under Five				
3 or fewer years old	72.30	65.96	78.64	
Between 3 and 5 years old	80.39	75.02	85.77	0.060
Accommodation Type				
Apartment/Condominium/Single Level House	79.61	71.93	87.30	
Double/Triple Level House	75.59	70.69	80.50	0.775
Separate Rooms in House				
3 rooms or less	76.96	68.55	85.37	
4 rooms or more	76.40	71.62	81.19	0.5635
House Ownership				
Own House	77.46	72.72	82.20	
Rented	73.35	64.51	82.19	0.234
Main Caregiver During Day				
Mother	80.84	75.55	86.14	
Father, Grandparents, Older Siblings, Aunt/Uncle, Friends, Other	71.54	65.12	77.96	**0.046**
Dual Occupation Family				
One or neither parent work outside the home	80.01	74.57	85.44	
Both parents work outside the home	72.82	66.53	79.12	0.149
Baseline Injury Experience				
Baseline Safety Score				
Above Average	68.42	62.03	74.82	
Below Average	83.36	78.34	88.38	**<0.001**
Baseline Knowledge Score				
Above Average	77.05	70.50	83.60	

Below Average	76.21	70.81	81.61	0.959
Baseline Injuries				
No Previous Injury	78.20	73.59	82.80	0.136
Previous Injury	70.38	60.85	79.91	

***Bold** indicates statistical significance

Table 23. Participant Acceptability Rating of the App (n=158)			
Variable	**Mean**	**Lower 95% CI**	**Higher 95% CI**
Mean Rate	3.95	3.83	4.07
Rating		**N**	**%**
5 Rate		37	23.42
4 Rate		82	51.90
3 Rate		35	22.15
2 Rate		2	1.27
1 Rate		2	1.27

Table 24. Simple Logistic Regression on the Odds of Giving the App a Five Star Rating (n=158)

Variable	Crude OR	Lower 95% CI	Higher 95% CI	P>Chi^2*
Participant Characteristics				
Relationship to Child				
Mother	2.30	0.83	6.42	0.089
Father, Grandparent, Aunt/Uncle, Other	REF			
Gender				
Female	2.84	0.93	8.67	**0.044**
Male	REF			
Age				
30 years or more	0.72	0.29	1.80	0.486
29 years or less	REF			
Education				
Undergraduate degree or more	0.31	0.14	0.68	**0.003**
STPM/Matriculation/A-level/Diploma or less	REF			
Household Characteristics				
Household Size				
5 members or more	0.88	0.40	1.95	0.757
4 members or less	REF			
Number of Children Under Five				
Multiple Children Under Five	0.77	0.36	1.62	0.482
Single Child Under Five	REF			
Age of Children Under Five				
Between 3 and 5 years old	1.62	0.75	3.53	0.214
3 or fewer years old	REF			
Accommodation Type				
Double/Triple Level House	0.38	0.17	0.82	**0.015**
Apartment/Condominium/Single Level House	REF			
Separate Rooms in House				
4 rooms or more	0.35	0.15	0.78	**0.012**
3 rooms or less	REF			
House Ownership				
Rented	1.75	0.78	3.96	0.183
Own House	REF			
Main Caregiver During Day				
Mother	1.59	0.74	3.41	0.228
Father, Grandparents, Older Siblings, Aunt/Uncle, Friends, Other	REF			
Dual Occupation Family				
Both parents work outside the home	0.59	0.27	1.26	0.168
One or neither parent work outside the home	REF			
Baseline Injury Experience				
Baseline Safety Score				
Below Average Score	1.18	0.56	2.50	0.661
Above Average Score	REF			
Baseline Knowledge Score				
Below Average Score	2.09	0.98	4.45	0.058
Above Average Score	REF			

Baseline Injuries				
Previous Injury	1.17	0.49	2.80	0.718
No Previous Injury	REF			

***Bold** indicates statistical significance

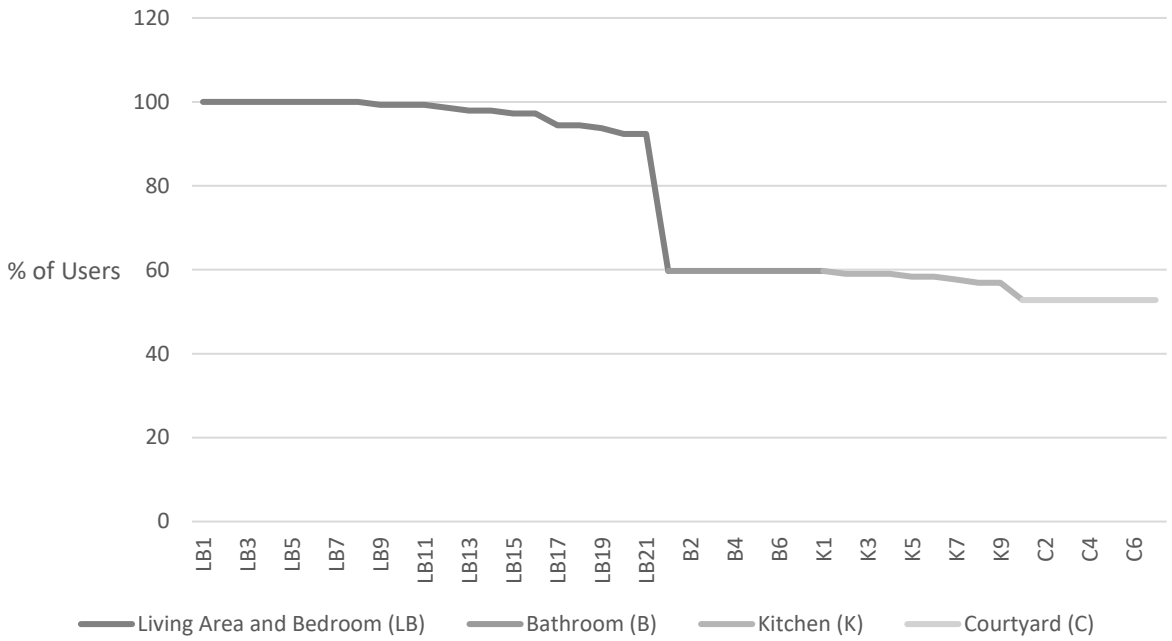
Table 25. Assessment Completion and Drop Out (n=144)

			Complete		Incomplete		Drop Out	
Room	**Question**	**Variable**	**N**	**%**	**N**	**%**	**N**	**%**
Type of Room								
Living and Bed	1	Is there a glass tabletop?	144	100.00	0	0.00		
	21	Does your home have a carbon monoxide detector?	133	92.36	11	7.64	11	7.64
Bath	1	Is there a lock on the inside of the bathroom door within reach of the child?	86	59.72	58	40.28		
	7	Is there a lock on the toilet to keep the seat closed?	86	59.72	58	40.28	0	0.00
Kitchen	1	Is there a stove within reach of the child?	86	59.72	58	40.28		
	9	Are long clothes placed over table where candles, cooking appliances, utensils, or hot foods are placed?	82	56.94	62	43.06	4	2.78
Courtyard	1	Are any structures with sharp/hard protruding components?	76	52.78	68	47.22		
	7	If there are animals in the home, are they kept in a cage that a child cannot open?	76	52.78	68	47.22	0	0.00
Assessment Question								
Living and Bed	1	Is there a glass tabletop?	144	100.00	0	0.00		
	2	Are there any breakable objects within reach of the child particularly on dressing tables, such as perfumes, etc.?	144	100.00	0	0.00	0	0.00
	3	Are any medicines within reach of the child?	144	100.00	0	0.00	0	0.00
	4	Are there cosmetics (lipsticks, etc.) that a child might ingest within reach of the child?	144	100.00	0	0.00	0	0.00
	5	Is there an iron, pedestal fan, or other hot or sharp appliance within reach of the child?	144	100.00	0	0.00	0	0.00
	6	Are there any small choking hazards such as marbles, plastic bags, hard candy, small toy parts, within reach of the child	144	100.00	0	0.00	0	0.00
	7	Are any of the child's toys too small (choking hazard), pointed, or sharp	144	100.00	0	0.00	0	0.00
	8	Are any houseplants within reach of the child	144	100.00	0	0.00	0	0.00
	9	Does the child have access to a walker?	143	99.31	1	0.69	1	0.69

	10	Do you have any cabinets (TV cabinets or entertainment centers), shelves, or chests of drawers that are unanchored or on a trolley with wheels without locks?	143	99.31	1	0.69	0	0.00
	11	Are there any loose mats/rugs?	143	99.31	1	0.69	0	0.00
	12	Are there any electrical outlets into which more than two items are plugged?	142	98.61	2	1.39	1	0.69
	13	Are there any frayed or loose cords within reach of the child?	141	97.92	3	2.08	1	0.69
	14	Are there any electrical cords in the walking area?	141	97.92	3	2.08	0	0.00
	15	Does the bed/furniture or wall have any sharp corners within reach of the child?	140	97.22	4	2.78	1	0.69
	16	Does anyone sleep with the child at night?	140	97.22	4	2.78	0	0.00
	17	Is there carpeting beneath the surface on which the child sleeps?	136	94.44	8	5.56	4	2.78
	18	Is there a door with locks on the rooms?	136	94.44	8	5.56	0	0.00
	19	Do you have curtains and/or blinds?	134	93.75	9	6.25	1	0.69
	20	Does your home have a smoke detector on every level?	133	92.36	11	7.64	3	2.08
	21	Does your home have a carbon monoxide detector?	133	92.36	11	7.64	0	0.00
Bath	1	Is there a lock on the inside of the bathroom door within reach of the child?	86	59.72	58	40.28	47	32.64
	2	Are uncovered or open containers of water present?	86	59.72	58	40.28	0	0.00
	3	Is there an uncovered large vat/pool of water within the bathroom?	86	59.72	58	40.28	0	0.00
	4	Are shampoos/soaps/acids within reach of the child?	86	59.72	58	40.28	0	0.00
	5	Is there a water heater (geyser)/pump/machine within reach of the child?	86	59.72	58	40.28	0	0.00
	6	Is there any anti-slip mat on the floor?	86	59.72	58	40.28	0	0.00
	7	Is there a lock on the toilet to keep the seat closed?	86	59.72	58	40.28	0	0.00
Kitchen	1	Is there a stove within reach of the child?	86	59.72	58	40.28	0	0.00
	2	Are matches/lighter/cooking fluids (i.e. paraffin or kerosene) within reach of the child?	85	59.03	59	40.97	1	0.69
	3	Are cleaning supplies/chemicals within reach of the child?	85	59.03	59	40.97	0	0.00

	4	Are there any knives or sharp objects within reach of the child?	85	59.03	59	40.97	0	0.00
	5	Is there any open fire/fireplace within reach of the child?	84	58.33	60	41.67	1	0.69
	6	Is there any fire extinguisher or bag of sand kept in the kitchen?	84	58.33	60	41.67	0	0.00
	7	Are cupboards with cooking fluids, cleaning supplies, knives, and matches secured and locked?	83	57.64	61	42.36	1	0.69
	8	Are lighter/cooking fluids, cleaning supplies/chemicals kept in non-original or non-labeled containers?	82	56.94	62	43.06	1	0.69
	9	Are long clothes placed over table where candles, cooking appliances, utensils, or hot foods are placed?	82	56.94	62	43.06	0	0.00
Courtyard	1	Are any structures with sharp/hard protruding components?	76	52.78	68	47.22	6	4.17
	2	Are open buckets of water present in the courtyard?	76	52.78	68	48.22	0	0.00
	3	If a rooftop is accessible to the child or people, are the side railings/walls high enough to block a child from falling?	76	52.78	68	47.22	0	0.00
	4	Is the child supervised when he plays in the street/road?	76	52.78	68	47.22	0	0.00
	5	Is there any fence/guardrail/barrier against any water (lake/pond/river) within child's access?	76	52.78	68	47.22	0	0.00
	6	Is there a water heater (geyser)/pump/machine within reach of the child?	76	52.78	68	47.22	0	0.00
	7	If there are animals in the home, are they kept in a cage that a child cannot open?	76	52.78	68	47.22	0	0.00

Figure 15. Percent of Users Completing the Assessment by Type of Room & Question (n=144)



CHAPTER 4

FACILITATORS AND BARRIERS TO USE AND IMPLEMENTATION OF A SMARTPHONE APP FOR CHILD INJURY PREVENTION IN MALAYSIA: A QUALITATIVE ANALYSIS

SECTION 1: ABSTRACT

Background

Almost all deaths due to injuries among children occur in low- and middle-income countries, where the issue remains largely unaddressed. Apps for health purposes have become increasingly popular, but there is limited understanding of their implementation, especially in these settings. We developed a smartphone app for child injury prevention that was pilot tested in Malaysia. The aim of this study was to understand caregivers' perceptions of facilitators and barriers to using the app and implementing the apps' recommendations.

