Designing mHealth Systems for Behaviour Change

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Statement of Originality

I hereby certify that the work embodied in the thesis is my own work, conducted under normal supervision.

The thesis contains no material which has been accepted, or is being examined, for the award of any other degree or diploma in any university or other tertiary institution and, to the best of my knowledge and belief, contains no material previously published or written by another person, except where due reference has been made. I give consent to the final version of my thesis being made available worldwide when deposited in the University's Digital Repository, subject to the provisions of the Copyright Act 1968 and any approved embargo.

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Acknowledgement of Authorship

I hereby certify that the work embodied in this thesis contains published paper/s/scholarly work of which I am a joint author. I have included as part of the thesis a written declaration endorsed in writing by my supervisor, attesting to my contribution to the joint publication/s/scholarly work.

Tyler J. Noorbergen

By signing below, I confirm that Tyler Noorbergen contributed to the following papers:

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Tyler J. Noorbergen

Contents

Chapter 1.

Motivation and Introduction

1.1. Potential of mHealth Systems

> *"We have to move from incidental healthcare to continuum-based healthcare. To do so, we don't need more technologies. They are already here. We need a culture change with a focus on prevention, instead of pumping money into hospitals."* - Christopher Ross, Mayo Clinic (HIMSS Europe, 2019)

In recent years, the burden on healthcare systems around the world has profoundly increased due to an unprecedented rise of preventable lifestyle diseases, also referred to as non-communicable diseases (NCDs), which have grown at an alarming rate. NCDs are the leading cause of death globally resulting in 38 million (68%) of the world's 56 million deaths in 2012 (WHO, 2014a) with more than 40% (16 million) being premature deaths under age 70 years (WHO, 2014a). The four leading NCDs: cardiovascular diseases (CVD), cancers, chronic respiratory diseases, and diabetes pose a significant economic burden estimated to be US$47 trillion which is expected to evolve staggeringly over the next two decades (Bloom et al., 2011). In Australia, NCDs are estimated to account for 91% of total deaths (WHO, 2014b). Reduction in mortality from NCDs has shown to result from lifestyle changes, among other factors, specifically changes relating to smoking, nutrition, alcohol consumption, and physical activity (SNAP; RACGP, 2015). Despite the influence of lifestyle behaviours on NCDs being well documented and understood, raw health information alone in most cases is not enough to motivate people in the adoption of health behaviour change (Pereira et al., 2013; Urrea et al.,

2015). Therefore, the problem lies in how to encourage positive health behaviour change in lifestyle. Novel approaches are required in order for more effective management of these behavioural factors which have been consistently identified as critical areas for intervention (Urrea et al., 2015). The recent advances in mobile computing and mobile sensor technology provide an opportunity to explore the efficacy of novel mobile-based solutions as they potentially offer significant advantages over traditional forms of health care.

Recently, mobile health systems (or *mHealth systems)* have emerged as a promising technology to increase people's control over their health and facilitate health behaviour change (O'Reilly & Spruijt-Metz, 2013). Enabled by advances in mobile devices and ubiquitous computing, mHealth refers to "medical and public health practice supported by mobile devices, such as mobile phones, patient monitoring devices, personal digital assistants (PDAs), and other wireless devices" (WHO, 2011, p. 6). The two primary application domains that have emerged for mHealth systems are: (1) disease management and (2) health promotion. Firstly, disease management empowers patients to manage their medical conditions more effectively and more independently (e.g., helping people with diabetes to control blood sugar levels; Kitsiou et al., 2017). Secondly, health promotion facilitates better health choices, that is, providing support and encouragement for users to engage in behaviors beneficial to their health outcomes (e.g., improved diet, smoking cessation). This precisely speaks to the challenge outlined in the opening paragraph of this thesis around supporting individuals in adopting healthy lifestyle behaviors to facilitate positive health outcomes. According to a recent industry forecast, the global mHealth market is expected to grow to US$115.6 billion by 2025 from US$25.17, which equates to a year-on-year increase by 35%.

> "*In the context of behavioral health interventions, the ubiquity of digital technologies and their adoption into day-to-day life translates into greater potential reach than*

traditional interventions, and consequently greater potential for positive public health impact." – Moller et al., 2017, p. 86

mHealth has the potential to provide significant benefits, some of which can give it an edge over traditional health interventions and, also, in combination with traditional interventions (e.g., public health education and training). Firstly, unlike traditional methods, mHealth is *cost-effective* and *scalable* (Burke et al., 2015; Naslund et al., 2016; Urrea et al., 2015). It is *cost-effective* as it for the most part takes advantage of devices that the majority of people already own, and it costs little or nothing to download an app. As of 2016, in the US alone over 46 million people use a health or fitness app over the span of one month (Hingle & Patrick, 2016). It is *scalable* because anyone with a smartphone and an internet connection can download an app regardless of their location or the resources around them, making it an ideal implementation method for populations and rural areas. Additionally, mHealth is personal to the user and is able to provide feedback which is individualised, just-in-time, on demand, and engaging in ways traditional interventions are not (Danaher et al., 2015; Free et al., 2013; O'Reilly & Spruijt-Metz, 2013). Lastly, mHealth can provide feedback on physiological markers of NCDs such as heart rate and heart rate variability which is normally imperceptible to the user and difficult to interpret in a meaningful way. By making the link between a person's behaviour and the subsequent change in physiological measurements salient and meaningful, this gives the user more understanding and control over their health. However, despite the widely-acknowledged potential of mHealth systems, there has been limited research that provides guidance for how mHealth systems can be designed to effectively support health behaviour change (Free et al., 2013; Kumar et al., 2013; Payne et al., 2015).

1.2. Challenges of Designing mHealth Systems

While the potential of mHealth systems for supporting such health behaviour change has been well documented, the are many challenges associated with designing mHealth systems which

require further research to address. For example, researchers have argued that the design process for mHealth systems often entails *limited stakeholder involvement* (Burke et al., 2015; Marzano et al., 2015). Given the vast number of stakeholders an mHealth system could potentially involve (e.g., healthcare providers, end-users, carers, health insurance providers, etc.), limited stakeholder involvement in the design of such systems could lead to solution artifacts that lack integration with other health systems (Winters et al., 2017). Winters et al. (2017, p.119) states that this limited stakeholder involvement is likely due to the *absence of a shared language* or *lack of a common framework* in mHealth research and that this has resulted in "a lack of informed engagement with health-sector stakeholders and key decision-makers on mHealth innovation, as well as a distinct lack of integration with the formal health system." In fact, many of the challenges in mHealth system design stem from a lack of stakeholder involvement, such as the commonly cited issues of mHealth systems *not being underpinned by evidence based content* (Burke et al., 2015; Garnett et al., 2016), and that *current apps do not lead to sustained behaviour change* (Patel et al., 2015).

In order to overcome these challenges, many researchers have suggested that the approach of *co-design* be used when designing mHealth systems. Co-design refers to "the creativity of designers and people not trained in design working together in the design development process" (Sanders & Stappers, 2008, p. 6). As an example of the many researchers who have called for co-design to be used in mHealth, Cecilia Bonefeld-Dahl, Director General of DIGITALEUROPE stated:

> *"There is an urgent need that the design of health systems should be done closely with patients and health professionals. Both must have a say in ensuring that healthcare remains relevant, easy to use and valuable."* (ICT&Health, 2018).

Similarly, George Crooks, CEO of the Digital Health and Care Institute in Scotland noted:

> *"To do all of these things [integrating mHealth systems into healthcare systems] there requires to be significant time and effort spent on co-design" (ICT&Health, 2018).*

Research on this matter has referred to two main reasons for using co-design approaches: (1) mHealth represents a complex environment which requires involvement of a diverse range of stakeholders (e.g., government, health practitioners, users, scientists, etc.) and co-design can facilitate the necessary collaboration therein (e.g., Eckman et al., 2016; Medhanyie et al., 2015; Noorbergen et al., 2019); (2) using co-design can ensure that mHealth systems are underpinned by expert insight and best practices (e.g., Burke et al., 2015; Garnett et al., 2016; Moller et al., 2017). However, despite the calls from researchers to use co-design when designing mHealth systems, there is limited research on how co-design can be effectively used in the mHealth context.

1.3. Research Questions and Objectives

Against the backdrop of the opportunities and challenges of designing mHealth systems, this research project sets out to advance the knowledge base on how system designers can build mHealth systems that support positive health outcomes. This wider goal is structured into four interrelated main research questions, as described in the following.

The first research question (RQ1) focuses on establishing the current state of research on how system designers can directly involve users in the different phases of designing an mHealth artifact. Even though there have been repeated calls for system designers to better involve users in the design of mHealth systems, there is currently no overview available on existing studies that have already used such a co-design approach and the methods that these studies have used in the different phases of design.

RQ1: *What is the current state of research on co-designing mHealth artifacts for disease management and health promotion?*

In order to address RQ1, we[1] performed a systematic literature review (SLR; Kitchenham & Charters, 2007; Webster & Watson, 2002) in Chapter 2 for several reasons. First, we wanted to provide the necessary background information for readers to understand the background and principles of co-design and position our research in this emerging field of research. Further, performing an SLR allowed us to analyse and synthesise the currently fragmented body of knowledge on co-designing mHealth artifacts for disease management and health promotion. In this way, we provide an overview of empirical studies that used co-design for developing mHealth systems and map the co-design activities carried out in these studies to a well-established co-design framework. By doing so, researchers and practitioners (such as human-computer interaction and health promotion scholars) can use this overview as a shared frame of reference when planning and executing their co-design activities. In addition, we performed the SLR in order to identify knowledge gaps and suggest new directions for future research[2].

Following up on this SLR, the following chapter focuses specifically on the potential of biosensors, an intriguing technological development that provides new sources of data collected in users' everyday environments.

RQ2: *How can one design mHealth systems to use mobile biosensors for health behaviour change?*

The SLR findings indicate that despite the goal of most mHealth systems being to support a behavioural change within either the disease management or health promotion context, many

[1] The *we* in this thesis refers to both; the readers of this work and my collaborators. I particularly thank Associate Professor Marc Adam, Professor Mario Minichiello, Professor John Attia, Dr. David Cornforth, Associate Professor Mark Roxburgh, and Professor Timm Teubner.

[2] Chapter 2 is based on joint research with Marc Adam, Marx Roxburgh, and Timm Teubner (cf. Noorbergen, Adam, Roxburgh, Teubner, Working Paper)

empirical mHealth studies are not underpinned by established behaviour change frameworks. To address RQ2, we set out to explore how one could design mHealth systems that use mobile biosensors to facilitate health behaviour change (see Chapter 3[3]). To accomplish this, we perform a hybrid approach of deductive and inductive reasoning (Gregory & Muntermann, 2011). In our deductive theorizing, we build on the extant literature to investigate the theoretical pathways for how mHealth systems can use mobile biosensors to facilitate health behaviour change and, from this investigation, develop a set of propositions through an integrative theoretical framework as Baumeister and Leary (1997) suggest. In our inductive theorizing, we conduct semi-structured interviews to develop a set of general design guidelines for how mHealth systems can use mobile biosensors for behaviour change.

A key theme from Chapter 3 is the emphasis on co-design methods. Yet, based on our SLR in Chapter 2 it became apparent that even though there is a comprehensive literature on co-design methods in general, there is only limited guidance provided for the specific challenges that system designers face when developing mHealth solutions. Specifically, the findings of the SLR also made clear that while there are many general co-design frameworks, there has been limited research that explores the unique challenges of applying co-design in an mHealth context and how systems designers can overcome these challenges. In the final empirical chapter of this thesis, we hence seek to address this gap.

> **RQ3:** *How can one contextualize existing co-design frameworks to the mHealth setting?*
>
> **RQ4:** *What are guidelines to address common challenges in using co-design in mHealth systems development?*

[3] Chapter 3 is based on joint research with Marc Adam, John Attia, David Cornforth, and Mario Minichiello (cf. Noorbergen et al., 2019).

To address RQ3 and RQ4, we conduct a qualitative study in Chapter 4[4] that explores how co-design can be used in mHealth systems development. Specifically, we conduct 16 semi-structured interviews to synthesize the theoretical and practical expertise of 8 established co-design method experts (CMEs) as well as 8 mHealth system developers (MSDs). Through this, we develop seven design guidelines which address common challenges when co-designing in mHealth and map these guidelines to the co-design framework by Sanders and Stappers (2014) in order to contextualize it to the mHealth context.

1.4. Research Methodology

To advance the knowledge base for how one can design mHealth systems to support positive health outcomes, three studies were conducted. These three studies aim at addressing the four main research questions and achieving the overall objectives of this research project. The research methods employed in these studies align with the specific research question that they address. Addressing RQ1, Chapter 2 engages in a SLR to establish the current state of research on co-designing mHealth artifacts for disease management and health promotion. Thereby, the SLR follows the guidelines of Kitchenham and Charters (2007) and Webster and Watson (2002). Additionally, we make use of co-reference coupling, a form of bibliographic analysis by Osareh (1996) to identify the level of fragmentation of the literature on co-designing mHealth artifacts and the publications that this field of literature builds on. Addressing RQ2, Chapter 3 engages in a hybrid approach that combines deductive and inductive reasoning (Gregory & Muntermann, 2011). Specifically, we use deduction to develop a set of propositions through an integrative theoretical framework as Baumeister and Leary (1997) suggest. Following this, we use induction through semi-structured interviews, and then use open and axial coding (Strauss & Corbin, 1990), leading to the formation of themes, and

[4] Chapter 4 is based on joint research with Marc Adam and Timm Teubner (cf. Noorbergen, Adam, Teubner, Working Paper)

eventually, design guidelines. Lastly, building on the results of the SLR presented in Chapter 2, Chapter 4 addresses RQ3 and RQ4 through the use of semi-structured interviews and thematic analysis as described in Braun and Clarke (2006).

1.5. Ethical Considerations

To address the research questions and achieve its objectives, this research project involved human participation which was approved by the Human Research Ethics Committee at the University of Newcastle, Australia. The approval numbers were: H-2016-0221 (Chapter 3) and H-2019-0064 (Chapter 4).

Human participation of research participants in this research was in the form of semi-structured interviews. In Chapter 3, we interviewed a total of 30 participants (19 male, 11 female). This included five designers, six health behaviour scientists, three health insurance providers, five health practitioners, three IT professionals, two policy makers, and six users. In chapter 4, we interviewed a total of 16 participants (3 male, 13 female). This included 8 established co-design method experts (CMEs) as well as 8 mHealth system developers (MSDs).

Participants received information sheets that clearly outlined the aims and objectives of the research and were provided with a description of the procedures involved. The information included a statement, which said that participation in the research project was voluntary, and that participants would not be at a disadvantage if they chose not to participate or chose to withdraw from the research at any stage without reason. Also, participants were allowed to request removal of any comment that could identify them or any other comments they wished to remove from the recordings. In order to participate, participants needed to sign and return a consent form. Finally, in order to ensure anonymity of the participants, the PhD candidate used code names to mask their real names and identities when reporting the data in research papers, conferences, as well as in this thesis.

Further, the information statement informed participants about the potential risks and benefits of participating in the research, how their privacy would be ensured and protected, and how the collected data would be used in the research. Also, participants were informed that the responses collected were anonymous, so that once submitted they could not be identified or linked to the data in any way. They were also informed that all data collected would be stored on a secure server (a password-protected computer) for a minimum of 5 years and would only be accessible to members of the research team.

1.6. Thesis Structure

To achieve the above aims and address the research questions of this project, this thesis is organised into five chapters as illustrated in Figure 1.1.

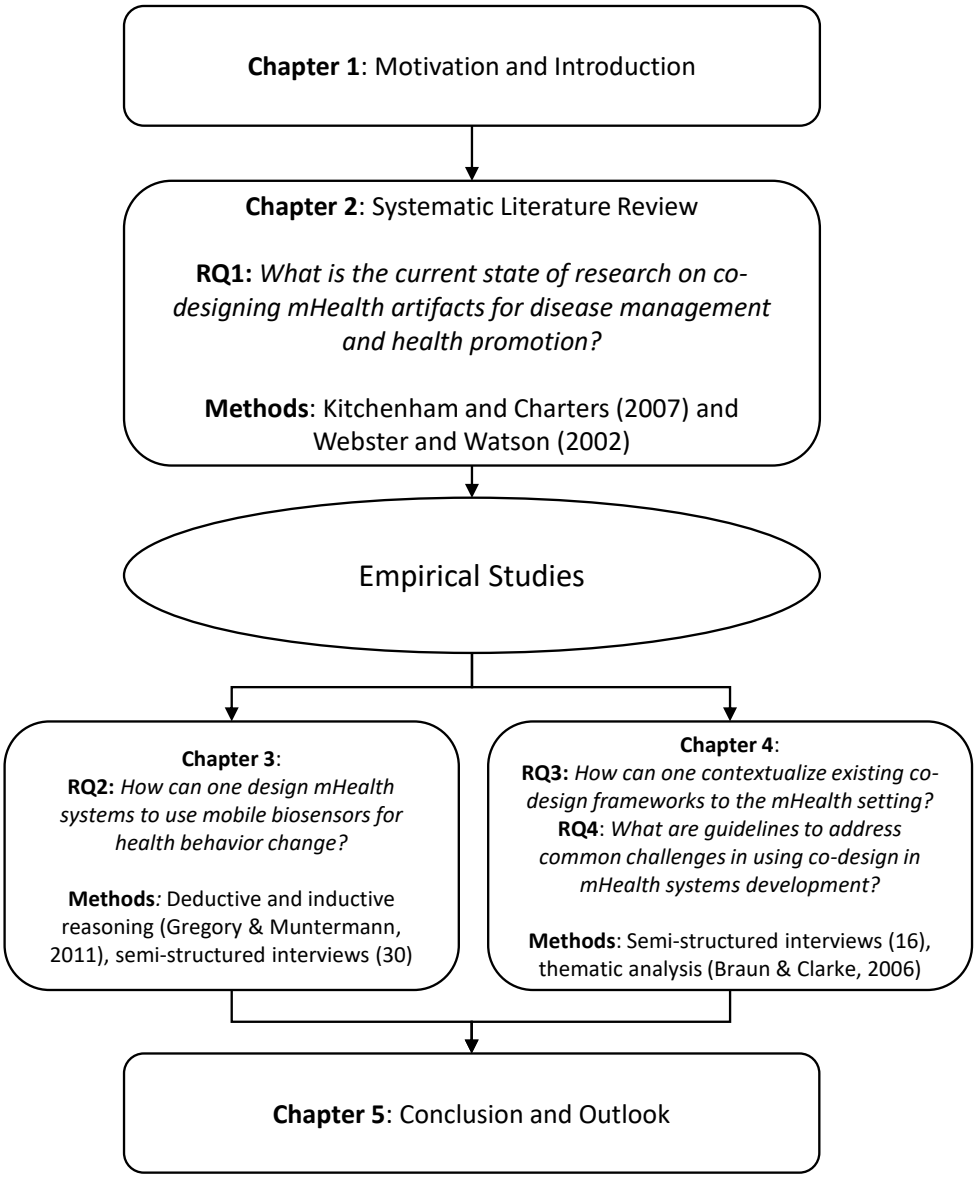

Figure 1.1. Overview of Thesis Structure

Chapter 2.

Co-design in mHealth systems development: Insights from a systematic literature review

2.1. Introduction

The ubiquity and increasing capability of mobile user devices have created new opportunities for the delivery of health services. mHealth is defined as "medical and public health practice supported by mobile devices, such as mobile phones, patient monitoring devices, personal digital assistants (PDAs), and other wireless devices" (WHO, 2011, p. 6). mHealth systems can support users in (1) disease management by enabling them to better self-manage a disease (e.g., diabetes, stroke) and (2) health promotion by supporting them in engaging in healthier lifestyle habits that reduce their individual risk of disease (e.g., increased fruit and vegetable intake, smoking cessation). However, and notwithstanding the opportunities, the design of an mHealth system is often a complex endeavour that involves a range of pitfalls such as limited stakeholder involvement (Burke et al., 2015), lack of integration of mHealth artifacts with the other health systems (Winters et al., 2017), and low use of empirically supported behaviour change strategies (Burke et al., 2015; Noorbergen et al., 2019).

In order to overcome these pitfalls, scholars have suggested to apply the approach of *co-design* to mHealth systems (e.g., Burke et al., 2015; Eyles et al., 2016; Slater et al., 2017; Winters et al., 2017). Co-design, sometimes also referred to as *participatory design* (Kensing, 2003; Kensing et al., 1998), refers to the "creativity of designers and people not trained in

design working together in the design development process" (Sanders & Stappers, 2008, p. 6). It is believed that using co-design in the development of mHealth systems could support system designers in better involving stakeholders in the design and thereby contribute to improved mHealth applications (Burke et al., 2015). However, despite repeated calls from researchers to use co-design in mHealth studies, there is a dearth of coherent understanding on the scope of empirical mHealth studies that have actually used co-design in terms of (1) the targeted disease management and/or health promotion context, (2) the involved stakeholder groups, and (3) the methods used in the different co-design phases. The present chapter aims to close this gap by addressing the following overarching research question:

> **RQ1:** *What is the current state of research on co-designing mHealth artifacts for disease management and health promotion?*

To address this question, we conducted a systematic literature review spanning multiple disciplines[5] of empirical studies which employed co-design methods in the development of mHealth artifacts for disease management and/or health promotion. While there has been extensive research on general frameworks and methods used in co-design, research on how co-design has been applied in the context of mHealth is sparse and highly fragmented. Hence, our aim is to provide an overview of empirical studies that used co-design for developing mHealth systems and map the co-design activities carried out in these studies to a well-established co-design framework. Specifically, we build on the framework by Sanders and Stappers (2014), which breaks down the co-design process into four interconnected phases (pre-design, generative, evaluative, and post-design) and has emerged as one of the most widely-recognized resources in the co-design literature (513 citations on Google Scholar, Dec 2020).

[5] The studies identified in the review are from the research areas of computer science, design, information systems, and public health.

The contributions of our study are fourfold. Firstly, we provide a comprehensive overview of the current state of research on how co-design is used in mHealth for disease management and health promotion. While Eyles et al. (2016) provided a first overview of 9 mHealth studies that were published between 2009 and 2015, our results show that the field has rapidly evolved with a marked increase in studies since 2015 (77% of the studies in our review were published after 2015). Secondly, based on a bibliometric co-citation analysis, our review brings to light that the current body of literature on this matter is fragmented. In this way, we demonstrate the need for a better integration of the literature to facilitate the development of common standards and best-practices for co-designing mHealth systems. To support this, we also identify a set of six publications that emerged as the most influential articles based on the number of times they were cited by the reviewed studies. Thirdly, by directly mapping the reported co-design activities to the established framework by Sanders and Stappers (2014), we provide a concise overview of the methods involved in different phases of co-designing mHealth artifacts. Within the structure of the framework, researchers and practitioners (such as human-computer interaction and health promotion scholars) can use this overview as a shared frame of reference when planning and executing their co-design activities. Finally, we identify gaps in the literature that warrant further investigation.

The remainder of this chapter is organized as follows. Section 2.2 provides a theoretical background on the foundations of co-design, the four co-design phases in framework by Sanders and Stappers (2014), and the application of co-design in mHealth. Section 2.3 outlines our research methodology. In Section 2.4, we present the results of our literature review with a specific focus on the different phases of the co-design process and the stakeholders and methods involved. Section 2.5 concludes with an overview of future research avenues and a discussion of practical implications of this research.

2.2. Theoretical Background

2.2.1. Foundations of Co-design

Since the 1970s, there has been a gradual shift from designing systems for users to designing systems with users (Sanders & Stappers, 2008). In particular, the paradigm of user-centered design acknowledges that systems need to be designed around the characteristics and needs of their users. However, scholars have raised concerns that the design process rarely involves actual users but instead relies on the opinions and experiences of domain experts (Sanders & Stappers, 2008). Against the backdrop of increased system complexity and issues related to poor user interface design, researchers and practitioners have recognized the critical importance of user experience for successful technology adoption (Prahalad & Ramaswamy, 2004). Hence, following the notion that users are experts in their own experiences, there has been a call to actively involve users in the design process (Sanders & Stappers, 2008).

Co-design, as described by Sanders & Stappers (2008, p.6), refers to "the creativity of designers and people not trained in design working together in the design development process". It has its origins in the social-democratic workplace relations of 1970s Scandinavia where practices of participatory design were developed to mitigate the threat of deskilling workers with the advent of computerized systems (Ehn, 1993). Ehn (1993, p.41) elaborated that participatory design was political because it raised "questions of democracy, power, and control at the workplace" by involving workers directly in decisions that impacted them. Yet, the original practices in Scandinavia were also concerned with design because, as Bødker et al. (2000, p.22) stated, it gave "the end users a voice in design and development of computer support in work places, thus enhancing the quality of the resulting system."

By directly involving users in the design process, co-design can contribute to capturing the tacit knowledge and latent needs of users. Thereby, Trischler et al (2018) found that co-

design can facilitate the creation of artifacts that yield high user benefit and novelty but not necessarily feasibility. Similarly, Steen et al (2011) noted that co-design can facilitate a better fit between system design and users' needs, resulting in better user experience and satisfaction. In contrast to non-participatory forms of user-centered design (where user testing is usually undertaken *after* the design phase), co-design involves the joint definition and solving of complex design problems (Lindström & Ståhl, 2015; Visser et al., 2005). Thereby, co-design includes a range of methods that allow stakeholders to express themselves as experts of their own experiences (e.g., cultural probes, paper prototyping, storytelling; Sanders & Stappers, 2008).

Sanders and Stappers (2008) argue that a key difference between co-design and conventional user-centered design is that conventional user-centered design is a designer-centric (or controlled) process as its focus on end users intends to create a better solution for – but not with them. Co-design, on the other hand, recognizes the expertise of users as partners through "the active and direct involvement of all product stakeholders in and throughout the design process" (Sanders, 1992, p. 53). It takes the view that users are experts in their use of the emerging artifacts and that they may use them in ways never imaged, let alone intended by designers. Following this paradigm, collaboration with users allows system designers to discover users' motivations, understand the contexts of artifact use, generate ideas, and understand users' wishes that go beyond what can be achieved from observations (in present or past) (Keller et al., 2006).

2.2.2. Co-design Frameworks

To facilitate the use of co-design in systems development, researchers have proposed a range of methodological frameworks (e.g., Sanders & Stappers, 2008, 2014; Visser et al. 2005). By creating a conceptual structure of the co-design process, these frameworks provide important

guidance as a shared frame of reference for researchers and practitioners. As noted by Sanders and Stappers (2014), the development of these frameworks was also driven by the increasing number of methods: "So many methods, tools and techniques have been introduced that it has become useful to provide frameworks for organizing them" (p. 7). For instance, the framework by Visser et al. (2005) structured the co-design process into the phases of preparation, sensitization, sessions, analysis, and communication. In a different conceptualization, Brandt et al. (2012) describe an iterative cycle of making, telling, and enacting.

Building on these earlier conceptualizations, the framework by Sanders and Stappers (2014) emerged as one of the most widely-recognized resources in the co-design literature (Google Scholar citations: 513; Web of Science citations: 162; Dec 2020). As shown in Figure 2.1, the framework breaks down the timeline of the co-design process (shown in blue) into four inter-connected phases. First, the Pre-design Phase (also known as fuzzy front end or context mapping, Sanders & Stappers, 2008, 2014; Visser et al., 2005) is concerned with understanding the surrounding context and people's experiences, establishing goals for future experiences, and sensitizing participants to the problem space.[6] This captures an "open world" notion, setting out to explore tacit knowledge in the actual user context and "values uncertainty" (Gaver et al., 2004, p. 53). Second, focusing on the future, the Generative Phase produces ideas, insights, and concepts that explore the "design space". Users take an active role in making through the co-creation of conceptual artifacts (e.g., journey maps, paper prototyping, storyboards) that embody and express ideas about how participants wish to live their future lives. Although the vision of the final artifact is still fuzzy, these methods are used to test,

[6] It is important to note that the pre-design phase is also common outside co-design. In conventional user-centered design, this phase often uses "methods of observation to look for patterns of activity, and general user concern" (Druin, 2002, p. 7). Similarly, there is a dedicated problem identification phase in the system development life-cycle (Kendall & Kendall, 2013). However, and in contrast to co-design, during these activities little to no feedback is sought from users about their experience of using objects and technology (Sanders & Stappers, 2014).

transform, and refine "ideas, insights, and concepts that may then be designed and developed" in order to explore their technical and social feasibility (Sanders & Stappers, 2014, p. 10).

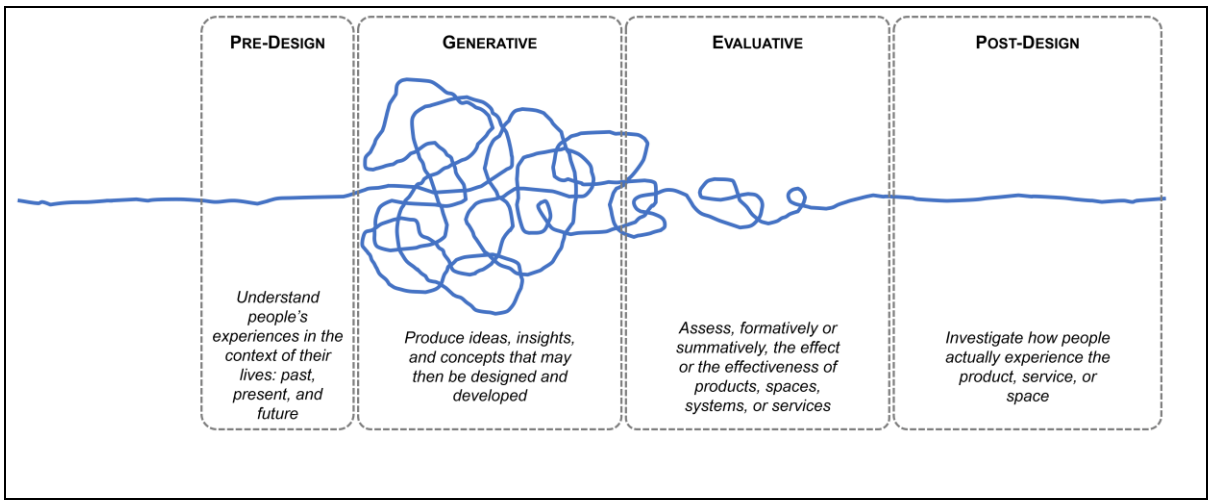

Figure 2.1. Co-design Framework by Sanders and Stappers
(illustration adapted from Sanders & Stappers, 2014)

Third, the Evaluative Phase allows users to assess the effects and effectiveness of the devised concepts. Here the vision of the final artifact becomes more tangible through the evaluation prototypes that allow for users "to experience a situation that did not exist before". Finally, the Post-design Phase refers to the notion that once a system is inhabited by users and becomes part of the users' lived experiences, the system needs to evolve along with the users' needs, habits, and use patterns. As such, "the tail end of the post-design phase [leads] to the front end of another design process" (Sanders & Stappers, 2014, p. 10). This captures the notion that no designed system is ever complete. Further, it is important to note that while there is an intuitive sequence from the left to the right, co-design projects can start in any of the phases (e.g., with an existing prototype that leads to further contextual and generative research, similar to the process model functions described by Peffers et al. 2007). In the following, we build on the structure of the framework by Sanders and Stappers (2014) to organize the results of our systematic literature review.

2.2.3. Co-design in mHealth Systems Development

Based on the increasing capabilities and ubiquity of mobile user devices, mHealth systems hold great potential for novel ways of delivering health services. Rather than limiting the delivery of health services to specific physical locations (e.g., offices of medical practitioners, specialist clinics), mobile user devices enable immediate access to health services in everyday situations (Nahum-Shani et al., 2018). In addition to the ability to communicate health advice through the user interface, these devices can also enable the cost-effective collection and processing of data that provide insight into the users' everyday activities (e.g., eating habits, physical activity) and health status (e.g., insulin, stress level) using a wide array of data collection methods (e.g., biosensors, cameras, questionnaires; Noorbergen et al. 2019). Based on this, mHealth systems can respond to the unique circumstances of the users to support disease management (e.g., diabetes, heart disease) and health promotion (e.g., healthy eating habits, smoking cessation) in a targeted way (Burke et al., 2015; Direito et al., 2017).

Notwithstanding the opportunities associated with mobile user devices, it is important to recognize that the advent of mHealth systems also entails new challenges for system designers. Given the mobile context, the mHealth systems need to smoothly "integrate into users' daily lives" (Bock et al., 2013). This requires a profound understanding of the users' environment and daily routines that the mHealth systems are integrated into. This complex environment is further compounded by the multiplicity of factors affecting and supporting a person's health which in turn requires careful consultation with domain-specific stakeholders. Depending on the focus of the application context (e.g., diabetes self-management, promotion of healthy eating habits), this includes domain-specific healthcare professionals with expertise on specific health conditions and physiological mechanisms (e.g., dietitians, endocrinologists) as well as interaction with end-users from potentially vulnerable populations (e.g., stroke survivors). Further, the effectiveness of mHealth systems commonly relies on a change in the

users' behaviour, both for disease management (e.g., adherence to medication regime, Vilarinho et al., 2017; performing rehabilitation exercises, Davis et al., 2017) and health promotion (e.g., reduction in alcohol consumption, Gustafson et al., 2014; forming healthy eating habits, Dol et al., 2016). It is hence vital for the design of the mHealth system to clarify the targeted behaviour and the strategy that the system follows to facilitate behavioural change (Burke et al., 2015; O'Reilly & Spruijt-Metz, 2013).

Against the backdrop of these challenges, scholars have suggested to apply the approach of co-design and directly involve stakeholders in the design of mHealth systems (e.g., Burke et al., 2015; Eyles et al., 2016; Slater et al., 2017; Winters et al., 2017). However, despite a growing number of studies applying co-design approaches in mHealth systems design, reviews on the use of co-design for mHealth systems development are scant. In 2016, Eyles et al. (2016) conducted a first review of nine studies published between 2009 and 2015. However, the field has rapidly evolved with a marked increase in the number of studies since 2015 (77% of the studies in our review were published after 2015). More recent reviews, such as Moore et al. (2019), have focused specifically on disease management (e.g., management of diabetes) while not considering health promotion (e.g., healthy eating habits) or the context of mHealth specifically. However, as stated earlier in this section, the mobile context of mHealth systems introduces a new array of challenges that require a profound understanding of the users' environment and daily routines. As such, to the best of our knowledge, there is currently no review available that (1) considers both disease management and health promotion, (2) provides an up-to-date mapping between methods (e.g., cultural probes, storytelling) to particular co-design phases in this context, or (3) provides an overview of the mHealth stakeholders involved in the co-design process.

2.3. Research Method

In order to establish the current state of research on co-designing mHealth systems, we conduct a systematic literature review following the guidelines and recommendations of Kitchenham and Charters (2007) and Webster and Watson (2002). Thereby, the review was subdivided into three stages (plan, conduct, and report; see Figure 2.2).

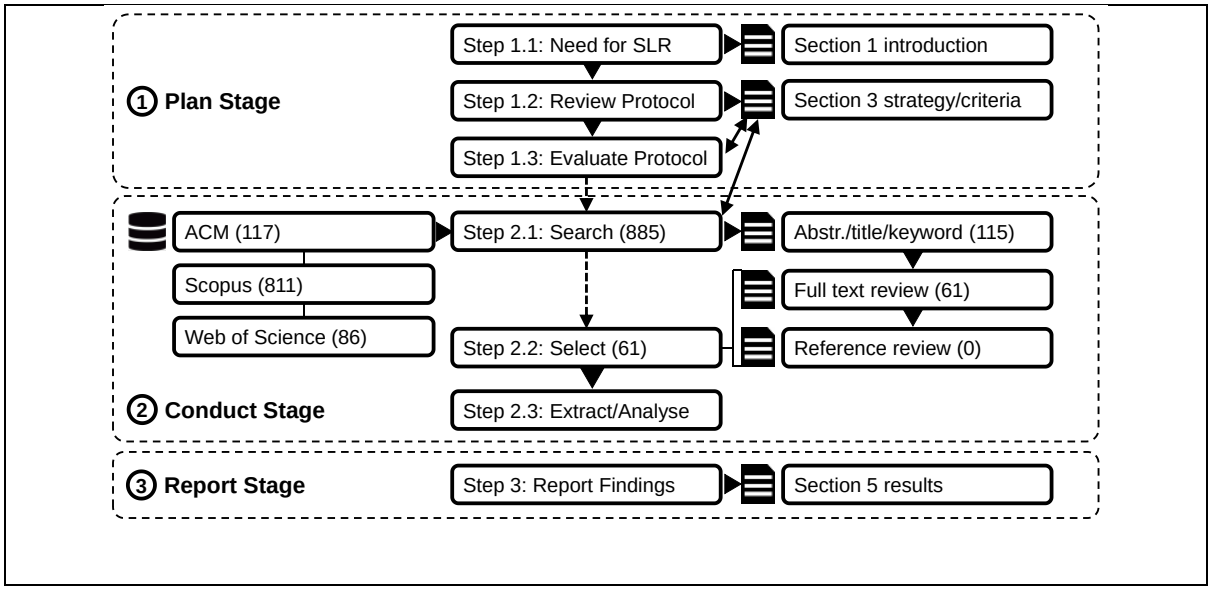

Figure 2.2. Stages of the systematic literature review based on the process of Kitchenham and Charters (2007)

2.3.1. Selection Criteria

In line with our overarching research question, we only included studies that used co-design to directly involve stakeholders (e.g., users, healthcare professionals, system designers) in the development of an actual mHealth system for disease management and/or health promotion. Hence, we excluded articles that were purely conceptual or that used co-design to develop a system outside the mHealth context. Also, we only included studies that were written in English and that were published as peer-reviewed book chapters, journals, or full-text conference articles.

2.3.2. Search Strategy

In order to develop our search string, we first conducted an initial search on Google Scholar using the search query (“co-design” OR “participatory design”) AND (“mHealth” or “m-Health”). After reviewing the results, we identified an initial set of 12 studies that matched the study selection criteria. After a full-text review of these studies, we refined the search string:

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("mHealth" OR "m-health" OR "mobile health") AND ("co-design" OR "codesign" OR "participatory design" OR "design game*" OR "storyboard*" OR "cultural probe*" OR "informational probe*" OR "technology probe*" OR "empathy probe*" OR "journey map*")
```

Given the interdisciplinary nature of the subject matter, we decided to conduct the search on three separate databases to cover a broad range of publications (ACM, Scopus, Web of Science). Also, to capture full years of research activity, the search is delimited to the end of 2019. As shown in Figure 2.2, the main search yielded 885 studies from three databases (after removing duplicates). The authors then screened the publications based on their title, abstract, and keywords, which narrowed down the set to 115 publications. After full-text screening the remaining articles and ensuring that they followed the selection criteria we identified 61 studies for inclusion in the review.

2.3.3. Data Extraction

In order to analyse how the studies applied co-design to mHealth systems development, the goal of the analysis was to extract information on the targeted disease management (e.g., asthma, diabetes) and/or health promotion (e.g., nutrition, physical activity) context as well as the stakeholders and methods involved in the different phases of the co-design process. To extract this information, we carefully perused each article with a particular focus on the information reported in the respective method section. Thereby, we extracted the exact wording

for the stakeholders and methods reported in the article, and then mapped this information to the four co-design phases in the framework of Sanders and Stappers (2014).

The mapping to the four phases was based on our own reading of the paper using the information reported in the articles as well as the original descriptions of the phases by Sanders and Stappers (2014). For instance, research activities as part of "contextual", "problem identification", and "requirement elicitation" research were mapped to the pre-design phase. Conversely, activities reported as part of "concept generation" and "generative workshops" were mapped to the generative phase. Further, activities where a "software prototype" was developed and/ or evaluated were mapped to the evaluative phase. Lastly, activities that mentioned the term "post-design" (e.g., "post-design interviews"; Ahmad et al., 2008) were mapped to the post-design phase.

2.3.4. Bibliographic Analysis

In addition to the information extracted from the articles, we are also interested in the level of fragmentation of the literature on co-designing mHealth artifacts and the publications that this field of literature builds on. To achieve this, we conduct a co-citation analysis that provides insight into the structure of the reviewed publications based on which literature they cite. Specifically, we draw on co-reference coupling, a variation of co-citation coupling, to establish a normalized measure of how "connected" any two papers are based on the overlap in the references they draw on (Osareh, 1996). This also allows us to identify the most influential articles that this stream of literature builds on.

2.4. Results

In our analysis, we first present the disease management and/or health promotion context addressed in the reviewed studies, followed by an overview of the stakeholders that were involved in the co-design process. After that, we provide an overview of the employed co-

design methods along with a mapping to the four phases in the framework by Sanders and Stappers (2014). Finally, we report the results of our bibliometric co-citation analysis to assess the conceptual overlap and fragmentation of publications in the field.

2.4.1. Application Contexts

As shown in Figure 2.3, the use of co-design methods in mHealth systems design has significantly increased over time (61 papers in our review compared to 9 papers in Eyles et al. 2016). In fact, the majority of studies have appeared after 2015 (47). Thereby, we can observe that the vast majority of studies either focus exclusively on the disease management context (38 studies, 62.3%) or the health promotion context (22 studies, 36.1%). Only one early study from 2010 focuses on both contexts.

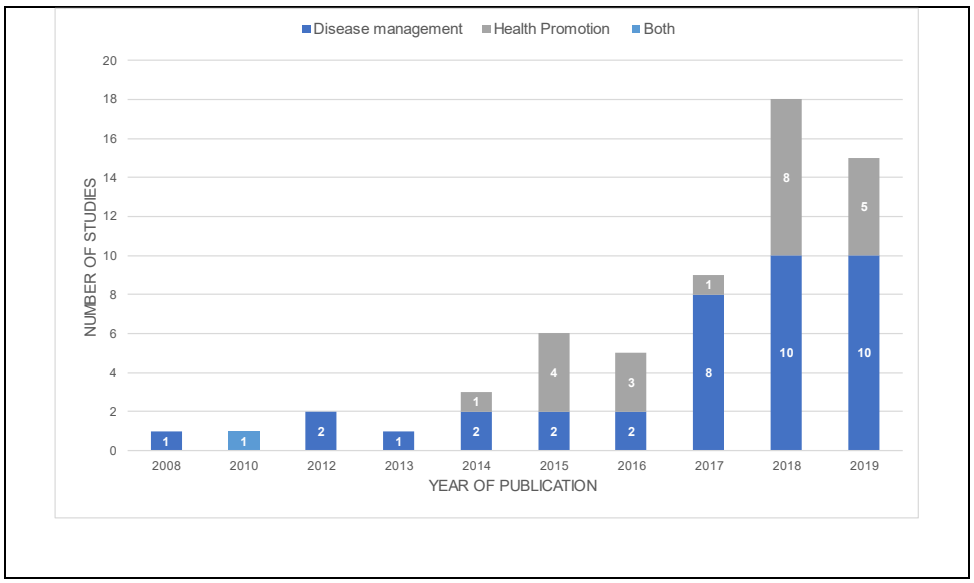


Figure 2.3. Empirical mHealth papers that use co-design over time

Table 2.1 provides a detailed overview of the specific areas within disease management and health promotion that were addressed. The focus of studies in disease management were primarily in heart disease (8), diabetes (5), asthma (3), home-based healthcare (3), and bipolar

disorder (3). Conversely, the focus in health promotion ranges across physical activity (6), mental health (6), nutrition (5), and smoking cessation (2).

Table 2.1. Overview of mHealth contexts investigated in the reviewed studies

Context/Focus	**References**
Disease Management – 39 (63.9%)	
Heart Disease – 8 (13.1%)	(Andersen et al., 2017; L. Woods et al., 2017b, 2017a, 2018a, 2018b; L. Woods, Duff, et al., 2019; L. Woods, Roehrer, et al., 2019; L. S. Woods et al., 2019)
Diabetes – 5 (8.2%)	(Castensøe-Seidenfaden et al., 2017, 2018; Kanstrup, 2014; Ledderer et al., 2019; Shin & Holtz, 2019)
Asthma – 3 (4.9%)	(Davis et al., 2018, 2019; Peters et al., 2017)
Home-Based Healthcare – 3 (4.9%)	(De La Harpe, 2012, 2014; De La Harpe et al., 2013)
Bipolar Disorder – 3 (4.9%)	(Bauer et al., 2017; Matthews et al., 2015, 2016)
Osteoarthritis – 3 (4.9%)	(Danbjørg et al., 2018; Jakobsen et al., 2018b, 2018a)
Cancer – 2 (3.3%)	(Lipson-Smith et al., 2019; Veale et al., 2019)
Depression – 2 (3.3%)	(Bauer et al., 2017; Løventoft et al., 2012)
HIV – 2 (3.3%)	(Marent, Henwood, Darking, et al., 2018; Marent, Henwood, & Darking, 2018)
Schizophrenia – 2 (3.3%)	(Terp et al., 2018, 2016)
Stroke – 2 (3.3%)	(Aljaroodi et al., 2017; Balatsoukas et al., 2019)
Misc – 6 (9.8%)	(Ahmad et al., 2008; Arslan et al., 2010; Bauer et al., 2017; Das et al., 2015; Grosjean et al., 2019; Vilarinho et al., 2017)
Health Promotion – 23 (37.7%)	
Physical Activity – 6 (9.8%)	(Capel et al., 2015; Dol et al., 2016; Ni Mhurchu et al., 2019; Partridge et al., 2019; Te Morenga et al., 2018; Van Velsen et al., 2019)
Mental Health – 6 (9.8%)	(Arslan et al., 2010; Christie et al., 2019; Deady et al., 2018; Halje et al., 2016; Peters et al., 2018; VanHeerwaarden et al., 2018)
Nutrition – 5 (8.2%)	(Dol et al., 2016; Ni Mhurchu et al., 2019; Partridge et al., 2019; Te Morenga et al., 2018; Verbiest et al., 2018)
Smoking Cessation – 2 (3.3%)	(Ni Mhurchu et al., 2019; Paay et al., 2017, 2015)
Menopause Self-Care – 2 (3.3%)	(Trujillo & Buzzi, 2016; Trujillo et al., 2018)
Positive Psychology – 2 (3.3%)	(Jessen, Mirkovic, & Ruland, 2018; Jessen, Mirkovic, & Westeng, 2018)
STI and Drugs – 2 (3.3%)	(Birrell et al., 2018; Cordova et al., 2015)
Misc – 3 (4.9%)	(Arslan et al., 2010; Danbjørg et al., 2014; Ni Mhurchu et al., 2019; Wechsler, 2015)

Note: The table lists all disease management and health promotion contexts targeted by the studies in at least two studies. All contexts that were only mentioned once are included in "misc". For disease management, this includes chronic obstructive pulmonary disease (COPD), cystic fibrosis, presbyopia self-diagnosis, post-myocardial infarction, and PTSD. For health promotion, this includes improving overall wellbeing, lowering alcohol consumption, lowering CVD risk, and postnatal care. Totals do not always match sums of subtotals as there is one study that focuses on both disease management and health promotion (Arslan et al. 2010).

It is important to note that there are also important connections between different health contexts. For instance, individuals with mental health conditions are also more likely to smoke and consume alcohol. However, despite these important connections, the health contexts of mental health, reduction in alcohol consumption, and smoking cessation are commonly referred to as separate fields in the literature (Noble et al., 2015).

2.4.2. Stakeholders

Overall, 57 studies (93.4%) involved users in the design process. As can be seen in Table 2.2, the most frequent user groups were patients (39, 64%), general population (13, 21.3%), family members (11, 18.0%), and care givers (9, 14.8%).

Table 2.2. Overview of users involved in the reviewed studies

Group	Disease Management [% of 39 studies]	Health Promotion [% of 23 studies]
Patients [39, 64%]	(Ahmad et al., 2008; Aljaroodi et al., 2017; Andersen et al., 2017; Arslan et al., 2010; Balatsoukas et al., 2019; Bauer et al., 2017; Castensøe-Seidenfaden et al., 2017, 2018; Danbjørg et al., 2018; Das et al., 2015; Davis et al., 2018, 2019; De La Harpe et al., 2013; Grosjean et al., 2019; Jakobsen et al., 2018b; Jessen, Mirkovic, & Ruland, 2018; Jessen, Mirkovic, & Westeng, 2018; Kanstrup, 2014; Ledderer et al., 2019; Lipson-Smith et al., 2019; Løventoft et al., 2012; Marent, Henwood, Darking, et al., 2018; Marent, Henwood, & Darking, 2018; Matthews et al., 2015, 2016; Peters et al., 2017; Shin & Holtz, 2019; Terp et al., 2018, 2016; Veale et al., 2019; Vilarinho et al., 2017; L. Woods et al., 2017a, 2017b, 2018a; L. Woods, Duff, et al., 2019; L. Woods, Roehrer, et al., 2019; L. S. Woods et al., 2019) – [37, 94.9%]	(Arslan et al., 2010; Dol et al., 2016; Trujillo et al., 2018) – [3, 13.0%]
General Population [13, 21.3%]	(Arslan et al., 2010; Bauer et al., 2017) – [2, 5.1%]	(Arslan et al., 2010; Birrell et al., 2018; Capel et al., 2015; Deady et al., 2018; Dol et al., 2016; Ni Mhurchu et al., 2019; Paay et al., 2017, 2015; Te Morenga et al., 2018; VanHeerwaarden et al., 2018; Verbiest et al., 2018; Wechsler, 2015) – [12, 52.2%]
Family Members [11, 18.0%]	(Andersen et al., 2017; Castensøe-Seidenfaden et al., 2017, 2018; Kanstrup, 2014; Ledderer et al., 2019; Shin & Holtz, 2019; Vilarinho et al., 2017; L. Woods et al., 2017b, 2018a) – [9, 23.1%]	(Birrell et al., 2018; Danbjørg et al., 2014) – [2, 8.7%]
Caregivers [9, 14.8%]	(Aljaroodi et al., 2017; Balatsoukas et al., 2019; De La Harpe, 2012, 2014; De La Harpe et al., 2013; Shin & Holtz, 2019; L. Woods et al., 2017a; L. Woods, Duff, et al., 2019; L. Woods, Roehrer, et al., 2019) – [9, 23.1%]	-
(Pre) Adolescents [4, 6.6%]	(Arslan et al., 2010) – [1, 2.6%]	(Arslan et al., 2010; Christie et al., 2019; Cordova et al., 2015; Partridge et al., 2019) – [4, 17.4%]
Elderly [2, 3.3%]	(Arslan et al., 2010) – [1, 2.6%]	(Arslan et al., 2010; Van Velsen et al., 2019) – [2, 8.7%]
Other [2, 3.3%]	-	(Te Morenga et al., 2018; Trujillo & Buzzi, 2016) – [2, 8.7%]

Note: The table lists all user groups that were involved in at least two studies. All groups that were only mentioned once are included in "other". This includes communities and pregnant women. Totals do not always match sums of subtotals as there is one study that focuses on both disease management and health promotion (Arslan et al. 2010).

Focusing on the inherent health component of mHealth systems, we now look into the involvement of health professionals. Overall, 37 studies (60.7%) involved healthcare professionals, rendering this group the second most involved after users (see Table 2.3). Thereby, studies with a context of disease management (28, 71.8%) tended to involve more healthcare professionals than studies in health promotion (9, 39.1%).

Table 2.3. Overview of healthcare professionals involved in the reviewed studies

Group	Disease Management (% of 39 studies)	Health Promotion (% of 23 studies)
General Clinicians [18, 29.5%]	(Ahmad et al., 2008; Aljaroodi et al., 2017; Castensøe-Seidenfaden et al., 2018; Davis et al., 2018; De La Harpe et al., 2013; Ledderer et al., 2019; Lipson-Smith et al., 2019; Løventoft et al., 2012;	(Christie et al., 2019; Halje et al., 2016; Partridge et al., 2019) – [3, 13.0%]

	Marent, Henwood, Darking, et al., 2018; Marent, Henwood, & Darking, 2018; Matthews et al., 2015, 2016; Peters et al., 2017; Terp et al., 2016; Veale et al., 2019) – [15, 39.5%]	
Nurses [15, 24.6%]	(Andersen et al., 2017; Castensøe-Seidenfaden et al., 2017, 2018; Grosjean et al., 2019; Ledderer et al., 2019; Marent, Henwood, Darking, et al., 2018; Terp et al., 2016; Vilarinho et al., 2017; L. Woods et al., 2017b, 2017a, 2018a, 2018b; L. Woods, Duff, et al., 2019; L. Woods, Roehrer, et al., 2019) – [13, 34.2%]	(Danbjørg et al., 2014; Wechsler, 2015) – [2, 8.7%]
Dieticians [14, 23%]	(Castensøe-Seidenfaden et al., 2017, 2018; Grosjean et al., 2019; Marent, Henwood, Darking, et al., 2018; Veale et al., 2019; Vilarinho et al., 2017; L. Woods et al., 2017a, 2017b, 2018a, 2018b; L. Woods, Duff, et al., 2019; L. Woods, Roehrer, et al., 2019) – [12, 31.6%]	(Dol et al., 2016; Partridge et al., 2019) – [2, 8.7%]
Health Behaviour Scientists [11, 18%]	(Aljaroodi et al., 2017; Castensøe-Seidenfaden et al., 2017; Davis et al., 2018; Marent, Henwood, & Darking, 2018; Matthews et al., 2015; Peters et al., 2017; Terp et al., 2016) – [7, 18.4%]	(Deady et al., 2018; Dol et al., 2016; Halje et al., 2016; Partridge et al., 2019) – [4, 17.4%]
Pharmacists [8, 13.1%]	(Davis et al., 2018; Marent, Henwood, Darking, et al., 2018; L. Woods et al., 2017a, 2017b, 2018a, 2018b; L. Woods, Duff, et al., 2019; L. Woods, Roehrer, et al., 2019) – [8, 21.0%]	-
Physiotherapists [8, 13.1%]	(Danbjørg et al., 2018; L. Woods et al., 2017a, 2017b, 2018a, 2018b; L. Woods, Duff, et al., 2019; L. Woods, Roehrer, et al., 2019) – [7, 18.4%]	(Dol et al., 2016) – [1, 4.4%]
Specialist Doctors [7, 11.5%]	(Ahmad et al., 2008; Andersen et al., 2017; Veale et al., 2019; Vilarinho et al., 2017; L. Woods et al., 2017a, 2018b; L. Woods, Duff, et al., 2019; L. Woods, Roehrer, et al., 2019) – [7, 18.4%]	-
Social Workers [2, 3.3%]	(Castensøe-Seidenfaden et al., 2017; Marent, Henwood, Darking, et al., 2018) – [2, 5.3%]	-
Misc [9, 14.8%]	(Ahmad et al., 2008; Balatsoukas et al., 2019; Bauer et al., 2017; Davis et al., 2018; Lipson-Smith et al., 2019; Marent, Henwood, Darking, et al., 2018; Terp et al., 2016) – [7, 18.4%]	(Birrell et al., 2018; Peters et al., 2018) – [2, 8.7%]

Note: The table lists all user groups that were involved in at least two studies. All groups that were only mentioned once are included in miscellaneous (misc). This includes care managers, occupational therapists, and sexologists. Specialist doctors included cardiologists, oncologists, opticians, paediatricians, pulmonologists, and respiratory specialists. Totals do not always match sums of subtotals as there is one study that focuses on both disease management and health promotion (Arslan et al. 2010).

Focusing on the inherent system design component of mHealth systems, we now look into the involvement of system designers. In total, 32 studies (52.5%) involved system designers. As shown in Table 2.4, this includes software production professionals (27 studies, 44.3%), user experience designers (8 studies, 13.1%), design researchers (5 studies, 8.2%), graphics designers (5 studies, 8.2%), and IT researchers (4 studies, 6.6%).

Table 2.4. Overview of system designers involved in the reviewed studies

Group	Disease Management (% of 39 studies)	Health Promotion (% of 23 studies)
Software production professionals [27, 44.3%]	(Ahmad et al., 2008; Aljaroodi et al., 2017; Andersen et al., 2017; Bauer et al., 2017; Birrell et al., 2018; Castensøe-Seidenfaden et al., 2017; Danbjørg et al., 2018; Davis et al., 2018; De La Harpe, 2012, 2014; De La Harpe et al., 2013; Grosjean et al., 2019; Jessen, Mirkovic, & Ruland, 2018; Ledderer et al., 2019; Lipson-Smith et al., 2019; Marent, Henwood, Darking, et al., 2018; Marent, Henwood, & Darking, 2018; Terp et al., 2016; Veale et al., 2019; L. Woods et al., 2017a, 2018a; L. Woods, Duff, et al., 2019) – [22, 56.4%]	(Christie et al., 2019; Danbjørg et al., 2014; Deady et al., 2018; Te Morenga et al., 2018; Verbiest et al., 2018) – [5, 21.7%]
User Experience Designers [8, 13.1%]	(Ahmad et al., 2008; Aljaroodi et al., 2017; Andersen et al., 2017; Arslan et al., 2010; Peters et al., 2017) – [5, 12.8%]	(Arslan et al., 2010; Deady et al., 2018; Dol et al., 2016; Peters et al., 2018) – [4, 17.4%]
Design Researchers [5, 8.2%]	(Aljaroodi et al., 2017; Das et al., 2015; De La Harpe, 2012, 2014; De La Harpe et al., 2013) – [5, 12.8%]	-
Graphics Designers [5, 8.2%]	(Andersen et al., 2017; Terp et al., 2016) – [2, 5.1%]	(Christie et al., 2019; Deady et al., 2018; Te Morenga et al., 2018; Verbiest et al., 2018) – [4, 17.4%]
IT Researchers [4, 6.6%]	(Aljaroodi et al., 2017; De La Harpe, 2012, 2014; De La Harpe et al., 2013) – [4, 10.3%]	-
Misc [3, 4.9%]	(Aljaroodi et al., 2017; Arslan et al., 2010) – [2, 5.1%]	(Arslan et al., 2010; Christie et al., 2019) – [2, 8.7%]

Note: The table lists all user groups that were involved in at least two studies. All groups that were only mentioned once are included in miscellaneous (misc). This includes bioengineers, health informatics researchers, and narrative designers. Totals do not always match sums of subtotals as there is one study that focuses on both disease management and health promotion (Arslan et al. 2010) System designers inside the research team were not included.

In addition to users, healthcare professionals, and system designers, some studies also involved other types of stakeholders (6, 9.8%). This includes three studies that included anthropologists (De La Harpe, 2012, 2014; Ledderer et al., 2019), three studies that included facilitators (Balatsoukas et al., 2019; Grosjean et al., 2019; Terp et al., 2016), and two studies that included advisory groups (Bauer et al., 2017; Birrell et al., 2018).

2.4.3. Employed Methods

This section provides an overview of the methods reported in the reviewed studies along with a mapping to the four co-design phases (i.e. pre-design, generative, evaluative, post-design) in the framework of Sanders and Stappers (2014). Thereby, we are particularly interested in the diversity of methods within individual phases, and how this differs between health promotion and disease management. Further, this analysis allows us to discern the methods most-widely used in co-designing mHealth artifacts.

2.4.3.1. Pre-design Phase

More than half of all reviewed papers (35 studies, 57.4%) engaged in the pre-design phase to involve stakeholders in the contextual research for the mHealth system. Table 2.5 provides an overview of the methods used in the pre-design phase. Thereby, the most widely used methods in disease management were interviews (41.0%), personas (17.9%), and focus groups (10.3%). For health promotion, the most widely used methods were interviews (30.4%), personas (21.7%), focus groups (17.4 %), and questionnaires (17.4%).

Scholars reported several benefits to incorporating co-design methods in the pre-design phase. First, they assisted in better understanding the latent needs and experiences of

participants and helped to better understand the data collected from more general methods (e.g., interviews, observation). For example, cultural probes were used to provide deeper understanding of the findings from interviews (Capel et al., 2015). Te Morenga et al. (2018, p.93) stated that these methods provide "deeper insight into the lives and aspirations of our participants than captured by traditional ethnographic methods, such as in-depth interviews and observations". Secondly, co-design methods in the pre-design phase were also used to sensitize participants to different aspects of the problem space so they were familiar with it before moving into the generative phase (Das et al., 2015).

Table 2.5. Methods used in the pre-design phase of the reviewed studies

Method (#studies)	Disease management (% of 39 studies)	Health promotion (% of 23 studies)
Interviews [22, 36.1%]	(Ahmad et al., 2008; Aljaroodi et al., 2017; Andersen et al., 2017; Arslan et al., 2010; Balatsoukas et al., 2019; Castensøe-Seidenfaden et al., 2017; De La Harpe, 2012; Grosjean et al., 2019; Jakobsen et al., 2018a; Kanstrup, 2014; Ledderer et al., 2019; Løventoft et al., 2012; Matthews et al., 2015; Vilarinho et al., 2017; L. Woods et al., 2017b, 2017a) – [16, 41.0%]	(Arslan et al., 2010; Capel et al., 2015; Christie et al., 2019; Cordova et al., 2015; Halje et al., 2016; Paay et al., 2017; VanHeerwaarden et al., 2018) – [7, 30.4%]
Personas [11, 18.0%]	(Arslan et al., 2010; De La Harpe, 2012; Jessen, Mirkovic, & Ruland, 2018; L. Woods et al., 2017a, 2017b, 2018a; L. Woods, Duff, et al., 2019) – [7, 17.9%]	(Arslan et al., 2010; Dol et al., 2016; Trujillo et al., 2018; VanHeerwaarden et al., 2018; Wechsler, 2015) – [5, 21.7%]
Focus Groups [8, 13.1%]	(Balatsoukas et al., 2019; Bauer et al., 2017; Danbjørg et al., 2018; De La Harpe, 2012) – [4, 10.3%]	(Christie et al., 2019; Deady et al., 2018; Paay et al., 2017, 2015) – (4, 17.4%]
Probes [6, 9.8%]	(Danbjørg et al., 2018; Kanstrup, 2014; Løventoft et al., 2012) – [3, 7.7%]	(Capel et al., 2015; Paay et al., 2017; Wechsler, 2015) – [3, 13.0%]
Questionnaires [5, 8.2%]	(Arslan et al., 2010; Løventoft et al., 2012) – [2, 5.1%]	(Arslan et al., 2010; Deady et al., 2018; Trujillo et al., 2018; VanHeerwaarden et al., 2018) – [4, 17.4%]
Storytelling [5, 8.2%]	(Aljaroodi et al., 2017; Das et al., 2015) – [2, 5.1%]	(Cordova et al., 2015; Te Morenga et al., 2018; Verbiest et al., 2018) – [3, 13.0%]
Observation [4, 6.6%]	(Andersen et al., 2017; Arslan et al., 2010; Ledderer et al., 2019; Løventoft et al., 2012) – [4, 10.3%]	(Arslan et al., 2010) – [1, 4.3%]
Misc [2, 3.3%]	(Jakobsen et al., 2018a; L. Woods, Duff, et al., 2019) – [2, 5.1%]	-

Note: Methods are sorted based on their usage in the reviewed studies (from highest to lowest). All methods that were only mentioned once are included in "misc". This includes field studies, journey maps, and stakeholder maps. Totals do not always match sums of subtotals as there is one study that focuses on both disease management and health promotion (Arslan et al. 2010).

2.4.3.2. Generative Phase

Like the pre-design phase, more than half of all reviewed papers (33 studies, 54.1%) also engaged in the generative phase to involve users in the creation of artifacts. As can be seen in Table 2.6, the most widely used methods specific in this phase for disease management were sketching (23.1%), storyboards (23.1%), mock-ups (23.1%), and paper prototyping (20.5%).

For health promotion, the most widely used methods were paper prototyping (13%) and wireframes (13%).

Scholars reported several benefits of involving users in the generative phase when designing mHealth systems. Firstly, the generative phase aided idea generation, discussion between participants, and further sensitizing the participants to the problem space. For example, Løventoft et al. (2012) used storyboards and sketching to facilitate idea generation and discussion among participants. Secondly, the generative phase allowed for early ideas to be refined in a way that is inexpensive and flexible as participants were viewing, interacting, and modifying with low-fidelity representations of the mHealth system (Ahmad et al., 2008; De La Harpe, 2012) (e.g., mock-ups, wireframes, paper prototyping).

Table 2.6. Methods used in the generative phase of the reviewed studies

Method (#studies)	Disease management (% of 39 studies)	Health promotion (% of 23 studies)
Paper Prototyping [11, 18.0%]	(Ahmad et al., 2008; Castensøe-Seidenfaden et al., 2017; Danbjørg et al., 2018; De La Harpe, 2012; De La Harpe et al., 2013; Grosjean et al., 2019; Løventoft et al., 2012; Terp et al., 2016) – [8, 20.5%]	(Peters et al., 2018; Van Velsen et al., 2019; Wechsler, 2015) – [3, 13.0%]
Wireframes [11, 18.0%]	(Andersen et al., 2017; De La Harpe et al., 2013; Grosjean et al., 2019; Jakobsen et al., 2018a; Matthews et al., 2015; Veale et al., 2019; L. Woods et al., 2017a, 2018a) – [8, 20.5%]	(Christie et al., 2019; Verbiest et al., 2018; Wechsler, 2015) – [3, 13.0%]
Sketching [10, 16.4%]	(Balatsoukas et al., 2019; De La Harpe, 2012; Grosjean et al., 2019; Jakobsen et al., 2018a; Kanstrup, 2014; Terp et al., 2016; Vilarinho et al., 2017; L. Woods et al., 2017a, 2018a) – [9, 23.1%]	(Paay et al., 2015) – [1, 4.3%]
Storyboards [10, 16.4%]	(Arslan et al., 2010; Bauer et al., 2017; De La Harpe, 2012; Løventoft et al., 2012; Terp et al., 2016; L. Woods et al., 2017a, 2017b, 2018a; L. Woods, Duff, et al., 2019) – [9, 23.1%]	(Arslan et al., 2010; Trujillo et al., 2018) – [2, 8.7%]
Mock-ups [9, 14.8%]	(Balatsoukas et al., 2019; Castensøe-Seidenfaden et al., 2017; Danbjørg et al., 2018; De La Harpe, 2014; De La Harpe et al., 2013; Jakobsen et al., 2018a; Løventoft et al., 2012; Matthews et al., 2015; Terp et al., 2016) – [9, 23.1%]	-
Journey Maps [4, 6.6%]	(De La Harpe, 2012; L. Woods et al., 2017a) – [2, 5.1%]	(VanHeerwaarden et al., 2018; Wechsler, 2015) – [2, 8.7%]
Interviews [3, 4.9%]	(Marent, Henwood, Darking, et al., 2018; Marent, Henwood, & Darking, 2018; Veale et al., 2019) – [3, 7.7%]	-
Scenarios [3, 4.9%]	(Arslan et al., 2010; Das et al., 2015; De La Harpe, 2012) – [3, 7.7%]	(Arslan et al., 2010) – [1, 4.3%]
Brainstorming [2, 3.3%]	(Løventoft et al., 2012; L. Woods et al., 2018a) – [2, 5.1%]	-
Card Sorting [2, 3.3%]	(Grosjean et al., 2019; Terp et al., 2016) – [2, 5.1%]	-
Design Games [2, 3.3%]	(Jakobsen et al., 2018a; Kanstrup, 2014) – [2, 5.1%]	-
Focus Groups [2, 3.3%]	(Balatsoukas et al., 2019; Bauer et al., 2017) – [2, 5.1%]	-
Idea Matrix [2, 3.3%]	(L. Woods et al., 2017a, 2017b) – [2, 5.1%]	-
Misc [6, 9.8%]	(De La Harpe, 2012; Kanstrup, 2014; Veale et al., 2019; L. Woods et al., 2017a) – [4, 10.3%]	(Peters et al., 2018; VanHeerwaarden et al., 2018) – [2, 8.7%]

Note: Methods are sorted based on their usage in the reviewed studies (from highest to lowest). All methods that were only mentioned once are included in "misc". This includes collaborative ideation, conversation cards, feature mapping, impact/effort matrix, questionnaires, reflection, "rose, thorn, bud", signposting, stakeholder maps, Venn diagrams, visual votes, and world café. Totals do not always match sums of subtotals as there is one study that focuses on both disease management and health promotion (Arslan et al. 2010).

2.4.3.3. Evaluative Phase

Almost half of the reviewed papers (30 studies, 49.2%) engaged in the evaluative phase and built a software prototype. As can be seen in Table 2.7, the most widely used methods specific in this phase for disease management were high-fidelity prototyping (33.3%), and interviews (20.5%). For health promotion, the most widely used methods were high-fidelity prototyping (21.7%) and questionnaires (21.7%).

Scholars reported that the main benefit of involving users in the evaluative phase was to enable testing and feedback of high-fidelity prototypes before moving on to the post-design phase. For instance, Kanstrup (2014) found that developing high-fidelity prototypes in a co-design environment was useful as it aided in testing the usability of the mHealth system in a playful, co-operative, and engaging way. Further elaborating on this notion, Kanstrup (2014, p. 56) stated: "Legitimacy is obtained via participation. One cannot perform wrongly—the consequences of actions are only simulated and breaking the rules can even be fun". Ahmad et al. (2008) and Castensøe-Seidenfaden et al. (2017) engaged with users in the evaluative phase to accomplish testing and feedback using usability testing (e.g., think-aloud technique).

One important challenge to consider in the evaluative phase that was commonly reported among the reviewed studies was to understand the distinction between the roles of designers and developers and the implications this has on stakeholder involvement. For instance, De La Harpe (2014, p. 27) noted that end-users and designers were excluded at certain points during development as "the translations required by the development process were just too technical to them". Based on the papers reviewed, the role of users in the evaluative phase should be focused on testing high-fidelity prototypes and providing feedback to ensure that the requirements of the mHealth system identified in the previous phases are being adequately translated by designers and developers (De La Harpe, 2012, 2014).

Table 2.7. Methods used in the evaluative phase of the reviewed studies

Method (#studies)	Disease management (% of 39 studies)	Health promotion (% of 23 studies)
High-fidelity Prototyping [18, 29.5%]	(Ahmad et al., 2008; Andersen et al., 2017; Bauer et al., 2017; De La Harpe, 2012, 2014; Jakobsen et al., 2018a; Kanstrup, 2014; Ledderer et al., 2019; Løventoft et al., 2012; Matthews et al., 2015; L. Woods et al., 2017a, 2018a; L. Woods, Duff, et al., 2019) – [13, 33.3%]	(Birrell et al., 2018; Christie et al., 2019; Danbjørg et al., 2014; Paay et al., 2017; Partridge et al., 2019) – [5, 21.7%]
Interviews [9, 14.8%]	(Jakobsen et al., 2018a, 2018b; Ledderer et al., 2019; Shin & Holtz, 2019; Terp et al., 2018; L. Woods, Duff, et al., 2019; L. Woods, Roehrer, et al., 2019; L. S. Woods et al., 2019) – [8, 20.5%]	(Danbjørg et al., 2014) – [1, 4.3%]
Questionnaires [7, 11.5%]	(Castensøe-Seidenfaden et al., 2018; Davis et al., 2019) – [2, 5.1%]	(Birrell et al., 2018; Deady et al., 2018; Ni Mhurchu et al., 2019; Partridge et al., 2019; Trujillo & Buzzi, 2016) – [5, 21.7%]
Pilot Testing [6, 9.8%]	(Davis et al., 2019; Jakobsen et al., 2018b; L. S. Woods et al., 2019) – [3, 7.7%]	(Birrell et al., 2018; Danbjørg et al., 2014; Deady et al., 2018) – [3, 13.0%]
Usability Testing [6, 9.8%]	(Ahmad et al., 2008; Bauer et al., 2017; Castensøe-Seidenfaden et al., 2017; Veale et al., 2019) – [4, 10.3%]	(Christie et al., 2019; Partridge et al., 2019) – [2, 8.7%]
Randomized Control Trials [2, 3.3%]	(Castensøe-Seidenfaden et al., 2018) – [1, 2.6%]	(Ni Mhurchu et al., 2019) – [1, 4.3%]
Misc [6, 9.8%]	(Castensøe-Seidenfaden et al., 2018; Jakobsen et al., 2018a; Veale et al., 2019; L. Woods, Roehrer, et al., 2019) – [4, 10.3%]	(Danbjørg et al., 2014; Trujillo & Buzzi, 2016) – [2, 8.7%]

Note: Methods are sorted based on their usage in the reviewed studies (from highest to lowest). All methods that were only mentioned once are included in "misc". This includes cognitive walkthrough, field studies, focus groups, laboratory testing, observation, roleplaying, "rose, thorn, bud", and storyboards. Totals do not always match sums of subtotals as there is one study that focuses on both disease management and health promotion (Arslan et al. 2010).

2.4.3.4. Post-design Phase

Only a limited number of papers engaged in the post-design (3 studies, 4.9%; see Table 2.8). This represents a profound research gap as several scholars have highlighted the importance of post-design (Sanders & Stappers, 2014) and secondary design (Germonprez et al., 2011). Interestingly, all the studies that engaged in the post-design phase were in the disease management context. Conversely, none of the health promotion studies engaged in the post-design phase. Methods such as post-design interviews, questionnaires, or focus groups were used to follow up with users and to evaluate the effectiveness of the mHealth system after it had been deployed (Ahmad et al., 2008; Davis et al., 2018; Løventoft et al., 2012).

Scholars reported the primary benefit of involving users in the post-design phase was that the mHealth system could be evaluated on how well it has achieved its intended goals (Davis et al., 2018). For instance, Davis et al. (2017) evaluated users' satisfaction with an mHealth system through focus groups, interviews, and questionnaires. Similarly, Løventoft et al. (2012) used a questionnaire, interviews, and data logging to measure compliance.

Table 2.8. Methods used in the post-design phase of the reviewed studies

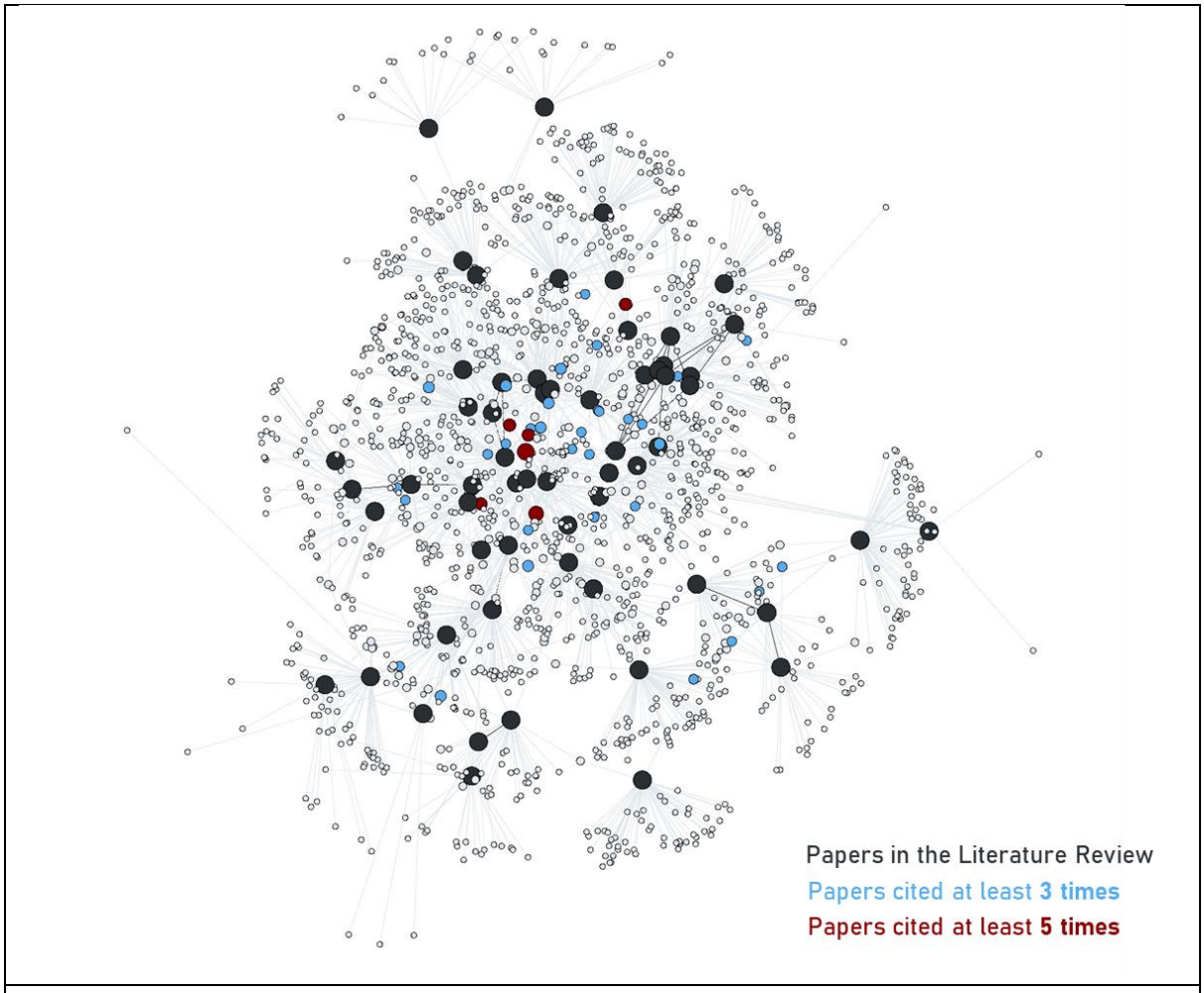
Method (#studies)	Disease management (% of 39 studies)	Health promotion (% of 23 studies)
Interviews [2, 3.3%]	(Davis et al., 2018; Løventoft et al., 2012) – [2, 5.2%]	-
Questionnaires [2, 3.3%]	(Ahmad et al., 2008; Davis et al., 2018) – [2, 5.2%]	-
Focus Groups [1, 1.6%]	(Davis et al., 2018) – [1, 2.6%]	-

Note: Methods are sorted based on their usage in the reviewed studies (from highest to lowest). Totals do not always match sums of subtotals as there is one study that focuses on both disease management and health promotion (Arslan et al. 2010).

2.4.4. Co-Citation Analysis

Finally, we look at the structure of the reviewed publications based on the literature they cite. This provides insight into (1) the overall body of knowledge and understanding these publications draw on and (2) the potential fragmentation of the field. Figure 2.4 shows three co-citation graphs of the reviewed papers (dark grey) and the literature they refer to (light grey, blue, and red). This includes one chart displaying the co-citation graph for all 61 studies, as well as two subgroups for disease management and health promotion studies, respectively.

a) All (61 studies)



b) Disease Management (left) and Health Promotion (right)

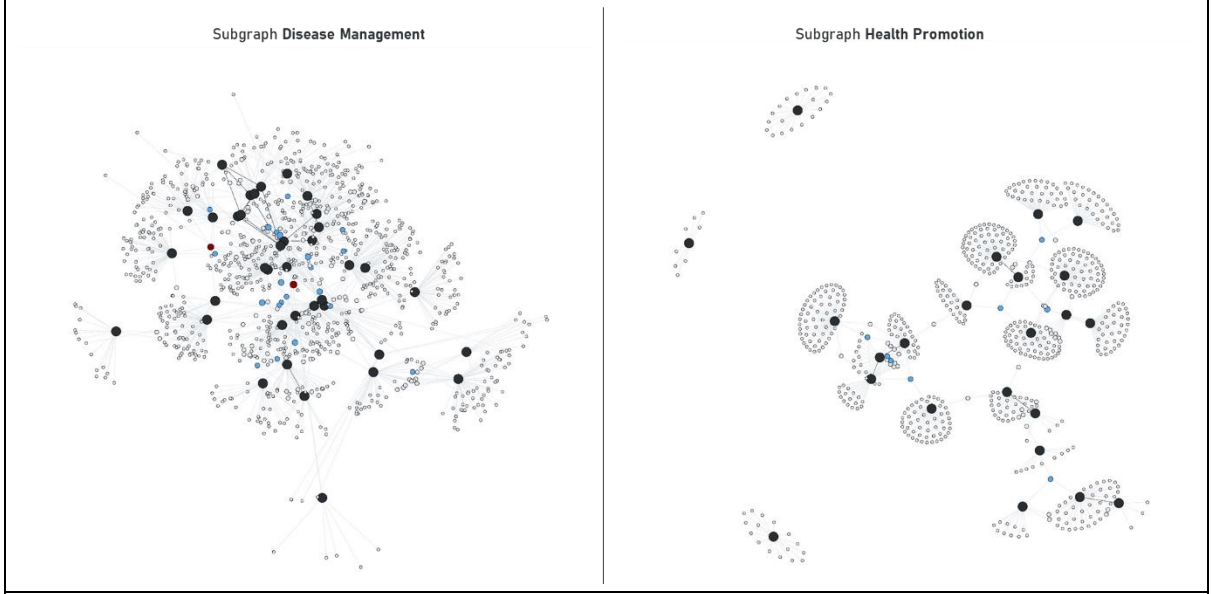


Figure 2.4: Co-citation graphs for the studies in the review corpus

Note: Publications coloured in blue (red) are referred to by three (five) or more of the reviewed papers. Edges coloured in black indicate citations among the reviewed papers. The co-citation graphs were created with R/igraph (Layout: Kamada-Kawai)

Two observations are striking. First, the number of co-citations among the reviewed papers is low. Only 28 (out of 1,881) citations actually link these papers. This can partially be explained by publication lags due to the fact that more than half of the papers have only appeared within the past two years (33 studies, 54.1%). Further, it needs to be noted that the studies cover a wide range of disease management and health promotion contexts with an associated body of literature. Second, the overall set of literature that is commonly cited across the studies in the fundus is small, particularly so for health promotion (see Figure 2.4b). Only very few papers (coloured blue in Figure 2.4a) are cited by three or more of the reviewed papers and only six papers are cited by five or more (coloured red), while each of them refers to their own library of relevant work. [7]

Taken together, this provides evidence for fragmentation of the literature. This is not surprising given that the field that has only emerged in 2009 and is exhibiting rapid growth (see Figure 2.2). However, it requires integrative work such as the present review to support the formation of common standards, best practices, and terminology. To support this, Table 2.9 provides an overview of the six most influential articles in this field based on how often they were cited by studies in the review corpus. Hence, this list of studies is not limited to articles within the review corpus, but instead all publications in the literature that were cited most frequently by the review corpus. Thereby, we observe a strong focus on co-design method sources (Kensing, 2003; Muller, 2008; Sanders & Stappers, 2008; Simonsen & Robertson, 2013). Notably, with Sanders and Stappers (2008), this also includes an important precursor to the co-design framework by Sanders and Stappers (2014) discussed in Section 2.2. Further, the

[7] To illustrate this further, consider the following example of a pairwise comparison. If Paper A (30 references) and Paper B (40 references) share 12 references, we observe an overlap of 20.7% (12 out of unique 58 references). Across all pairwise comparisons in our case, we find an average overlap of 0.37%. In fact, in 87.6% of all pairwise comparisons, there does not occur one single common reference. Unsurprisingly, the highest degree of overlap was found by two articles with the same first author (L. Woods et al., 2018b; L. Woods, Roehrer, et al., 2019).

list includes a widely-established resource on thematic analysis (Braun & Clarke, 2006). At this stage, only one study specifically refers to the health context (Clemensen et al., 2007).

Table 2.9. Top 6 most central publications that influence studies in the review corpus

Publication			Citations	
Author(s) (Year)	**Title**	**Outlet**	**Review Corpus**	**Google Scholar**
Clemensen et al. (2007)	Using cooperative experimental methods in developing health services and computer technology	Qualitative Health Research	9	198
Braun & Clarke (2006)	Using thematic analysis in psychology	Qualitative Research in Psychology	7	89,127
Kensing (2003)	Methods and practices in participatory design	Book	5	134
Muller (2008)	Participatory design: The third space in HCI	Book Chapter	5	150
Sanders & Stappers (2008)	Co-creation and the new landscapes of design	CoDesign	5	3,981
Simonsen & Robertson (2013)	Routledge international handbook of participatory design	Book	5	881

Note: The listed publications were cited at least five times by studies in the review corpus. Citations from Google Scholar as of Dec 2020. Citation numbers for Muller (2008) on Google Scholar are aggregated based on the individual records.

2.5. Discussion and Conclusions

In this chapter, we conducted a systematic review of empirical studies that have employed co-design in mHealth systems development. Thereby, we provide a comprehensive overview of the targeted disease management and health promotion context as well as the stakeholders involved in the co-design activities. Further, building on the framework by Sanders and Stappers (2014), we provide a mapping of the methods used in co-designing mHealth systems to the four phases of the co-design process. In the following, we discuss the knowledge gaps we have identified as well as practical implications of this work.

2.5.1. Knowledge Gaps

Even though the importance of the post-design phase is repeatedly highlighted in the literature (Germonprez et al., 2011; Sanders & Stappers, 2014), the great majority of studies in our review (95.1%) did not engage in this phase of co-design. However, engaging with users in

post-design is important for system designers because "people engage systems in ways that were not planned by the designers" (Germonprez et al., 2011, p. 663) and, therefore, information required to refine the design of an mHealth system cannot be acquired until the artifact has been deployed in the real world and inhabited by users. This is reflected in the fact that the design process often has some degree of circularity, starting off from a minimum viable product and adding features incrementally.

Another important goal of many mHealth systems is to facilitate health behaviour change, for instance, for facilitating knowledge for heart disease self-management (L. Woods et al., 2017a) or for improving nutrition by providing information about healthy eating (Verbiest et al., 2018). Therefore, it is important that the design process does not end after the evaluation phase, but that it continues and factors in user needs over time in an incremental way. This can only be accomplished by making active use of the post-design phase for the development and refinement of mHealth systems.

Methodologically, the dearth of co-design studies on post-design calls for (1) research into how existing methods commonly used in earlier phases can be applied to the post-design phase and (2) the development of new methods that aid system designers in involving users in post-design. For instance, methods such as cultural probes (Sanders & Stappers, 2014) and storytelling (Visser et al., 2005) may also uncover unexpected insights. Sanders and Stappers (2014) noted that research in the contextual (pre-design) phase is concerned with the larger context in which users' lived experiences take place. Similarly, research in post-design is concerned with how users "actually experience the product, service, or space" (Sanders & Stappers, 2014, p. 10). Hence, both design phases refer to experiences of users that take place in the real world. It is for this reason that Sanders and Stappers (2014) argued that the methods used for the pre-design phase are also suited for post-design research. Further, scholars may devise new methods that allow a better involvement of users to champion artifacts in post-

design and to bring to light potential improvements of mHealth systems in post-design. In this vein, secondary design (Germonprez et al., 2011) could potentially play an important role in facilitating feedback from stakeholders in the post-design phase to further refine the mHealth system.

An interesting pathway in this regard is the potential of mHealth systems to capture data pertaining to how users interact with its different components (e.g., objectively measuring user engagement with behaviour change interventions; Moller et al., 2017). At this stage, none of the reviewed studies elaborated on whether, and if so, how data collected in the post-design phase was used in subsequent design cycles or ongoing developments. However, the majority of the reviewed studies were conducted within the past two years and hence further studies may emerge that report on subsequent refinements of initial designs.

As for the facilitation of behaviour change, it is noteworthy that only eleven (Aljaroodi et al., 2017; Castensøe-Seidenfaden et al., 2017; Davis et al., 2018; Deady et al., 2018; Dol et al., 2016; Halje et al., 2016; Marent, Henwood, & Darking, 2018; Matthews et al., 2015; Partridge et al., 2019; Peters et al., 2017; Terp et al., 2016) of the reviewed studies involved health behaviour scientists as stakeholders in the co-design process and only five studies linked the design of their mHealth artifact to an established behaviour change framework (Theory of Planned Behaviour (Lipson-Smith et al., 2019), TransTheoretical Model of Health Behaviour Change (Paay et al., 2015), Theoretical Domains Framework (Ni Mhurchu et al., 2019; Verbiest et al., 2018), and Michie's BCT taxonomy (Ni Mhurchu et al., 2019; Partridge et al., 2019; Verbiest et al., 2018)). This lack of integration with the behaviour change literature also became evident in our co-citation analysis. However, the goals of mHealth systems often implicitly involve some form of behaviour change in the context of a person's health (e.g., facilitating the formation of healthy eating habits). Further, previous reviews have shown that the effectiveness of mHealth systems is positively associated with the number of behaviour

change techniques that are implemented in their design (Noorbergen et al., 2019). Hence, building on existing behaviour change frameworks and involving health behaviour scientists in the design process will provide a strong foundation to facilitate behaviour change.

Finally, it is noteworthy that we observe a diverse range of co-design methods that are used in the different phases of the reviewed studies. While some methods were used more often than others (e.g., 33 interview studies; 18 high-fidelity prototyping studies), none of the methods emerged as a de-facto standard in the field. This might be explained by a complex set of ever-changing circumstances in the mHealth context. For example, different stakeholder groups have varying levels of confidence in their creative ability and therefore require different methods to suit them (Sanders & Stappers, 2008). Moreover, different contexts entail different considerations of timeframes and require new methods to be developed (Sanders & Stappers, 2014). Also, researchers' backgrounds, individual preferences, and familiarity with particular co-design methods are relevant factors for the selection and development of methods (Sanders & Stappers, 2008, 2014). Future research may explore the usefulness of particular methods for specific boundary conditions. For instance, the inherent focus on a person's health often involves interaction with vulnerable cohorts (e.g., patients with diabetes or cardiovascular disease) and issues related to power distance between stakeholder groups (e.g., joint workshops with patients, nurses, and specialist doctors).

2.5.2. Practical Implications

This chapter makes several practical contributions. Firstly, we provide a concise overview of the methods and stakeholders involved in the co-design of existing mHealth artifacts in different disease management and health promotion contexts. The overview of studies focusing on disease management and health promotion allows system designers to identify existing work on a particular mHealth topic and closely related research. Further, the present study constitutes

a starting point for identifying stakeholder categories typically involved in the design process and suitable methods to facilitate this involvement in different stages of the process. Table 2.10 provides an overview of the most frequently used methods along with a brief description and methodological reference.

Table 2.10. Frequently used methods for co-designing mHealth systems

Method (#studies) – Brief Description	Pre-design	Generative	Evaluative	Post-design
Interviews (33). A conversation where questions are asked to discover the views, experiences, beliefs and/or motivations of the participants on specific matters. These can be *structured*, *semi-structured*, or *unstructured* (Gill et al., 2008; Kendall & Kendall, 2013)..	22	3	9	2
High-Fidelity Prototyping (18). A prototype made to closely represent the final design in terms of appearance and functionality (Walker et al., 2002).	-	-	18	-
Questionnaires (13). Questionnaires are any written instruments (e.g., surveys, inventories) that present participants with a series of questions or statements where they respond either by writing out their answers or selecting from among existing answers (Dörnyei & Taguchi, 2009; Kendall & Kendall, 2013).	5	1	7	2