Methods

This study employed a qualitative approach to data collection using in-depth interviews and a deductive approach to analysis based on the Consolidated Framework for Implementation Research. Respondents were caregivers of children under five involved in the pilot study of ChildSafe with different user status (continuing user or discontinuing

user). Themes were structured around shared perceptions or experiences that users described as facilitators or barriers to use and implementation. These facilitators and barriers were assessed and presented across user groups.

Results

We conducted 26 caregiver interviews with 13 continuing users and 13 discontinuing users of the app. We identified a total of 20 facilitators and 15 barriers related to the intervention, the individual user, and the process of using the app and implementing the recommended changes for child injury prevention. We identified both facilitators and barriers for most constructs in the framework. The most common facilitators identified were related to the complexity, relative advantage, execution, reflection and evaluation constructs of the model. On the other hand, the most common barriers were related to the stage of change, complexity, engagement, and execution constructs. In general, the most common facilitators and barriers were consistent across user types; however, some notable differences related to self-efficacy, cost, role within household, planning, and engagement were identified.

Conclusion

This study revealed several facilitators and barriers to implementation of a smartphone app for child injury prevention in Malaysia. This was a novel application of the Consolidated Framework for Implementation Research that identified several factors and complexities for consideration when implementing health apps targeting general population users in low- and middle-income countries.

Key Words: Implementation; Smartphone app; Health app; Malaysia; Childhood injuries; Child injury prevention; Digital health; Mobile health; mHealth; Low- and Middle-Income Country

SECTION 2: BACKGROUND

Globally, an estimated 950,000 children and adolescents die of injury and violence each year, and more than 95% of these deaths occur in LMICs and 90% are unintentional (112). Most childhood injuries occur in the home environment and can be prevented (112). Policy, product and environmental modification, supportive home visits, safety devices, education and behavior change, and community-based approaches have all been shown to be effective and are recommended by the WHO for child injury prevention (112,117–123,125). However, these interventions have primarily been tested and adopted in HICs and there remains limited evidence from lower income settings (112). Home visits in particular have been shown to be effective in some middle-income settings, but they are a resource-intensive option and may not be feasible or scalable in all settings, especially in the midst of the Coronavirus pandemic when in-person interventions are limited (1–4,119,124,126–129). Thus, the adoption of child injury prevention measures in LMICs remains a significant gap, leaving the problem in these settings largely unaddressed.

At the same time, the past two decades have experienced the emergence of many digital technologies around the world, including in LMICs. Coverage of 3G mobile networks in developing areas reached almost 92% in 2019 (1). Approximately 65% of the population living in developing areas had an active mobile broadband subscription, far exceeding those with a fixed subscription and demonstrating the important role of mobile phones these settings. This expansion of smartphones and high-speed mobile networks in

developing areas has presented new opportunities to leverage digital technologies to improve health in LMICs.

Many mobile phones are now smartphones that have the capability to access the Internet run apps, which are small software programs designed for a specific purpose. Smartphone apps have become increasingly popular for health and wellness but targeted in HICs. According to a recent report by IQVIA, there were more than 318,000 health apps available in 2017 that have been downloaded more than 3.35 billion times (6). On average, countries have between 210,000 and 250,000 health apps in their apps stores and more are becoming available in languages other than English, representing a growing interest in health apps among global populations, including those in LMICs (6). Several health apps have been developed and tested in LMICs for multiple health issues and functions, including a comprehensive smartphone app for child injury prevention in China (132,217).

Further, despite the promise and growing popularity of smartphone apps as a means to deliver health interventions in LMICs, there has been little focus on their use and implementation (105). Many digital health technologies including smartphone apps are piloted but never fully implemented or scaled, in part because of limited consideration for implementation from the onset of the project (104). Developing novel digital health interventions with these considerations in mind has been recognized as a best practice for digital health development (104,108). However, a scoping review of health apps in LMICs revealed that implementation was not considered for more than one-third of apps (217). Most studies that did consider implementation were small pilot studies that assessed the feasibility or acceptability of the app (217). Very few studies assessed the

broader implementation considerations or applied a recognized implementation framework (217). A more comprehensive understanding of the implementation of health apps in these settings will be important as health systems transition to greater reliance on digital technologies like smartphone apps for service delivery.

As in many other LMICs, childhood injuries are a common cause of death and disability in Malaysia (114,143,146). While a recent study found that home visits were effective at reducing hazards for childhood injury in the home, they were not scaled up because of the high human and financial costs (151). Further, in-person interventions may be limited because of the coronavirus pandemic. At the same time, adoption of mobile broadband subscriptions and Internet use are high in this setting (153). This presents an opportunity to leverage these digital technologies to address the burden of childhood injuries in Malaysia. To this end, we developed a smartphone app for childhood injury prevention called ChildSafe that was piloted in Malaysia from November 2017 – February 2018. The design of the app, research strategy, and results of the pilot study will be reported elsewhere. The aim of this analysis was to better understand and thereby strengthen the design, implementation, and dissemination of the ChildSafe app by examining the implementation facilitators and barriers from the perspective of caregivers of children under five with different user status.

SECTION 3: METHODS

We employed a qualitative approach to data collection and analysis. Qualitative methods were most appropriate for this study as we aimed to capture the experiences and perceptions of users who were caregivers of children under five with regards to childhood injuries and the design and implementation of the ChildSafe app to achieve our objective.

Study Setting

The ChildSafe pilot study was conducted in Petaling District, Malaysia. Malaysia has a high coverage of mobile broadband subscriptions, at 126.55 subscriptions per 100 inhabitants, and most of the population report using the Internet (153). This peri-urban district is also located near to the capital city of Kuala Lumpur, where access to high-speed mobile broadband networks is likely. Android devices are the most common type of smartphone used in Malaysia (155).

Intervention

ChildSafe is a comprehensive smartphone app for child injury prevention in the home. It consists of an evidence-based assessment and tailored tutorial for child injury prevention delivered through the smartphone app. Content in the app addressed 43 common childhood injury hazards in four (4) areas of the home: 1) living and sleeping areas; 2) bath area, 3) kitchen and dining room; and 4) courtyard, rooftop, and outdoors. The app

content was informed by WHO recommendations for child injury prevention, a review of the literature, prior work on home injury prevention in Malaysia and other LMIC settings, and a consultative process with IKU in Malaysia (112,116,126,151,152).

Caregivers of children under five were the target users of the app. Caregivers were provided with a brief orientation on how to the access and navigate the app by trained data collectors. Caregivers then downloaded the app and created a profile including information on the home environment (ex. type and number of rooms). After setting up their profile, they could complete a home safety assessment consisting of a series of "Yes/No" response questions on the presence or absence of common child injury hazards in the home. They then received a tailored tutorial based on the assessment results that guided them through changes to address the identified hazards. Users had to complete the assessment for each room before moving on to the tutorial section of the app. The app was developed for an Android platform as this is the most common platform used in Malaysia (155)**.** The app could be accessed in English or Bahasa Malaysia. Caregivers participating in the pilot study could implement the intervention through the smartphone app during a period of two-months.

Respondents, Sampling, Recruitment, and Consent

Respondents for the qualitative analysis were caregivers of children under five involved in the pilot study of ChildSafe. Caregivers who completed the assessment and reached the tutorial were considered "continuing users". "Discontinuing users" were those who downloaded the app but did not complete the assessment or reach the tutorial. At the time

of recruitment for the pilot study, caregivers were asked whether they agreed to be followed up for the qualitative component of the study. Caregivers who met the eligibility criteria for the pilot study and consented to follow-up for the qualitative component were later identified and purposive sampling was used to select an equal balance of continuing and discontinuing users. Selected participants were approached by the research team to arrange an in-depth interview. Recruitment continued until we reached a minimum of 20 respondents. Consent was obtained from respondents prior to conducting and recording the interview.

Theoretical Orientation and Conceptual Framework

We used the CIFR to guide this study (Figure 3). This framework provides a consolidated menu of constructs that enables a systematic assessment of implementation of health interventions (109). Constructs in the framework are organized according to the broad domains of the intervention, individual, process, and setting (109). We focused our analysis of implementation barriers and facilitators on three of the five categories in the framework- intervention, individuals, and process- as we thought that insights in these areas were more likely to inform and strengthen the design, implementation, and dissemination of the app. The CFIR has been applied in studies assessing a variety of intervention types and health purposes, but primarily within health organizations (163). Few studies have applied the CFIR to assess implementation of health-related smartphone apps and most applications have been from the perspective of health workers, assess implementation in a health care setting, and from HICs (164).

Data Collection

We conducted in-depth interviews with caregivers to capture their experiences and perceptions of childhood injuries and the app. We used a semi-structured interview guide that consisted of two separate sections on child injuries and the ChildSafe app. The guide was developed by incorporating selected constructs from the CFIR identified as most relevant to user implementation of a smartphone app. Revisions to the initial draft were made based on the experience of the first few interviews. Interviews were conducted by study team members from the Institute of Behavioral Research within the Ministry of Health in Malaysia who have a background in public health and experience with qualitative methods. Qualitative interviewers were both male and female and did not have any prior relationship with study participants. Interviewers received training in qualitative methods and use of the guide prior to data collection by a senior member of the team who is an expert in qualitative methods. Interviews were conducted in the respondent's home in their preferred language by at least one interviewer and one notetaker. Most interviews lasted approximately one hour. No follow-up or repeat interviews occurred. Interviewers audio-recorded the interviews and took notes. The recorded content was translated into English and transcribed.

Data Analysis

Interview transcripts were uploaded to NVivo©. AM applied a deductive approach to content analysis to analyze the data. First, she carefully read the transcripts and sorted

data into the broad constructs of the CFIR. Next, she developed initial codes within each construct that were the basis for a codebook based on the framework adapted to the app. This codebook was then applied to the interview data and further refined as needed based on the fit between the codes and the data. Multiple iterations of data analysis using the final codebook was done to refine the initial codes and identify emerging themes within each construct. Themes were shared perceptions or experiences that respondents identified as facilitators or barriers to implementation of the smartphone app. Factors were considered facilitators when they were perceived by respondents to contribute to their use of the app and implementation of the changes. Barriers were identified when respondents perceived the factor to limit their use of the app and implementation of the changes. When users identified a factor as both a facilitator and barrier, we developed distinct themes to identify these complementary perspectives within each construct (ex. complexity) or focused on the perspective shared by the greatest number of users and noted the differences. When continuing and discontinuing users disagreed on whether a factor was a facilitator or barrier, the discrepancy was noted, and we focused on the perspective of the discontinuing user (ex. adaptability, design quality and packaging). The data was then summarized and presented. Factors were organized by their framework category and construct. The facilitators and barriers were ranked by number of respondents reporting that factor. The five most common facilitators and barriers were identified and described in detail. The most common facilitators and barriers were then compared across user groups (all users, continuing users, and discontinuing users) and any differences noted and described. When several factors were tied for the five most common rank, all tied facilitators and barriers were considered. We determined that

saturation was reached because users expressed common perspectives and no additional themes were emerging from the data.

Ethics

Ethics approval to conduct the study was obtained from the Institutional Review Board (IRB) at Johns Hopkins Bloomberg School of Public Health (JHSPH) and the Medical Research and Ethics Committee at the Ministry of Health in Malaysia. Informed consent was obtained from respondents prior to conducting and recording the interviews.

SECTION 4: RESULTS

Respondent Characteristics

We conducted a total of 26 interviews: 13 interviews with continuing users and 13 with discontinuing users (Table 26). Most respondents were fathers of children under five (n=20) and between the ages of 30 and 39 (n=15). Most discontinuing users had a secondary school certificate or less (n=5), while most continuing users had an undergraduate degree or more (n=5). All respondents were married.

Facilitators and Barriers

We identified a total of 20 facilitators and 15 barriers to use and implementation of the ChildSafe app related to the intervention, individuals, and process elements of the CFIR. The facilitators and barriers for each category and construct are presented in Table 27, while Table 28 shows the frequency of facilitators and barriers by user type (all users, continuing users, discontinuing users).

Most Common Facilitators and Barriers Among All Users

The facilitators and barriers are ranked by frequency among all users in Table 28. Descriptions of the most common facilitators and barriers are included below. The most common facilitators were related to the complexity, relative advantage, execution, reflection and evaluation constructs from the model. The most common barriers were related to the stage of change, complexity, engagement, and execution constructs of the model.

Facilitator: App creates new knowledge or awareness

Users described that the app created new knowledge or awareness that helped them implement changes in support of childhood injury prevention (n=24). The app content increased their awareness of the danger of childhood injuries and prevention strategies for new and experienced caregivers. They described how there were some changes that they did not know about before using the app, but that the app taught them to do these changes to prevent child injuries and why these changes were important. Users communicated that the app helped them to be aware of childhood injuries, especially those that they had

never experienced or when they were new to caregiving. Even users who were aware of childhood injury prevention prior to the app described learning about additional changes they could do to prevent them. Many also mentioned that the app was the first time they had received formal information about childhood injury prevention, especially for home injuries. They added that the app could also be useful for caregivers outside of the home, such as nannies and nursery caregivers.

Facilitator: App was easy to use or understand

Most respondents, both continuing and discontinuing users, felt that the app was "easy" to use and understand (n=21). They described the flow through the app as "straightforward", with an assessment consisting of questions that were easy to answer and a tutorial with directions that were simple to follow, facilitating implementation of the recommended changes. A few users described being confused when moving from assessment to tutorial and would benefit from clearer instructions.

Facilitator: Recommendations in the tutorial are simple and easy to implement

Users communicated that every user could implement the changes and they were practical to implement. Users described challenges to implementing a few suggestions in the tutorial, such as installing a smoke detector, fire extinguisher, and window grills. Simplicity and ease of implementation helped them make the changes suggested in the app.

Facilitator: App is more accessible, timely and convenient than other sources

Both continuing and discontinuing users talked about the app as more accessible, timely and convenient than other sources of child injury prevention information (n=21). Many

people had smartphones and they were able to access the app through the PlayStore© on their phone, facilitating access, and interpreted the use of smartphones to mean that it was easy to access information on childhood injury prevention. Other sources of child injury prevention information were more difficult to access because they had to search or join a group to access it. Compared to books or magazines, they described the app as less costly and a quick read. They could download and use the app when they needed it or when it was convenient, rather than wait for the information to be posted on social media or aired on television. They also appreciated that they could use the app in their homes rather than travel to a health facility or school for support. As one continuing user said:

> *"We are too busy to find the information through Google about safety for our child. So with this app, we can know what we should be aware of, what is a danger to our kids, what we should do to improve safety in our house."*

Facilitator: App is helpful or useful in preventing child injuries

Most users viewed the app as "helpful" or "useful" in preventing childhood injuries (n=20) because it provided them with useful actionable information. They emphasized that all caregivers should use the app, but it would be most useful for new parents who had little information about childhood injuries and their prevention. Some experienced users maintained the app was still important, even though they already knew some of the information. Users also communicated the value of the app in addressing childhood injury prevention in their communities and society.

Barrier: User has time constraints or other priorities

Many users described time constraints or other priorities as challenges to completing the app or implementing the recommendations (n=20), including taking care of children, completing household tasks, or working. A few talked about how the study was done at a time when they had other priorities, such as their sick child or current pregnancy, thus the timing was not ideal. Others said that they let their children use their phone most of the time so they were unable to keep or use the app on their phone. All of these constraints, according to users, prevented them from using the app or implementing the recommendations. Many of these users did share that they would continue to use the app when they had time or were able to prioritize it.

Barrier: User has already experienced or implemented child injury prevention recommendations

Almost all respondents described being experienced or having implemented the recommendations prior to engaging with the app (n=20). This was common among both continuing and discontinuing users. Many respondents described how they had experienced a childhood injury or close incident previously and this caused them to become more aware and make changes to prevent an incident from happening in the future. Others described that they had previous experience with childhood injuries through their family or friends. Many described how they had become aware of childhood injuries as a new caregiver or in thinking about the safety of their household and daily activities, and some described finding information on the Internet or learning about it from family and friends. Many also said they had already implemented the recommendations and considered these changes to be standard parenting practice.

Barrier: User did not receive notifications from the app to encourage use and implementation

Users (n=18) forgot about the app even though they wanted to receive reminder notifications to alert them to app content, remind them about outstanding recommendations, inform them about the next steps they needed to do to complete the app, or update the app with upgrades. Users shared their opinion that these notifications should be done routinely on a biweekly or monthly basis. They thought that the notifications could be pop-up messages on their phone. Users also communicated that they wanted to be able to post comments, ask questions, and receive feedback or a response within the app. Such notifications and communication would be important and helpful to encourage their use of the app and implementation of the suggested recommendation. According to one respondent:

> *"Sometimes, we will forget within a month. Some items are changed in our house, such as new items that we just bought, so when there is notification, it is good as a reminder for us to check again. […] Thus, notifications are very important."*

Barrier: App is too limited or repetitive

Users described the app as "limited" or "repetitive" (n=16), and some specified it did not have enough content or that the content was too "general" or "normal". Others said the assessment questions or tutorials were repetitive. Feedback that the app ended abruptly was also an aspect of this barrier. Once they completed it, the tutorial continued to cycle through the same recommendations, and they felt that there was nothing else for them to do in the app. Thus, users did not feel the need for continued use.

Barrier: User has problems logging into the app or with the phone or Internet connection

Access problems were common (n=16). Many users described that they forgot their login information and were unable to reset it which preventing them from continuing to use it. Some also described buffering when they opened the app, slowness as they moved through it, or a slow connection. A few users lost their phone or had to reformat it and had not reinstalled the app. Others commented that it might be difficult for new users to search for and download the app if they did not know about it. These issues with the login, phone, or Internet prevented users from continuing to use the app.

Most Common Facilitators and Barriers Among Continuing Users

While the top four most common facilitators and barriers among continuing users remained the same as those for all users, there were several additional facilitators that were common for this group. These facilitators were related to the role within household, self-efficacy, cost, planning, and reflection and evaluation constructs of the model. One identified barrier related to engagement replaced the fifth most common barrier for continuing users compared to all users. These differences are shown in bold in Table 28 and these additional facilitators and barriers are described further below.

Facilitator: App is suitable or beneficial to all parents

Many users, both continuing and discontinuing, felt that the app was suitable or beneficial to all parents (n=18). They felt that all parents, both new parents and those with multiple children, should use the app to improve their knowledge and prevention of

childhood injuries. They felt that new parents may not have the knowledge or experience of childhood injuries and the app could support them in generating new knowledge and making changes to prevent them. They also felt that the app could benefit parents with multiple children, who may be more aware and experienced with childhood injuries but needed a reminder for how to prevent them. The also felt that there were some changes that even parents with multiple children might not be aware of and could benefit from learning.

Facilitator: User has adequate technical capacity and believe that child injuries can be prevented and the recommendations can be implemented

Most users felt that they had adequate technical capacity and believe that child injuries can be prevented and the recommendations can be implemented (n=17). This was common among both continuing and discontinuing users. Most respondents acknowledged that childhood injuries were preventable. Respondents felt that most of the changes suggested in the app could be done; there were only a few changes that they felt could not be done, notably installing a smoke detector, obtaining a fire extinguisher, or putting protective bars on windows. Some respondents also mentioned that they felt they had the technical capacity to use their phone or an app for childhood injury prevention.

Facilitator: App is a good reminder for child injury prevention

Many users felt that the app was a good reminder for childhood injury prevention (n=17). Even though they felt that they already knew many of the changes suggested by the app, they felt that the app reminded and encouraged them to do the changes especially when they forgot or overlooked them. Users also described that they routinely referred to the

app as a reference or reminder about the changes they had to do. When users experienced a childhood injury, it triggered them to refer to the app to learn what to do to prevent it from happening again. They also felt that the repeating messages reminded and motivated them to use the app make the changes suggested. Users felt that if they regularly engaged with the app that it would remind them about childhood injury prevention. According to one respondent:

> *"I've been thinking about it before but I take it for granted. So, it's more like notification. It notifies me to do it."*
>
> -Continuing user

Facilitator: Users has enough memory to download app and it is compatible with their phone

Most respondents said that the app was compatible with their phone and that their phone had enough space to download the app (n=15). Users described the app as "simple" and "light", referring to the amount of phone memory and storage needed for the app, so they didn't have any problems in the process of downloading and using it. Most described using unlimited wireless Internet to access the app rather than mobile data. They said that this compatibility and adequate memory enabled them to use the app.

Facilitator: App orientation was necessary or helpful

Most users felt that the orientation to the app was "necessary" or "helpful" (n=15). They felt that they needed to be shown how to find, download, and use the app. Users described how the introduction that was done by the data collectors at baseline helped them to understand and be able to move through the app and use it. They thought that

some introduction or orientation to the app was needed for future users. They thought that this orientation could come from health providers, local government, or neighborhood associations as well as within the app.