Focus Groups (12). A form of group interview where research participants communicate with one another in order to generate data (Kendall & Kendall, 2013; Kitzinger, 1995).	8	2	1	1
Paper Prototyping (11). A type of usability testing where the intended users of the design perform realistic tasks by interacting with a paper version of the interface. Lower fidelity than mock-ups (C. Snyder, 2003).	-	11	-	-
Personas (11). The creation of condensed user profiles and usage situations in order to model the user, communicate with stakeholders, and speculate on future user needs (Vestergaard et al., 2016).	11	-	-	-
Wireframes (11). An image or set of images which displays the functional elements of a design, typically used for planning a design's structure or functionality. Higher fidelity than sketching. (Morson, 2014)	-	11	-	-
Sketching (10). Drawings, often freehand, that are used as a quick and simple way of exploring initial ideas for designs. Lower fidelity than paper prototyping (Buxton, 2010).	-	10	-	-
Storyboarding (10). A type of visualization to represent use cases, often in the form of pictures or drawings put in a narrative sequence that allows for experiencing, testing, transforming, developing, and completing of early ideas (Sanders & Stappers, 2014).	-	10	-	-
Mock-ups (9). An initial and rough representation of design, usually a scale or full-size model, built for the intent of study, testing, or display. Level of fidelity can vary greatly, but often higher fidelity than paper prototyping (Ulrich & Eppinger, 2012).	-	9	-	-
Probes (6). Materials that have been designed to provoke or elicit response. Users reflect on and verbalize their experiences, feelings and attitudes, and visualize their actions and contexts in order to provide inspiration to designers. Types of probes include: *cultural*, *empathy*, *informational*, and *technology* (Sanders & Stappers, 2014).	6	-	-	-
Usability testing (6). Systematic collection of data (e.g., think-aloud, behavioural) and analysis of how users engage with a system with a particular focus on ease of use and usefulness (Dumas & Redish, 1999).	-	-	7	-
Pilot testing (6). A small scale preliminary study conducted to evaluate feasibility, duration, cost, adverse events, and improve upon the study design prior to implementation of a system (Herman et al., 1992)	-	-	6	-
Storytelling (5). A natural vehicle for capturing and sharing experiences through the communication of stories in order to increase sensitivity to the problem space (Visser et al., 2005).	5	-	-	-

Note: The table lists all methods that were used in at least five studies for any of the four co-design phases. The methods are ordered based on how often they were used in the review corpus, starting with the most frequently used.

Secondly, by building on the co-design framework of Sanders and Stappers (2014), we are able to provide a mapping of the employed methods to the four interconnected phases of co-design (pre-design, generative, evaluative, post-design). The framework has emerged as one of the most widely used resources in the co-design literature. By mapping the methods in the reviewed studies to this framework, we contribute to the knowledge base of system designers engaging in mHealth systems design and scholars aiming to extend the methodological toolbox in this area. The mapping provided in Figure 2.5 may provide researchers and practitioners with a shared frame of reference of the different activities involved in co-designing mHealth artifacts along the four interconnected co-design phases. This frame of reference may support the design team in planning activities and setting goals.

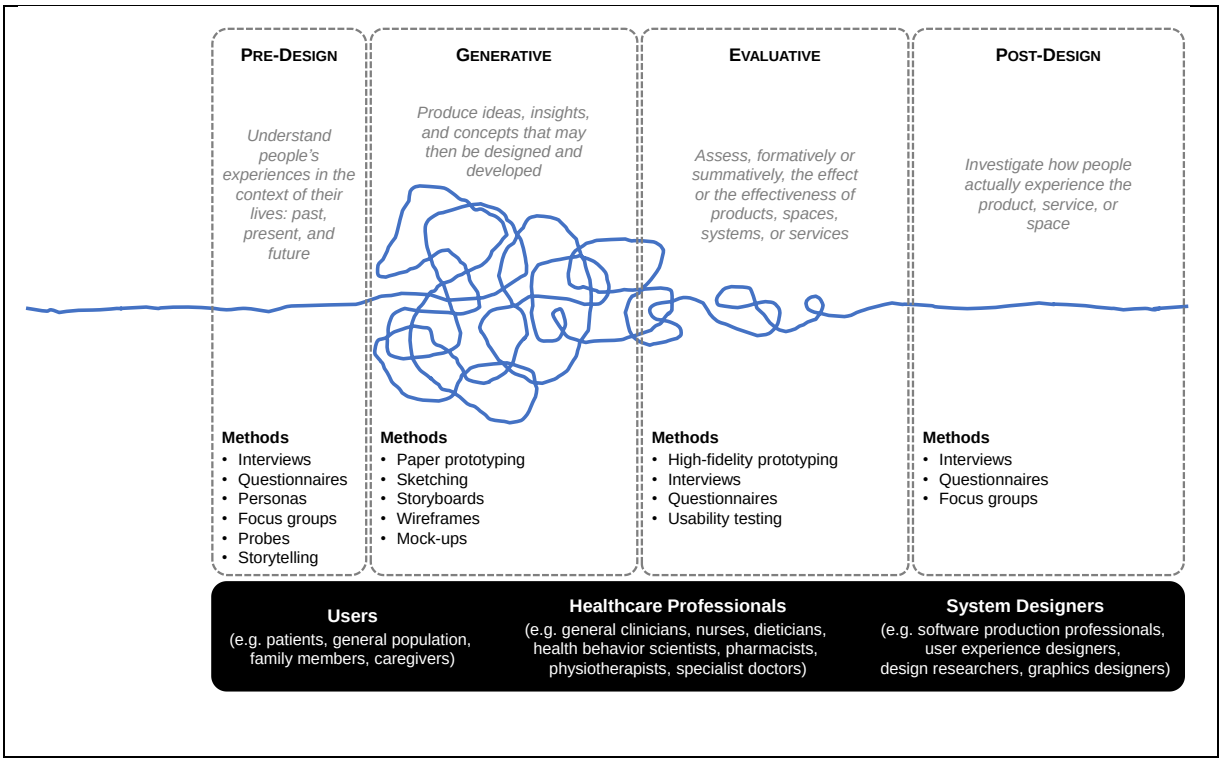


Figure 2.5. Mapping of methods and stakeholders reported in the review corpus to the co-design framework by Sanders & Stappers (2014).

Finally, our study identifies knowledge gaps in applying co-design to mHealth systems development (e.g., limited research in post-design). These knowledge gaps may provide a starting ground for researchers who intend to extend the methodological toolbox in this area (e.g., by devising methods to support user involvement in the post-design phase).

2.5.3. Limitations

There are several limitations of our study that need to be considered. First, while our search string and inclusion criteria were carefully crafted to identify articles that followed a co-design approach to directly involve stakeholders in mHealth systems development, we cannot rule out that there are studies following a closely related approach that used a different terminology to refer to a similar paradigm. Secondly, the application of co-design to mHealth systems design is a nascent field of research, with more than half of the studies only published in the two most recent years of the review. Hence, it is important to note that the results of our review provide a snapshot of the current landscape in a rapidly evolving field. Yet, the fragmentation evidenced by the co-citation analysis corroborate the need for studies that contribute to consolidating the field to facilitate the formation of common standards, best practices, and terminology.

2.6. Concluding note

Taken as a whole, our study provides a concise overview of the contexts, stakeholders, and methods involved in co-designing mHealth systems. We hope this study can serve researchers and practitioners as a reference guide for how co-design can be conducted in an mHealth context and to what advantage. Further, it identifies a gap in the literature concerning the post-design phase. This gap makes it evident that more research is necessary on how the post-design phase of co-design can be better utilized when developing mHealth systems, thereby assisting

system designers to develop systems which evolve over time with, and are responsive to, the changing needs of users.

Chapter 3.

Exploring the Design of mHealth Systems for Health Behaviour Change using Mobile Biosensors

3.1. Introduction

According to the World Health Organization (WHO), health promotion refers to "the process of enabling people to increase control over, and improve, their health" (WHO, 2016). In addition to systemic factors (e.g., availability and pricing of food) and access factors (e.g., ability to pay for food), an individual's own choices, known as health behaviour, plays a vital role in determining their risk of disease and promoting positive health outcomes[8]. Overall, researchers have estimated that the health burden of diseases related to lifestyle behaviors (e.g., cardiovascular disease, diabetes) will amount to US$47 trillion over the next two decades (Bloom et al., 2011), a large portion of which could be prevented by changing people's health behaviour. For instance, researchers have shown that more than 80 percent of cardiovascular events could be prevented if people engaged in health behaviour to modify the four main lifestyle risk factors (namely, alcohol overconsumption, inadequate nutrition, physical inactivity, and smoking) (Urrea et al., 2015). Similarly, engaging in a healthier diet and increasing physical activity can substantially reduce the incidence of diabetes (Hamman et al.,

[8] Note that the terms health promotion and health behavior refer to *people* in general rather than *patients*. Hence, promoting a person's health does not focus only on treating a particular disease. Instead, acknowledging people as the main health resource, health behavior refers to mitigating risk factors and pursuing positive health outcomes (WHO, 1986).

2006). However, despite the staggering loss in economic welfare and the associated detrimental impact on people's quality of life, achieving sustained and lasting change in people's health behaviour remains a societal challenge.

Over the past decade, mobile health systems (or mHealth systems) have emerged as a promising technology to increase people's control over their health and facilitate health behaviour change (O'Reilly & Spruijt-Metz, 2013). Enabled by advances in mobile devices and ubiquitous computing, mHealth systems refer to mobile technology that enhances access to health services (Wowak et al., 2016). With respect to health behaviour change in particular, mHealth systems offer novel modes for delivering technology-mediated interventions that support users in modifying their behaviour for improved health outcomes (Direito et al., 2017). Thereby, we can define a behaviour change intervention (BCI) as a "coordinated [set] of activities designed to change specified behaviour patterns" (Michie et al., 2011, p. 1)[9]. For instance, an education intervention may help a user engage in a healthier diet by providing educational material on the health benefits of increased vegetable consumption through advice in the mHealth interface (Mummah et al., 2016). With the wide proliferation and ubiquity of mobile technology in society, mHealth systems enable the delivery of BCIs in a practical and cost-effective way that can reach a large number of individuals and that may be tailored to the individual user (Direito et al., 2017).

The increasing availability of mobile biosensors represents one recent key development for mHealth systems design; that is, sensors that collect physiological data (e.g., heart rate, respiration, skin conductance) that individuals wear, carry, or access during their normal daily activities (Kumar et al., 2013; Urrea et al., 2015). Combined with contextual information (e.g.,

[9] As Michie et al. (2015) describe, an effective BCI commonly builds on one or more specific behavior-change techniques (i.e., observable and replicable components for changing behavior). The authors identified 93 different techniques (e.g.,, self-monitoring of behavior, information about health consequences, feedback on behavior) that BCIs commonly employ.

location and self-report data), the data obtained from mobile biosensors provide valuable insights into a person's health status and their lifestyle choices (e.g., risk for cardiovascular disease and diabetes) (Ballinger et al., 2018). For instance, mobile heart rate sensors can provide insights into how a person's self-reported smoking habits affect their resting heart rate, and researchers have linked high resting heart rates to an increased risk of cardiovascular disease (Palatini et al., 2006; Papathanasiou et al., 2013). Similarly, biosensors for measuring heart rate, respiration, and skin conductance provide insights into a person's (physiological) stress levels even before individuals consciously perceive stress (Riedl, 2013). mHealth system designers have started to use this source of health information to deliver BCIs. For instance, Xiong et al. (2013) used mobile biosensors to deliver a training intervention for building individuals' capability to perceive and control physiological stress responses. By creating a feedback loop between a user's behaviour and the physiological changes resulting from that behaviour, the system enables users to train to control their physiology with paced breathing exercises while receiving real-time biofeedback on their heart rate and respiration. However, despite the widely acknowledged potential of mobile biosensors, little research provides guidance for how one can design mHealth systems to use mobile biosensors for health behaviour change (Free et al., 2013; Kumar et al., 2013; Payne et al., 2015).

In this chapter, we address this gap by conducting an exploratory study to inform the design of mHealth systems that use mobile biosensors for facilitating health behaviour change. In particular, we follow a hybrid approach that combines deductive and inductive reasoning. First, we integrate a body of fragmented literature (deduction) to develop a theoretical framework (Gregory & Muntermann, 2011). We used this body of (albeit fragmented) literature to derive specific propositions that bring to light the theoretical pathways for how mHealth systems may facilitate health behaviour change by using mobile biosensors. In doing so, the framework may support systems development by providing researchers and

practitioners with a shared frame of reference that allows them to systematically map out how mHealth interface elements can target individual components of behaviour and the types of BCIs that allow them to do so. Second, building on this theoretical groundwork and the stakeholder groups that we identified in the mHealth literature, we conduct a series of exploratory interviews (induction) with representatives from the identified stakeholder groups (health practitioners, health insurance providers, health behaviour scientists, IT professionals, designers, policy makers, and users) based on which we developed six general guidelines for designing such systems. The guidelines add to the mHealth knowledge base by providing system designers with a starting point of practical design considerations that consider multiple stakeholders' perspectives. In this vein, we address the following overarching research question:

> **RQ2:** How can one design mHealth systems to use mobile biosensors for health behaviour change?

This chapter proceeds as follows. In Section 3.2, we overview previous research on designing mHealth systems for behaviour change and the challenges that arise in that context. In Section 3.3, we present the research methodology for the hybrid approach we employed. In Section 3.4, we present the results of our deductive theorizing and introduce an integrative theoretical framework for mHealth systems in the context of health behaviour change. In Section 3.5, based on thematically analysing the interviews, we derive six general design guidelines for designing mHealth systems that use mobile biosensors. In Section 3.6, we discuss our findings, the study's limitations, and opportunities for future research. Finally, in Section 3.7, we conclude the chapter.

3.2. Related Work and Background

3.2.1. Related Work on Designing mHealth Systems for Behaviour Change

Driven by the ubiquity and increasing capabilities of mobile user devices in recent years (Danaher et al., 2015; O'Reilly & Spruijt-Metz, 2013), mHealth systems have become a growing area for IS research and practice. *mHealth* can be defined as "medical and public health practice supported by mobile devices, such as mobile phones, patient monitoring devices, personal digital assistants (PDAs), and other wireless devices" (WHO, 2011, p. 6). According to recent estimates, the number of mHealth apps on the major online stores related to mHealth exceeds 250,000 (R2G, 2016). The two primary application domains that have emerged for mHealth systems over the past decade are: (1) disease management and (2) health behaviour change. Firstly, for *disease management* the focus builds on patient-centred care (Stewart, 2001), that is, empowering patients to manage their medical conditions more effectively and more independently (e.g., helping diabetics control their blood sugar; Kitsiou et al., 2017). Secondly, for *health behaviour change* the focus is on prevention and facilitating better health choices to prevent disease, that is, supporting and encouraging users to engage in health behaviors for the promotion of positive health outcomes (e.g., improved diet, smoking cessation). In this chapter, we focus specifically on the latter category.

Scholars have recognized that the design of a mHealth system plays an important role in its effectiveness for bringing about behaviour change. Several factors for the effective design of such systems have been identified. Firstly, scholars have argued that the design of a mHealth system for behaviour change needs to be guided by a theoretical framework rooted in the BCI literature (Free et al., 2013; Hingle & Patrick, 2016; Oinas-Kukkonen & Harjumaa, 2009). For instance, Hingle and Patrick (2016) argued that a profound understanding of BCIs is critical when making recommendations to users in regards to changing their behaviour and that this ideally should be accomplished through the use of an established intervention framework.

Similarly, Labrique et al. (2013) argued that the lack of a common framework creates difficulties in identifying, cataloguing, and synthesizing evidence for the design of mHealth systems. Hence, guiding the design with a theoretical framework also facilitates the evaluation of such systems. However, as noted by Davey et al. (2014, p. 181), at this stage "most m-health studies are not guided by any conceptual framework, neither the research questions are instigated by existing theories." Hence, there is a need for research that explores how mHealth system design for health behaviour change can be guided by a theoretical framework that is rooted in the BCI literature.

Secondly, recent reviews of existing mHealth systems (Samdal et al., 2017) and web-based eHealth systems (van Genugten et al., 2016) have shown that systems are more effective in bringing about behaviour change if their design implements a higher number of behaviour change techniques. However, at this stage, the number of techniques employed in the delivery of BCIs is small (Conroy et al. 2014, Direito et al. 2017). For instance, in a review of the 200 most popular mHealth apps (free and paid apps on Apple iTunes and Google Play), Conroy et al. (2014) found that apps for physical activity on average only implement four techniques in the delivery of BCIs (see also Direito et al. 2017). Similarly, a review of systems for alcohol reduction has shown that the reviewed systems implemented less than four behaviour change techniques on average (Crane et al., 2015). Hence, it is vital for system designers to consider how they can implement a larger number of techniques through the different pathways of BCIs. As described in the first point, the implementation of these techniques should be guided by a framework grounded in the BCI literature (Garnett et al., 2016; Hingle & Patrick, 2016; Vandelanotte et al., 2016). In particular, guiding the design with an established BCI framework enables system designers to implement a higher number of behaviour change techniques because they can systematically consider a range of different potential pathways for implementing BCIs in their artifact (Michie et al., 2015).

Thirdly, scholars have argued that system designers should consider the potential of mobile biosensors in the delivery of BCIs. More broadly, the design strategy of utilizing biosensors as built-in functions of information systems (vom Brocke et al., 2013, p. 3) allows designers to develop "systems that recognize the physiological state of the user and that adapt, based on that information, in real time" (Riedl et al., 2014, p. i, see Lux et al., 2018 for a review). In doing so, mobile biosensors can facilitate a feedback loop between a user's health behaviour and their physiological state (e.g., biofeedback, Xiong et al. 2013, Uddin et al. 2016; just-in-time interventions, Gutierrez et al., 2015). For instance, Adam et al. (2017) conducted a series of interviews to explore how employing biosignals may lead to the development of stress-sensitive enterprise systems that support users in the management and reduction of stress through interventions at the individual (e.g., biofeedback to increase stress awareness) and organizational levels (e.g., organize break schedules by understanding stress patterns). Based on systematic reviews of academic literature on the effectiveness of mHealth systems, Free et al. (2013) and Schoeppe et al. (2016) conclude that overall there is (1) limited evidence for the effectiveness of mHealth systems (with the exception of SMS) and (2) a need to further explore how technologies such as mobile biosensors and video can be utilized in the delivery of BCIs.[10] Hence, in the present chapter, we specifically focus on the case of mobile biosensors as a promising technology for bringing about behaviour change.

Fourthly, the involvement of mHealth stakeholders plays a critical role for the design process (Facchinetti et al., 2012; Lobelo et al., 2016; Petersen et al., 2015). For instance, Eckman et al. (2016) argued that enabling a collaboration between all stakeholders and making sure that all voices are heard is critical for successful mHealth design. Several scholars have

[10] Reviewing 26 randomized control trials, Free et al. (2013) found that, other than SMS-based interventions (e.g.,, for smoking cessation), mHealth-based BCIs had limited effects on health outcomes. Specifically, Free et al. (2013 p.3) refer to *primary outcomes* (i.e., objective measures of health or health service delivery or use) as well as *secondary outcomes* as (i.e., self-reported outcomes). Similarly, Schoeppe et al. (2016) found limited effectiveness in a review of 30 studies with a focus on diet and physical activity.

suggested co-design methods as a potential mechanism for stakeholder collaboration. For instance, Marzano et al. (2015, p.947) argued that the challenge of mHealth systems design "is a multidisciplinary one and is likely to be best met through a careful process of co-design." Similarly, Burke et al. (2015) argued that many of the pitfalls in current mHealth approaches can be addressed through a process of interdisciplinary collaboration that encompasses the inclusion of end users in all phases. However, despite suggestions for the use of co-design in mHealth, research that uses co-design in the context of mobile biosensors and health behaviour change is sparse.[11] In the present chapter, we engage with different mHealth stakeholder categories to conduct a set of exploratory interviews with the goal of developing a set of general guidelines to support system designers in mHealth systems design for behaviour change. Hence, this chapter does not carry out the co-design of an actual mHealth system artifact, but instead engages with stakeholders to explore design considerations based on multiple perspectives.

3.2.2. Involvement of Stakeholders and Remote Systems

While scholars have recommended to better involve stakeholders in the mHealth design process (e.g., Eckman et al., 2016; Lobelo et al., 2016), to our knowledge there has been limited research that defines the necessary mHealth stakeholders and their degree of involvement in this process. Based on our review of the literature, Figure 3.1 provides an overview of stakeholders and remote systems and how they interact in the context of mHealth systems and health promotion. Overall, we identify seven different stakeholder groups that may contribute important information to the design, these being: *designers (D)*, *health behaviour scientists (HBS)*, *health insurance providers (HIP)*, *health practitioners (HP)*, *IT professionals (ITP)*, *policy makers (PM)*, and *users (U)* (Facchinetti et al., 2012; Lobelo et al., 2016; Petersen et al.,

[11] Donetto et al. (2015) investigate the application of co-design in the healthcare context, but do not discuss mHealth specifically. There have also been several instances of mHealth system design in the context of mental health (Bardram et al., 2013; Ben-Zeev et al., 2015; Thieme et al., 2016), however none of these studies specifically look at the potential of mobile biosensors.

2015; Vandelanotte et al., 2016). Thereby, the term direct stakeholders refers to stakeholders involved in the design and usage of the system, whereas indirect stakeholders are involved in the design of the system, but do not use the system directly themselves. For instance, HPs are direct stakeholders as they could use a mHealth system to monitor users through a remote system, whereas HBSes and PMs have important influencing and supporting roles. Specifically, the expertise of HBSes is vital for the design of a mHealth system as this ensures that it builds on an established BCI framework (Lobelo et al., 2016; Petersen et al., 2015). PMs and HIPs, on the other hand, can provide financial support for mHealth systems and make policy decisions based on the data obtained from them (Facchinetti et al., 2012).

Further, the identification of different stakeholder categories highlights the need to understand how other systems can be integrated into the approach. Specifically, we identify a set of *remote systems* which arise in the context of mHealth systems. These remote systems are separate from the user device and allow for more complex data analysis and involvement of other stakeholders (e.g., HPs). The first remote system is the *data aggregation and analysis service* which aggregates and analyses user data to allow for more detailed feedback such as social comparisons between users. The *health care provider IS* provides information relevant to HPs and allows them to send feedback to users. Lastly, the *health insurance provider IS* provides information to HIPs which can help them become more involved in health promotion. Overall, remote systems are vitally important for mHealth if there is to be any involvement of other stakeholders with the system, and the importance of involving these stakeholders has been heavily emphasized in the literature (Burke et al., 2015; Hingle & Patrick, 2016; Lobelo et al., 2016). In our interviews, we have recruited representatives from all seven stakeholder groups shown in Figure 3.1.

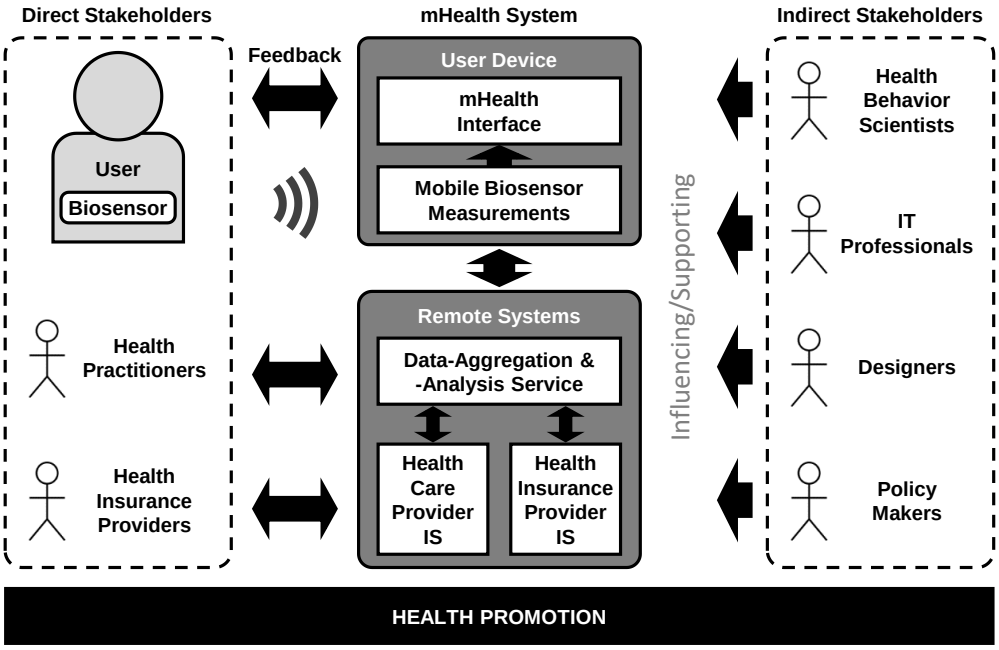


Figure 3.1. Overview of Stakeholders and Remote Systems

3.3. Research Methodology

To address our research question, we conducted an exploratory study and followed a hybrid approach that combined deductive and inductive reasoning (Gregory & Muntermann, 2011). By combining deduction and induction, we could build on the advances in the established behaviour-change literature to provide a theoretical grounding and focus for our research and could explore a broad range of design considerations based on multiple stakeholder perspectives in the mHealth space. We summarize our research methodology in Figure 3.2 (see Arnitz et al., 2017 for a similar conceptualization).

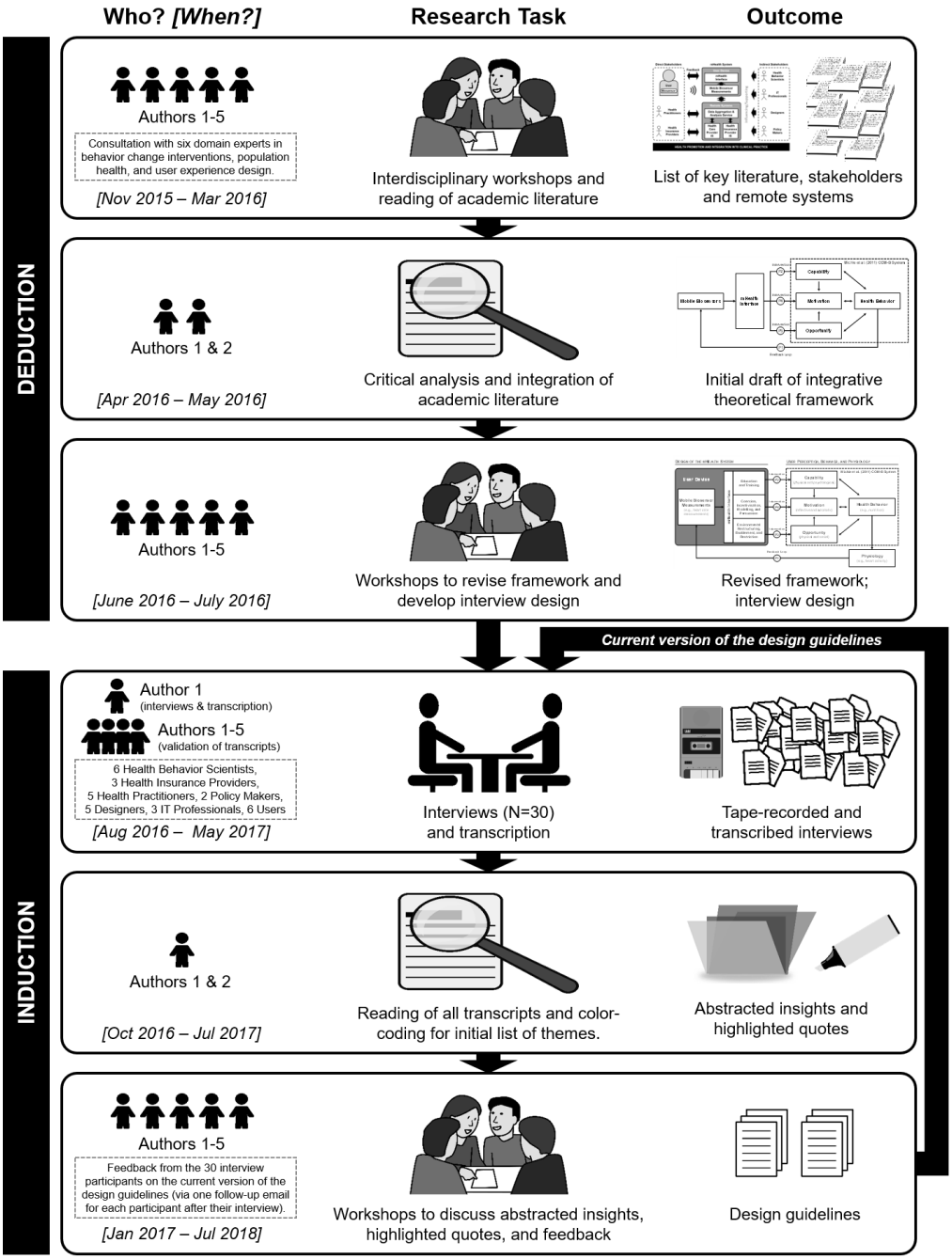


Figure 3.2. Summary of the Research Methodology

3.3.1. Deduction: Development of an Integrative Theoretical Framework

Recent research on mHealth systems' efficacy has argued that the design of such systems needs to be appropriately underpinned by a framework grounded in the BCI literature (e.g., Free et

al., 2013; Morrissey et al., 2016; see also Section 3.2.1). Thus, in our deductive theorizing, we build on the extant literature to investigate the theoretical pathways for how mHealth systems can use mobile biosensors to facilitate health behaviour change and, from this investigation, develop a set of propositions through an integrative theoretical framework as Baumeister and Leary (1997) suggest. In order to address technological and behavioural aspects in designing mHealth systems, in synthesizing the literature, we cover research in the computer science, health, information systems, and psychology disciplines. As Gregory and Muntermann (2011) describe, deductive theorizing in designing information systems builds on critically analysing and integrating the literature to develop propositions about designing artifacts and the way these artifacts provide utility to their users. Hence, it provides a theoretical underpinning for designing artifacts that has a foundation in the literature.

In the first stage of our deductive theorizing, we used recent reviews on mHealth systems' efficacy (e.g., Direito et al., 2016; Free et al., 2013; Payne et al., 2015), BCIs (e.g., Fogg, 2009; Michie et al., 2011; Weinmann et al., 2016), and the integration of biosignals into information systems (e.g., Riedl et al., 2014; vom Brocke et al., 2013) to guide our study. From reading the academic literature, we (with backgrounds in design, information technology, and public health) conducted several interdisciplinary workshops to create a list of key literature, stakeholders, and remote systems for the study's subsequent stages. During these workshops, which lasted between one and two hours each, we engaged in group discussions on existing approaches, findings, and frameworks in the literature that could form the foundation for developing a theoretical framework. In order to actively seek outside expertise, we invited six domain experts to three of these workshops. We selected the domain experts to include a mix of expertise in BCIs, population health, and user experience, and they had between five and 30 years of research experience (avg. 16 years; one industry practitioner, two postdoctoral researchers, three professors). In line with the exploratory nature of this research, we actively

encouraged the domain experts to bring in their expertise and suggest key research streams, stakeholders, and remote systems for our study's context. Thereby, we explicitly told them that we sought to work across disciplinary boundaries and integrate a body of fragmented literature. From consulting with these experts, we assembled a list of key literature in the respective areas (i.e., BCI frameworks, biosensor-enabled mHealth systems, co-design, and mHealth stakeholders) and created an overview of stakeholders and remote systems that we needed to investigate further (see Figure 3.1).

In the second stage of our deductive theorizing, the first (student researcher) and second authors developed an initial draft of the framework by critically analysing and integrating the academic literature that we identified in the first stage. Based on a set of propositions derived from the literature, the framework conceptualizes the different pathways for how one may use mobile biosensors to facilitate behaviour change in a mHealth context. In the third stage, we all then iteratively refined the framework in three subsequent workshops. During these workshops, which lasted between one and two hours each, we discussed the framework's components and how to formulate the propositions. Each author individually prepared for those workshops by working through key literature on BCI interventions and already existing biosensor-enabled mHealth approaches. As such, we could better distinguish the different components of human behaviour, separate human physiology from mobile biosensor measurements, and map specific BCI categories with the components of human behaviour. We discuss how we formulated the propositions in the theoretical framework in Section 3.4.

3.3.2. Induction: Development of Design Guidelines

In our inductive theorizing, we conduct semi-structured interviews to develop a set of general design guidelines for how mHealth systems can use mobile biosensors for behaviour change. As Gregory and Muntermann (2011) describe, inductive theorizing in designing information

systems enables researchers to integrate domain knowledge by considering multiple viewpoints and perspectives based on real-world experience. We conducted our inductive theorizing to develop general guidelines that can help developers develop mHealth systems that use mobile biosensors for health behaviour change.

3.3.2.1. Interview Design

We used the overview of stakeholders and remote systems (Figure 3.1) and the results of our deductive theorizing to guide our interview design. We decided to conduct semi-structured interviews because we could use the structure of the theoretical framework that we developed in our deductive theorizing as a shared frame of reference with the interview participants and explore how appropriate design could address the theoretical pathways that the framework captures. We (all five authors) developed the interview design in several workshops, and it comprised three parts (see Appendix A1.1). In the first part, which built on the overview of stakeholders and remote systems, we explored how participants understood mHealth systems in the context of health behaviour change and how it affected their own stakeholder domain. In the second part, which concerned the theoretical pathways for how mHealth systems may use mobile biosensors for behaviour change, we explored how stakeholders can realize such pathways from their own perspective and whether we missed any theoretical pathways. In the third part, we developed general design guidelines based on the stakeholders' experience and expertise. In order to keep the interviews focused, we decided to refer to mobile heart rate measurements as an example technology of mobile biosensors because heart rate sensors provide important insights into a person's health status (Acharya et al., 2007) and have become increasingly accessible for daily use (e.g., Apple Watch, Samsung Gear). In particular, lifestyle behaviors such as smoking (Papathanasiou et al., 2013) and physical activity (Carter et al., 2003) influence heart rate, and research has shown heart rate measurements to be powerful

markers for health, specifically as a risk factor for cardiovascular disease, diabetes, and all-cause death (Fox et al., 2007; Palatini & Julius, 1997). For instance, research has linked a high resting heart rate to an increased risk of cardiovascular disease and all-cause death (Fox et al., 2007; Palatini et al., 2006; Palatini & Julius, 1997) and shown a low resting heart rate to protect against cardiovascular disease (Palatini, 2009).

Our early interviews had less structure so we could better grasp the subject matter of the discipline and its role in mHealth. However, as the study progressed, our interview questions became more focused (Easterby-Smith et al., 2002). All interviews included graphical representations that depicted the integrative theoretical framework that we developed in our deductive research and the overview of stakeholders and remote systems. As the study progressed, we showed the current version of the design guidelines to participants in order for them to evaluate the guidelines and suggest refinements. Further, emphasizing the exploratory nature of our interviews, we explicitly asked participants to identify stakeholders, theoretical pathways, and design aspects that they felt our work lacked. We refined the questions over time as we collected more data. We audio-recorded the interviews so that we could later analyse the responses and use them to iterate on and refine the design guidelines.

3.3.2.2. Sample

We chose the sample based around the seven stakeholder categories that we identify in Section 3.2.2 (see Table 3.1; 30 interviews in total, one interview per participant). We sourced participants by contacting the directors of a medical research institute and of a local health district. We asked them for domain experts as specified in the stakeholder categories. Further, we sourced users from the general population via face-to-face contact and email. None of the participants participated in conducting this research in any capacity. The ethics committee at the University of Newcastle, Australia, approved the study (H-2016-0221), and we obtained

informed consent from all participants. Interviews occurred on campus or a location of the participant's choosing. Alternatively, we also conducted interviews via Skype. The interviews lasted for an hour on average; however, they varied in focus and length as the study progressed.

Table 3.1. Interview Table

Stakeholder category	Number of interviews
Designers (D)	5
Health behaviour scientists (HBS)	6
Health insurance providers (HIP)	3
Health practitioners (HP)	5
IT professionals (ITP)	3
Policy makers (PM)	2
Users (U)	6
Total	**30**

Note: Abbreviations for the stakeholders categories will be subsequently used in Section 3.5 as identifiers for the participants

3.3.2.3. Data Analysis and Development of Design Guidelines

The first author (student researcher) transcribed the interviews after which at least one other co-author validated each transcript and sent it to the interview participants to check for potential corrections or omissions. Afterwards, the first (student researcher) and second author (an experienced scholar in research on human-computer interaction) used open and axial coding (Strauss & Corbin, 1990) to analyse the transcripts, which involved carefully reading and color-coding the transcripts in order to identify an initial list of themes for developing design guidelines (91 codes linked to 14 themes). The authors identified the themes by critically analysing the codes assigned to the interview statements against the backdrop of the theoretical framework and by identifying similar design concepts presented across the interviews. Afterwards, in five workshops in which we all participated in, we iteratively refined these 14 themes, which became the basis of the design guidelines. We prepared for the workshops by reading the interview transcripts and carefully checking the second author's analyses. We used the workshops, which lasted between one and two hours each, to arrive at consensus around

the themes and design guidelines through a process of selective coding (Strauss & Corbin, 1990). In this process, we examined the initial list of themes and the linkages between them in order to identify general guidelines that best reflected the expressed design considerations. We continued this process until we reached unanimous agreement that the guidelines coherently represented the observations. Finally, we sent each participant one email with the current version of the design guidelines that asked for their feedback. We used any feedback that we received to further refine the design guidelines in the workshops.

3.4. An Integrative Theoretical Framework

In this section, we develop a framework to capture the theoretical pathways for how mHealth systems can use biosensors to support behaviour change. We reviewed existing BCI frameworks to support our framework development, which led to our selecting Michie et al.'s (2011) behaviour-change wheel as the main underlying building block. We built on Michie et al.'s (2011) work for several reasons. First, the behaviour-change wheel builds on an extensive review of existing BCI frameworks and, hence, comprehensively synthesizes the behaviour-change literature. Second, the health-promotion literature has used this BCI framework expansively; as such, stakeholders in health research, which we focus on in our study (e.g., dietary interventions, Robinson et al., 2013; cardiovascular disease risk management, Bonner et al., 2013), recognize it well. Third, due to its simplicity and accessibility, one can apply the framework to a wide range of contexts—an essential consideration to address behaviour-change challenges that require cross-disciplinary collaboration such as in our study.

3.4.1. The Behaviour Change Wheel and the COM-B System of Behaviour

Michie et al.'s (2011) behaviour-change wheel, a BCI framework, allows various users to select and design interventions and policies via analysing the nature of behaviour, the components

that one must change to initiate a behavioural change, and the interventions and policies necessary for changing those components. The framework has three layers from outside to inside: 1) policies, 2) interventions, and 3) components of behaviour. In this chapter, we focus on the latter two layers as developing political interventions lies outside the scope of mHealth system design. The behaviour-change wheel catalogues nine different BCI categories (education, persuasion, incentivization, coercion, training, enablement, modelling, environmental restructuring, and restriction) and illustrates how they link to the components that make up behaviour. These BCI categories can influence one or more components in the inner most layer of the behaviour-change wheel, which Michie et al. (2011) refer to as the COM-B system (see Figure 3.3).

The COM-B system comprises continually interacting components that generate behaviour: capability, opportunity, and motivation (Michie et al., 2011). Capability refers to an "individual's psychological and physical capacity to engage in the activity concerned" (Michie et al., 2011, p. 4). For example, psychological capability involves having the necessary knowledge to achieve a behavioural target, whereas physical capability involves being physically able to achieve a behavioural target. Opportunity refers to "all the factors that lie outside the individual that make the behaviour possible or prompt it" (Michie et al., 2011, p. 4). Further, one can subdivide it into physical opportunity (opportunities in the physical environment such as having access to healthy foods) and social opportunity (opportunities in the social environment, such as language and concepts). Finally, motivation refers to "brain processes that energize and direct behaviour" (Michie et al., 2011, p. 4). One can break down motivation into reflective motivation (conscious reflective processes, such as planning and evaluation) and automatic motivation (affective processes, such as emotions and impulses)[12].

[12] System designers need to distinguish between reflective and automatic motivation for mHealth since it enables them to systematically explore different pathways for addressing user motivation. As Michie et al. (2014) describe, interventions that target reflective motivation focus on instigating and supporting conscious processes that involve

The single and double-sided arrows in the right part of Figure 3.3 conceptualize how a change in one component may indirectly influence another and how the generated behaviour can re-influence the components in the COM-B system. For instance, an environmental restructuring intervention (e.g., increasing the availability of healthy food) that increases physical opportunity may also indirectly increase motivation due to improving the convenience and access to performing the health behaviour (e.g., eating more healthily). Further, achieving this behaviour may increase physical capability (e.g., weight loss) and motivation (e.g., self-efficacy), which, in turn, can enable individuals to perform new behaviors.

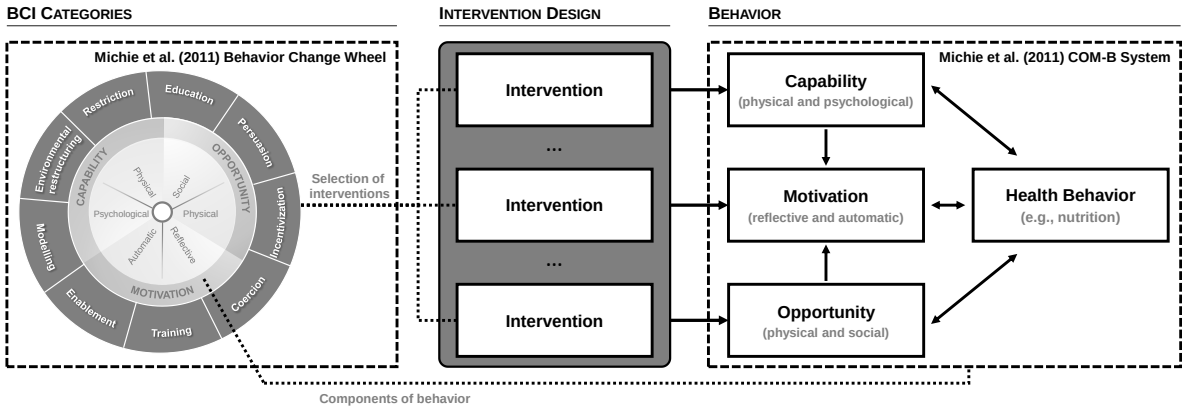


Figure 3.3. BCI Categories and the COM-B System in the Inner Two Layers of the Behaviour-change Wheel

3.4.2. Framework

In this section, we propose an application of the behaviour-change wheel and the COM-B system in the form of an integrative theoretical framework with four propositions (see Figure 3.4).

plans and evaluations (e.g.,, making a plan to stop smoking after reflecting on the health benefits of smoking cessation). By contrast, interventions that target automatic motivation focus on affective responses and the reinforcement of routines and habits (e.g.,, reminders to reinforce the habit of reduced alcohol consumption). By considering these different pathways, system designers may be more effective in addressing user motivation as they can directly map out and consider how each element of their mHealth interface may target one or even both types of motivation (see also Section 3.4.6).

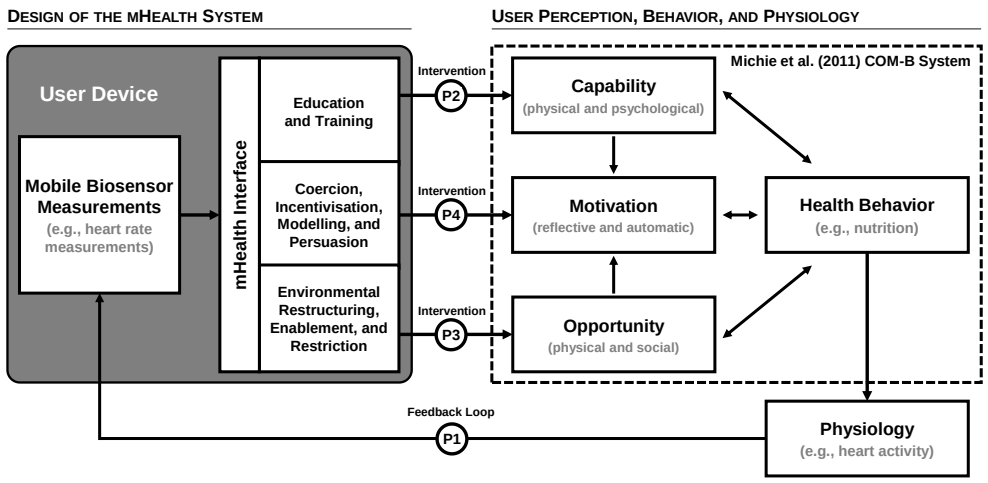


Figure 3.4. An Integrative Theoretical Framework for Using Mobile Biosensors in mHealth Systems for Health Behaviour Change (adapted from Michie et al., 2011)

On the right-hand side, we conceptualize user perception, behaviour, and physiology, which represent the boundary of the user's internal processes. Therefore, note that the perception of the user, which involves their individual circumstances including their physical and social opportunities, influences the effect that an intervention delivered through the mHealth interface (P2, P3, and P4) will have on their COM-B system configuration. Further, we extend the COM-B system in this framework by elaborating on the link between health behaviour and its accompanying change in physiology. For example, in the instance of the health behaviors, researchers have shown both physical activity and endurance training to reduce resting heart rate (Carter et al., 2003; Woodward et al., 2014). We argue that mobile biosensors can capture the changes in physiology as a result of enacted health behaviors, which creates a feedback loop between the user's physiology and their perception, a link that users cannot normally perceive (P1).

3.4.3. Feedback Loop and Mobile Biosensor Measurements (P1)

The feedback loop in our framework encompasses the link between 1) a user's physiology as a result of their health behaviour, 2) mobile biosensor measurements that allow the mHealth system to quantify changes in the user's physiology and use it as a system input, and 3) the interventions embedded in the mHealth interface that targets a user's health behaviour through capability, opportunity, and motivation. Importantly, a user's health behaviour has a direct influence on their physiology regardless of whether the user receives feedback or not. The established literature has documented these links between health behaviour and physiology well and shown physiological measurements to reveal early indicators of health conditions (Fox et al., 2007; Palatini et al., 2006; Palatini & Julius, 1997). However, users normally would not be able to discern how their health behaviour affects their physiology, and the long-term consequences on their health only become apparent over years or even decades. By using mobile biosensors, mHealth systems have the capacity to close the loop between health behaviour, physiology, and user perception; to provide saliency to underlying physiological processes that users cannot usually perceive; and to aid decision making in a motivating and timely way [13]. In other words, while users normally would not be able to see how their health behaviour affects their physiology, the mHealth system can make this link apparent and use it in providing interventions (e.g., showing positive physiological consequences of enacted health behaviour). These BCIs materialize through the mHealth interface where they can influence capability, opportunity, and/or motivation, which the feedback loop that emerges based on mobile biosensor measurements facilitates.

Research has shown feedback to play an important role for bringing about behaviour change. For instance, in control theory (Carver & Scheier, 1982), which sees behaviour as a

[13] Miller (1978) states that feedback is important for instrumental learning (also referred to trial-and-error learning or operant conditioning) in that feedback provides information about the successes and/or failures, which provides an opportunity for users to adjust their response. Without feedback, users are "like a blindfolded novice trying to learn to shoot baskets" (p. 291).

goal-driven process, feedback facilitates behaviour change by revealing the discrepancy between current behaviour and a behavioural goal. Revealing the discrepancy between one's current behaviour and their behavioural goal creates a feedback loop where one can make corrective adjustments to lower this discrepancy until they attain their behavioural goal or until the discrepancy becomes too great and causes one to disengage from the goal due to a lack of capability, opportunity, or motivation. In the IS context, persuasive systems design also incorporates feedback as a method to change users' attitudes or behaviors (Oinas-Kukkonen & Harjumaa, 2009). Fogg (2009) specifically looks at the link between persuasive design and behaviour change through the Fogg behaviour model, which posits that, in order for behaviour change to occur, a person must have sufficient motivation, have the ability to perform the target behaviour, and be timely triggered to perform the behaviour. We can see feedback as one form of a trigger in this model. As for Michie et al. 's (2011) COM-B system, note that this framework does not explicitly include feedback as it operates at a higher level of abstraction. However, in subsequent works, Michie et al. (2015) developed a taxonomy of 93 behaviour-change techniques for delivering BCIs of which feedback accounts for seven (e.g., biofeedback, feedback on behaviour, feedback on outcome(s) of behaviour). Therefore, while Michie et al. (2011) do not explicitly mention the feedback concept in their COM-B system, the relationships between the components implies it.

We argue that feedback based on biosensor measurements plays a particularly important role in facilitating behaviour change in the mHealth context for several reasons. First, people cannot easily monitor changes in their physiology and, hence, see how changes in their health behaviour affect physiological processes because, for the most part, they cannot perceive these processes (Astor et al., 2013; Riedl et al., 2014). However, with the increasing power, accuracy, and accessibility of mobile sensors that collect physiological and contextual data relating to lifestyle behaviors (e.g., location, time of day), one can make these processes salient

to the user via feedback—an important factor because changes in physiology (e.g., decreased resting heart rate) usually precede changes that users can visually perceive (e.g., weight loss). By making users aware of their physiological processes that they cannot normally perceive, it makes the relationship between specific behaviors and their resultant physiological changes more salient, which provides users with the opportunity to make more informed decisions. Second, providing feedback can increase self-efficacy or the belief people hold in their ability to influence events that affect their lives (Bandura, 2010). This belief can change based on how capable people perceive themselves to be in their own abilities. By providing feedback on a person's current physiological state, the person will be more psychologically capable due to having access to additional information that they would otherwise not possess. Mobile biosensors can provide information about the connection between behaviors performed and their subsequent effects on physiology. As a result, this access to information may lead to an increase in a person's perceived control over the outcome of their health and, therefore, lead to an increase in self-efficacy and possibly an increase in motivation to engage in related behaviors.

In sum, feedback plays an important role in behaviour change as it can provide users with timely information about their physiological processes in relation to lifestyle behaviors that would normally remain imperceptible and, subsequently, increase users' understanding of how their actions lead to a change in their bodily states. Hence, it makes the connection between health behaviour and changes in physiological process accessible to the user in a timely manner. Therefore, we propose the following proposition:

Proposition 1 (P1): One can use mobile biosensor measurements to facilitate behaviour change interventions through the mHealth interface by creating a feedback loop between users' health behaviour and their physiology.

However, the feedback loop that we describe here only refers to the general pathway of mobile biosensor measurements as a facilitator for BCIs. Hence, in order to leverage the potential of the established feedback loop for health behaviour change, appropriate mHealth interface design that addresses the components of the COM-B system needs to complement mobile biosensor measurements. Building on this feedback loop, we elaborate on the theoretical pathways for how the mHealth interface can address capability (P2), opportunity (P3), and motivation (P4) in subsequent sections.

3.4.4. The Influence of the mHealth Interface on Capability (P2)

Capability refers to the psychological and physical capacity to engage in an activity. Without the capability to engage in the targeted activities, an individual cannot achieve a change towards health behaviour. Michie et al. (2011) identifies two interventions that one can use to increase capability: education and training. In this section, we discuss how mHealth system designers can use the mHealth interface to increase physical and psychological capability through education and training interventions.

Michie et al. (2011) elaborate that one can increase physical capability through training interventions that facilitate physical skill development. Numerous training interventions use activity sensors for improving physical activity (Glynn et al., 2014), muscular fitness, movement skills, and weight-related behaviors (Smith et al., 2014) by providing instructions on how to perform these behaviors through the mHealth interface. Researchers in the mHealth space have also used biofeedback training to develop skills and improve users' physical capability to regulate their own physiological processes (Lux et al., 2018). For instance, Uddin et al. (2016) developed a mobile training app called Beat that uses an electrocardiographic sensor to provide real-time biofeedback of heart rate variability. The application uses this biofeedback to build the user's skill in controlling their breathing rate to reduce stress and blood

pressure. Similarly, Dillon et al. (2016) used biofeedback for training based on mobile apps that use heart rate and skin conductance for stress management. Hence, one may use biosensors to help users learn to regulate their physiological processes to improve their stress-management capabilities.

On the other hand, Michie et al. (2011) explain that one can accomplish an increase in psychological capability through education and training interventions that impart emotional, cognitive, and/or behavioural skills. Common forms of education interventions in mHealth systems include self-monitoring and performance feedback. Glynn et al. (2014) and Smith et al. (2014) employed education interventions by providing users with performance feedback in relation to previously set health behaviour goals (step count and calories burned). Similarly, the Beat app that we mention above employs an education intervention in the form of a performance review that occurs at the end of the training intervention. This review provides the user with feedback on their performance and visualizes the impact of the breathing exercises and biofeedback on stress over time—a relationship between health behaviour and physiology that users could not normally perceive. One can also increase psychological capability through training interventions, such as through biofeedback based on heart rate or skin conductance for improving users' emotion regulation capabilities (Astor et al., 2013; Peira et al., 2014). Therefore, we propose the following proposition:

Proposition 2 (P2): Mobile biosensor-based interventions that focus on education and training increase users' psychological and physical capability to engage in health behaviors.

3.4.5. The Influence of the mHealth Interface on Opportunity (P3)

Opportunity refers to the physical and social factors outside an individual that prompt behaviour or make it possible. Without the opportunity to engage in a particular activity, one cannot change their behaviour. The BCIs that Michie et al. (2011) identify to increase opportunity include environmental restructuring, enablement, and restriction. In this section, we discuss how the mHealth interface can use mobile biosensors to facilitate interventions for increasing physical and social opportunity.

The mHealth interface can assist users in changing the physical factors in their environment that prompt behaviour or make it possible via environmental restructuring, enablement, and/or restriction interventions (Michie et al., 2011). Environmental restructuring interventions focus on changing users' physical or social context. One way the mHealth interface can increase physical opportunity through environmental restructuring includes just-in-time interventions; that is, interventions that "deliver support at the moment and in the context that the person needs it most and is most likely to be receptive" (Nahum-Shani et al., 2018, p. 446). Researchers have begun to use mobile biosensors to facilitate just-in-time interventions and, thereby, change how users perceive their environment and, as a result, increase their opportunity to engage in health behaviors. For instance, Saleheen et al. (2015) developed a mHealth system that uses respiration biosensors in combination with movement sensors (accelerometers, gyroscopes) and contextual information (location based on GPS) to detect smoking behaviors and trigger just-in-time interventions to stop smoking. Similarly, Gutierrez et al. (2015) developed a mHealth system that detects alcohol intake for just-in-time interventions using heart rate and skin temperature biosensors in combination with movement sensors (accelerometers, gyroscopes) and location sensors (GPS). The mHealth interface can also increase physical opportunity through enablement, which includes interventions that increase means or reduce barriers beyond education or training (Michie et al., 2011). For instance, based on biosensor measurements (e.g., a detected increase in resting heart rate over

time), the mHealth interface may provide individualized behavioural support (e.g., advise on a change in routine), which increases the user's means to engage in a targeted health behaviour (e.g., decrease sodium intake). Lastly, the mHealth interface can increase physical opportunity through restriction interventions that focus on reducing the opportunity to engage in adverse behaviors. In this sense, one could also view Saleheen et al. 's (2015) and Gutierrez et al. 's (2015) systems as restriction interventions as they focus on reducing the opportunity that individuals have to engage in consuming alcohol or smoking.

By extending the user's social context (e.g., facilitating access to communities), the mHealth interface can also increase social opportunity in their cultural milieu. To do so via environmental restructuring, mHealth system designers can use mobile biosensors to facilitate social support (i.e., practical or emotional help from friends, relatives, or colleagues). For example, Snyder et al. (2015) developed a mobile biosensor-based system that facilitates social support for stress management. The system displays a user's current stress level (using skin conductance measurements) to people around the user, who can then consider the user's stress levels in their interactions with that individual. Further, Curmi et al. (2013) developed a system that enables the opportunity for social support during physical activity by sharing the heart rates of triathlon participants with members of their individual social networks in real time. Members of the social network can express their social support by pressing a "cheer" button and the triathlon participant will receive a direct feedback about it through their wearable device. Social comparison represents another way to increase social opportunity through environmental restructuring (i.e., comparing a person's own performance with a peer's). For instance, pointing out the percentile rank of users' physiological stress levels (e.g., based on heart rate and skin conductance) compared to their peers (e.g., same age and gender) creates a social opportunity for them to improve their relative ranking (Lyons et al., 2014). Further, mHealth system designers may also use such social comparisons for enablement. For instance,

an enablement intervention may facilitate behavioural support by enabling users to engage in online discussions with their peers (e.g., users who exhibit a similar diet and resting heart rate) about practical approaches to attain a certain health goal (e.g., their individual best practice for how they include additional servings of vegetables in their diet in order to lower their resting heart rate), which, in turn, increases their means to engage in that behaviour. Similarly, one can address social opportunity through restriction interventions, such as by using mobile biosensor measurements to identify individuals or social groups who exhibit risk behaviors with adverse health effects (e.g., unhealthy diet) and to reduce the number of prompts that the user sees about such behaviors. Therefore, we propose the following proposition:

> **Proposition 3 (P3):** Mobile biosensor-based interventions that focus on environmental restructuring, enablement, and restriction increase users' physical and social opportunity to engage in health behaviors.

3.4.6. The Influence of the mHealth Interface on Motivation (P4)

Motivation refers to reflective and automatic processes that energize and direct behaviour (Michie et al., 2011). Motivation has central importance to behaviour change because, even if users have the capability and the opportunity to carry out targeted activities, they cannot change their health behaviour without a sufficient motivation. The BCIs that Michie et al. (2011) identify to increase motivation include coercion, incentivization, modelling, and persuasion.

Reflective motivation focuses on instigating and supporting conscious processes that involve plans and evaluations. BCIs in the behaviour-change wheel that one can use to increase reflective motivation include coercion, incentivization, and persuasion. Coercion interventions involve creating an expectation of punishment or cost, while incentivization interventions create an expectation for a reward (Michie et al., 2011). One way the mHealth interface can use coercion or incentivization involves providing the user with information about current and

projected health benefits or ramifications based on their current physiological data and behaviour (e.g., future self; Rho et al., 2017). In particular, the health information extracted from physiological data allows to project a user's expected level of wellbeing (e.g., low stress levels) and risk of disease (e.g., cardiovascular disease, diabetes). In this sense, the prospect of disease serves as an expected punishment or cost while the prospect of wellbeing and good health serves as an expected reward. By providing this information to the user, the mHealth system can instigate reflective processes of planning and evaluation (e.g., setting goals to reduce stress levels as measured by skin conductance) in order to change behaviors that lead to these health outcomes (e.g., engaging in stress management). For example, Murray et al. (2013) discuss how an avatar may mirror users' health information based on biosensors (e.g., stress) and support them in devising a plan to change their health behaviour. Building on this notion, the commercial Oakwood Medical Avatar 1) uses an avatar that projects users' current and future health by extracting information from biosensors (e.g., blood pressure, muscle activity) and contextual data (e.g., sleep patterns, weight) and, based on this data, 2) supports the user in planning health behaviors such as following a diet, performing physical activity, and ceasing to smoke (Medical Avatar, 2018). On the other hand, persuasion interventions focus on triggering affective responses and stimulate action (Michie et al., 2011). Persuasion interventions resemble coercion and incentivization interventions except that they focus more on how a message is communicated. For instance, one could make future health consequences based on the user's current behaviour that come from mobile biosensors (e.g., smoking and drinking habits detected from respiration, heart rate, and skin temperature) (Gutierrez et al., 2015; Saleheen et al., 2015) even more salient via showing images that depict those consequences (e.g., visually showing weight gain from drinking) or via facilitating a discussion with a health professional to devise a plan for action.

Automatic motivation involves processes that include "emotional reactions, desires (wants and needs), impulses, inhibitions, drive states, and reflex responses" (e.g., reminders to reinforce the habit of reduced alcohol consumption) (Michie et al., 2014, p. 63). BCIs that the mHealth system can use to increase automatic motivation include coercion, incentivization, modelling, and persuasion. Coercion interventions can address automatic motivation, such as by providing well-timed reminders with information about the health consequences of risk behaviors (e.g., reminders containing imagery of negative health outcomes). For instance, the system could use biosensors to detect smoking (Saleheen et al., 2015) or alcohol consumption (Gutierrez et al., 2015) and use reminders to reinforce the formation of healthy habits. Conversely, it could use reminders to increase automatic motivation through incentivization. For instance, Martin et al. (2015) used an incentivization intervention in the form of smart texts that provided positive reinforcement messages to users based on their daily activity goal. Similarly, the system could send positive reinforcement messages to users for every day that it did not detect that they smoked or drank alcohol based on biosensors. Systems can also use modelling interventions, defined as "provid[ing] an example for people to aspire to or imitate" (Michie et al., 2011, p. 7), to increase automatic motivation. For instance, using social comparison based on mobile biosensors (e.g., using respiratory sinus arrhythmia measurements (Xiong et al., 2013) to display a paced breathing leaderboard for stress management) can allow a user's friends or people in a similar demographic to become an example to aspire to for the user based on their positive example. Lastly, a system can use persuasion to increase automatic motivation. Similar to reflective motivation, imagery that makes salient the consequences or benefits of behaviour (e.g., visually showing the consequences of having a high resting heart rate) can influence automatic motivation by triggering emotional responses to such visual stimuli. Therefore, we propose the following proposition:

Proposition 4 (P4): Mobile biosensor-based interventions that focus on coercion, incentivization, modelling, and persuasion increase users' reflective and automatic motivation to engage in health behaviors.

3.5. Design Guidelines

Based on the thematic analysis, in this section, we derive six general design guidelines for designing mobile biosensor-enabled mHealth systems for health behaviour change (see Appendix A1.2 for an overview). As we describe in Section 3.3.2, the interviews referred to mobile heart rate measurements as an example technology of mobile biosensors.

3.5.1. Guideline 1: Mobile Biosensor Recordings

This guideline refers to how mHealth systems can measure biosensor data to better understand a user's circumstances and to how it collects contextual data to help it do so. The measurements provide the basis for the feedback loop between lifestyle behaviour and physiology. We extensively discussed this topic with participants, and they first noted that the measuring device must be physically tuned to the person. HP1[14]and HP5 explicitly supported this perspective. Participants also discussed other measurement aspects such as duration, frequency, time of day, and position. In regards to duration, HP1 recommended that, for the example technology (i.e., mobile heart rate measurements), "five minutes is fairly acceptable from current guidelines", which concurs with the Task Force of the European Society of Cardiology and the North American Society of Pacing Electrophysiology (1996) that recommend that "5 min recordings of a stationary system are preferred unless the nature of the study dictates another design" (p. 364). The advice from the HPs in regards to time of day and position indicated that consistency in these aspects (e.g., measurement start always around 8 am, always sitting position) has more

[14] Abbreviations for the stakeholder categories are used as identifiers for participants. Table 3.1. clarifies these abbreviations.

importance than the specific condition itself (e.g., 8 am vs. 3 pm; sitting position vs. standing position). Further, HP5 added that, in addition to these specific, five-minute recordings, the technology would generally need to keep continuous recordings using a rolling time window of the last 48 hours in order to access this data in case the user exhibited a "funny turn"[15]. Generally, users expressed strong support for using biosensor measurements in mHealth due to two main reasons: to focus on improved visibility and to better understand physiological data in the health context.

In order to better understand biosensor measurements, HPs emphasized that the mHealth interface needs to collect contextual data to interpret the physiological data. A major theme that emerged concerned the degree to which the mHealth interface should passively measure physiological and contextual data or whether the user should manually enter it. Types of passive data discussed included steps, contextual location, blood pressure, and pulse. HP2 and HP4 supported using steps as feedback due to it being a discrete and cheap measure that can complement physiological measurements for determining movement (resting vs. moving heart rate). Further, HIP1 identified contextual location from GPS as useful data as it could assist in understanding the circumstances leading up to health events. However, some users (e.g., U6) disliked using contextual location for privacy reasons. Manually entered data that users discussed included corrective factors for physiological data (e.g., age, sex, medical / family history), whether the user used healthcare resources (e.g., hospital visits), and mood. The mHealth interface needs to collect corrective factors to improve the accuracy of physiological measurements. For instance, β-blocker and rate-limiting medications pharmacologically lower heart rate and, hence, impair the usefulness of physiological

[15] Storing continuous biosensor recordings over a rolling time window of 48 hours allows the user and their health practitioner access to health information in case of exceptional circumstances. For instance, having access during and/or before a user experiences a "funny turn" provides important information to health practitioners to better understand the circumstances of the event (e.g.,, atrial fibrillation, tachycardia).

measurements as a feedback measure (Palatini, 2009). However, HPs emphasized that this issue concerned chronic disease management more rather than prevention. For example, HP2 stated: "resting heart rate is a measure of fitness as long as people are not confounded with rate limiting drugs". The majority of participants favoured using passive collection due to convenience and accuracy. For instance, in regards to manual entry, U4 stated that they would "[try] to overdo it, which would provide inaccurate results". In sum, to better understand physiological measurements, the mHealth interface should collect a mixture of passive and manually entered contextual data but use passive measurement as the predominant method.

3.5.2. Guideline 2: Affective Visual Assets

This guideline refers to using affective visual assets to convey the health information extracted from physiological data in an intuitive and meaningful way in order to increase users' capability and motivation. This guideline addresses the challenge that users do not find physiological data *intuitive* to understand (capability) and *meaningful* to change their behaviour (motivation).

Throughout the interviews, we found that users found it difficult to understand the information embedded in physiological data and how it related to their health goals. For instance, HBS1 emphasized that "as someone from the general population, [heart rate] is not something that you know what it means in terms of what's good and what's bad". U2 echoed this sentiment in stating:

> *Most people aren't aware of their health. A lot of people don't go to the doctor unless they've got a health issue, so most people would have no idea what their blood pressure or heart rate is, or what it means.*

Hence, in order to support users' psychological capability to engage in healthy behaviors, the mHealth interface needs to convey this information in an intuitive way. In the interviews,

participants expressed that appropriately designed visual assets could help bridge the gap between biosensor measurements and user understanding by visually representing the relevant physiological measure. Recent examples in the literature support this notion. For example, Tan et al. (2014) used visual assets that resemble human elements (heart changing size, sweat droplets) to convey a user's stress levels extracted from mobile heart rate and skin conductance measurements in an intuitive way. Similarly, scholars have used nature-inspired visualizations as analogies to represent a user's health status. For instance, Al Osman et al. (2016) and Feijs et al. (2013) used visual assets representing trees and flowers that change their appearance based on heart rate and respiration measurements. Hence, by reducing the complexity of the underlying physiological data and by building on analogies, visual assets can aid in making these measurements more intuitive to understand for users and, hence, increase their psychological capability to engage in targeted behaviors.

Further, HBSs emphasized that, even if visual assets convey the health information in an intuitive way, it would not motivate users to engage in health behaviour change unless this change becomes meaningful to them. For instance, reducing a stress level measure extracted from respiration or skin conductance data may in and by itself not sufficiently motivate individuals to change their behaviour. Hence, in order to not only address capability but also motivation, designers should design visual assets in a way that makes it meaningful for the user to change their behaviour. In particular, HBSs argued that designers should design visual assets to be affective in the sense that they can create an emotional bond with the user. For instance, HBS3 suggested that using affective visual assets could make interventions more personal as it "might feel like you're actually talking to a person rather than just getting a brochure telling you to not smoke". During our interviews, three particular types of visual assets emerged for this goal: 1) mirrored-self avatars, 2) persuasive avatars, and 3) embodied agents. The mirrored-self avatar concept that Behm-Morawitz (2013) employed showed that the

appearance of an avatar representing a user can influence the real-world behaviour of that user[16]. For instance, a mirrored-self avatar could change its appearance (e.g., weight, age, skin) based on the user's physiological data (e.g., stress level, smoking, and alcohol intake). Hence, by mirroring the user's health status, a mirrored-self avatar may establish a meaningful and, at the same time, intuitive link between the user's physiology and their health behaviour. HBS1 supported the mirrored-self concept, particularly for increasing self-efficacy, in stating:

> *I think it does tie into the self-efficacy because, when people are doing well, their avatar can reflect that. But I think it's also reinforcing in terms of the capability in the COM-B model because that's one of the issues is people not believing that they can do it or how to do it.*

In contrast, a persuasive avatar represents another person, typically an authority figure (Hanus & Fox, 2015) such as virtual doctors (Fujita et al., 2010) and virtual coaches (Buttussi et al., 2006). For example, the mHealth interface could provide feedback on biosensor data (e.g., stress levels based on respiration and skin conductance) through a persuasive avatar representing a HP (increasing trust and credibility when users interpret physiological data; see Guideline 4). While participants generally supported the concept of a persuasive avatar, HBS4 added that one needs to carefully consider the level of persuasiveness considered against the backdrop of the "person's relationship with authority figures". Several users raised similar concerns. Finally, embodied agents emerged as a third type of visual asset in the interviews. For instance, virtual pets represent a type of embodied agent that employ a mix of anthropomorphic and non-human elements and are influenced by user engagement (Kromand, 2007). Similarly, the mHealth interface can use nature-inspired elements such as trees and

[16] An avatar refers to "a perceptible digital representation whose behaviors reflect those executed, typically in real time, by a specific human being" (Bailenson & Blascovich, 2004, p. 64). Yee and Bailenson (2007) show that users that had more physically attractive avatars displayed increased confidence and kept shorter personal distances in virtual interactions compared to users who operated less physically attractive avatars. The authors explained this behavior with the Proteus effect.

flowers (e.g., reflecting physiological stress; Al Osman et al., 2016, Feijs et al., 2013) that we discuss above to address motivation via an embodied agent that makes a change in physiology more meaningful. In the interviews, participants saw virtual pets as suitable for younger users since game settings typically feature such pets.

While all participants generally embraced affective visual assets that convey the user's physiological state (particularly in terms of addressing capability), we realized that users themselves need to choose which visual assets the mHealth interface employs in order for it to effectively address motivation. For instance, in the context of avatars and embodied agents, participants expressed a large variance in their preferences. Further, U1 stated that avatars would not work for them at all but that other affective visual assets would with the key that the user could individualize the asset: "if somebody is an enthusiast in a different area, it could be aimed at the things that they are enthusiastic about". Among the assets, the mirrored-self avatar received the most support but also the most criticism. Participants saw the degree of realism as both a strength and a weakness. While users preferred the directness of the feedback on their physiological state from this avatar (e.g., U2 stated: "I think that people sometimes need to be scared into doing something about their health.… I think it certainly would hit home to us more than just reading numbers and things on a screen"), D1, D5, and ITP2 stated that it could be very confronting and eerie if the avatar became too realistic to a human (see Mori's (1970) "uncanny valley" notion); therefore, designers might prefer deliberately pursuing a design with moderate human likeness. In sum, while all participants embraced using affective visual assets to convey the user's physiological state overall, when designing affective visual assets, designers need to adequately identify and reflect the motivational factors of a particular target audience in order to effectively address motivation.

3.5.3. Guideline 3: Goal-setting Support

This guideline refers to how the mHealth interface can use mobile biosensor measurements to provide users with effective goal-setting support. Goal setting represents an important factor for behaviour change as it facilitates: 1) capability by showing users *how* they can achieve their goals, 2) opportunity by showing users *when* they can achieve goals, and 3) motivation by showing feedback on *progress* towards goals and boosting self-efficacy (Michie et al., 2015). From the interviews with HBSs and HPs, we found that mobile biosensor measurements have particular usefulness in providing goal-setting support because they can make visible the short-term changes in physiology in response to healthy and unhealthy behaviors (and, hence, increase the saliency of the pathways between physiology and health behaviour) and, thereby, help users better understand their progress towards their health goals. For instance, heart rate and skin temperature biosensors can bring to light short-term physiological changes in response to alcohol intake—something users cannot normally perceive (Gutierrez et al., 2015)—which enables them to set and monitor short-term goals around their drinking behaviour. In a different example, Paalasmaa et al. (2012) developed a system where users could specify and monitor goals for their sleep quality (measured by respiration and heart rate) and link this health information to lifestyle behaviors (e.g., alcohol intake, exercise). As such, using mobile biosensors in goal setting allows the mHealth system to break down a user's health goals (e.g., reduced risk for cardiovascular disease) into small and achievable tasks that it can measure and reinforce with biosensors (e.g., reduced resting heart rate). Taken together, using mobile biosensors for facilitating goal-setting support 1) makes lifestyle behaviour change more approachable, 2) allows for more opportunities to reinforce or correct behaviors and, 3) attempts to mitigate the problem wherein long-term consequences of unhealthy lifestyle behaviors only become apparent to the user after years or even decades by shortening the time between when the user performs a behaviour and when the user receives feedback.

In the interviews, two user interface concepts emerged recurrently when discussing goal-setting support: gamification and serious games[17]. D1 emphasized the importance of gamification for designing mHealth systems in stating "every app we build will be based around the gamification principle in some capacity". Combining gamification with mobile biosensors can facilitate goal setting in numerous ways. First, gamification can break down unwieldy long-term health goals (e.g., improving stress management) into incrementally achievable goals (e.g., first stabilizing and then reducing stress levels as measured by skin conductance) and reinforce these goals through reminders, which encourage habitual use and facilitate automatic motivation (e.g., reminders reinforcing paced-breathing when detecting high stress levels). HBS5 stated that "[health goals] have to be achievable [and]…something that you inherently want to achieve". Second, gamification can mitigate the problem associated with the long-term consequences of unhealthy lifestyle behaviors that only become apparent to the user after years or even decades (e.g., onset of cardiovascular disease and diabetes) by providing short-term incentives based on game-like elements and provide feedback on how changes in behaviour affect the user's physiology (e.g., changes in physiological stress levels). However, the participants broadly agreed that the game-like elements represent only a means to an end and that the mHealth system needs to focus on intrinsic goals. For instance, U5 stated: "goals should be intrinsic motivators—things from within". Self-comparisons and social comparisons represent important factors in this context. All participants strongly supported self-comparison as it provides feedback that focuses solely on users themselves and visualizes their individual progress. Further, self-comparison can increase self-efficacy as it can

[17] Gamification, which refers to using "game design elements in non-game contexts" (Deterding et al., 2011, p. 10), leverages design and interface elements from entertainment games (e.g.,, achievements, badges, leaderboards, etc.) that provide additional motivation for behavioral changes typically hard to motivate, such as lifestyle behaviors (Schoech et al., 2013). However, as with every user interface concept, it became apparent that the actual choice and design of the employed user interface concept strongly needs to consider the target audience as gamification and serious games likely have more or less efficacy for particular groups and depend on how the designer ultimately designs these concepts. For instance, HBS6 and U3 suggested that gamification may be effective with younger users but not as effective with the elderly. Similarly, U4 stated that "a serious game could be more of a fad".

demonstrate a user's individual progress over time (e.g., reduction in smoking and drinking occasions as detected from respiration, heart rate, and skin temperature) (Gutierrez et al., 2015; Saleheen et al., 2015). On the other hand, social comparison allows users to compare their physiological state with other similar users (e.g., leaderboards for managing physiological stress levels). Social comparison can be a motivating factor; however, the sense of competition associated with it may also be detrimental for some users. For instance, U5 stated: "I'm the type of person that believes you should only be assessed based on yourself.… Assessing against others can be a demotivator.".

Next, participants identified serious games, which refer to "games used for purposes other than mere entertainment" (e.g., learning or training; Wattanasoontorn et al., 2013, p. 231), as another important concept for goal-setting support based on mobile biosensors. By creating a tailored and engaging virtual environment, serious games can provide users with the opportunity to improve their capabilities in a motivating and controlled way. In the context of mobile biosensors and health behaviour change, mHealth systems can use serious games to provide users with an opportunity to increase their capability to engage in targeted health behaviors by directly linking game elements to biosensor recordings. For instance, serious games can use heart rate, respiration, and skin conductance biosensors to facilitate paced breathing exercises for relaxation (Dillon et al., 2016; Xiong et al., 2013). HP1, HP2, and HBS2 supported using serious games. Specifically, HP1 stated: "why I like it is that you can in essence control the environment.… You're controlling the input.… You've got the sensor recording and you've got a known environment and you can put stressors in there.". In this vein, serious games can use biosensors to adjust the game environment to achieve a particular goal. For instance, Dillon et al. (2016) developed a mHealth serious game for stress reduction that used users' skin conductance levels to progress the interface from a winter scene to a summer scene. In sum, adjusting serious game elements based on physiological data can support goal setting

by facilitating a tailored virtual environment that provides users with new opportunities to engage with health goals and improve their capabilities to engage in targeted health behaviors. Because users cannot usually perceive changes in their physiology, they have limited opportunity for such training.

3.5.4. Guideline 4: External Support

This guideline refers to facilitating a link between mobile biosensor recordings and external resources, which we refer to as external support. Through discussion with participants, we identified two primary types of external support. The first type involves closing the gap between mHealth systems and external stakeholders, particularly HPs. For instance, HP5 stated that mobile biosensor recordings could help them understand a user's physiological state as these measurements better reflect a user's typical day-to-day experience, and phenomena such as white coat hypertension (i.e., elevated blood pressure in the presence of a HP) do not affect them (Martin & McGrath, 2014). By enabling the link to external stakeholders, mHealth systems can address user capability by facilitating information exchange regarding the user's physiological state between the user and their HPs, a source of data that most users do not intuitively understand and, hence, find difficult to interpret. This notion resembles a design concept by Barakah and Ammad-uddin (2012), who proposed a virtual doctor platform where HPs can remotely provide health advice to users based on their medical history and mobile biosensor data (e.g., blood pressure, heart rate). Such information exchange could be made more intuitive and meaningful for users via using affective visual assets (e.g., a persuasive avatar of a doctor; see Guideline 2). Additionally, this form of external support addresses opportunity because it allows the mHealth systems to detect and the user or their health practitioner to act on characteristic patterns in physiological and contextual data where they could not before (e.g., abnormalities in blood pressure, detection of smoking and drinking

occasions from biosensors) (Gutierrez et al., 2015; Saleheen et al., 2015). For instance, HP5 stated that, if they had access to physiological and contextual data from mHealth devices, it would help them "to determine what sort of intervention the [user] needs, if at all.… It may be on the wrist of the [user], but it's not available to me.". Also, involving external stakeholders such as HPs into mHealth systems further integrates mHealth into clinical practice. Specifically, participants expressed that involving external stakeholders in analysing their biosensor data can motivate them by building trust in mHealth systems and these systems' credibility. For example, U5 stated: "doctors are seen as...the ones that you can trust" and that "linking this quite closely with the health professional would support the [mHealth system] and create credibility".

The second type of external support identified involves using physiological and contextual data to provide the user with contextually relevant information from external resources that address psychological capability through education and by creating awareness of opportunities in the physical environment. Among its many benefits, mHealth can provide the user with just-in-time feedback (e.g., when detecting physiological stress based on skin conductance and respiration biosensors) as individuals can immediately access mHealth devices in everyday situations (Danaher et al., 2015; Nahum-Shani et al., 2018). Designers can leverage this ability to point users to external support material (e.g., video materials for paced breathing) and opportunities in the physical environment (e.g., support hotlines, local meditation and healthy eating classes) to reach users when most relevant. In the interviews, HBSs and users emphasized that links to relevant external support resources can support the information that the mHealth system provides directly (e.g., when the user requires further assistance). For instance, U5, who stated "a lot of people don't know how to access places where resources are", argued that this form of external support may be useful as some people lack knowledge of resources available to them. HBS3 added to this sentiment in stating: "It's a

really nice way to connect people up with those kind of services that they might not know exist otherwise". In this sense, a mHealth system might prompt users to contact their HP when their physiological data (e.g., blood pressure, heart rate) exhibit anomalies or provide them with a list of relevant services (e.g., local HPs, healthy food options based on location data) based on their location (GPS).

3.5.5. Guideline 5: Levels of Data Integration

For this guideline, we elaborate on four levels of data integration that connect mobile biosensor data that mHealth systems collect with external stakeholders. Considering the sensitivity of the health information that such systems can extract from physiological data, designers need to adequately address any potential security and privacy issues when integrating these four levels to ensure that all stakeholders can trust the data and have confidence in its provenance.