Barrier: User could not continue to engage with the app

Many users did not feel that they could continue to engage with the app (n=12). They felt that the app was limited or repetitive. Once they completed the assessment or tutorial, they did not feel that there was anything else for them to do. They felt that the app was a one-off activity, the activities in the app ended abruptly, and all they could do after they completed the app was to check back occasionally. They also did not feel that the app was updated with new information regularly, so they continued to receive the same information multiple times. Users felt that if the app were updated with new features and information that they would continue to engage with the app to implement and sustain changes overtime. As one respondent said:

> *"I have settled it already, then it is just stuck there. There is no continuation after that. What I mean is when I open it again, the information is still the same.*
>
> -Continuing user

Most Common Facilitators and Barriers Among Discontinuing Users

While the second through fifth most common facilitators remained the same as those for all users, one facilitator related to planning replaced the most common facilitator among discontinuing users. For barriers, the four most common barriers remained the same as

those for all users, but several additional barriers were tied for the fifth most common rank for discontinuing users. These barriers were related to the execution, role within household and engagement constructs. These differences are indicated in bold in Table 28 and descriptions of the additional facilitators and barriers are provided below.

Facilitator: User is interested in trying or continuing to use the app

Most users described being interested in trying or continuing to use the app (n=18). Users described that this was the first time they learned about an app for childhood injury prevention and thought that it would be good or helpful for them. They felt that there was a need to know about childhood injury prevention and purpose for the app. They described wanting to know more about the content in the app. Users described how they discontinued the app for other reasons than not being interested, such as difficulty logging in or losing their phone. Many wanted to keep the app on their phone and continue using it in the future, even after the study completed. As one respondent said:

> *"I have the desire to know what this app is about. […] Then, I want to complete the app at night after my kids went to sleep, but suddenly it's not possible to access, so I had stop there. If possible, I want to continue until the end."*
>
> -Discontinuing user

Barrier: Users believe that child safety in the home is an individual responsibility

A few respondents felt that addressing childhood injuries in the home was an individual responsibility (n=9). Many respondents discussed how the perception made them more aware of childhood injuries and take the issue more seriously, even before using the app. Some respondents also discussed how this perception caused them to already make many

of the changes included in the tutorial prior being introduced to the app. Thus, many respondents felt that they had already taken responsibility for childhood injuries and did not feel a need to use the app. As one respondent said:

> *"Those daily things that as a father already know about it; his routine and responsibilities…so there is no need to put the information inside it (the app)"*
>
> -Discontinuing user

Barrier: Family members are not engaged in using the app or implementing recommendations

Some users, continuing and discontinuing, said they did not engage other family members in using the app or implementing the recommendations (n=8). Many described wanting to engage other family members. Users wanted the app to be child-friendly so children and their older siblings could use the app to learn about childhood injury prevention. Others also wanted to share the app with their husbands or wives. A few described how engaging their children helped them to be able to use the app because their children are more familiar with smartphones and apps and have more technical capacity to use them. One respondent said:

> *"I mean not just to the parent but also to the children. […] If the parent is absent, children either sisters or brothers must have the knowledge so that they can do something during the incident."*
>
> -Discontinuing user

SECTION 5: DISCUSSION

We identified several facilitators and barriers to the individual, intervention, and process domains of the CFIR for implementation of a childhood injury prevention smartphone app among caregivers with different user status in Malaysia. The most common facilitators were related to the reflecting and evaluating, complexity, executing, and relative advantage constructs from the model, while the most common barriers were related to the executing, individual stage of change, engaging, and complexity constructs.

First, our study suggests that a health app may be a solid option for delivering child injury prevention instruction in LMICs. Home visits are a recommended, evidence-based intervention for child injury prevention; however, implementation is often challenging in LMICs due to their resource intensive nature (112,119,120,122,124,126–129). Our study found that many users in Malaysia viewed the ChildSafe app as useful, created new knowledge or awareness, was a good reminder for child injury prevention, and was beneficial or suitable to all parents. The caregiver feedback is especially promising given early findings from studies in other countries. One randomized controlled trial exploring the use of a comprehensive app for child injury prevention targeting caregivers in China showed a larger increase in prevention behaviors among the intervention group compared to the control group (132). Another randomized controlled trial on an app for child injury prevention targeting mothers also in China is still ongoing (133). Further evidence is needed on the use of comprehensive smartphone apps for child injury prevention targeting caregivers across multiple settings.

We also found that health apps may be a preferable option for delivering certain health interventions, such as those for prevention and education. Many users described the ChildSafe app as more accessible, timely, and convenient than other sources of child injury prevention information. With the growing coverage and adoption of mobile phones and broadband subscriptions around the world, and rapid deployment in many LMICs, smartphone apps are emerging as an increasingly popular way to deliver health interventions (1,6). While evaluations of the effect of health apps on client outcomes or service delivery remains an ongoing area of research, future consideration should be given to further examining the advantages and challenges of employing these approaches as has been done for digital health and mHealth more broadly (104,109,223,224). Implementation research in particular offers approaches to better understand these types of factors and questions of how and why interventions are working or not (109–111).

Our study found that user's stage of change was an important consideration for the implementation of a health app for child injury prevention in Malaysia (109,225). Users of the ChildSafe app in Malaysia expressed being at different stages of change. Some did not recognize child injuries as a problem and needed awareness-raising, while others described already making changes but needing reinforcement or reminders. Disconnect between users' needs and the technological innovation being employed have been identified as a barrier to the implementation and scale up of digital health interventions (104,223). At the same time, health apps offer opportunities to assess and adapt to users' stage of change or needs and consideration should be given to how the design and features of the health app can be used for this purpose. Other apps have applied built-in algorithms to assess user characteristics, needs, or stage from the onset of engagement,

while others have used machine learning through the process of user engagement to achieve this adaptability (170,171,203).

Fourth, we found that user engagement was especially challenging for implementation of the ChildSafe app and note this is a common challenge for many health apps (226–228). The ChildSafe app was developed by adapting an existing, proven-effective intervention for child injury prevention based on home visits for delivery to caregivers through an app. While evidence-based, such an approach may not consider the needs of different users involved in implementation (health worker vs. caregiver) or the incorporation of innovative features supported by smartphone apps. This highlights the importance of user-centered design approaches and consideration of innovative features of smartphone apps that may be used to foster better engagement (221). Examples of such features include reminders and notifications (222), gamification (132,170,171,229–231), peer networking and support (132,229,232–234), and linkages to health care actors and organizations (130,132,203,209,232,235–237).

Finally, this study examined the implementation of the ChildSafe app through the novel application and adaptation of the CIFR to an app targeting caregivers in a home environment (109). This framework offers a comprehensive, shared menu of constructs related to facilitators and barriers for implementation across multiple implementation and behavior change frameworks. To the best of our knowledge, this is the first application of the CFIR to a smartphone app targeting general population users in an LMIC. While many of the constructs align with those from other frameworks that have been traditionally used in assessments of health technology, in particular the Health Technology Acceptance model, this framework also enabled us to identify additional

factors and delve into the complexities of implementing health apps (238). Implementation is not often considered in assessments of health apps in LMICs and when it is, recognized frameworks are typically not applied (217). Future health app studies in LMICs should consider implementation from the onset, move beyond assessments of feasibility, acceptability, and adoption, and apply consistent methods and frameworks to contribute to a shared understanding (104,108,223).

Limitations

This study has several limitations. First, caregivers who agreed to participate in this qualitative study were mostly fathers, even though more mothers participated in the pilot study. Thus, these results may be more reflective of the perspectives of fathers rather than mothers and other types of caregivers. Second, there may be some response and social desirability bias to the results as users may have felt that they needed to share positive experiences or perceptions of the app. We used data collectors who were trained in qualitative approaches such as probing, had no prior association with respondents, and were not affiliated with the organization involved in the development and implementation of the app to help mitigate this bias. Further, all respondents shared both positive and negative aspects from their experience with the app. Finally, this study did not examine the perspectives or experiences of decision-makers, health workers, or other stakeholders who may be involved in the implementation and scale up of the app within the health sector in Malaysia. This is an important area for further research on the ChildSafe app.

Conclusion

This study revealed several facilitators and barriers to implementation of a smartphone app for child injury prevention in Malaysia. The most common facilitators identified were related to the complexity, relative advantage, execution, reflection and evaluation constructs of the model. On the other hand, the most common barriers were related to the stage of change, complexity, engagement, and execution constructs. This was a novel application of CIFR that identified several factors and complexities for consideration when implementing health apps targeting general population users in LMICs.

Table 26. Respondent Characteristics

Variable	All Users (n=26) N	Continuing Users (n=13) N	Discontinuing Users (n=13) N
Relationship to Child			
Mother	6	4	2
Father	20	9	11
Age Group			
Less than 29 years	4	2	2
Between 30 and 39	15	7	8
More than 40 years	7	4	3
Education Level			
Secondary school certificate or less	9	4	5
Higher school certificate (pre-university)	8	4	4
Undergraduate degree or more	9	5	4
Marital Status			
Married	26	13	13
Not Married	0	0	0

Table 27. Facilitators and Barriers by Framework Category and Construct

Construct	Facilitator	Barrier
Individual		
Role within Household*	• **User is primary caregiver responsible for child safety in the home** • **App is suitable and beneficial to all parents**	• **User believes child safety in the home is an individual responsibility**
Individual Stage of Change		• **User has already experienced or implemented child injury prevention recommendations**
Knowledge and Beliefs	• User believes child injuries are a problem or serious issue	
Self-Efficacy	• **User has adequate technical capacity and believes child injuries can be prevented and recommendations can be implemented**	
Other personal attributes	• User has significant prior experience caring for children	• User did not feel need for app given age or behavior of child
Intervention		
Adaptability	• App is adaptable to needs and situation	
Complexity	• **App is easy to use or understand**	• **App is too limited or repetitive** • App is too demanding
Cost	• **User has enough memory to download app and it is compatible with phone**	• Recommendations in the app cost too much to implement
Design Quality and Packaging	• Images in the app are suitable and adequate	• App is boring or static
Intervention Source	• App is developed by a credible source • App is relevant to context	
Relative Advantage	• **App is more accessible, timely, and convenient than other sources** • App is more credible than other sources	• App had less information and was less frequently updated than other sources • App is less engaging than other sources

Process		
Planning	• **User is interested in trying or continuing to use the app** • **App orientation is necessary or helpful**	
Engaging		• **User did not receive notifications from the app to encourage use and implementation** • **Family members were not engaged in using the app or implementing recommendations** • **User could not continue to engage with the app** • App is not interactive
Executing	• **Recommendations in the tutorial are simple and easy to implement**	• **User has problems logging into the app or with the phone or Internet connection** • **User has time constraints or other priorities**
Reflecting and Evaluating	• **App is helpful or useful in preventing child injuries** • **App creates new knowledge or awareness** • **App is good reminder for child injury prevention** • User recommends app for scale up	

*This construct was adapted from the framework construct of "Individual Identification with Organization" to "Role within Household" to be applied to an app targeting users who were caregivers of children under five. In this application of the model, the "organization" of relevance to users (caregivers) was conceptualized as the household and the adapted construct "Role within Household" assessed their perceptions of the role and responsibility of caregivers for childcare and safety within the household.

Bold indicates facilitators and barriers that were among the most common for user groups.