The first level (level A: individual feedback) refers to the feedback the user sees through the mHealth interface (e.g., using skin conductance to show changes in stress through a mirrored-self avatar). To facilitate this feedback, most current mHealth systems primarily focus on the data stream between the user and the mHealth device; however, this data stream alone cannot effectively address behaviour change and neglects integration into clinical practice. Thus, in order to effectively address the propositions, other data connections need to exist as well. Throughout the interviews, we identified three other levels that designers need to consider.

The second level (level B: data-aggregation and -analysis service) refers to a remote system that analyses mobile biosensor and contextual data from the mHealth device and sends it back in the form of feedback (e.g., facilitating social comparison of health information extracted from physiological data). For instance, ITP1 stated that the design needs to consider the computational complexity of analysing and aggregating biosensor data by "just [using] this mobile device to collect data and pass this data to a normal computing system and use the most

powerful technology to do the aggregation and analysis". ITP1 further explained that implementing a data-aggregation and -analysis service could allow mHealth systems to perform more intelligently than current mHealth systems as it could allow them to apply more sophisticated machine learning techniques, which they need to suggest targeted interventions that consider a user's individual situation. For example, linking the user device to a data-aggregation and -analysis service has the potential to facilitate statistical methods that not only allow mHealth systems to better personalize interventions but also reduce follow-up time due to the ability to "track changes within the individual that predict outcomes (e.g., heart arrhythmias) rather than waiting for the development of discrete, but rare, events (e.g., heart attacks)" (Nilsen et al., 2012, p. 8). Additionally, as several PMs and HIPs emphasized, aggregated data (e.g., average physiological stress levels, severity of smoking and alcohol overconsumption as detected by biosensors) (Gutierrez et al., 2015; Saleheen et al., 2015) could serve as an important source of information for policy creation and resource allocation (e.g., testing effectiveness of health promotion interventions for particular user groups). For instance, PM1 elaborated that: "if you can actually improve the clarity of their vision as to the effectiveness of interventions, then the policy decision becomes much clearer to [PMs] in terms of where should they be investing public dollars". In sum, the data-aggregation and -analysis service not only allows mHealth systems to provide more effective feedback to users but also provides insights about different user groups that could help policymakers craft health promotion policy and indirectly improve behaviour change (e.g., better access to support for smoking cessation and related resources in the environment).

The third level (level C: integration with health practitioner information system) refers to a data link that allows HPs to monitor users' physiology and send feedback back to their mHealth device. Enabling this data link between users and HPs addresses users' 1) capability by facilitating individualized feedback from HPs, which can educate them about their

physiological state in relation to their health goals (e.g., what their resting heart rate means; hence increasing psychological capability to engage in health behaviour); 2) opportunity by enabling users to detect abnormal measurements and act on them proactively (e.g., by suggesting specific health behaviors based on the analysed biosensor data); and 3) motivation by better integrating mHealth systems into clinical practice, which increases trust and credibility. Users generally supported the data link to a health practitioner IS. For instance, U2 particularly emphasized the usefulness of the system's remote aspect in stating:

> *It would be amazing and very helpful to doctors to not have to sit there and get half an hour's worth of conversation out of somebody as to how they've been. They can just pretty much download that straight onto their system.*

On the other hand, U3 argued that some users may not be open to involving HPs and disliked the idea of having their data visible to them. HPs strongly supported the data link as it further integrates mHealth into clinical practice, allows for in-context measurements, and allows them to monitor users directly. For instance, HP5 stated:

> *If I had a [person] who had extra heart beats in 24 hours and I'm at a conference in Hong Kong, [mHealth systems] should be linked to the [health practitioner IS] in some way so that it's captured and when I see the patient again…, I can look at it.*

Finally, the fourth level (level D: integration with health insurance provider information system) refers to a data link that gives HIPs access to user data. Regarding HIPs' potential role, HIP1 stated:

> *Health and healthier outcomes isn't just about medical advice, but about lifestyle choices…. We can potentially help people make better decisions about their health through getting information to them sooner, and helping connect people who can help each other out.*

However, HIPs currently have a limited role in preventative health as HP2 stated: "we get no data out of primary care until a person has a declared significant medical condition that's had to result in a hospitalization". Using mobile biosensors has the potential to provide important data for preventative health such as whether the user used healthcare resources, factors that lead up to health events, and risk status. HIPs may use this data to provide individual users with direct incentives (e.g., bonus points, financial support) to motivate them and create new opportunities for health behaviour change (e.g., support gym membership, discounts for healthy foods)[18]. HIP1 strongly supported this function in stating: "definitely wearables, and definitely phones, and definitely technology would give us that data". Overall, HIPs' involvement in mHealth systems received a mixed response in the interviews with several participants expressing strong reservations. On the one hand, HPs expressed caution about HIPs' involvement. For example, HP5 said: "Whether users would trust you to transmit that data to the insurance provider is a big issue. They might use it for their own commercial purpose…. I don't know if we are ready to involve them yet.". Conversely, users generally supported HIPs' involvement, particularly when they received rewards to increase their motivation for health behaviour change. For example, U4 stated: "I like the idea that you can use the application and be rewarded for that by your insurer". PM1 argued that an important factor for convincing users to provide their physiological data to other mHealth stakeholders is that the user should benefit from providing this data and that this benefit, along with a narrative for why the data is being collected and how it will be used, should be clearly communicated. In sum, level D could motivate users on an individual level through targeted incentives and

[18] For instance, the Australian health insurer Medibank engaged in a joint incentive scheme with Coles, a major chain of supermarkets. In this scheme, Medibank customers receive additional rewards that can be redeemed in their grocery shopping at Coles if their activity levels (as measured by a wearable fitness device) reach a certain goal and/or if they buy healthy foods (e.g., fresh fruit and vegetables) at Coles (https://flybuys.medibank.com.au). A similar incentive scheme was introduced by the South African health insurance company Discovery, where insurance clients were provided with discounts for healthy food purchases at certain supermarkets (An et al., 2013).

create new opportunities for them through promoting improved health at the population level. However, particularly against the backdrop of the sensitivity of the health information that one can extract from mobile biosensors, designers need to carefully handle HIPs' involvement to ensure that they predominantly consider users' needs.

3.5.6. Guideline 6: Stakeholder Involvement

This guideline refers to stakeholders' involvement in all design phases. Despite, and more explicitly due to, the promising potential in using mobile biosensor measurements in mHealth systems, system designers must acknowledge that designing such systems for behaviour change represents a challenging task and involves difficulties associated with the long-term consequences of unhealthy lifestyle, imperceptibility of short-term changes in physiology, the way in which users understand physiological data, multiple direct and indirect stakeholders with diverse background and interests, sensitive health information from biosensors, and a complex landscape of remote systems. Addressing these challenges and ensuring that the artifact design adequately reflects the intricacies of increasing individual users' capability, opportunity, and motivation to engage in targeted behaviors requires the involvement of all relevant stakeholders in all design phases (Burke et al., 2015; Lobelo et al., 2016). Participants from all stakeholder categories also consistently emphasized this call for a co-design approach in which stakeholders actively participate from the early design stages through to adoption. As HIP1 stated: this involvement ensures that the "technology seamlessly entwines its way in our lives".

Co-design, also known as participatory design, refers to an approach to "facilitate users, researchers, designers and others…to cooperate creatively, so that they can jointly explore and envision ideas, make and discuss sketches, and tinker with mock-ups or prototypes" (Steen, 2011, p. 52). Critically, co-design involves the "user as a partner" rather than designing for the

user as a subject (Sanders & Stappers, 2008, p. 5). Supporting this notion, D1 stated that, "if you don't have key decision makers involved in that initial stage, you're doomed". Further, co-design shifts the focus away from technological aims to an emphasis on collaborative activities in contextual and generative design phases (Sanders & Stappers, 2014). As D1 described, "the development is completely…. It's irrelevant". Thereby, co-design emphasizes *contextual* research activities (e.g., using cultural probes and storytelling; Gaver et al., 2004, Mitchell et al., 2015) which, as D2 described, help mHealth system designers "to understand the situation that…the problem exists in, and what other various kind of inputs or context surround that" (e.g., individual motivators for health behaviour change and contextual factors that may affect biosensor recordings).

3.6. Discussion and Conclusion

3.6.1. General Discussion

While researchers have conducted extensive research on how biosensors can provide insightful information about a person's health and lifestyle behaviors, they have only recently begun to use the information from biosensors in designing mHealth systems to deliver behaviour-change interventions (Free et al., 2013). As such, we lack any established guidelines for designing such systems, and scholars have raised the concern that a BCI framework often does not guide mHealth systems for behaviour change (Davey et al., 2014; Hingle & Patrick, 2016). Against this backdrop, our study's knowledge contribution constitutes an *improvement* (Gregor & Hevner, 2013) because it extends the knowledge base for a known problem with low solution maturity (i.e., mHealth systems design) and high application domain maturity (i.e., health promotion). In particular, our research draws on the BCI literature's deep understanding of health behaviour change and develops prescriptive knowledge for designing biosensor-enabled mHealth systems. In doing so, this research makes two core contributions.

First, we contribute the integrative theoretical framework, which formulates the theoretical pathways for how biosensor-enabled mHealth systems can bring about health behaviour change. The framework contributes to the prescriptive knowledge base by 1) providing researchers and practitioners with a shared frame of reference for implementing a feedback loop between the user's physiology and their perception and 2) enabling system designers to systematically map out how the elements of their mHealth interface can target individual components of behaviour and the types of interventions through which they can do so. Following a deductive theorizing approach, we ground our propositions in Michie et al. 's (2011) well-established BCI framework, which emphasizes that mHealth systems design needs to simultaneously consider users' capability, opportunity, and motivation. In particular, as we discuss in Section 3.2, previous research has argued that the design of mHealth systems for health behaviour change should be guided by a theoretical framework rooted in the BCI literature and that systems more effectively bring about behaviour change if their design implements a higher number of behaviour-change techniques (Garnett et al., 2016; Hingle & Patrick, 2016; Vandelanotte et al., 2016). Many existing studies focus primarily on increasing users' psychological capability by providing them with additional information or providing that same information in a more intuitive way (Michie et al., 2011). However, putting the focus only on increasing capability would fail to address motivation, which lifestyle behaviour change requires (Vandelanotte et al., 2016). Hence, the framework allows more informed decisions as it enables system designers to consider a range of different potential pathways and BCI categories for facilitating behaviour change through the mHealth interface.

Second, we contribute six general guidelines for designing mobile biosensor-based BCIs, which we developed in an inductive theorizing approach based on interviews with key mHealth stakeholders. Constructing a mHealth system involves many design choices with links to various different stakeholders and remote systems. In this sense, the guidelines contribute to

the prescriptive knowledge base by providing system designers with practical design considerations that consider multiple stakeholders' perspectives. Hence, the guidelines can serve as groundwork for developing new solution artifacts to deliver technology-mediated interventions that support users in modifying their behaviour. Importantly, the guidelines do not apply only to a particular type of biosensor (e.g., heart rate, skin conductance) or lifestyle behaviour (e.g., nutrition, physical activity). Hence, while individual studies usually focus on an individual solution artifact and a particular type of intervention (e.g., biofeedback training for stress management; Xiong et al., 2013), our guidelines provide general considerations for a bigger class of problems that system designers can then refine for their individual solution artifact. For instance, while several studies have used avatars to convey the health information extracted from biosensors (e.g., Murray et al., 2013), our study abstracts from the particular type of visual asset and instead emphasizes the need for the asset to be intuitive and meaningful to the user. Hence, instead of directly adopting a solution that worked in a different context or for a different cohort, our guidelines allow system designers to make the actual purpose of their individual design choices explicit and to ensure they focus on this purpose throughout the design process. Figure 3.5 graphically summarizes the direct connections between the six design guidelines and the theoretical framework, which we discuss next.

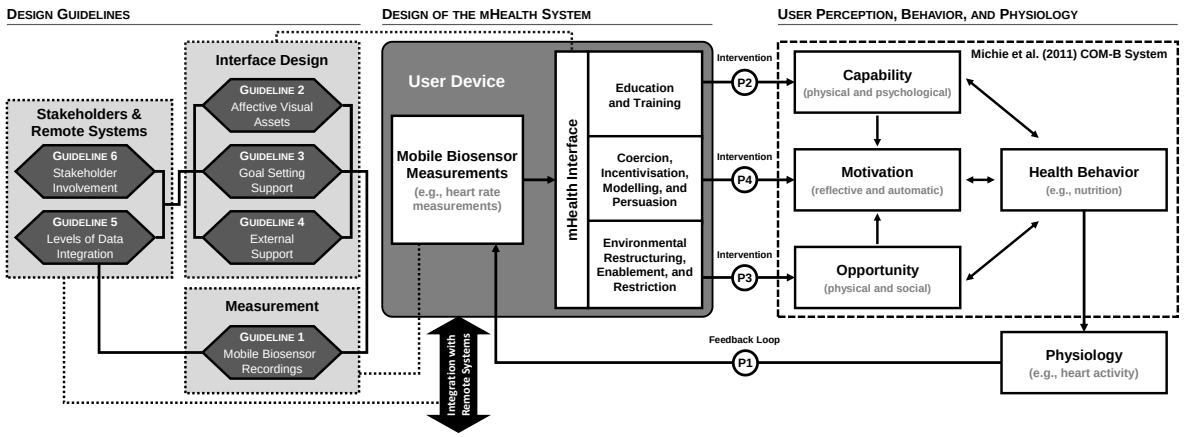


Figure 3.5. Mapping of the Design Guidelines to the Integrative Theoretical Framework

3.6.1.1. Measurement

By identifying important considerations in measuring physiological data, Guideline 1 directly relates to creating a feedback loop between users' physiology and their perception (P1). Further, as Figure 3.5 shows, Guideline 1 also has important links with other design considerations. First, in order to close the feedback loop, the mHealth interface needs to convey the collected physiological data to the user (Guidelines 2 to 4). Second, mHealth systems can use mobile biosensors not only for individual feedback but also to provide external support (Guideline 4) by leveraging data integration with remote systems (Guideline 5). Despite the increased accessibility of sensor technology for consumers, mHealth system designers currently underuse the link to healthcare providers. HP5 emphasized this missing link in stating "all these apps can monitor [heart rate] continuously even now, but it may not be available to your medical practitioner…. We need to close the loop.". Similarly, researchers have called for better integrating mHealth systems into clinical practice (Clifton et al., 2013; Lobelo et al., 2016) due to the promise to remotely monitor users and detect medical complications early on (Dobkin & Dorsch, 2011). Hence, by creating a link between a user's physiological measurements and remote systems, external support may assist the feedback loop between a person's health behaviour and the resulting physiological changes. This support may help users to better understand how their lifestyle behaviour affects their physiology and, subsequently, their health.

3.6.1.2. Interface Design

The design that the mHealth interface adopts has critical importance for addressing a user's capability, motivation, and opportunity as it mediates the information flow to the user. Building on the foundations of the established feedback loop, Guidelines 2 to 4 directly relate to how designers can implement P2 to P4 in BCIs in the mHealth interface (see Figure 3.5), which needs to convey the information extracted from mobile biosensors for the user in an intuitive

way (P2), create an emotional bond that makes it meaningful for the user to engage in a targeted behaviour (P3), and create opportunities for the user to do so (P4). Importantly, these three guidelines relate to one another. For instance, by employing a persuasive avatar, designers can use affective visual assets (Guideline 2) to effectively facilitate external support (Guideline 4). One way of accomplishing this is by using persuasive avatars that receive input from subject matter experts. Further, by leveraging a health practitioner stereotype, persuasive avatars may be able to activate similar responses from users (e.g., increased trust and credibility) through priming mechanisms (i.e., situational cues and social stereotypes that activate concepts and behaviors) (Bargh & Chartrand, 2000)[19]. Similarly, affective visual assets (Guideline 2) can incorporate goal setting (Guideline 3) in an engaging and motivating way. For instance, showing a future projection of users' mirrored-self avatar based on their physiology could increase self-efficacy as it provides an incentive for healthy behaviors and an opportunity to change their behaviour before their projection becomes real (Rho et al., 2017). Users strongly supported using projection. For instance, U5 stated:

> *I would love something like that [future self] because you actually know what the end results are going to be and you can see if you need to tweak or do something for your end goal. It's good to set those goals and be able to visually see what you're aiming for.*

HBS6 argued that using a mirrored-self avatar for projecting the future self may "slowly build some sort of capability in [users] to make that sort of prediction". However, HBS2 added that projections that directly concern goals should focus on the short term in stating "you don't want

[19] Overall, participants agreed that persuasive avatars may be particularly beneficial in the elderly cohort since they could connect to healthcare providers and, thus, increase the cohort's trust in and adherence to the feedback. In the disease-management context, for instance, Javor et al. (2016) show that Parkinson's disease patients had higher initial trust in avatar faces than in human faces. Therefore, a persuasive avatar of a health practitioner may elicit more trust in Parkinson's disease patients than a real health practitioner. However, some participants had concerns about using persuasive avatars. For example, U6 stated: "I know a lot of people have issues with authority so it could be a downfall". Therefore, the success of persuasive avatars may depend on how the user perceives authority figures.

to be projecting something in a week because a week is too long, especially if they're anticipating or struggling now, that's far too long". Therefore, designers can incorporate goal setting into affective visual assets in order to better address capability, opportunity, and motivation.

Importantly, goal setting also has important connections with external support (Guideline 4) as the goal-setting process around physiological data involves consultation with external stakeholders (e.g., HPs). To this end, HP3 and HP5 suggested that mHealth should involve a prescription-like process where the user can set goals with a HP and refine these goals over time through routine check-ups. By doing so, HP5 argued, mHealth could better address long-term behaviour change. Specifically, HP5 stated: "It should be a long-term process. If you're giving somebody blood pressure medication, you're not in it for a short term. You're for the rest of the [person's] life. It needs to be similar.". Further, users brought up several other benefits of involving HPs in the goal-setting process such as increased trust in the feedback and increased compliance with advice. For example, U4 stated in regards to accountability and long-term use:

> *It puts a face behind what the app is, so then they know if someone of that stature, that profession, has taken the time out to be involved in this, then it's something they would consider not only using, but continue using.*

Therefore, given the difficulty of interpreting users' physiological data and the long-term process and implications of health behaviour change, the goal-setting process (Guideline 3) should involve external stakeholders (Guideline 4) in order to tailor users' goals and to increase trust their trust in and compliance with advice.

3.6.1.3. Stakeholders & Remote Systems

By integrating remote systems (Guideline 5), HPs can not only monitor users' physiological and contextual data remotely but also send feedback back to them (e.g., in the event that a user has a "funny turn" and the doctor wants to arrange an appointment with the user). Furthermore, we clearly found that many existing mHealth systems focus heavily on the data link between the *user* and the *user device* (level A) but do not integrate the *user device* with *remote systems* (levels B, C, and D) (Free et al., 2013). For instance, Winters et al. (2017, p. 119) emphasizes this missing link by stating that a "lack of informed engagement with health-sector stakeholders and key decision-makers on mHealth innovation…[and] a distinct lack of integration with the formal health system" exists. With the design guidelines that we present in this study, we contribute to better understanding the relationship between mHealth systems and remote systems, which can help to bridge the gap between mHealth and clinical practice. Creating this data link between users and other stakeholders and considering the privacy and security issues that this link entails can improve behaviour change outcomes by enabling opportunities that would not exist otherwise (e.g., detection of abnormal measurements that a HP can act on) and improving the credibility of mHealth systems by involving HPs, which could motivate usage intentions and the sustainability of mHealth interventions (external support; see Guideline 4). After all, most people see their HP as a partner in their health and trust them (Roy Morgan, 2017). In this vein, through its connections with the other guidelines, Guideline 5 has indirect links to designing the mHealth interface and the mobile biosensor measurements.

Finally, previous research has emphasized that designers need to include stakeholders early in the design process (Burke et al., 2015; Petersen et al., 2015). By involving stakeholders in all phases of the design process, we can see Guideline 6 as facilitating Guidelines 1-5 in designing BCIs. Hence, Guideline 6 has important indirect links with designing the mHealth system. For instance, co-design can help designers create visual assets that users find intuitive

in conveying health information from mobile biosensors and meaningful by addressing a particular target cohort's motivational factors (e.g., adapting a self-avatar or a persuasive avatar; see Guideline 2). By involving stakeholders early in the design process, designers can already determine these motivational factors in the contextual phase. For example, as D1 described, by engaging users in co-design workshops, designers can collaboratively explore how meaningful users find a selection of a particular user interface concept according to their individual motivational pathways, which allows the designers to "find out what that selection means to [the user] as opposed to what you subjectively interpret that information as". Similarly, in order to address the problems associated with the long-term consequences of poor lifestyle behaviour, co-design can help designers create compelling goal-setting support (e.g., self-comparison and/or social comparison; see Guideline 3). Further, when devising the information streams between the user device and remote systems, co-design can help to ensure that the mHealth system meets agreed-on ethical privacy and data-protection standards when it handles information from biosensor recordings and other data sources (levels of data integration; see Guideline 5). Thereby, designers need to involve not only the user but also other mHealth stakeholders in the design process in order to address the problem in a way that meets the entire mHealth system's needs.

3.6.2. Limitations

Our study has several limitations. First, we do not design an actual solution artifact but instead explore general considerations for designing biosensor-enabled mHealth systems at a conceptual level. Hence, designing, implementing, and evaluating a specific mHealth system will require designers to consider the individual problem domain and user cohorts' individual characteristics (e.g., differences in motivational factors for different age groups). For instance, Guideline 2 emphasizes that users face difficulty in understanding and interpreting mobile

biosensor recordings, which means that mHealth systems require affective visual assets that convey the embedded health information in an intuitive and meaningful way. However, we did not investigate which particular visual assets prove most effective for a particular user cohort (e.g., young adults) and health behaviour (e.g., healthy nutrition). Nevertheless, considering multiple stakeholder perspectives, our design guidelines provide system designers with general points to consider when implementing the theoretical pathways for bringing about health behaviour change. Further, our framework can provide researchers and practitioners with a shared frame of reference to map their mHealth interface design to and consider which other theoretical pathways are worth pursuing in it. For instance, using the framework to guide the design may enable system designers who focus on implementing a just-in-time intervention to address automatic motivation (e.g., by using mobile biosensors to detect unhealthy behaviors) to complementarily pursue other BCIs (e.g., education, training) to address capability.

Second, while we developed design guidelines that we contextualize to biosensor-enabled mHealth systems for behaviour change, the guidelines may at least partially also apply to designing other types of complex end-user information systems. For instance, affective visual assets (Guideline 2) and goal-setting support (Guideline 3) also represent important design considerations for end-user systems in education (mLearning; Garcia-Cabot et al., 2015). Similarly, external support (Guideline 4) and data integration with remote systems (Guideline 5) have much importance when designing mHealth systems in disease management (e.g., managing diabetes; Kitsiou et al., 2017)[20]. However, and notwithstanding that some or even all of the design guidelines may also apply to other areas, we note that we developed the guidelines in a process of inductive reasoning based on exploratory interviews for the specific context of

[20] In this context, note that designing complex end-user systems in other contexts may additionally also require other design considerations. Notably, when designing mHealth systems for disease management (e.g.,, managing diabetes), designers need to consider the specific characteristics and treatment requirements of the respective disease. Because disease management falls outside our scope here, we did not consider such factors in our interviews.

mobile biosensors and health promotion. In all stages of this process, we made the exploratory nature of this research explicit to interview participants, and we actively encouraged them to raise any further design considerations that they felt we should include. Further, in our study, we elaborate on why and how the developed design guidelines are important for biosensor-enabled mHealth systems for health behaviour change (e.g., difficulty to interpret physiological data, imperceptibility of short-term changes in physiology, sensitivity of health information extracted from biosensors).

Nevertheless, we acknowledge that the guidelines may not all apply at all times and that one may need to adjust them based on the requirements of the system in question. Hence, even though we believe that our guidelines constitute a useful starting point for developing biosensor-enabled mHealth systems, we advise against the mandatory or rote use of the design guidelines. Also, evaluating and refining the proposed guidelines to a particular problem domain (e.g., improved nutrition, reduced alcohol intake) and user cohort (e.g., young or middle-aged adults) will require dedicated design science projects that involve their own data collection to test the theoretical propositions and evaluate the effectiveness of their solution artifact in bringing about behaviour change.

3.6.3. Future Research

Researchers can extend our findings to future research in several areas. To evaluate the design guidelines we present, we suggest that researchers develop a methodological framework for co-design in a mHealth context since, to our knowledge, no such methodological framework that captures the intricacies of mHealth systems, such as the necessity to include clinical trials at different stages in the design process (particularly for integrating the mHealth system as a facilitator for health behaviour change into clinical practice), currently exists. From here, researchers could conduct a co-design study that focuses on a specific cohort from which they

can create prototype applications to evaluate and refine the design guidelines. On another note, many mHealth studies have only established the efficacy of intervention effects over a short time (Vandelanotte et al., 2016). Therefore, researchers need to conduct further studies to better understand what BCIs and techniques can effectively bring about sustainable behaviour change in a mHealth context over the long term (Burke et al., 2015).

3.7. Concluding Note

Mobile biosensors hold great potential for developing mHealth systems that support users in mitigating their risk of disease and promoting positive health outcomes through health behaviour change. We hope this study serves researchers and practitioners as a reference guide for designing biosensor-enabled mHealth systems by overviewing stakeholder perspectives that mHealth system designers need to consider, conceptualizing the theoretical pathways for how mHealth system designers can address the components of behaviour through different BCIs in the mHealth interface, and providing general guidelines for developing such systems.

Chapter 4.

Using co-design in mHealth systems development: A qualitative study

4.1. Introduction

Over the past decade, the wide proliferation of mobile devices (e.g., smartphones, tablets) has enabled researchers and practitioners to engage in new ways of delivering health services through so-called mobile health (or *mHealth*) systems (Chow et al., 2016; Eckman et al., 2016). Broadly speaking, mHealth can be defined as "medical and public health practice supported by mobile devices, such as mobile phones, patient monitoring devices, personal digital assistants (PDAs), and other wireless devices" (WHO, 2011, p. 6). The ubiquity and increasing capabilities of these systems have created enormous potential to support individuals in self-managing existing health conditions (e.g., diabetes, stroke) as well as reducing their health risks by supporting healthier lifestyle habits (e.g., increase vegetable intake). Thereby, adoption of mHealth systems is steadily growing. In 2018, nearly half of consumers in healthcare used mHealth systems compared to one sixth in 2014. Overall, the global mHealth market is expected to grow from US$28.320b in 2018 to US$102.35b by 2023 (Liquid State, 2018).

Notwithstanding the increasing importance of mHealth systems, researchers and practitioners have repeatedly emphasized that the design and development of such systems is a complex endeavour that involves a range of pitfalls that can limit the adoption and effective usage of mHealth systems in practice (Burke et al., 2015). For instance, researchers have argued that the design process often only entails limited stakeholder involvement (Burke et al.,

2015; Marzano et al., 2015) and that individual solution artifacts lack integration with other health systems (Winters et al., 2017). To address these complexities, scholars have suggested to incorporate a co-design approach for mHealth systems development. Co-design refers to "the creativity of designers and people not trained in design working together in the design development process"(Sanders & Stappers, 2008, p. 6). Research has referred to two main reasons for using co-design approaches: (1) mHealth represents a complex environment which requires involvement of a diverse range of stakeholders (e.g., government, health practitioners, users, scientists, etc.) and co-design can facilitate the necessary collaboration therein (e.g., Eckman et al., 2016; Medhanyie et al., 2015; Noorbergen et al., 2019); (2) using co-design can ensure that mHealth systems are underpinned by expert insight and best practices (e.g., Burke et al., 2015; Garnett et al., 2016; Moller et al., 2017).

Despite a rich body of literature on the co-design methodology in general, and the repeated recommendations to use co-design for mHealth systems development, there is only limited guidance on how to do so. Given the high level of complexity surrounding a person's health and the multitude of stakeholders, there is a need for research that identifies the specific challenges researchers and practitioners face when applying co-design in mHealth and to illustrate ways in which these challenges can be addressed. In this chapter, we set out to address this research gap by conducting a qualitative study that explores how co-design can be used in mHealth systems development. Specifically, we conducted 16 semi-structured interviews to synthesize the theoretical and practical expertise of 8 established co-design method experts (CMEs) as well as 8 mHealth system developers (MSDs). We transcribed and analysed these interviews using thematic analysis as described in Braun & Clarke (2006). Specifically, we focused on themes relating to our overarching research questions:

> **RQ3**: *How can one contextualize existing co-design frameworks to the mHealth setting?*

RQ4: *What are guidelines to address common challenges in using co-design in mHealth systems development?*

In addressing these research questions, this study makes three core contributions to the literature. First, while existing literature on co-design methodology provides important *general* guidance in the application of co-design methods, the framework contextualization presented in the present study considers the complexities that arise in the mHealth context *specifically*. Second, by directly building on the expertise of CMEs and MSEs, we capture and synthesize tacit knowledge in a rapidly growing application area. Third, by linking the individual stages in the contextualized co-design framework to specific guidelines, we provide a shared frame of reference to facilitate interdisciplinary collaboration at the nexus of information systems and health research.

The remainder of this chapter is organized as follows. Section 4.2 provides an overview of foundations and related work on mHealth systems development, co-design methodology, and existing co-design frameworks. Section 4.3 presents our research methodology, including the interview and analysis approach. Then, in Section 4.4, we present the contextualization of the framework to the mHealth context and the guidelines that emerged from the interviews. Lastly, in Section 4.5, we discuss the implications of these results.

4.2. Theoretical Background and Related Work

4.2.1. Related Work on mHealth Systems Design

Driven by the ubiquity and increasing capabilities of mobile devices in recent years (Danaher et al., 2015; O'Reilly & Spruijt-Metz, 2013), mHealth systems have become a growing area for IS research and practice. The two primary application domains that have emerged for mHealth systems are: (1) disease management and (2) health promotion. Firstly, disease management empowers patients to manage their medical conditions more effectively and more

independently (e.g., helping people with diabetes to control blood sugar levels; Kitsiou et al., 2017). Secondly, health promotion facilitates better health choices, that is, providing support and encouragement for users to engage in behaviors beneficial to their health outcomes (e.g., improved diet, smoking cessation). The design of mHealth systems is often a complex endeavour that involves a range of pitfalls such as limited stakeholder involvement (Burke et al., 2015), lack of integration of mHealth artifacts with other health systems (Winters et al., 2017), and disregard of evidenced effective strategies for behaviour change (Burke et al., 2015).

Over the last decade, there have been various studies attempting to better understand how mHealth systems can be designed. In 2012, McCurdie and colleagues discussed how a user-centered design (UCD) process could be used to develop mHealth systems. In 2015, Banos and colleagues developed an architecture which showed how specific functionalities and components of an mHealth system could be implemented. Building on UCD, Schnall et al. (2016) developed a three-cycle (relevance, design, and rigor) design framework to better incorporate end-users' preferences when designing mHealth systems. Later, Eckman et al. (2016) developed a conceptual framework for designing mHealth systems that builds on design thinking principles, that is, "a hypothesis-driven method of generating and validating new concepts" (p. 424). Further, Nahum-Shani et al. (2018) explored how just-in-time adaptive interventions (JITAIs) can support users' health behaviour. While these studies provide insight into how mHealth systems can be designed, there has been limited focus on how to specifically apply a co-design approach to involve stakeholders in the mHealth context.

4.2.2. Co-design Frameworks

To facilitate co-design in systems development, researchers have proposed a range of frameworks (e.g., Sanders & Stappers, 2008, 2014; Visser et al. 2005). By creating a conceptual structure of the process, these frameworks provide guidance as a shared frame of reference for

researchers and practitioners. As noted by Sanders and Stappers (2014), the emergence of these frameworks is a response to the increasing number of co-design methods: "So many methods, tools and techniques have been introduced that it has become useful to provide frameworks for organizing them" (p. 7). For instance, the framework by Visser et al. (2005) structured the co-design process into the five phases of preparation, sensitization, sessions, analysis, and communication. Brandt et al. (2012) described an iterative cycle of making, telling, and enacting. Building on these earlier conceptualizations, the framework by Sanders and Stappers (2014) emerged as one of the most widely-recognized resources in the co-design literature (506 citations on Google Scholar, Nov 2020). As shown in Figure 4.1, the framework breaks down the timeline of the co-design process (shown in blue) into four interconnected phases.

1. First, the Pre-design Phase (also known as fuzzy front end or context mapping, Sanders & Stappers, 2008, 2014; Visser et al., 2005) is concerned with understanding the surrounding context and people's experiences, establishing goals for future experiences, and sensitizing participants to the problem space.[21] This captures an "open world" notion, setting out to explore tacit knowledge in the actual user context and "values uncertainty" (Gaver et al., 2004, p. 53).

2. Second, the Generative Phase focuses on producing ideas, insights, and concepts that explore the "design space". Users take an active role in making through the co-creation of conceptual artifacts (e.g., journey maps, mock-ups, storyboards) that embody and express ideas about how participants wish to live their future lives. Although the vision of the final artifact is still fuzzy, these methods are used to test, transform, and refine "ideas, insights, and concepts

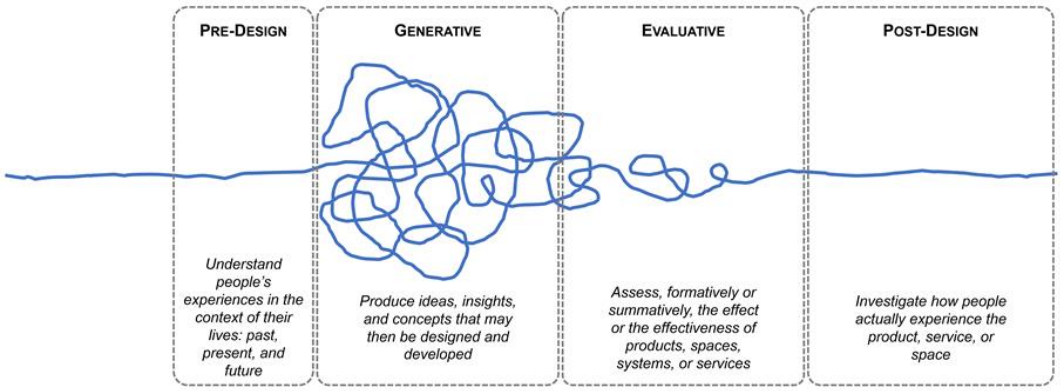
[21] It is important to note that the pre-design phase is also common outside co-design. In conventional user-centered design, this phase often uses "methods of observation to look for patterns of activity, and general user concern" (Druin, 2002, p. 7). However, and in contrast to co-design, during these activities little to no feedback is sought from users about their experience of using objects and technology.

that may then be designed and developed" in order to explore their technical and social feasibility (Sanders & Stappers, 2014, p. 10).

3. Third, the Evaluative Phase allows users to assess the effects and effectiveness of the devised concepts. The vision of the final artifact becomes more tangible through the evaluation prototypes that allow for users "to experience a situation that did not exist before" (Sanders & Stappers, 2014, p. 6).

4. Finally, the Post-design Phase refers to the notion that once a system is inhabited by users and becomes part of the users' lived experiences, the system needs to evolve along with the users' needs, habits, and use patterns. As such, "the tail end of the post-design phase [leads] to the front end of another design process" (Sanders & Stappers, 2014, p. 10). This captures the notion that no designed system is ever complete.

Figure 4.1. Co-design Framework by Sanders and Stappers



Note: Adapted from Sanders & Stappers (2014)

4.2.3. Co-design in mHealth

In recent years, an increasing number of mHealth studies have started to use co-design methods. A literature review by Eyles et al. (2016) identified early mHealth studies that used co-design

methods. Many of the mHealth studies that have used co-design methods followed a co-design approach similar to approached described in the framework by Sanders and Stappers (2014). A wide range of co-design methods has been applied in this area, including cultural probes (Capel et al., 2015; Danbjørg et al., 2018; Kanstrup, 2014; Wechsler, 2015), storytelling (Aljaroodi et al., 2017; Cordova et al., 2015; Das et al., 2015; Te Morenga et al., 2018; Verbiest et al., 2018), or journey maps (De La Harpe, 2012; VanHeerwaarden et al., 2018; Wechsler, 2015).

Of these studies, we observe systems both in the context of disease management and health promotion. Examples of areas in the disease management context where work has been done includes diabetes (Castensøe-Seidenfaden et al., 2017; Kanstrup, 2014), cancer (Lipson-Smith et al., 2019), asthma (Davis et al., 2018; Peters et al., 2017), heart failure (L. Woods et al., 2017b, 2017a, 2018a), and depression (Løventoft et al., 2012). On the other hand, examples of areas in the health promotion context where work has been done includes nutrition (Dol et al., 2016; Te Morenga et al., 2018; Verbiest et al., 2018), physical activity (Capel et al., 2015; Dol et al., 2016; Te Morenga et al., 2018), smoking cessation (Paay et al., 2017, 2015), and mental health (Arslan et al., 2010; VanHeerwaarden et al., 2018).

4.3. Method

Despite repeated calls for the use of co-design methods in mHealth systems development (e.g., Burke et al., 2015; Marzano et al., 2015), research in this area is still in its infancy. We hence conducted a qualitative study that (1) contextualizes the widely used co-design framework by Sanders and Stappers (2014) to the mHealth setting and (2) derives guidelines for addressing the most common challenges when applying a co-design approach in the mHealth context.

4.3.1. Interview Participants

We identified two stakeholder groups for the interviews: Co-design Method Experts (CMEs) and mHealth System Developers (MSDs). CMEs were recruited thorough online research using Google, Google Scholar, LinkedIn, Twitter, and ResearchGate to identify individuals with strong expertise in co-design (e.g., book authors, academics, consultants). The MSD group was recruited by searching papers and reports published by authors with co-design experience in the field of mHealth. In order to participate, interviewees had to be at least 18 years old and fluent in English. Interviewees were contacted by the first author via email with an information statement about the study to seek their written consent to participate. Participation was entirely voluntary and did not involve any monetary reward or other compensation.

Data collection and analysis (see Sections 4.3.2 and 4.3.3 for details) were carried out concurrently. The recruitment process continued until saturation (i.e., no further unique themes emerged; inductive thematic saturation; Saunders et al., 2018). At that point, we concluded that the sample of 16 interviews was sufficient for our study. All interviews were audio-recorded and had a total duration of about 14 hours. All participants completed the study. Table 4.1 summarizes the number and length of interviews for each stakeholder group (see Appendix B.1.2 for details of the interviewees' backgrounds). Ethics approval for the research was granted by the ethics committee at the University of Newcastle, Australia (H-2019-0064).

Table 4.1. Interviews' summary table

Stakeholder Group	**Number of Interviews**	**Interview Length**
Co-design Experts (CME)	8	48 to 72 minutes
mHealth System Developers (MSD)	8	36 to 66 minutes
Total	16	36 to 72 minutes

4.3.2. Data Collection

Data was collected between July 2019 and January 2020. Before the interview, participants received a two-page information statement via email with details on the research questions, interview duration, and assurance of data anonymization. Individuals who provided written

consent to participate were interviewed by the first author at a mutually convenient time using video conferencing (Zoom or Skype as per interviewee's preference). Before the interview started, participants were able to ask questions regarding the research questions and were assured that their identities would remain confidential. The interviews were of a semi-structured nature, with the interviewer using a protocol composed of open-ended questions and probing for additional information when required. Thereby, along two research questions, the interviews focused on (1) contextualizing an existing co-design framework to the mHealth space and (2) deriving guidelines to address common challenges in this context (see interview guide in Appendix B.1.1). Open-ended questions gave the interviewees opportunities to speak freely and to guide the discussion in directions of interest.

4.3.3. Data Analysis

The audio-recorded interviews had a total duration 14 hours and 15 minutes. To address our research questions, the first author coded the transcripts following the procedure of Braun and Clarke (2006), which includes 1) familiarization with the data, 2) coding, 3) searching for themes, 4) reviewing themes, 5) defining and naming themes, and 6) writing up. In Step 1, this involved familiarizing with the data to verify the accuracy of transcriptions. This required the first author to repeatedly read and re-read the transcripts (i.e., prolonged engagement). In Step 2, the first author performed initial coding in NVivo. The second author then checked these codes and validated them against the transcripts. Initially, we identified 154 codes from all the interviews (e.g., power distance, integration into clinical practice). In Step 3, the first and second author clustered nodes to common theme(s) based on coherent patterns. After that, in several discussions between the authors, the identified themes became the foundation of the guidelines (see Table 4.3). In the results section, data extracts are quoted to showcase the

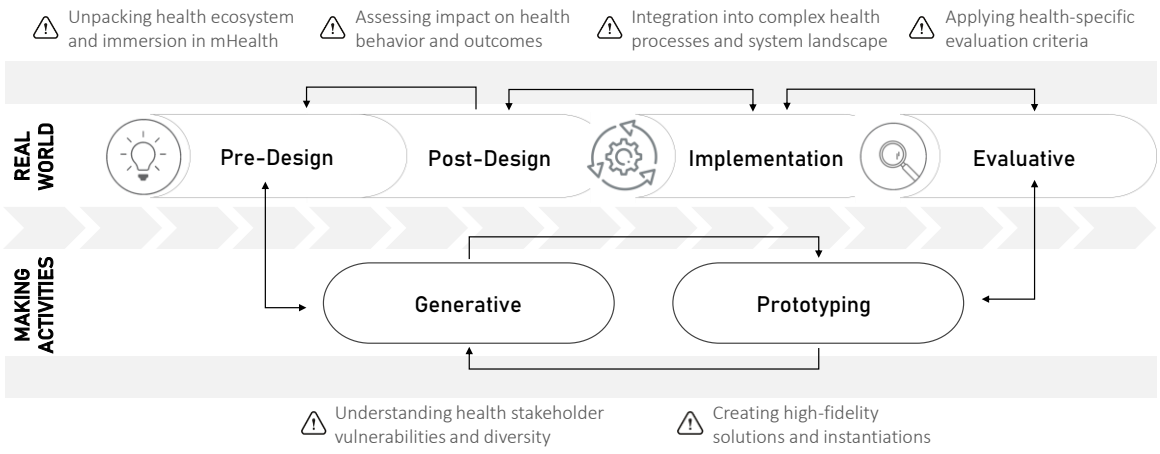
identified guidelines' suitability. In Step 5, the authors further refined the guidelines by eliminating redundant themes and naming the guidelines.

4.4. Results

4.4.1. Contextualization of co-design framework to mHealth context

Addressing our first research question, we first focus on the contextualization of the Sanders and Stappers (2014) co-design framework to the mHealth setting. Figure 4.2 shows the contextualized framework emerging from the analysis. It includes several important extensions which emerged from the interviews and which we elaborate on in the following. Table 4.2 provides a summary of the contextualization along with example quotes from the interviews.

Figure 4.2. Contextualized co-design framework for mHealth



Note: Contextualization of the co-design framework by Sanders and Stappers (2014) for mHealth.

The first extension of the framework pertains to the inclusion of a separate implementation phase when co-designing in mHealth. This differs from Sanders and Stappers (2014)'s original framework where the evaluative phase is directly followed by the post-design

phase. However, from the interviews it emerged that for the mHealth context the separation of the implementation phase is important to (1) facilitate the integration of the mHealth artifacts into the complex system and stakeholder environment, (2) account for the sensitivity of highly personal health data, and (3) address challenges arising from the complexities of existing processes (e.g., documentation, training, user acceptance).

The second extension pertains to a separate prototyping phase before the evaluative phase. A separate prototyping phase after the generative phase acknowledges the complexity of mHealth artifacts and their inherent evaluation requirements (e.g., pilot testing, randomized control trials). Including a separate prototyping phase assists in separating generative co-design methods in the generative phase (e.g., paper prototyping), from instantiations in which the idea of the solution has become more mature and where (high fidelity) prototyping occurs (i.e., hardware and software prototypes). Further, it emphasizes the need for a fully functional prototype at the end of the prototyping phase, suitable for rigorous evaluation (e.g., clinical and randomized control trials). Further emphasizing this aspect, Figure 4.2 positions the evaluation phase in the real-world context as compared to the prototyping phase.

Beyond these two additional phases, interview participants also emphasized several other important aspects when co-designing mHealth artifacts. For instance, they referred to the importance of the post-design phase following the implementation in the real world. In general, the post-design phase is important to assess the artifact's impact (Sanders & Stappers, 2014). However, CMEs noted that this step is frequently not carried out due to time and cost constraints. However, the post-design phase was especially important for several reasons. First, it is difficult to fully understand how well a system has accomplished its intended goals until it has been implemented into the real world, particularly in the health context where impact is driven by changes in health behaviour (Noorbergen et al., 2019). Therefore, follow up is necessary to understand the impact of the system and make changes if necessary. Further,

mHealth systems are intended to be used over long time spans (e.g., diabetes self-management). Therefore, it is important that the mHealth system can adapt to the changing needs of the end-users:

> *"I think post-implementation and the collection of evidence of the impact of that change is absolutely essential because you are talking about people changing their behaviour for better health outcomes."* **[CME7]**

A second important aspect is the context in which the co-design phases occur, for instance, whether a co-design phase is conducted in a real-world context (e.g., conducting interviews or observation in a hospital during the pre-design phase) or a context in which the participants are brought together for joint activities (e.g., co-design workshops). This is particularly true for mHealth, for which, as pointed out by interviewees, researchers should immerse themselves in the problem's actual real-world context in order to render the co-design process effective. Given the inherent focus on the real-world context, this immersion is hence especially important for the pre-design, evaluation, implementation, and post-design phases

Table 4.2. Contextualization of the Co-Design Framework

	Contextualization to mHealth	**Example Quote from Interviews**
Pre-Design Phase	Unpacking of the person's complex health ecosystem	"[…] part of the process in the pre-design phase is unpacking the ecosystem for the person. Who are the organizations they interface with relating to their health? Who are the people that they interface with related to their health? That helps you build up a bigger picture and where the leverage points for change are." **[MSD3]**
	Researcher immersion into the context the mHealth system resides in	"I think a really important part of that was the fact that we were working on-site" **[MSD1]** "[…] we position ourselves in the context by submerging ourselves in all the relevant stakeholders" **[MSD8]**
Generative Phase	Vulnerability of end-users in the mHealth context requires participants' involvement in co-design activities to be as safe and accessible as possible	"It is about getting people to participate on the level that they are comfortable with […]. Sometimes that means it is not actually appropriate or ideal to bring a diverse group together because that might not be safe, fun, or easy […]. Sometimes [you] might need to do work with participants in advance of bringing a diverse group together to make sure that every single person there understands what they can do [to be as inclusive as possible]." **[CME6]**
	Diversity of mHealth stakeholders requires low fidelity prototypes to be sufficiently simplistic to	"[It] was really important that it [prototype] was not anything too complex or new software. I developed the wireframes and went back to every team member, so those that participated in the design workshops, but also others that did not want to come. They were too intimidated to come to the design workshops. I met

	engage with and provide feedback	with them one-on-one, had a coffee with them, and showed them the PowerPoint so that they could comment and improve on the design." **[MSD2]**
Prototyping Phase*	Separation of prototyping in the generative phase (e.g., paper prototyping) from solution instantiations (e.g., high fidelity prototypes) due to complexity of mHealth systems	"Even design professionals themselves are sometimes reluctant to do really low-fi prototyping. I think people often feel if we are making something, we need to make it really high quality and show people how good it is going to be. But there is real value in making stuff with paper, or plasticine […] in the health context. I have seen some good examples of people using little figurines and models of how people interact in places like emergency rooms […] and acting it out […]. What is a cheap and fast way to test out some of these ideas? […] What are the questions we need to answer to know what we need to move on to the next phase and actually start designing or developing a fuller scale higher fidelity solution." **[MSD6]** "You go from low fidelity [generative], to high fidelity [prototyping], and then to user testing [evaluative]. Generative is like low fidelity brainstorming. Generative design research and making is not user testing. It is different. What you are calling the generative phase is more like wire framing and stuff. So, you increase the fidelity of your prototypes as you go and test along the way. That is key for this." **[MSD3]**
Evaluative Phase	Health-specific evaluation requirements due to impact on people's health (e.g., pilots, randomized control trials)	"You would not naturally do a clinical trial or a randomized control trial in your implementation phase because you first need to be able to test the feasibility. So, you would not do […] the randomized control trial until you have got some pilot data back and done it. I would definitely split that up because they are pretty high-level kind of quality study designs, so you would only save that for once you have got some pilot data. We would never as a health researcher or a health clinician move straight into a randomized controlled trial without pilot data first […]. In terms of costings, randomized control trials are much more expensive to run and they are the gold star or grade one evidence." **[MSD8]** "You have to have a pilot test of it for feasibility of deploying it in the real world because there is going to be quite a difference between what you have generated in the generative phase and what can actually be taken up day-to-day in the real world […]. You need to do it in stages, especially because there is such a massive cost involved in terms of the upkeep of apps and other technologies too. So if you can have a prototype, it is not just about testing the prototype, it is also about testing how the prototype works in the real world before you turn it into the end product." **[MSD1]**
Implementation Phase*	Training and supportive materials for end-users and health practitioners to seamlessly integrate the mHealth system into the complex process and system landscape	"It is not just about the end-product, it is about everything that goes with it that we need to test and work out too. So the instructions that we give to people as to how to use it, how we advertise it, who we train in the facility in terms of helping patients to use it, how we promote it to staff so that they know it is available to their patients as well. So all of that is about the implementation, and I think the implementation needs a generative phase as well as the development of the mHealth system needing a generative phase, and maybe that generative phase is pilot testing it in some way." **[MSD1]** "If they were not taught how to use [the app] properly, if they were not given the right support materials, or if it did not get to the right people because the people who did the roll out of it were not briefed well enough around the sorts of people we want it to go to, even if it was really beautifully designed, then it would have failed. So, I am talking about the wraparound services of the thing. It is not just a thing." **[MSD3]**
	Complexity of processes and systems in the health context requires the implementation to be a consideration right from the start of the co-design process (who and what is involved to be successful)	"You really need to work with the [health system] and that is where that whole implementation phase becomes crucial because even if your thing is beautiful, if they do not have the support to make it work, it will fall down." **[MSD3]** "So typically, you would want implementation to be on the agenda right from the initial co-design process. You need to have a plan. If you are going to co-design something, you need to have a plan that if it is effective, how could it be brought about, and those discussions or those people involved in that process. Even when you do that, the co-design process is hugely lengthy, typically. It is very hard to do that quickly. And then also the research process: if you are going to do robust

		research, that is extremely lengthy. By the time you actually get to a position where you might be looking at implementation, the climate can have changed drastically. Having those people involved from the start is fundamental to the success of implementation, and having plans around that." **[MSD7]**
Post-Design Phase	With the inherent focus of mHealth systems on user health behaviour, it is essential to collect and analyse post-design usage data	"I think post-implementation and the collection of evidence of the impact of that change is absolutely essential because you are talking about people changing their behaviour for better health outcomes." **[CME7]** "In this post-implementation phase […] you can get post-design interviews and scenarios, but the additional part of that is that you have got all these functionality and metrics that you can get from mHealth that you cannot get anywhere else. So, like Google metrics, Google Analytics, and usage statistics and stuff like that. That is a whole avenue of data that you do not have when you do not have mHealth." **[MSD8]**

Note: * = extension beyond the original Sanders and Stappers (2014) framework

4.4.2. Guidelines for Co-Designing in mHealth

Based on the interviews, we derived seven guidelines which address common challenges when using co-design in mHealth systems development (see RQ4).

4.3.2.1. Guideline 1: Understand specific mHealth context

The interviews revealed important differences to consider between health promotion and disease management, including 1) the fact that mHealth users have unique sensitivities which must be taken into account, 2) the diverse array of (to be) involved stakeholders, 3) the significance of evaluation, and 4) the actual implementation and translation of mHealth tools.

Due to the inherent focus on health outcomes, mHealth users are typically sensitive. While this is already the case for health promotion applications (e.g., healthy eating, alcohol reduction), the sensitivity of end-users is often even higher for disease management (e.g., dementia, stroke). This sensitivity creates a number of challenges in terms of (1) recruiting representatives from the target cohort and (2) being mindful of their health sensitivities.

> *"I mean, the first thing that comes to mind that I can think of is getting access to participants. It's really impossible in healthcare."* **[CME2]**

> *"It might be really hard to get people to open up and be honest about their experiences of having a stoma bag […] It could be that [you] think a subject is not sensitive, but then in the case of another culture […] it's just not a subject that ever gets discussed with family members around. [You] can talk to patients one-on-one maybe, but you [not] with all their family around them. I suppose there could be really interesting cultural sensitivities or just general health sensitivities that might make co-design inappropriate."* **[CME2]**

> *"Especially when we are talking about long-term conditions […], there were high numbers of [indigenous] people who were involved and needed to be involved, and that's just one example of how you have got to think about what the cultural norms are too in terms of participating […] Especially when we had projects that were around young people […], young people who were following cultural norms would never contradict or talk before an elder […]. That's also something to be mindful of. What are the cultural norms of the people that will affect their participation?"* **[CME6]**

With the specific focus of supporting positive health outcomes, the co-design process inherently touches on sensitive, deeply personal aspects which, in turn, requires very high levels of trust in the research team and process. It is hence vital to select co-design tools and methods that are appropriate in this context and allow sensitive end-users to participate to the best of their capabilities.

> *"One [challenge] is a lack of trust. [It] might be that you are being invited to participate in a co-design process and you do not trust the person or organization to actually [really] listen to you. It happens, in particular, with government led and funded projects where people who may have had a lifetime of being let down by organizations*

and institutions and they may find it difficult to trust that their voice will really be heard and that things will really change as a result of their participation." **[CME6]**

"[As] soon as you bring a group together [there] needs to be trust and disclosure happening. [One] of the people said to us afterwards, 'I have all this personal stuff I did not want to talk about it in the group. So, I didn't say anything.' [There] is that aspect of the deeply personal secrets […] because we talk about behaviour change and […] resisting that change. [Otherwise] you would not have your app. […] They have to be really honest about why they can't and a lot of people do not want to be honest about that and not in a group situation." **[MSD6]**

"I think we have got this real problem at the moment where workshops have become a default and sometimes people then think that is the only way, but it is not […]. You might especially have some people with health conditions that mean they don't want to or cannot participate well. Maybe they cannot get there." **[CME6].**

Each specific mHealth context also has its own diversity of stakeholders that needs to be identified and involved in the co-design process. There may be also more than one category of end-users (e.g., both the patient and the health practitioner may be end-users), with associated requirements in terms of evaluation.

"You have got app designers, [marketing people, health professionals], and you have got the end-users who are trying to grapple with their medical challenges that they have. […] That would be one of the biggest challenges, getting those people together. […] Depending on what part of mHealth, but you might get people with illnesses that have a bit of time on their hands and actually welcome a bit of attention to their condition and something that might help them. On the other hand, you have got clinicians who are absolutely massively busy and would not want to spend more than five minutes on

> *this. […] There will be other people who would not even be convinced of the benefits of it and you would have to try and persuade them that this is something worthwhile."* **[MSD5]**

> *"In healthcare you cannot give patients a medical device or something that might impact on their health without going through the appropriate ethical channels – it is then classified as a medical device. That is a whole different process in terms of adoption, and the health service might not be interested in implementing something that is not proven."* **[MSD2]**

The last element of this guideline is the integration of mHealth tools into the wider system landscape. One of the largest identified differences between co-design in mHealth and other contexts is that mHealth systems need to integrate into a highly complex health ecosystem involving a complex array of health processes, systems, and stakeholders.

> *"What we found through making the app is that it is not just about the end product, it is about everything that goes with it that we need to test and work out too. So the instructions that we give to people as to how to use it, how we advertise it, who we train in the facility in terms of helping patients to use it, how we promote it to staff so that they know it is available to their patients as well."* **[MSD1]**

> *"You really need to work with the organization and that is where that whole implementation phase becomes crucial because even if your thing is beautiful, if they do not have the supports to make it work, it will fall down."* **[MSD3]**

Guideline 1	*Carefully consider the unique circumstances of the targeted disease management or health promotion context with respect to its evaluation and*

integration requirements, stakeholder involvement, and end-user sensitivities relating to highly personal aspects of a person's health.

4.3.2.2. Guideline 2: Immerse in mHealth context to identify and understand stakeholders

Co-design inherently involves an effective collaboration of system designers with users and other stakeholders. The key elements that were frequently brought up were 1) the importance for system designers to be immersed in the context where stakeholders are for optimal problem identification, 2) identification of relevant stakeholders as early as possible to drive their own involvement and contribute to the study design (including ethics approval), and 3) the need for an ongoing relationship with stakeholders in mHealth that recognizes the inherent power distance between stakeholders and prioritizes the needs of end-users.

The multiplicity of factors affecting and supporting a person's health renders the environment of mHealth system design inherently complex. Interviewees repeatedly stressed the importance for system designers to immerse themselves deeply to effectively identify stakeholders, understand pain points and relationships with one another, and correctly determine the problems they can (and cannot) address.

> *"You do have to be embedded in the space in order to identify it, or you have to be listening to people who are embedded in the space in order to identify it"* **[MSD1]**

> *"When you work with other people you have to immerse in their situation"* **[CME3]**

> *"So we started with a empathize phase, [which] was around interviewing all different types of stakeholders individually to try and understand what their experiences are, what their frustrations are, what their behaviors are, and their pain points are, what*

> *they really struggle with, and really that is a process of a needs analysis […] If I had my time again, I would have some kind of hospital administrator, someone that had power within their health service to give us feedback in terms of what would work in planning for the implementation phase."* **[MSD2]**

A second aspect linked to the complexities of the health environment pertains to the importance of involving stakeholders as early as possible. While one can argue that identifying stakeholders early is important for any systems design, failing to do so is particularly critical, and possibly fatal, in the realm of mHealth. First, due to the multiplicity of factors around a person's health, the number of potential stakeholders is high which requires buffer times for planning, organizing, communicating, and scheduling. Second, the health sector naturally encompasses high levels of regulation and procedures to protect and support vulnerable populations. It is hence vital for stakeholders to be become involved early enough to be able to point out procedural constraints in their particular domains (e.g., requirements and time frames for ethics approvals).

> *"I would say involve them right from the start. […] Ascertain to what extent they are going to be able to contribute any of their time […] and ask them what stage they think they want to be involved amongst and let them drive that process."* **[MSD5]**

> *"Ethics was a real challenge. I think we were brought in too late. […] I think that you need to bring the designers in as early as possible. […] What I would have done is get us involved before the ethics application went in. Engage somebody who has got co-design expertise to help shape the ethics, ideally the people that you want to commission to do the work."* **[MSD3]**

> *"Before you can even figure out how to facilitate their participation, you need to start to understand those people a little bit. So sometimes it might mean you need to do a bit*

of research, or just hanging out with people, just some ways to get to know those user groups or stakeholders or participants a bit better first to understand why they might want to participate and how they might want to participate" **[CME6]**

"I think it was essential to have [app developers] involved [at the beginning of the co-design] because it meant that they could identify what was most important because they are the experts in developing this tech. We do not know how to do it. […] We were there as experts in health services and in research, and the consumers and the other stakeholders were there from their expert perspectives, but we needed the app developers and also IT and health management as well because we wanted it to be a viable solution. So blue sky thinking is one thing, but we actually wanted it to happen as well. So, we had to be aware of what limitations were there." **[CME7]**

"The best way to manage the different stakeholders and the management is at different stages [to] highlight the appropriate stakeholders that are necessary and let them know what their voice is and what their purpose is. Basically, letting stakeholders know when their input is important and needed and what the reason for their input is." **[CME8]**

Supporting positive health outcomes is an ongoing process. It follows that also the relationship with stakeholders of mHealth systems design needs to be managed and supported in an ongoing way. While this holds true for both health promotion and disease management applications, it is particularly critical in the disease management space. In order to manage these relationships well, it is also critical to balance the number of participants involved in co-design activities and avoid a potential power-imbalance that is geared towards senior medical practitioners. Given the diversity of stakeholders, the resulting power distances between stakeholders must be considered carefully. After all, the person most affected by the system will be the end-users and, hence, there is a vital need to adequately capture and address their needs.

"The problem should really be generated in part by the people who are affected when it has something to do with health management. That means that there is a need for more discussion early on. It also means there has to be more of an ongoing relationship [with end-users in disease management] even if there is not a particular problem yet. Just like maintaining a relationship with the consumers that you work with is important because you do not know what might come up." **[MSD1]**

"I get really concerned when I see just one or two people with lived experience brought on as kind of the token users to a predominantly professional group and you just think how can those people feel confident and comfortable in that setting, especially in a health context where they are used to being told by the professionals." **[CME6]**

"You do need to have a kind of hierarchy of who your stakeholders are I suppose. So, the app developers are IT stakeholders, but really our most important stakeholders were the patients and so I would tell someone, remember your hierarchy." **[MSD1]**

Guideline 2	*Immerse yourself in the underlying complex health context in order to identify and understand stakeholders early, include them in defining their involvement in the co-design process along existing health process requirements, recognize the diversity and inherent power distances among stakeholders, and prioritize the needs of the end-user.*

4.3.2.3. Guideline 3: Consult health behaviour change literature and experts

The third theme that emerged from the interviews was the importance of consulting the behaviour change literature and possibly, even directly involving behaviour change experts in the co-design process. Overall, the importance to consult the behaviour change literature was mentioned in 9 of the interviews (4 CMEs, 5 MSDs). The importance of behaviour change for mHealth systems design relates back to the very nature of the underlying health promotion and disease management contexts, in that the purpose of these system inherently involves some change in user behaviour to address a health goal (see Free et al., 2013 for a review of behaviour change targeted by mHealth systems). For health promotion, the change in behaviour commonly refers to a change in lifestyle behaviors, such as reducing alcohol consumption and smoking (Gustafson et al., 2014; Paay et al., 2017), or forming healthy eating habits (Dol et al., 2016), For disease management, examples include regularly performing rehabilitation exercises (Davis et al., 2018), following a specific medication regime (Vilarinho et al., 2017), or recording specific aspects of daily activities (Castensøe-Seidenfaden et al., 2017; Davis et al., 2018). Thereby, participants emphasized that because behaviour change is not only a by-product of the mHealth system, but integrally link to its purpose, it is important to already explore in the early stages of the co-design process which behaviors are addressed and in what way.

> *"You have to engage in the behaviour change literature […]. A health practitioner probably knows that there is behaviour change literature to go to, but someone outside that health domain may not know to go to that literature."* **[MSD8]**

> *"I do not think it necessitates psychologists or behavioural scientists, but it does necessitate if you are not any of those things, looking into those fields. I do not think it is something that you necessarily need to be an expert on as long as you know that that*

is important, and then you know where to look. And I do think there is a particular stage where it should be involved and that is right at the start." **[MSD1]**

MSD6 elaborated that a key distinguishing factor between mHealth and other contexts is that co-designing mHealth systems is inherently linked to changes in behaviour that are often deeply personal to the end-users, that are linked to deeply-embedded long term habits (e.g., eating, physical activity, sleep patterns):

"You are talking about changing behaviors that are there for a reason. They are not just trivial behaviors, they are deeply embedded and they have really unusual reasonings that […] surprise you. Whereas if you are just designing a booking system or whatever, it is not that emotive." **[MSD6]**

Finally, given the focus on mHealth systems on achieving positive health outcomes, it is critical to careful tailor the co-design activities to the individual circumstances and capabilities of the stakeholders, and in particular the end-user.

"One of the main challenges is that the way co-design frameworks [are] very focused on picking a series of methods for a workshop, and then saying 'okay participants, I all want you to do this method using these kinds of materials.' [This] is just completely unfeasible when you have people with only one hand or those kinds of things. […] Co-design […] for healthcare […] does have to be approached differently." **[CME2]**

Guideline 3 *As early as possible in the co-design process, consult the behaviour change literature and/or involve experts in behaviour change relevant to the problem context in order to effectively identify the targeted change in behaviour and adequately plan the type and stakeholder involvement of co-design activities.*

4.3.2.4. Guideline 4: Co-design facilitators with an intimate understanding of mHealth context

Interviewees emphasized the critical role that facilitators play in co-designing mHealth systems. Here, co-designing inherently involves a high stakeholder diversity (e.g., app developers, health practitioners, health insurance providers) while at the same time addressing highly intimate issues and concerns regarding a person's health (e.g., quitting smoking, diabetes self-management). Against this backdrop, the facilitator takes a critical role in involving stakeholders in the different stages of design in a trust, meaningful, and effective way.

Without adequately considering the important role of the facilitator, a range of critical challenges can emerge such as a lack of true involvement due to a power distance between end-users and health professionals, or system designers having a lack of understanding about end-users lived experiences and perspectives.

> "*In most of these fields usually experts get to make decisions about what should happen and what people should do […], and the very idea that people are the experts in their own lives is a radical idea, especially for a lot of medical professionals, as well as a lot of academic researchers […]. Some of them really struggle with the idea that they may not know what is best for other people. So that idea I think is quite as quite a radical one in co-design. It is not to say there is no place for experts and specialization, but it is to try and even out the playing field a bit more so that people's lived experience […] are also respected, and I think that is a real challenge for people who have been trained to privilege different kinds of expertise and authority.*" **[CME6]**

> "*I think that power balance is particularly interesting in healthcare because it is really hard to say that you do not agree [with] a doctor. […] They're held up in such high*

> *esteem as being experts of the subject matter […]. So to then put up patients in a room [saying] ' co-design with your doctors', it could be really confronting to [say] 'oh I have a different opinion to you and I do not usually get to express it in my experiences with you, but now can I?'*" **[CME2]**
>
> *"I think that is probably how we ended up offending people because we did not really know what it is like to give up [smoking], we just sort of went 'you just give up'. So we were a little bit disconnected from knowing what it truly means to struggle with [an] addiction that you want to give up and you know is bad for you […]. All these issues are quite emotional and unless you understand how it really feels I think it is important for whoever is running the workshop [to] have a feel for the topic, a knowledge of what it means."* **[MSD6]**

To address potential challenges (e.g., power distance, lack of empathy), interview participants emphasized that co-design facilitators need an authentic understanding of end-users' real-world experiences (e.g., first-hand experience, immersing in problem context, literature consultation). Based on this understanding, facilitators are able to operate in a more empathetic way which can help participants feel more comfortable sharing their deeply personal experiences regarding their own health. For example, MSD6 stated that the facilitators in their smoking cessation project had personal experience in the problem context. Based on ice-breaking exercises, the authentic experiences of the facilitators enabled them to support workshop participants in becoming more comfortable to actively engage with the co-design activities. As a result, the facilitators were perceived more like co-design participants than authority figures. Empathy, or a "soft human touch" (CME4), is a critical skill for a facilitator running co-design workshops to overcome the inherent power distance issue in the mHealth space.

"I think the more practical power distance issues in sessions can be easily navigated if you just have a bit of a soft human touch to ensure that people don't feel like you're the cocky arrogant researcher or expert or designer or however you're positioning yourself." **[CME4]**

"There is comfort that comes from people who are like you. [This] is why I saw the two [facilitators] being so successful with the low self-esteem kids because they themselves started the session talking about their problems. The designers running the session were able to talk about their experiences and how they dealt with it and so then they immediately became not the person leading the co-design activity, but a true co-designer." **[MSD6]**

"There's few researchers that I do not necessarily put in a room because I know that they will probably rather drag down the vibe than really give the participants the feeling that we are here to […] make stuff happen and that our ideas and our input is valuable […]. So, a lot has to do with the facilitators in the way they kick off a session, the way they talk to the participants, the way they deal with the participants. So that is obviously one important element and that can make a massive difference." **[CME4]**

Guideline 4	*Select and engage co-design facilitators that have an authentic understanding of the intimate problem context (e.g., first-hand experience, immersing in problem context, literature consultation), and operate in an empathetic way in order to mitigate potential barriers associated with the inherent power distance between stakeholders in the mHealth context.*

4.3.2.5. Guideline 5: Identify post-design advocates to aid in implementation and post-design

Interview participants repeatedly stressed the complexity of implementing and rolling out an mHealth system. This is linked to the complexity and inherent risk of processes in the health sectors, and the multitude of stakeholders that need to effectively work together. Against this backdrop, the importance of post-design advocates emerged as an important theme. CME1 described post-design advocates as "end-users who are really interested in what you're doing, how you're doing it, and what it could mean for them." MSD7 elaborates that post-design advocates are the "[…] people behind it that are going to drive, push, and refer patients or their communities to [the mHealth system]". Identifying post-design advocates is critical for system designers to support the implementation and post-design of the mHealth system.

Post-design advocates need to be stakeholders that are well-connected and respected in the application context. By actively involving them early in the co-design process, their contributions can already be considered in the pre-design and generative phases of design. This inherently establishes a "buy-in" of stakeholders that can later assist in championing the system in the implementation and post-design phases with the people and communities that are going to use the system. This is important in the mHealth context because there are many challenges (e.g., integration into clinical practice, collecting data in the post-design phase) that can be mitigated by identifying post-design advocates.

> *"Implementation of mHealth tools is extraordinarily challenging […]. There are a lot of barriers of getting things into practice and getting that buy-in from communities or end-users […] can actually aid your implementation because they have already bought in. Because they are invested in it, they are more likely to try and help make it happen*."
>
> **[MSD7]**

Beyond the technical aspects of the design system, interviewees argue that the integration into the highly complex processes and the various stakeholders in the health space renders the implementation and rollout of the system exceptionally challenging. Post-design advocates can be critical to inform and support the implementation the mHealth system in the real world. After all, if health practitioners do not believe that the system is going to be useful, they will not promote it to their patients.

> *"If you are integrating into health systems, that has its own challenges, and the other thing is actually getting people to use and promote these tools. So, we talk about champions, you have got to have people behind it that are going to drive it and push it. They are going to refer patients or their communities to it, or they are going to support services to use these tools"* **[MSD7]**

> *"It is not just about the end product, it is about everything that goes with it that we need to test and work out too. So the instructions that we give to people as to how to use it, how we advertise it, who we train in the facility in terms of helping patients to use it, how we promote it to staff so that they know it is available to their patients as well."* **[MSD1]**

> *"If they were not taught how to use [the app] properly, if they were not given the right support materials, or if it did not get to the right people because the people who did the roll out of it were not briefed well enough around the sorts of people we want it to go to, even if it was really beautifully designed, then it would have failed. So, I am talking about the wraparound services of the thing. It is not just a thing*." **[MSD3]**

Lastly, another reason for why involving post-design advocates is important is that stakeholders in practice are vitally important to measure the impact of the mHealth system once it has been implemented into the real world (e.g., based on usage data) and being available for follow up

co-design activities in the post-implementation phase (e.g., post-design interviews) to make sense of the usage data.

> *"You will find some end-users in this process who are really interested in what you are doing and how you are doing it and what it could mean for them. Those are the kind of people who might become your post-design advocates who would actually collect this data for you and at a reasonable price because they have a vested interest in seeing how it worked and helping other people manage their lives for example. So, you could build it into the whole process.*" **[CME1]**

Guideline 5	*Throughout every phase of co-design, identify potential post-design advocates from different stakeholder categories who can aid in implementing the mHealth system (e.g., training staff in the use of the system) and championing its usage in the post-design phase (e.g., providing feedback on system usage in practice).*

4.3.2.6. Guideline 6: Ensure that health-specific evaluation criteria are applied

Another critical aspect of applying co-design to mHealth are the requirements for evaluating mHealth systems, which commonly require some additional considerations in comparison to other contexts due to the intended (and possibly unintended) effects of the artifact on people's health. The main elements uncovered from the interviews were: 1) the risks and ethical issues associated with developing solutions in a healthcare context, and 2) the need for feasibility testing in the real world (e.g., clinical trials, pilot testing) before implementation to ensure the mHealth system accomplishes what it set out to do and does not pose a risk to the end-users.