Table 28. Facilitators and Barriers by User Type and Frequency

#	Construct	Facilitator	All Users (n=26) N	Continuing Users (n=13) N	Discontinuing Users (n=13) N
1	**Reflecting and Evaluating**	**App creates new knowledge or awareness**	**24**	**12**	**12**
2	**Complexity**	**App is easy to use or understand**	**21**	**11**	**10**
3	**Executing**	**Recommendations in the tutorial are simple and easy to implement**	**21**	**11**	**10**
4	**Relative Advantage**	**App is more accessible, timely, and convenient than other sources**	**21**	**9**	**12**
5	**Reflecting and Evaluating**	**App is helpful or useful in preventing child injuries**	**20**	**10**	**10**
6	**Role within Household**	**App is suitable or beneficial to all parents**	18	**9**	9
7	**Planning**	**User is interested in trying or continuing to use the app**	18	5	**13**
8	**Reflecting and Evaluating**	**App is good reminder for child injury prevention**	17	**9**	8
9	**Self-efficacy**	**User has adequate technical capacity and believes child injuries can be prevented and recommendations can be implemented**	17	**9**	8
10	**Cost**	**User has enough memory to download app and it is compatible with phone**	15	**9**	6
11	**Planning**	**App orientation is necessary or helpful**	15	**9**	6
12	Role within Household	User is primary caregiver responsible for child safety	15	8	7
13	Knowledge and Beliefs	User believes child injuries are a problem or serious issue	10	5	5
14	Other Personal Attributes	User has significant prior experience caring for children	8	5	3
15	Reflecting and Evaluating	User recommends app for scale up	8	5	3
16	Adaptability	App is adaptable to needs and situation*	7	6	1
17	Relative Advantage	App is more credible than other sources	5	4	1
18	Intervention Source	App is developed by a credible source	5	2	3

19	Design Quality and Packaging	Images in the app are suitable and adequate*	5	1	4
20	Intervention Source	App is relevant to context	4	2	2
#		**Barriers**	**N**	**N**	**N**
1	**Executing**	**User has time constraints or other priorities**	**20**	**9**	**11**
2	**Individual Stage of Change**	**User has already experienced or implemented child injury prevention recommendations**	**20**	**10**	**10**
3	**Engaging**	**User did not receive notifications from the app to encourage use and implementation**	**18**	**12**	**6**
4	**Complexity**	**App is too limited or repetitive**	**16**	**10**	**6**
5	**Executing**	**User has problems logging in to the app or with the phone or Internet connection**	**16**	7	**9**
6	**Engaging**	**User could not continue to engage with the app**	12	**8**	4
7	**Role within Household**	**User believes child injuries in the home are an individual responsibility**	9	3	**6**
8	**Engaging**	**Family members are not engaged in using the app or implementing recommendations**	8	2	**6**
9	Engaging	App is not interactive	8	5	3
10	Relative Advantage	App is less engaging than other sources	8	5	3
11	Other Personal Attributes	User did not feel need for app given age or behavior of child	7	5	2
12	Relative Advantage	App had less information and was less frequently updated than other sources	7	4	3
13	Design Quality and Packaging	App is boring or static	6	2	4
14	Complexity	App is too demanding*	6	2	4
15	Cost	Recommendations in the app cost too much to implement	4	3	1

*These are themes where continuing and discontinuing users disagreed on whether the factor was a facilitator or barrier and we focused on the perspective of the discontinuing user.

Bold indicates facilitators and barriers that were among the most common for user groups.

CHAPTER 5

CONCLUSION

SECTION 1: IMPLICATIONS

Through this work, we generated a better understanding of the extent and how implementation is being considered in the peer-reviewed literature on health-related smartphone apps targeting general population and patient users in LMICs. We identified a significant gap in the literature on the implementation of health apps in LMICs. Acceptability and feasibility were the most assessed implementation outcomes, but other implementation outcomes and the process were not frequently considered, and an established implementation research framework was rarely used. Further, implementation research concepts and approaches were were not applied consistently in the context of a health app. This may partially explain why a lot of health-related smartphone apps are short-lived and rarely go beyond the pilot phase; highlighting the need for greater consideration of implementation in assessments from the early stages of digital development. This echoes calls by WHO and other researchers in recognition of the challenges with implementation and scale up for digital health approaches broadly (104–107). Consideration of implementation is also a best practice in digital health development (104,108). There involves a need for consensus on how implementation research concepts and approaches can be applied in the context of a health app.

Addressing this gap, our assessment of the ChildSafe app in Malaysia showed how different dimensions of implementation (adoption, fidelity, acceptability, process, facilitators, and barriers) could be considered in the context of a health app. To the best of our knowledge, this is the first application of the Consolidated Framework for Implementation Research to a health app targeting general population and patient users in LMICs. While this framework shares many of the constructs that can be found in other frameworks that are typically used in assessments of health apps, such as the Technology Acceptance Model, it is much more extensive and revealed the complexity of implementation of health apps (179,238). For example, we identified facilitators and barriers for most constructs in the model and the duality of many constructs for consideration in implementation. Our work contributes to a better conceptual understanding of the implementation of health apps and showed the value of the insights gleaned of considering implementation from the early stages of digital development to strengthen the design, implementation, and dissemination of a health app in LMICs.

We also generated insight on the state of the literature on the use of health-related smartphone apps for general population and patient users in LMICs. In terms of the state of the literature, we identified a small but expanding body of peer-reviewed literature on health apps for general population and patient users across LMICs for a range of health issues and functions. This supports consideration of health apps as a distinct and increasingly popular digital health approach for delivering health interventions in LMICs (6). However, the state of the literature is still in its infancy and many of these assessments were done using small-scale pilot studies with 49 participants or less. This is potentially a lost opportunity as the increasing spread of high-speed mobile networks and

smartphones presents an opportunity to reach a large number of people (2,6). More large-scale studies and randomized trials of health apps that show promise in initial assessments are needed and several large-scale studies and trials have been conducted more recently. This represents the evolution and growing maturity of the field. As such, there is a need to continue to monitor the state of the peer-reviewed literature for new insight as it continues to expand, evolve, and mature.

We identified both concentrations and gaps in the literature on health apps for general population and patient users in certain areas and for specific health issues and functions. Most health apps were developed in MICs, Southeast Asia, China, India, and Brazil. Most apps addressed cancers and chronic diseases, mental and physical disability, prevention, management, education, self-monitoring, and communication. These concentrations in the literature present opportunities to further assess, summarize, and learn about health apps for these contexts, health issues, and functions. On the other hand, there were fewer apps developed in LICs and for child and adolescent health, obesity and lifestyle, and injuries and safety. Fewer apps were also for treatment, support, and gamification. There was also a notable lack of apps developed for maternal health and HIV and infectious diseases despite the burden of these issues that exists in LMICs (181). These gaps in the literature present opportunities to further explore the potential of health apps for these contexts, health issues, and functions. There may also be new opportunities to leverage health apps in other settings, including LICs, as coverage of smartphones and mobile broadband networks continue to deploy at a rapid pace (1,2,153).

Our study of the ChildSafe app in Malaysia provides one such example of a larger scale study on a health app for child injury prevention in LMICs. From the pilot study

involving more than 300 participants, we found that a smartphone app may be an acceptable, remote option for delivering child injury prevention information in LMICs. We also found that mothers were an important target group for dissemination and early adoption of an app for child injury prevention. Thus, the results of the ChildSafe pilot study provides an example of a health app and contributes new evidence on the use of smartphone apps for child health and injuries in LMICs. This knowledge can be used to strengthen the design, implementation, and dissemination of the ChildSafe app in Malaysia that may be relevant for other similar contexts and health apps.

We also found that governments were not typically engaged in the development and assessment of health apps in LMICs. Government involvement in the development and deployment of health apps is especially important for integration and sustainability within the health system and ecosystem (104,108,239). Development and implementation of apps in collaboration with government stakeholders and within the existing health ecosystem in a country is also a best practice for digital health development (104,108,239). Consideration should be given to the context in which the health app is to be implemented and its end-goal. In contexts where the government is primarily responsible for operating health facilities and the aim of the app is to be integrated within routine service delivery, government involvement may be necessary for implementation and sustainability. With these considerations in mind, the ChildSafe app was developed in collaboration with the Institute for Public Health in Malaysia (part of the Ministry of Health). We even found that this collaboration strengthened the perception of the health app as being a credible source of information by users. This warrants the need for greater involvement of LMIC governments in the development of health apps in the future.

Our analysis of the ChildSafe app revealed several lessons that could be applied to health apps targeting the general population and patient users in LMICs. We found that the individual's knowledge and beliefs about child injury prevention, self-efficacy to use a smartphone app, and adaptability of the app to user needs were important considerations for implementation of the app. On the other hand, the individual's stage of change, the process of engaging with the app, and the execution of the app were notable challenges. These considerations may be relevant to other similar health apps. While many of these benefits and challenges have been independently noted in other studies, our conceptual-based analysis begins to develop and contribute to a broader understanding of the benefits and challenges for implementation of health apps in LMICs. A greater understanding of the benefits and challenges for the implementation of health apps in LMICs is needed based on the experiences of more health apps in these settings.

Of important consideration for the implementation of health apps is their ability to be tailored and responsive to users. Adaptability of the app was found to be an important facilitator while the individual's stage of change was found to be a significant barrier. Aligning the intervention with user needs has been identified as an important consideration for the implementation of digital technologies broadly (104). Apps offer many opportunities to respond to individual user needs through novel in-app strategies based on algorithms or machine learning (170,171,203). This unique ability of health apps may be important for ensuring their success and further consideration should be given to how these strategies can be incorporated in the design of health apps. However, this ability of health apps to adapt to users also creates challenges for their assessment as

users may have different results and perspectives from their individual experience with the app that makes measurement and comparisons difficult to meaningful accomplish.

We also found that user engagement was a major challenge for the ChildSafe app. Many users stopped using the app and engagement was found to be an important barrier to its implementation. Engagement has also been a common challenges for many other health apps (226–228). Health apps also offer many approaches to foster user engagement. Examples of such features include reminders and notifications (222), gamification (132,170,171,229–231), peer networking and support (132,229,232–234), and linkages to health care actors and organizations (130,132,203,209,232,235–237). These findings also support consideration of user preferences and experiences beyond the design stages and into implementation (221). These are areas where further innovation and work is needed to enable apps to achieve their optimal effectiveness, improve the quality of apps for health purposes, and reduce lost investments in research and development.

SECTION 2: STRENGTHS

This dissertation had several strengths. First, this dissertation consisted of both a scoping review of the peer-reviewed literature and an assessment of a health app in a LMIC setting. Our assessment of the ChildSafe app built off many of the gaps and learnings identified through the scoping review. These included the limited consideration for implementation, focus on initial acceptability and feasibility in assessments of implementation of health apps, and limited assessment of the implementation process and

use of an implementation framework. Our assessment of the implementation of the ChildSafe app included multiple dimensions of implementation in addition to acceptability, such as adoption, fidelity, and the process (161). We also applied an established implementation research framework, the Consolidated Framework for Implementation Research, in the context of the app (240). In this way, our assessment of the ChildSafe app responded to the gaps identified from the scoping review and contributed new knowledge on the implementation of health apps in LMICs.

We assessed multiple dimensions of implementation using mixed methods applied to an example of the ChildSafe app in Malaysia. We used quantitative methods to assess the adoption, fidelity, acceptability, and process of user engagement of the ChildSafe app and qualitative methods to examine the facilitators and barriers to its use and implementation. Consideration of these multiple dimensions of implementation enabled a more holistic understanding of the implementation of the ChildSafe app and triangulation of the results. Several factors emerged as important across several implementation dimensions, such as the role of mothers and responsibility of caregivers in the household. On the other hand, several factors were found to be relevant from one perspective but not from others. For example, while users with larger houses were found to complete more of the child injury hazard assessment, they were less likely to find the app to be acceptable. Qualitative results indicated that the amount of time and burden placed on users were important considerations. Thus, this analysis of the ChildSafe app moved beyond initial assessments of acceptability to account for the complexity of implementation achieved through consideration of these multiple dimensions of implementation.

We used established implementation research definitions and frameworks adapted to the context of an app. We used Proctor et al.'s definitions of implementation outcomes and the Consolidated Framework for Implementation Research (161,240). Proctor et al.'s implementation outcomes are recognized dimensions for assessing implementation are frequently used in the implementation research literature as an indication of implementation success, measurement for the implementation process, and intermediary to health systems and treatment outcomes. The Consolidated Framework for Implementation Research is an established framework in implementation research that compiles factors from several other foundational frameworks in implementation research including Roger's Diffusion of Innovations and Greenhalgh's Diffusion of Innovations (110,162). Thus, our assessment of the implementation of the ChildSafe app drew strongly from the conceptual foundations of implementation research.

Our assessment of the implementation of the ChildSafe app in Malaysia was embedded within a pilot study that involved more than 300 participants. Many of our assessments were based on a larger number of participants that what is typical in initial assessments of health apps that usually involve 49 participants or less. We also reached saturation during our qualitative analysis based on 26 participants with no new themes emerging from interview transcripts, a diversity of perspectives, and strong consensus around certain themes. This larger number of participants and achievement of saturation strengthens our confidence in the results from our analysis.

SECTION 3: LIMITATIONS

However, this work also had several limitations. Our scoping review represents the results from the peer-reviewed literature on health-related apps in LMICs. Thus, we did not consider apps that were reported in the grey literature or available in app stores. Our reason for this focus on the peer-reviewed literature is because it represents the body of evidence that provides the foundation for further scientific and academic work and we were interested in determining how implementation had been considered in assessments of health apps. There are likely several apps that have been developed and implemented in LMICs but are never evaluated or reported in the peer-reviewed literature and were excluded from this analysis. Several reasons could be because they were developed outside of a study setting, were never assessed or reported, or the results were reported elsewhere.

Similarly, we did not aim to evaluate the content of effectiveness of the health apps or the quality of the evidence reported in our scoping review. This remains an area of future exploration. Similarly, as the aim of many of the studies included in our scoping review was to report the efficacy or effectiveness of health apps, implementation may have been considered but never reported and could not be assessed. We did not reach out to study authors to inquire about their implementation experience or considerations, but this could be done to expand the learnings from this work.

These dissertation results are based on a small number of studies on health apps that were published in the peer-reviewed literature or one example of a health app in a particular

context. As a result, the results from our scoping review reflects the small body of literature on health apps that is currently available will need to continue to be monitored and updated as it expands. Our assessment of the ChildSafe app in Malaysia also represents the experience of an app for child injury prevention in one LMIC context. Consideration should be given to the generalizability of these findings to other health apps and contexts.

Our assessment of the ChildSafe app also reflects the experience from a pilot study rather than a randomized trial and larger scale implementation in a less controlled environment. We did not have a control group to compare experiences and perceptions of child injury prevention interventions. While these results represent an initial assessment to inform and strengthen the future design, implementation, and dissemination of the ChildSafe app in Malaysia, it is unclear how relevant these results would change as it reaches fuller implementation and scale up. Thus, consideration for implementation of health apps is not a one-time activity but rather embedded in real-time assessments throughout the process of scale up.

This work also reflects the perspective of users of the ChildSafe app in a household setting. We did not include the perspective of other implementation stakeholders or the healthcare setting for implementation. For example, we did not include the perspective of government stakeholders such as the Ministry of Health or other implementers including doctors and pediatricians in our assessment. We did not consider how the app would be implemented if integrated into the health system and delivered as part of routine service delivery. These stakeholders and settings would likely generate important and

complementary perspectives to inform implementation that may be important for the next iteration and stages of the ChildSafe app.

Finally, our assessment of the implementation of the ChildSafe app faced several challenges. First, recruitment for the pilot study took place during childcare visits at health facilities. As a result, participants who were enrolled in the study are those who already have access and have decided to receive healthcare and may be different from those who do not attend routine healthcare services.. There was a concentration of users and households with similar characteristics making differences across factors difficult to distinguish. Users who agreed to participate in the qualitative interviews were also characteristically different from most users involved in the pilot study. Notably, more users who agreed to participate in the qualitative interviews were fathers even though more mothers participated in the pilot study overall. Many users involved in the pilot study did not adopt the app or were lost to follow up. While we were able to assess adoption as part of this work, acceptability was only assessed during follow up and does not represent users who dropped out of the study.

SECTION 4: FUTURE CONSIDERATIONS

There are several future areas of consideration for the development and assessment of health apps. Consideration should be given to who is participating in studies and engaging with smartphone apps. While coverage of smartphones and mobile networks may be high, these numbers may not consider who has access to these devices and

networks, how they are being used, and whether they are being used for health purposes. Certain types of potential users may be excluded from participating and engaging with smartphone apps and digital health, such as women, elderly, children and adolescents, and those with limited technological access and capacity. Digital divides and equity in digital health interventions is an area of ongoing discussion and concern that has been exacerbated with the reliance on digital technologies during the coronavirus pandemic (2–4,241–243).

While smartphone apps present a promising approach for the delivery of health interventions in LMICs, there are emerging questions around user consent, privacy, and data ownership for health apps (244,245). Health apps generate and store an enormous amount of personal data from users. Users may not always be fully aware of the type and extent of data being collected through the apps they use. Further, adequate protections may not always be in place to ensure security and this health data may be targeted by hackers. Given the private nature of health data, these protections are incredibly important and more work is needed to make systems more secure as they become more extensive and sophisticated. There are also concerns related to the ownership of data collected through apps and how it can be used. Data can be owned by the app developers, implementers, users, or some combination. Whether it can be accessed or shared with third parties and for what purposes is not always clear. Users may not always be informed or able to fully understand the digital sphere of health apps. This also raises questions about how to handle informed consent in the context of health apps. As smartphone apps become more popular, further consideration and work should be given to these emerging areas of concern.

REFERENCES

SECTION 1: APPENDICES

Appendix 1: Acronyms

BCS	Breast Cancer e-Support Program
CIFR	Consolidated Framework for Implementation Research
DALYs	Disability Adjusted Life Years
GDP	Gross Domestic Product
HIC	High-Income Country
IRB	Institutional Review Board
IKU	Institute of Public Health
JH-IIRU	Johns Hopkins International Injury Research Unit
JHSPH	Johns Hopkins Bloomberg School of Public Health
LIC	Low-Income Country
LMIC	Low- and Middle-Income Country
MIC	Middle-Income Country
MMR	Maternal Mortality Ratio
PINGS	Phone-Based Intervention under Nurse Guidance after Stroke
SDG	Sustainable Development Goals
US	United States
U5MR	Under Five Mortality Rate
WHO	World Health Organization

Appendix 2: PubMed Search

Concept: Smartphone app

(("Cell Phone"[Mesh] OR "cell phone"[tw] OR "Smartphone"[Mesh] OR "smartphone"[tw] OR "smart phone"[tw] OR "mobile phone"[tw] OR "mobile telephone"[tw] OR “mobile”[tw] OR "cellular telephone"[tw] OR "iphone"[tw] OR "android"[tw]) AND (“application”[tw] or “app”[tw])) OR "Mobile Applications"[Mesh] OR "mhealth"[tw] OR "m health"[tw] OR "m-health"[tw] OR "ehealth"[tw] OR "e health"[tw] OR "e-health"[tw]

Concept: Low- and Middle-Income Country

(“emerging country”[all fields] OR “emerging countries”[all fields] OR “emerging nation”[all fields] OR “emerging nations”[all fields] OR “emerging population”[all fields] OR “emerging populations”[all fields] OR "developing country"[tiab] OR "developing countries"[tiab] OR "developing nation"[tiab] OR "developing nations"[tiab] OR "developing population"[tiab] OR "developing populations"[tiab] OR "developing world"[tiab] OR "less developed country"[tiab] OR "less developed countries"[tiab] OR "less developed nation"[tiab] OR "less developed nations"[tiab] OR "less developed population"[tiab] OR "less developed populations"[tiab] OR "less developed world"[tiab] OR "lesser developed country"[tiab] OR "lesser developed countries"[tiab] OR "lesser developed nation"[tiab] OR "lesser developed nations"[tiab] OR "lesser developed population"[tiab] OR "lesser developed populations"[tiab] OR "lesser developed

world"[tiab] OR "under developed country"[tiab] OR "under developed countries"[tiab] OR "under developed nation"[tiab] OR "under developed nations"[tiab] OR "under developed population"[tiab] OR "under developed populations"[tiab] OR "under developed world"[tiab] OR "underdeveloped country"[tiab] OR "underdeveloped countries"[tiab] OR "underdeveloped nation"[tiab] OR "underdeveloped nations"[tiab] OR "underdeveloped population"[tiab] OR "underdeveloped populations"[tiab] OR "underdeveloped world"[tiab] OR "middle income country"[tiab] OR "middle income countries"[tiab] OR "middle income nation"[tiab] OR "middle income nations"[tiab] OR "middle income population"[tiab] OR "middle income populations"[tiab] OR "low income country"[tiab] OR "low income countries"[tiab] OR "low income nation"[tiab] OR "low income nations"[tiab] OR "low income population"[tiab] OR "low income populations"[tiab] OR "lower income country"[tiab] OR "lower income countries"[tiab] OR "lower income nation"[tiab] OR "lower income nations"[tiab] OR "lower income population"[tiab] OR "lower income populations"[tiab] OR "underserved country"[tiab] OR "underserved countries"[tiab] OR "underserved nation"[tiab] OR "underserved nations"[tiab] OR "underserved population"[tiab] OR "underserved populations"[tiab] OR "underserved world"[tiab] OR "under served country"[tiab] OR "under served countries"[tiab] OR "under served nation"[tiab] OR "under served nations"[tiab] OR "under served population"[tiab] OR "under served populations"[tiab] OR "under served world"[tiab] OR "deprived country"[tiab] OR "deprived countries"[tiab] OR "deprived nation"[tiab] OR "deprived nations"[tiab] OR "deprived population"[tiab] OR "deprived populations"[tiab] OR "deprived world"[tiab] OR "poor country"[tiab] OR "poor countries"[tiab] OR "poor nation"[tiab] OR "poor nations"[tiab] OR "poor

population"[tiab] OR "poor populations"[tiab] OR "poor world"[tiab] OR "poorer country"[tiab] OR "poorer countries"[tiab] OR "poorer nation"[tiab] OR "poorer nations"[tiab] OR "poorer population"[tiab] OR "poorer populations"[tiab] OR "poorer world"[tiab] OR "developing economy"[tiab] OR "developing economies"[tiab] OR "less developed economy"[tiab] OR "less developed economies"[tiab] OR "lesser developed economy"[tiab] OR "lesser developed economies"[tiab] OR "under developed economy"[tiab] OR "under developed economies"[tiab] OR "underdeveloped economy"[tiab] OR "underdeveloped economies"[tiab] OR "middle income economy"[tiab] OR "middle income economies"[tiab] OR "low income economy"[tiab] OR "low income economies"[tiab] OR "lower income economy"[tiab] OR "lower income economies"[tiab] OR "low gdp"[tiab] OR "low gnp"[tiab] OR "low gross domestic"[tiab] OR "low gross national"[tiab] OR "lower gdp"[tiab] OR "lower gnp"[tiab] OR "lower gross domestic"[tiab] OR "lower gross national"[tiab] OR lmic[tiab] OR lmics[tiab] OR "third world"[tiab] OR "lami country"[tiab] OR "lami countries"[tiab] OR "transitional country"[tiab] OR "transitional countries"[tiab] OR Africa[tiab] OR Asia[tiab] OR Caribbean[tiab] OR West Indies[tiab] OR South America[tiab] OR Latin America[tiab] OR Central America[tiab] OR "Atlantic Islands"[tiab] OR "Commonwealth of Independent States"[tiab] OR "Pacific Islands"[tiab] OR "Indian Ocean Islands"[tiab] OR "Eastern Europe"[tiab] OR Afghanistan[tiab] OR Albania[tiab] OR Algeria[tiab] OR Angola[tiab] OR Armenia[tiab] OR Armenian[tiab] OR Azerbaijan[tiab] OR Bangladesh[tiab] OR Benin[tiab] OR Byelarus[tiab] OR Byelorussian[tiab] OR Belarus[tiab] OR Belorussian[tiab] OR Belorussia[tiab] OR Belize[tiab] OR Bhutan[tiab] OR Bolivia[tiab] OR Bosnia[tiab] OR Herzegovina[tiab] OR Hercegovina[tiab] OR

Botswana[tiab] OR Brasil[tiab] OR Brazil[tiab] OR Bulgaria[tiab] OR Burkina Faso[tiab] OR Burkina Fasso[tiab] OR Upper Volta[tiab] OR Burundi[tiab] OR Urundi[tiab] OR Cambodia[tiab] OR Khmer Republic[tiab] OR Kampuchea[tiab] OR Cameroon[tiab] OR Cameroons[tiab] OR Cameron[tiab] OR Cape Verde[tiab] OR Central African Republic[tiab] OR Chad[tiab] OR China[tiab] OR Colombia[tiab] OR Comoros[tiab] OR Comoro Islands[tiab] OR Comores[tiab] OR Mayotte[tiab] OR Congo[tiab] OR Zaire[tiab] OR Costa Rica[tiab] OR Cote d'Ivoire[tiab] OR Ivory Coast[tiab] OR Cuba[tiab] OR Czechoslovakia[tiab] OR Slovakia[tiab] OR Djibouti[tiab] OR French Somaliland[tiab] OR Dominica[tiab] OR Dominican Republic[tiab] OR East Timor[tiab] OR East Timur[tiab] OR Timor Leste[tiab] OR Ecuador[tiab] OR Egypt[tiab] OR El Salvador[tiab] OR Eritrea[tiab] OR Ethiopia[tiab] OR Fiji[tiab] OR Gabon[tiab] OR Gabonese Republic[tiab] OR Gambia[tiab] OR Gaza[tiab] OR Georgia Republic[tiab] OR Georgian Republic[tiab] OR Ghana[tiab] OR Gold Coast[tiab] OR Grenada[tiab] OR Guatemala[tiab] OR Guinea[tiab] OR Guiana[tiab] OR Guyana[tiab] OR Haiti[tiab] OR Honduras[tiab] OR India[tiab] OR Maldives[tiab] OR Indonesia[tiab] OR Iran[tiab] OR Iraq[tiab] OR Jamaica[tiab] OR Jordan[tiab] OR Kazakhstan[tiab] OR Kazakh[tiab] OR Kenya[tiab] OR Kiribati[tiab] OR Korea[tiab] OR Kosovo[tiab] OR Kyrgyzstan[tiab] OR Kirghizia[tiab] OR Kyrgyz Republic[tiab] OR Kirghiz[tiab] OR Kirgizstan[tiab] OR "Lao PDR"[tiab] OR Laos[tiab] OR Lebanon[tiab] OR Lesotho[tiab] OR Basutoland[tiab] OR Liberia[tiab] OR Libya[tiab] OR Macedonia[tiab] OR Madagascar[tiab] OR Malagasy Republic[tiab] OR Malaysia[tiab] OR Malaya[tiab] OR Malay[tiab] OR Sabah[tiab] OR Sarawak[tiab] OR Malawi[tiab] OR Nyasaland[tiab] OR Mali[tiab] OR Marshall Islands[tiab] OR Mauritania[tiab] OR Mauritius[tiab] OR

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SECTION 3: BIOGRAPHICAL STATEMENT AND CURRICULUM VITAE

Dr. Arielle Mancuso is a public health researcher focused on the role of novel digital technologies to strengthen health systems and improve the health of vulnerable populations internationally and in the United States. She earned a Doctor of Philosophy and Master of Science in Public Health in the Department of International Health at Johns Hopkins Bloomberg School of Public Health. She also has a Bachelor of Arts in Honors International Development Studies and Biochemistry from McGill University. Dr. Mancuso has extensive experience in public health spanning from the community to the global levels. She is currently serving as the Research and Data Analytics Advisor to the Connect2Health Taskforce at the Federal Communications Commission where she provides expert guidance and support to research activities to explore the intersection of broadband connectivity, digital innovations, and health. Prior to joining the commission, Dr. Mancuso worked with the Alliance for Health Policy and Systems Research at the World Health Organization to coordinate a portfolio of global research initiatives that aimed to embed research into decision-making processes and real-world contexts to strengthen the implementation of health interventions towards greater improvements in health. Dr. Mancuso also served as a Peace Corps Volunteer in Rwanda from 2010-2013. Her research interests include digital health, mHealth, implementation research, policy and action-oriented research, and health information systems. She was the recipient of the Implementation Research Fellowship by the World Health Organization, World Bank,

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Johns Hopkins Bloomberg School of Public Health Baltimore, MD
Department of International Health: Health Systems GPA: 4.0/4.0

Thesis: *Implementation of Health-Related Smartphone Applications in Low- and Middle-Income Countries: Scoping Review and Learnings from the ChildSafe Application in Malaysia*

Relevant Coursework: Introduction to Digital Health in LMICs; Stata Programming and Data Management; Management and Technology Consulting; Formulating Policy; Health Policy Analysis in LMICs; Design and Conduct of Community Trials; Health Survey Research Methods; Qualitative Research; Statistics for Psychosocial Research; Communication Network Analysis in Public Health Programs

HEALTH FINANCE AND MANAGEMENT CERTIFICATE September 2017
Johns Hopkins Bloomberg School of Public Health Baltimore, MD
Department of International Health: Health Systems GPA: 4.0/4.0

Relevant Coursework: Foundations in Organization Leadership; Organizational Behavior and Management, Fundamentals of Budgeting and Financial Management; Economic Evaluation; Applications in Managing Health Organizations; Negotiation in Health Care Settings; Quality Assurance Management Methods; Evaluating Quality Improvement and Patient Safety Programs

MASTER OF SCIENCE IN PUBLIC HEALTH January 2016
Johns Hopkins Bloomberg School of Public Health Baltimore, MD
Department of International Health: Health Systems GPA: 4.0/4.0

Thesis: *A Theory of Change for Embedded Implementation Research: Experience from Six Projects in Latin America*

Relevant Coursework: Statistical Methods; Epidemiological Methods; Introduction to International Health; Health Systems in LMICs; Health Systems Research and Evaluation in Developing Countries; Effectiveness Evaluation; Implementation Research; Spatial Analysis and GIS; Health Financing in LMICs; Applying Summary Measures to Improve Health; Program Planning for Health Behavior Change; Epidemiological and Public Health Impact of AIDS; Clinical and Epidemiological Aspects of Tropical Diseases

BACHELOR OF ARTS (HONORS PROGRAM) May 2009
McGill University Montreal, Canada
Faculty of Arts: International Development; Biochemistry GPA: 3.1/4.0

Thesis: *The Nutritional Impact of the Complex Humanitarian Emergency in Sudan*

PROFESSIONAL POSITIONS & EXPERIENCE

RESEARCH & DATA ANALYTICS ADVISOR July 2019 – present
Federal Communications Commission Washington, DC
Connect2Health Taskforce

Provided strategic and technical guidance on research and data analytics initiatives to explore the intersection between broadband connectivity, digital technologies, and health, namely:

Mapping Broadband Health in America: a mapping platform that enables users to visualize, intersect, and overlay data on broadband connectivity and health across the United States.

- Oversaw an interdisciplinary team to expand the mapping platform to incorporate and intersect data on **drug abuse and opioids**;
- Researched available **national-level datasets** on drug abuse and opioids considering fit, appropriateness, and interoperability for purpose;
- Developed and reviewed **methodological approaches and calculations** underlying the mapping platform and corresponding datasets;
- Wrote **narratives** for the website to explain advanced analytic concepts and methods for public audiences;
- Led an analytic team to produce a **report** using descriptive analysis to identify and characterize counties with low connectivity and high opioid burden in the United States to inform policy, action, and investment to address the opioid crisis.

Linking and Amplifying User-Centered Networks through Connected Health: a collaboration between the Federal Communications Commission and National Cancer Institute to leverage broadband connectivity to improve cancer care in rural areas.

- Generated **national-level datasets** merging available data on broadband connectivity, cancer, and demographic/socioeconomic data across counties in the United States;
- Led an **analysis** to explore the intersection between broadband connectivity and cancer in the Appalachian region;
- Conducted **statistical analyses** to better understand the relationship between broadband connectivity and cancer.

RESEARCH & TEACHING ASSISTANT December 2014 – March 2021
Johns Hopkins Bloomberg School of Public Health Baltimore, MD
Department of International Health

Coordinated research and teaching activities, specifically:

Intervention Strategies for Childhood Injury Prevention: Portfolio of studies to test intervention strategies to prevent child injuries in the home in low- and middle-income countries.

- Developed a **proposal** submitted to the National Institutes of Health for a study on the dissemination and implementation of a smartphone application for child injury prevention;
- Coordinated a **pilot study** employing mixed methods on the efficacy, feasibility, acceptability, and implementation of a smartphone application to prevent child injuries;
- Collaborated in a **cluster randomized trial** to compare the effectiveness of intervention strategies on reducing injury hazards and child injuries.

Global Road Safety Leadership Course: Initiative by the Johns Hopkins International Injury Research Unit to build the capacity of decision-makers for road safety in low- and middle-income countries.

- Served as teaching assistant for **2 Global Road Safety Leadership Courses**;
- Contributed to the development of the **Global Road Safety Leadership Workbook** to guide the development of country action plans to address the problem of road safety.

Systematic Review on Implementation Research: Systematic review on implementation research publications for global health.

- Led a team of **3 research assistants** to screen and extract data from more than 7,000 articles on implementation research in low- and middle-income countries.

Use of Mobile Phones to Strengthen Health Systems: Initiative by Future Health Systems to support emerging researchers from low- and middle-income countries to carry out research on the use of mobile phones to strengthen health systems.

- Conducted a **literature review** of evaluation approaches and frameworks for mobile phone interventions;
- Facilitated a **protocol development workshop** to strengthen the capacity of emerging researchers to test and evaluate mobile phone interventions for health systems.

Teaching Assistant: Assisted in the design and implementation of graduate-level courses.

- Served as a teaching assistant for **4 courses**: DrPH Proposal Development, Health Systems in Low- and Middle-Income Countries, Health Policy Analysis in Low-

and Middle-Income Countries, and Hospital-Based Trauma Surveillance in Low- and Middle-Income Countries.

INDEPENDENT CONSULTANT March 2015 – December 2019
World Health Organization Geneva, Switzerland
Alliance for Health Policy and Systems Research

Managed or contributed to a portfolio of embedded implementation research initiatives, specifically:

Decision-Maker Led Implementation Research: Partnership with UNICEF and Gavi to support 24 embedded implementation research studies led by decision-makers to improve immunization programs and coverage.

- Managed 2 solicitations for research totaling **1,400,000 USD**;
- Supervised **2 consultants** supporting implementation of the initiative;
- Facilitated **3 workshops** for research teams on protocol development, data analysis and interpretation, and dissemination and implementation of research findings;
- Developed **guides, templates, and tools** to strengthen the quality of research studies;
- Approved and provided feedback to **study protocols and technical reports**;
- Cultivated studies to achieve impact highlighted through a **presentation** to the Board of Directors;
- Coordinated the development of a **journal supplement** on Decision-Maker Led Implementation Research for Immunizations;
- Led a **study** to evaluate the cross-cutting learnings from the research studies;
- Oversaw **donor relations, engagement, and reporting.**

Strengthening Capacity for Implementation Research: Collaboration with 6 regional institutions to introduce small grant and capacity strengthening programs to support 33 embedded implementation research studies.

- Managed a solicitation for institutions totaling **900,000 USD**;
- Developed grants management and capacity strengthening **materials and tools** for institutions;
- Approved and provided feedback on the **technical reports** of the projects and institutions;
- Produced a **case study compendium** of the embedded implementation research studies;
- Generated a **final report** to document the overall initiative.

Embedded Implementation Research Course: Development of a course in embedded implementation research targeting decision-makers and implementers.

- Produced a **concept note** for a course on embedded implementation research;
- Developed **presentations, agendas, facilitator notes, and participant handouts** for the course;

- Conducted **2 pilot tests** of the course with a total of 70 participants.

Improving Program Implementation through Embedded Research: Partnership with the regional offices of the Pan American Health Association and Eastern Mediterranean Regional Office to establish regional embedded implementation research portfolios.

- Co-led a **study** to conduct a process evaluation of the embedded implementation research studies using mixed methods;
- Collaborated in the development of a **journal series** to present the findings from the projects;
- Facilitated a **workshop** for research teams on protocol development.

Embedded Health Systems Research: Activities to further understand and promote the embedded approach to health systems research in which research is integrated into decision-making processes and real-world contexts to inform policy and action.

- Developed a **concept note** to outline the rationale and planned activities for the development of a theory of change for embedded health systems research;
- Collaborated in a **scoping review** to identify the available evidence on embedded health systems research;
- Contributed to the development of an **embedded health systems research framework**;
- Organized a **consultative meeting** to build consensus on the embedded health systems research framework;
- Organized a **global leadership meeting** to build consensus on the way forward for embedded research to strengthen health systems towards Universal Health Coverage;
- Contributed innovative activities for embedded health systems research included in the **biennium work plan and budget**.

Collaboration for Implementation Research and Delivery Science: Collaboration between leading global health partners to elevate and promote implementation research and delivery science.

- Coordinated a **solicitation** for case studies of implementation research and delivery science;
- Collaborated in the development of **joint advocacy and capacity strengthening products** for implementation research and delivery science.

MONITORING AND EVALUATION COORDINATOR May 2012 – December 2013
Chemonics International, Inc. Kigali, Rwanda
USAID Rwanda Family Health Project

Coordinated project activities in health information systems, monitoring and evaluation, and integrated management of childhood illnesses notably malaria:

- Contributed to Rwanda's **technical working group** on health information systems;
- Improved the quality of data reported from **24 hospitals and health centers;**

- Strengthened the capacity of **26 Data Coordinators and Officers** in data reporting;
- Facilitated meetings on data analysis and use for **2 District Health Management Teams;**
- Organized a **workshop** on data analysis and use for Data Coordinators and Officers;
- Developed a **tool** for use by Data Coordinators and Officers to compare data reported through multiple health information systems to identify and correct errors to strengthen the quality of reported data;
- Developed a **plan** to assess and strengthen the capacity of Community Health Workers in reporting to the national community health system;
- Conducted a **needs assessment** for the Integrated Management of Childhood Illnesses program;
- Contributed to the development of **guidelines, training materials, and tools** for integrated community case management of childhood illnesses;
- Conducted an **audit** on the quality of malaria data reported to the national health information system;
- Produced a **protocol** for a study on household practices affecting the durability of long-lasting insecticide treated bed nets to inform the national communication strategy for malaria;
- Authored a **blog** on gender violence in Rwanda published on USAID's Impact Blog as part of the campaign against Gender-Based Violence;
- Generated **donor reports** on the outcomes and impact of the project.

PROJECT MANAGER February 2010 – May 2012
Plan International Kiramuruzi, Rwanda
Isangano Youth Center Project

Managed the Isangano Youth Center Project to establish a center to provide training and life skills strengthening to youth in Gatsibo District, specifically:

- Conducted a **baseline survey and needs assessment** on the status and needs of youth in Gatsibo District;
- Produced a grant application to receive **150,000 USD** to establish a youth center;
- Produced a **strategic and implementation plan** for the youth center project;
- Developed and implemented a context-specific **health course** tailored to youth in Rwanda.

KNOWLEDGE & SKILLS

RESEARCH/ANALYTICS

- Randomized trials, health systems/implementation research, mixed methods studies, user-centered design, and evaluation/monitoring/learning activities
- Formative and summative phases
- Epidemiological and statistical approaches

- Descriptive and inferential statistics
- Quantitative and qualitative data collection and analysis
- Policy, geospatial, and communication analysis
- Linear, logistic, and non-parametric regression
- Programming and data management
- Data interpretation, presentation, and visualization
- Evidence-informed decision-making for policy and action

COMPUTERS

- Microsoft Office Suite
- Stata
- NVivo
- Qualtrics
- ArcGIS

COMMUNICATION

- Adaptive leadership style
- Active speaker and listener
- Strong interpersonal and relationship-building skills to foster trust and engagement
- Work individually and on diverse, transdisciplinary teams
- Produce high-quality analytical outputs
- Generate rigorous and relevant analytical insights

VOLUNTEER SERVICE & ACTIVITES

PEER REVIEWER March 2016 – present
Multiple Academic Journals

GRADUATE SCHOOL CONSULTING CLUB September 2016 – March 2021
Johns Hopkins University Baltimore, MD

TECHNOLOGY ENTREPRENEURSHIP WORKSHOP September 2016 – November 2016
Johns Hopkins Carey Business School Baltimore, MD

GLOBAL HEALTH CASE COMPETITION February 2015 – March 2015
Emory University Atlanta, GA

NATIONAL MALARIA PROGRAM COORDINATOR May 2012 – June 2013
Stomp Out Malaria in Africa Kigali, Rwanda

PEACE CORPS VOLUNTEER February 2010 – May 2012
United States Peace Corps Kiramuruzi, Rwanda

CAMP COORDINATOR January 2008 – August 2008
The DREAM Project Cabarete, Dominican Republic

HONORS & AWARDS

INTERNATIONAL HEALTH SCHOLARSHIP 2015 – 2021
Johns Hopkins Bloomberg School of Public Health Baltimore, MD

HEALTH SYSTEMS DOCTORAL SCHOLARSHIP 2018 – 2019
Johns Hopkins Bloomberg School of Public Health Baltimore, MD

HEALTH SYSTEMS PRACTICUM SCHOLARSHIP 2015 – 2016
Johns Hopkins Bloomberg School of Public Health Baltimore, MD

IMPLEMENTATION RESEARCH FELLOWSHIP March 2015
World Health Organization, World Bank, & USAID Geneva, Switzerland

BAKER, REINKE & TAYLOR AWARD March 2014
Johns Hopkins Bloomberg School of Public Health Baltimore, MD

LANGUAGES & INTERNATIONAL TRAVEL

ENGLISH Native

FRENCH Professional

SPANISH Conversational

KINYARWANDA Basic

INTERNATIONAL TRAVEL 34 countries

PUBLICATIONS & PRESENTATIONS

Mancuso, A., Gibbons, C., Onyeije, K., Ahern, D., Ellison, M. A regional analysis of cancer and connectivity in Appalachia. Journal of Appalachian Health. [Forthcoming]

Mancuso, A., Malm, S., Sharkey, A., Shahabbuddin, A., Shroff, Z. Cross-cutting lessons from the Decision-Maker Led Implementation Research Initiative. Health Research Policy and Systems. [Forthcoming]

Mancuso, A. 2021. Implementation of health-related smartphone applications in low- and middle-income countries: scoping review and learnings from the ChildSafe application in Malaysia. Dissertation & Presentation. Johns Hopkins Bloomberg School of Public Health.

Mancuso, A. 2020. Overcoming implementation barriers: understanding user perspectives of the ChildSafe App in Malaysia. Presentation. National Institutes of Health mHealth Network Meeting. Bethesda, MD.

Langlois, E., **Mancuso, A.**, Elias, V., Reveiz, L. 2019. Embedding implementation research to enhance health policy and systems: a multi-country analysis from ten settings in Latin America and the Caribbean. Health Research Policy and Systems.

Mancuso, A., Nagarajan, M., Bachani, B. 2018. Implementation and dissemination of a mobile phone application for childhood injury prevention in Malaysia. Poster. Safety Conference. Bangkok, Thailand.

Bachani, A., Nagarajan, M., **Mancuso, A.,** Mani, K., Hyder, A. 2018. Assessing the effectiveness of intervention strategies to address home injuries among children in Malaysia: a cluster randomized trial. Presentation. Safety Conference. Bangkok, Thailand.

George, A., Lefevre, A., Sheif, M., **Mancuso, A.**, Sacks, E., Sarriot, E. 2018. Hubris, humility, and humanity: expanding evidence approaches for improving and sustaining community maternal, newborn, and child health. BMJ Global Health 3.

Tilahun, B., Taklu, A., **Mancuso, A.**, Abebaw, Z., Dessie, K., Desaelgn, Z. 2018. How can the use of data within the immunization programme be increased in order to improve data quality and ensure greater accountability in the health system: protocol for an implementation research study. Health Research Policy and Systems 16(37).

Mancuso, A. 2017. Embedding research: global lessons from the Alliance for Health Policy and Systems Research. Presentation. Meeting on Embedded Research for Health Systems Strengthening. Accra, Ghana.

Javadi, D., Feldhaus, I., **Mancuso, A.**, Ghaffar, A. 2017. Applying systems thinking to task shifting for mental health using lay providers: a review of the evidence. Global Mental Health 4.

Tran, N., Langlois, E., Reveiz, L., Varallyay, I., Elias, V., **Mancuso, A.**, Becerra-Posada, F., Ghaffar, A. 2017. Embedding research to improve program implementation in Latin America and the Caribbean. Revista Panamericana de Salud Publica 41.

Mancuso, A. 2016. A theory of change for embedded implementation research. Masters Thesis. Johns Hopkins Bloomberg School of Public Health.

Mancuso, A., Xi, T., Qiu, M., Chang, C., Tan, M., Brooks, K. 2015. Juntos Podemos-innovative program to address the problem of gun violence in Honduras. Proposal & Presentation. Emory Global Health Case Competition.

Mancuso, A. 2010. Baseline assessment on the development priorities and needs of youth in Gatsibo District, Rwanda. Report. Plan Rwanda.

Mancuso, A. 2009. The nutritional impact of the complex humanitarian emergency in Sudan. Honors Thesis. McGill University.

Mancuso, A. 2008. Sex worker policy and HIV/AIDS in the Dominican Republic and Thailand: a comparative analysis. Honors Research Project. McGill University.