Interview participants emphasized that due the focus on people's health, there are additional risks and ethical considerations when co-design mHealth systems that come with working in a healthcare context. For example, MSD1 and MSD2 elaborate:

> *"Even though your interruption through technology might end up with things being better, you still have to be very conscious of the fact that there is more at stake if anything goes wrong because I would not want to be involved in a technology that made things more complicated for people who are already in a complicated and stressful situation."* **[MSD1]**

> *"In healthcare you cannot give patients a medical device or something that might impact on their health without going through the appropriate ethical channels."* **[MSD2]**

In order to navigate these risks, it becomes increasingly important to ensure that an mHealth system goes through feasibility testing such as pilot testing and randomized control trials in the real world so that it can be established that the mHealth system accomplishes its goals and does not pose a risk to the end-users.

> *"It is then classified as a medical device. So that is a whole different process in terms of implementation. The health service might not be interested in implementing something that is not proven. So, you need a randomized controlled trial of the app first, so that is in the evaluation phase, not the implementation phase, to then prove that it increases patient outcomes and then they might adopt it."* **[MSD2]**

> *"You definitely need user engagement and prototype testing before [the mHealth system] is deployed. You want to make sure your product is as good as that can be before it can be deployed, particularly for mHealth interventions where it can be*

> *accessed readily by a large population. You need a lot of consumer testing or prototype testing before it is deployed."* **[MSD8]**

MSD8 further explained that it is important to understand that there are different levels of feasibility testing and the differences between them tend to be the quality of the test and the cost to run the test. For example, MSD8 recommended performing pilot testing before doing randomized control trials for these reasons.

> "*You would not naturally do a clinical trial or a randomized control trial in your implementation phase because you first need to be able to test the feasibility. So, you would not do the clinical trial or the randomized control trial until you have got some pilot data back and done it. I would definitely split that up because they are pretty high-level kind of quality study designs, so you would only save that for once you have got some pilot data. We would never as a health research or a health clinician move straight into a randomized controlled trial without pilot data first […] in terms of costings, randomized control trials are much more expensive to run and they're the gold star or grade one evidence.*" **[MSD8]**

MSD1 adds that feasibility testing is not only important for making sure that the mHealth system works and poses no risk to end-users, but that due to the massive costs of upkeep for mHealth systems after they have been implemented, finding problems at this stage is beneficial because they can be fixed by re-entering the earlier co-design phases. Thereby, some problems are more likely to be found due to testing being done in a real-world setting:

> *"You have to have a pilot test of it for feasibility of deploying it in the real world because there is going to be quite a difference between what you have generated in the generative phase and what can actually be taken up day-to-day in the real world. […] You need to do it in stages, especially because there is such a massive cost involved in*

terms of the upkeep of apps and other technologies too. So if you can have a prototype, it is not just about testing the prototype, it is also about testing how the prototype works in the real world before you turn it into the end product" **[MSD1]**

Guideline 6	*In the evaluative phase, ensure that the mHealth system goes through feasibility testing in the real world (pilot testing and randomized control trials) to adequately address ethical considerations in the health context, determine potential risks to the end-users caused by the artifact, and clarify whether it accomplishes its intended goals before implementation.*

4.3.2.7. Guideline 7: Collect usage data and use contextual methods to understand impact

Another theme that became apparent while conducting the interviews was the importance of post-design. Participants explained that the post-design phase of co-design is necessary to understand the impact the mHealth system has had in the context with which it has been implemented. One of the ways of measuring impact is determining whether the mHealth system has led to the intended behaviour change in the target users.

"I think post-implementation and the collection of evidence of the impact of that change is absolutely essential because you are talking about people changing their behaviour for better health outcomes." **[CME7]**

"[The impact,] you do not necessarily know until something is out in the real world." **[CME6]**

Additionally, participants explained that mHealth is in a unique position to measure this impact due to having access to participant usage data from the mHealth system.

> *"In this post-implementation phase, […] you can get post-design interviews and scenarios, but the additional part of that is that you have got all these functionality and metrics that you can get from mHealth that you cannot get anywhere else. So, like Google metrics, Google Analytics, and usage statistics and stuff like that. That is a whole avenue of data that you do not have when you do not have mHealth."* **[MSD8]**

However, another participant urged that it is important that qualitative co-design methods (e.g., post-design interviews) are used to make sense of this participant usage data.

> *"There are ways to get feedback, like usage statistics. Those do not tell you <u>why</u>. So, having more qualitative methods to get feedback is really important."* **[CME6]**

The other reason participants expressed why post-design is important when co-designing in mHealth is because mHealth systems must be updated to meet changing user needs.

> *"All apps need to be updated, and one of the biggest issues with health apps is they are not."* **[MSD7]**

> *"You do not just put something out in a digital form and it is done."* **[CME6]**

Guideline 7	*In the post-design phase of co-design, collect usage data (the what) through the mHealth system to observe the impact of the system after it's been implemented and use contextual co-design methods (the why) to understand this impact.*

4.5. Discussion

4.5.1. General Discussion

While there exists extensive research on co-design methodology and its application in general, limited research has examined the complexities that arise from applying co-design in mHealth specifically. In this study, we sought (1) to contextualize an existing co-design framework to mHealth, and (2) to develop guidelines for addressing common challenges in the process of using co-design for mHealth systems development. To address these questions, we conducted 16 semi-structured interviews with CMEs and MSDs and analysed the interviews using thematic analysis as described in Braun and Clarke (2006). This led to a contextualization of the widely-used co-design framework by Sanders and Stappers (2014) for the mHealth context (see Figure 4.2) and a set of seven guidelines (see Table 4.3).

Regarding our third research question, several important aspects emerged from contextualizing Sanders and Stappers (2014)'s co-design framework to mHealth. First, it became apparent that some of the co-design phases should be split up. Specifically, while the original framework has only an overall generative phase, a separate *prototyping phase* was suggested for mHealth to distinguish between the *generation of early concepts* (e.g., low-fidelity prototyping) in the generative phase compared to the *testing of more mature concepts* where maturity is higher (e.g., high-fidelity prototyping). Further, a dedicated *implementation phase* allows to distinguish between activities performed during evaluation (e.g., pilot testing, randomized control trials) and implementation (e.g., creating documentation, training, user acceptance). Second, mHealth has its idiosyncrasies with regard to the *front-end* of co-design, including the importance of researchers immersing themselves in the problem context and diverse stakeholder landscape. Further, this diversity of stakeholders can lead to a power distance issue in the *generative phase.* Therefore, it is important to recognize that the inherent

vulnerability of mHealth end-users and their relationships with other stakeholders could impede participation. The *evaluative phase* is also affected as mHealth problems are typically inherently more risky than in other contexts. Thus, pilot testing and randomized control trials were mentioned by interviewees as prime examples for suitable evaluation methods in mHealth. Lastly, the *post-design phase* plays a special role in mHealth due to its intended effects on health behaviour. This, however, cannot be assessed until the system has been deployed. The post-design phase is hence necessary to understand this impact on user behaviour and to allow for continued monitoring and maintenance.

Addressing our fourth research question, we identified seven guidelines for applying co-design to mHealth (labelled G1 to G7). As shown in Table 4.3, the guidelines pertain to specific phases of the co-design process. Emphasizing the importance of the front-end of co-design, G1 to G4 focus on ensuring that researchers and practitioners establish an intimate understanding of the problem context as early as possible. Interviewees noted that, by following these steps, common challenges such as stakeholder identification, power distance, and lack of trust can be addressed effectively. For instance, by immersing oneself in the mHealth problem context (G2), researchers and practitioners can better understand how the end-users interface with stakeholders in their health ecosystem, aiding in stakeholder identification. Note that G5 maps to all phases in the framework as (post-design) advocates (i.e., users championing the system) can be identified in any phase. Interviewees noted that these advocates can help mitigate many issues that can potentially surface in the implementation phase, for instance, by championing the system themselves and by training others. Next, G6 maps to the evaluative phase and emphasizes the importance of health-specific evaluation (e.g., pilot testing, randomized control trials) given the high-risk nature of mHealth challenges. Lastly, G7 maps to the post-design phase to ensure that the impact is measured post-implementation along with contextual research that informs further system refinements.

Table 4.3. Mapping of guidelines to the different co-design phases

Guideline	Pre-Design	Generative	Prototyping	Evaluative	Implementation	Post-Design
Guideline 1: Carefully consider the unique circumstances of the targeted disease management or health promotion context with respect to its evaluation and integration requirements, stakeholder involvement, and end-user sensitivities relating to highly personal aspects of a person's health.	×					
Guideline 2: Immerse yourself in the underlying complex health context to identify and understand stakeholders early. Include them in defining their involvement in the co-design process along existing health process requirements. Recognize the diversity and inherent power distances among stakeholders. Prioritize the end-user's needs.	×					
Guideline 3: Consult the behaviour change literature and/or involve experts in behaviour change relevant to the problem context as early as possible in the process in order to effectively identify the targeted change in behaviour and adequately plan the type and stakeholder involvement of co-design activities.	×					
Guideline 4: Select and engage co-design facilitators that have an authentic understanding of the intimate problem context (e.g., first-hand experience, immersing in problem context), and operate in an empathetic way in order to mitigate potential barriers associated with the inherent power distance between stakeholders in the mHealth context.	×	×				
Guideline 5: Throughout every phase of process, identify post-design advocates who could potentially aid in implementing the mHealth system (e.g., training staff) and in the post-design phase (e.g., providing usage data and commenting on their usage of the system).	×	×	×	×	×	×
Guideline 6: In the evaluative phase, ensure that the mHealth system goes through feasibility testing in the real world (pilot testing and randomized control trials) to adequately address ethical considerations in the health context, determine potential risks to the end-users caused by the artifact, and clarify whether it accomplishes its intended goals before implementation.				×		
Guideline 7: In the post-design phase, collect usage data (the *what*) to observe the impact of the system after it's been implemented and use contextual co-design methods (the *why*) to understand this impact.						×

Additionally, there is also an important interplay between these guidelines. First, G1 – G3 are linked to G4 as the *authentic understanding* of the problem context that is needed to effectively apply G4. This highlights the importance of the front-end of co-design in mHealth, as without it, many of the challenges identified by the interviewees (e.g., power distance, lack of trust, accessibility of tools and methods) could impact the later co-design phases. Second, there is a link between G1/G3 to G6/G7. G1 and G3 primarily focus on understanding the problem context and establishing desired goals of the mHealth system while G6 and G7 refer to the evaluation of how well the mHealth system addresses these goals, both pre- and post-implementation. Lastly, there is a link between G5 and G7 since the identified advocates will invariably be needed for understanding the impact of the mHealth system in the real world.

4.5.2. Implications

There are several important implications for researchers and practitioners from this work. First, building on the extensive expertise of CMEs and MSDs who participated in this research, the contextualized framework may provide a shared frame of reference to guide mHealth systems development projects, which are inherently interdisciplinary in nature (Burke et al., 2015; Marzano et al., 2015). Rooted in the well-established co-design framework by Sanders and Stappers (2014), the contextualized framework brings to light a range of critical considerations that arise in the health context. As a shared frame of reference, the contextualized framework may aid mHealth researchers and practitioners in planning co-design activities and involving stakeholders in all stages of design (Eckman et al., 2016; Marzano et al., 2015).

> *"This is great work. There is definitely work in what you are doing. [...] Any type of framework that helps us to do this on the ground more effectively and in [the mHealth] context, that is the kind of work that we need."* **[CME4]**

Complementary to the framework, the guidelines point to a range of pitfalls that emerge in mHealth systems development along with specific suggestions on how these challenges can be navigated. By facilitating stakeholder engagement and involvement in co-design activities, these guidelines may aid researchers and practitioners in ensuring that mHealth system are underpinned by expert insight, adequately reflect the lived experiences of end-users, and effectively integrate into the existing system and process landscape (e.g., Burke et al., 2015; Moller et al., 2017). In doing so, co-designed mHealth artifacts may enable end-users and health professionals to develop a stronger sense of ownership and agency over the outcome. As an inherent part of this, researchers and practitioners can actively engage post-design advocates that may assist in increasing buy-in from stakeholders, overcoming barriers, and championing the system's implementation and use.

4.5.3. Limitations and Opportunities for Future Research

Naturally, this study is not without limitations. First, while our research builds on the extensive expertise of the interviewed experts, future research is warranted to evaluate the usefulness of the contextualized framework and guidelines for the development of actual mHealth systems. By applying and critically reflecting on these concepts real-world contexts, future research can assess their effectiveness and further refine individual guidelines. Second, because this work focused on the co-design process as a whole, it was beyond the scope of the present research to assess the applicability of specific co-design methods for mHealth (e.g., cultural probes, journey maps). Building on the foundations laid in this overarching view, future research could investigate the usefulness and boundary conditions of individual co-design methods for mHealth. Among other insights for the early design stages, this may bring to light specific activities that can assist in stakeholder engagement and impact determination in post-design.

4.6. Concluding Note

With the inherent focus of supporting positive health outcomes, researchers and practitioners encounter unique challenges when engaging in mHealth systems development. We hope that the contextualized framework and guidelines presented in this work will serve as a useful shared frame of reference to facilitate interdisciplinary collaboration at the nexus of information systems and health research.

Chapter 5.

Conclusion and Outlook

The growing health burden caused by lifestyle diseases (e.g., diabetes, heart disease) is well known, yet despite the preventable nature of these diseases, motivating the required health behaviour change remains a societal problem. In recent years, the use of mHealth systems to support health behaviour change has gained more attention (Free et al., 2013; Moller et al., 2017). The main goal of this thesis is the development of design guidelines and conceptual frameworks which build on our understanding of how mHealth systems can be designed in a way that effectively supports health behaviour change. This chapter summarizes the main contributions of this thesis, discusses its implications, and outlines avenues for future research in mHealth.

5.1. Contributions

Despite the repeated calls from researchers to use a co-design approach when designing mHealth systems, there has been limited research on how precisely this can be accomplished in an effective way. Therefore, it is important that we look at the empirical mHealth studies in disease management and health promotion and how they have applied the co-design approach. In Chapter 2, we conduct an SLR on empirical mHealth papers which use co-design methods and map which methods were used and when they were used in the design process to an established co-design framework by Sanders and Stappers (2014). This objective is reflected in Research Question 1.

Research Question 1: *What is the current state of research on co-designing mHealth artifacts for disease management and health promotion?*

As a result of the SLR in Chapter 2, it became clear that many mHealth systems are designed without an underpinning of established behaviour change frameworks and rarely consult behaviour change experts in the design of mHealth systems. We observed similar patterns for disease management and health promotion in terms of how and where co-design methods were applied. In the pre-design phase, interviews, personas, and focus groups were the most frequently used co-design methods. In the generative phase, this was paper prototyping, wireframes, and sketching. In the evaluative phase, this was high-fidelity prototyping, interviews, and questionnaires. Lastly, in the post-design phase, the most widely used co-design methods interviews, questionnaires, and focus groups, however, the number of empirical studies that engaged in the post-design phase were extremely limited.

After conducting the SLR, it became clear that the increasing availability and potential of mobile biosensors represents one recent key development for mHealth systems design; that is, sensors that collect physiological data (e.g., heart rate, respiration, skin conductance) that individuals wear, carry, or access during their normal daily activities (Kumar et al., 2013; Urrea et al., 2015). Combined with contextual information (e.g., location and self-report data), the data obtained from mobile biosensors provide valuable insights into a person's health status and their lifestyle choices (e.g., risk for cardiovascular disease and diabetes) (Ballinger et al., 2018). However, from the limited empirical studies included in the SLR that did discuss physiological measures (e.g., L. Woods, Duff, et al., 2019, measuring blood pressure and pulse for heart failure self-management), research on how these biosensors could be used to support health behaviour change was limited. Therefore, in Chapter 3, we sought out to do an exploratory study on how mHealth systems that use mobile biosensors can be designed for health behaviour change. This translates into Research Question 2.

Research Question 2: *How can one design mHealth systems to use mobile biosensors for health behaviour change?*

In Chapter 3, we use a hybrid approach of deductive and inductive reasoning (Gregory & Muntermann, 2011) to develop an integrative theoretical framework which extends on the work of Michie et al. (2011) as well as a set of design guidelines. The framework contributes to the prescriptive knowledge base by 1) providing researchers and practitioners with a shared frame of reference for implementing a feedback loop between the user's physiology and their perception and 2) enabling system designers to systematically map out how the elements of their mHealth interface can target individual components of behaviour and the types of interventions through which they can do so. Our design guidelines contribute to the prescriptive knowledge base by providing system designers with practical design considerations that consider multiple stakeholders' perspectives. Both the framework and the design guidelines address the research gap we identified in Chapter 2 that many studies in mHealth do not build on an established behaviour change framework, despite the importance of doing so for mHealth systems to be effective (Hingle & Patrick, 2016; Moller et al., 2017). Further, Chapter 3 highlights the importance of better understanding the relationship between mHealth systems and remote systems, which can help to bridge the gap between mHealth and clinical practice.

Following the SLR in Chapter 2, it was also evident that there were clear research gaps when using co-design in mHealth (e.g., limited co-design methods used in post-design phase). Further, we began to recognize that there are many unique challenges and factors involved when co-designing in mHealth which are not currently captured by general co-design frameworks. This motivated the work in Chapter 4 and the creation of Research Question 3 and 4, which builds on the expertise of mHealth system developers and co-design method experts.

Research Question 3: *How can one contextualize existing co-design frameworks to the mHealth setting?*

Research Question 4: *What are guidelines to address common challenges in using co-design in mHealth systems development?*

In Chapter 4, we conduct qualitative study that explores how co-design can be used in mHealth systems development. Specifically, we conducted 16 semi-structured interviews to synthesize the theoretical and practical expertise of 8 established co-design method experts as well as 8 mHealth system developers. From this, the core contributions are a contextualization of the co-design framework by Sanders and Stappers (2014) to the mHealth setting and a set of seven design guidelines which address common challenges when co-designing in mHealth. The contextualized framework contributes by providing a shared frame of reference to guide mHealth systems development projects, which are inherently interdisciplinary in nature (Burke et al., 2015; Marzano et al., 2015). Rooted in the well-established co-design framework by Sanders and Stappers (2014), the contextualized framework brings to light a range of critical considerations that arise in the health context. As a shared frame of reference, the contextualized framework may aid mHealth researchers and practitioners in planning co-design activities and involving stakeholders in all stages of design (Eckman et al., 2016; Marzano et al., 2015). On the other hand, the guidelines point to a range of pitfalls that emerge in mHealth systems development along with specific suggestions on how these challenges can be navigated. By facilitating stakeholder engagement and involvement in co-design activities, these guidelines may aid researchers and practitioners in ensuring that mHealth system are underpinned by expert insight, adequately reflect the lived experiences of end-users, and effectively integrate into the existing system and process landscape.

5.2. Implications

As it can be seen from Chapters 2 and 3, in order for mHealth system design to effectively support health behaviour change, various stakeholders must be involved. Accordingly, this thesis has important implications for a variety of stakeholders. These implications will be discussed in the following.

The first stakeholder group for which there are implications are *mHealth system designers*. As has been mentioned in various sections of this thesis, while mHealth systems hold great potential for supporting health behaviour change over traditional vehicles for behaviour change interventions (e.g., scalability, cost, ubiquitous, etc.), there are various pitfalls surrounding the design of these systems (e.g., involving the relevant stakeholders, consulting established behaviour change frameworks, etc). Part of the contribution of this thesis was to further build on our understanding of the challenges of designing in mHealth, not just challenges that have been cited in the literature, but to conduct an exploratory study which builds on this understanding through compiling the experiences of various systems designers and experts in design. By doing this, we were able to develop general design guidelines which can help systems designers overcome common challenges experienced in this area (see Chapter 4.4.2). In Chapter 2 and 3, the importance of underpinning the design of mHealth systems with established behaviour change frameworks became abundantly clear, as the objective of many mHealth systems is, in fact, behaviour change (e.g., adherence to medication schedule, adopting healthy physical activity, increase in vegetable intake). This thesis also assists systems designers by providing them with a theoretical framework (see Chapter 3) which allows them to underpin the content of their systems to an established behaviour change framework by Michie et al. (2011). Through these contributions, we hope that systems designers will be in a better position to avoid the commonly cited pitfalls of designing in mHealth.

Another stakeholder group for which this thesis hold implications are *health professionals*. As can be seen throughout this thesis, health professionals are a broad stakeholder category (see Chapter 2.4.2), and it is important to ensure that all relevant stakeholders are involved in mHealth system design in order to ensure that the system will be effective. However, this involvement of healthcare professionals working alongside end-users and various other types of stakeholders in the design process can cause issues such as power distance (a situation where some stakeholders may have their contributions prioritised over another group, e.g., healthcare professionals vs end users or designers vs end users) to arise. This is expected due to the nature of healthcare professionals being experts in their field. However, in co-design, it is important that end-users are allowed equal participation due to them being experts in their own experiences. This thesis provides some direction to healthcare professionals through the form of general design guidelines (see Chapter 4.4.2) which can support effective participation. It also emphasizes the early involvement of this stakeholder group in pre-design and generative phases of the process rather than when IT artefacts are already implemented. This can contribute to overcome the challenges related to the high complexities inherent to the health sector in general and integrating systems into day-to-day health routines in particular.

Public health organisations and *funding bodies* are another stakeholder group for which this thesis has implications. One of the big challenges of co-designing in mHealth that was discussed in Chapter 4.4 was the problem of funding for mHealth projects. There has been a vast number of resources provided for the research on the treatment of disease, and while it is common knowledge that changing lifestyle behaviours such as smoking, nutrition, alcohol, and physical activity, plays a major role in preventing NCDs, mHealth systems designers explained that often there is little incentive for industry-based funding bodies to fund these projects. After all, there is limited revenues attached to drinking less alcohol, buying less processed foods, etc.

The health benefits on the other hand are difficult to document as they often only materialize over an extended period of time (e.g., reduced risk of diabetes and cardiovascular disease over ten years). Nevertheless, the health crises associated with lifestyle disease is very real and causes enormous costs. Hence, speaking from the perspective of a public health perspective rather than an individual health perspective, there is a need to complement 'pumping money into hospitals' with focusing on the prevention of these lifestyle diseases in the first place. This thesis emphasizes the important for public health funding bodies and philanthropic agencies to consider making co-design a requirement for the design of such system in their funding agreement, as this can contribute to increasing the effectiveness, usability, and usefulness of mHealth artefacts for disease management and health promotion.

Lastly, this thesis has implications for *end-users.* The importance of co-design for designing in mHealth is becoming increasingly understood. As a result, there is a shift in the approach of many researchers from a mentality of *designing for users* to *designing with users*. This will lead to more end-user involvement in the development of mHealth systems. For instance, many websites and apps already provide the ability to enter feedback in the post-design phase (e.g., using feedback systems such as Hotjar). Further, there is a growing body of knowledge showing the effectiveness of underpinning mHealth system design with established behaviour change frameworks. As technology becomes more advanced, mHealth systems may be able to support behaviour change even further.

5.3. Outlook

This thesis provides the main elements to help designers to underpin mHealth systems design with established behaviour change frameworks and guidelines around how co-design can be implemented in mHealth. Moreover, there are challenges for future research on designing mHealth systems, which have only gained little attention in the literature at this stage and are,

therefore, frequently neglected. These challenges will be discussed in the remainder of this thesis.

One challenge for future research relates to the 'back-end' the co-design process in mHealth. In Chapter 2 and 4, we highlighted that much of the mHealth system designers in the literature and the participants involved in Chapter 4 stated that while there has been strong contributions in the early co-design phases (e.g., pre-design and generative phases), there is a dearth of research in the implementation and post-design phases, as well as targeted methods that can be specifically applied in these phases. The importance of undergoing these co-design phases is clear. Post-design is essential for mHealth systems because it is needed in order to understand the impact of the system in the real world (e.g., has the mHealth system led to behaviour change? Will it lead to sustained behaviour change over time?). Further, the complexities and ongoing development in the health sector require an ongoing monitoring and adaptation of the system as habits, technological opportunities, and interlinked systems develop. More research is needed to identify appropriate co-design methods that could be used in these phases as well as what stakeholders should be involved and how should they be involved.

Lastly, a challenge exists in that the research we discuss in this thesis is relevant and constrained to the state of technology that currently exists. Currently, we have access to various mobile biosensors through mobile devices which provide data that could potentially support behaviour change. However, despite this technology existing, it currently is not being utilised in an effective way for behaviour change. For instance, even though commercial-grade systems for tracking heart rate variability, breathing, blood oxygen levels, and other vital parameters are readily available and widely used by end-users, our investigation in Chapter 3 showed that currently this data is currently not well integrated and accessible for health practitioners. Part of the purpose of this thesis was to investigate how such technologies that are already available could be accomplished. However, as technology changes over time, new biosensors, and

subsequently, new data with higher accuracy may become available which provides new opportunities for supporting behaviour change. However, just as it is currently, it will take time before these biosensors and data are implemented into meaningful design. Further, other technology improvements may also have impacts on current biosensors and the way they currently operate such as increasing in battery life and accuracy. In the end, it is important that all mHealth systems are designed with behaviour change at their core. Otherwise, as we can see with the current integration of technology, the potential of technology does not necessarily result in actual adoption and integration for the betterment of health outcomes.

Appendix A.

A.1. Exploring the Design of mHealth Systems for Health Behaviour Change using Mobile Biosensors

This appendix lists the interview guide and design guidelines table for Chapter 3.

A.1.1. Interview Guide

In this appendix, we provide an example interview guide. Each interview comprised three parts, which we summarize here. While we used the questions provided below as a guide for the interviews, we also asked follow-up questions to the participants' responses.

Part 1: General Understanding of mHealth for Health Behaviour Change

Questions:

- What is your opinion on the current state of health promotion? Why do you think it is/isn't working? (HBS, HP, P, U, HIP)
- What advantages do you think mHealth systems could have over traditional forms of health promotion? (All)
- What are the biggest challenges for mHealth systems from a [stakeholder's area] perspective? Why do you think this is the case? Is there anything missing in the existing approaches? (All)
- What do you see as the role of [stakeholder's area] in health promotion? (All)

- From an economic and policy perspective, should mHealth systems focus on rehabilitation/recovery or prevention? Are there specific cohorts should be prioritized initially? (P, HP, HIP, HBS)
- What might the shifts in laws and governance look like as a result of mHealth systems? How can we address them? (P)
- How can we better integrate mHealth systems into clinical practice? (HP)

Material:

- Figure: overview of stakeholders and remote systems (see Figure 3.1)

Part 2: Theoretical Pathways for how mHealth can utilize Mobile Biosensors

Questions:

- How can we ensure that mHealth systems are tailored to the individual circumstances of the user? (e.g., their baseline). What should the beginning of the health behaviour change process look like in a mHealth system context? Who should be involved? (All)
- What are some important considerations when attempting to change health behaviour? (HBS, HP, U)
- How important is it that you actually believe that you're going to be successful when trying to change your health behaviour? (HBS, HP, U)
- What feedback can heart rate give us about someone's health? How could this feedback be represented in a mHealth system to support health behaviour change in the context of a user's capability, opportunity, or motivation? (HP, HBS, U)

- How can resting heart rate and heart rate variability be measured? Would you be able to walk me through the process? What are the factors that need to be considered in a mHealth system context? (HP, ITP)
- How could we use mHealth systems to increase a user's capability / opportunity / motivation in the context of health behaviour change? (HBS, HP, U)
- Is there any other data that can be collected from mobile biosensors that would be useful for supporting health behaviour change? How should this data be measured and how should it be represented in mHealth systems to address user capability, opportunity, or motivation? (All)
- What do you think is the difference psychologically between starting a health behaviour change and maintaining a health behaviour change? How should these difference approaches be represented in a mHealth system? (HBS, HP, U)
- What do you think is important for bringing about lasting health behaviour change in lifestyle? How can this be applied in mHealth systems? (HP, HBS, HIP, P, U)
- Are there any theoretical pathways that we are missing? (All)

Material:

- Figure: Integrative theoretical framework (see Figure 3.4)

Part 3: Development of General Design Guidelines

Questions:

- What kinds of measurements could be collected that would be useful in a health promotion context? (HP, U, HIP, HBS, ITP, P)

- Is there any other data (e.g., contextual data such as location, or corrective factors such as age and sex) that should be collected to improve accuracy and/or provide deeper insights into physiological measurements? How should these be implemented in mHealth systems? (HP, ITP, HIP, HBS, U, P)
- What are the challenges or limitations of using mobile biosensors such as heart rate in a health promotion context? How can we overcome/adjust for these? (HP, ITP)
- How frequently can/should heart rate be measured? Why? (HP, HIP, HBS, U, ITP)
- What position should the user be in when measuring heart rate? Why? (HP)
- What aspects of design do you think are important for creating an empathic connection with the user? (All)
- How do you think the mHealth interface should look? What things must be there? How should feedback be represented? Why? (All)
- What stakeholders should be involved in the goal-setting process? Why? (All)
- How should the approach/feedback of mHealth system change for long-term goals and short-term goals? (All)
- How do you think mHealth systems could be utilized for supporting the setting and accomplishment of goals? (All)
- What level of involvement do you think health practitioners and health insurers should have in the use of mHealth systems? (All)
- What are the emerging social, privacy, and security issues to arise as a result of mHealth? How can we address these? (All)

- How can the data collected through mHealth systems be used to support policy decision making? What data is this, and what form should it take? (P)
- What are some potential pitfalls and challenges of designing mHealth systems? (D)
- Would you be able to walk me through the design process? (D)
- Are there any particular design methods and techniques you think would be particularly useful for designing mHealth systems? (D)
- Who are the stakeholders in mHealth? What role do you think these stakeholders should have in the design and operationalization of mHealth systems? (All)
- Are there any other design considerations that we are missing? (All)

Material:

- Table: Current version of the design guidelines (see Appendix A1.2)

A.1.2. Design Guidelines Overview

Table A1.2 Design Guidelines for mHealth Systems that Use Mobile Biosensors for Health Behaviour Change

Design guideline	Brief description
Guideline 1: employ dedicated mobile biosensor recordings of adequate length in a resting state combined with contextual data to assess users' overall health status over time while also keeping a continuous recording using a rolling time window to retain critical information in case of a "funny turn".	Mobile biosensor recordings enable a feedback loop between users' physiological state and their perception (P1). For instance, these sensors can easily obtain a user's heart rate, which provides critical information on a person's health status. The recording length of five minutes is an inevitable compromise between convenience and completeness/accuracy. Further, the measurement conditions (i.e., body position, frequency, time of day) should remain as consistent as possible. Contextual data include other collected data such as age, location based on GPS, or medication regime. The mHealth system then interprets the biosensor recordings in the context of the user's holistic health environment to provide timely feedback that appears in and considers the user's individual situation. In case of an adverse event or "funny turn", for example, arrhythmia in heart rate, users and their health practitioners may access additional data by collecting it continuously in a rolling time window (e.g., the past 48 hours).

Table A1.2 Design Guidelines for mHealth Systems that Use Mobile Biosensors for Health Behaviour Change

Guideline 2: use affective visual assets to convey users' physiological state r and make the health information embedded in the biosensor recordings from mobile biosensors more intuitive and meaningful to them.	Users find biosensor recordings difficult to understand in relation to their health goals and lifestyle behaviour, which impairs their capability and motivation to engage in healthy behaviors. Appropriate visual assets can address capability (P2) by making the health information embedded in biosensor data *intuitive* for users to understand in the context of their health goals. Further, *affective* visual assets that link their appearance to the user's physiological state (e.g., mirrored-self avatars, persuasive avatars, virtual pets that adjust based on biosensor measurements) can address motivation (P4) by creating an emotional bond between the user and the visual asset that makes a change in behaviour *meaningful* to them.
Guideline 3: provide effective goal-setting support to help users develop achievable health goals relating to their physiological state, identify actions they can take to achieve those goals, and increase their self-efficacy through the feedback loop enabled by mobile biosensor data.	The consequences of lifestyle behaviour often only become salient over a long period of time, while users cannot usually perceive short-term changes in physiology. Mobile biosensors allow users to identify short-term effects of lifestyle behaviors (e.g., changes in physiological stress levels) and, hence, to break down health goals into small and achievable tasks that link to the users' physiology. Through their user interface, mHealth systems can use mobile biosensors to provide goal-setting support that facilitates capability (P2) by showing users *how* they can achieve their goals (e.g., gamified targets for physiology, biosensor-enabled serious games to train capabilities for behaviour change), opportunity (P3) by showing users *when* they can achieve goals (e.g., triggering reminders by using biosensors to detect health behaviors), and motivation (P4) by showing feedback on *progress* in users' physiology and boosting self-efficacy (e.g., self-comparison of physiological data over time).
Guideline 4: provide external support to users by allowing health practitioners to review the biosensor recordings, to allow health practitioners to give feedback to the user, and to provide the user with access to contextually relevant resources based on their physiological state.	Assessing a user's health status based on biosensor recordings is a complex task that goes beyond what an individual user device can achieve. Health practitioners need to be involved and to support the user by reviewing the biosensor recordings, making adjustments to the user's targeted activities and health goals, and providing feedback to the user on their physiological state. External support can extend to recommending a visit to a health practitioner or provide access to external sources of information. Integrating external support into the user interface addresses capability (P2) by facilitating information exchange and opportunity (P3) by making individual adjustment to targeted activities and health goals. The involvement of trusted health practitioners can increase user trust and compliance and can help them to monitor users' physiological data to intervene if necessary.
Guideline 5: consider the four levels of data integration in collecting, managing, and using biosensor recordings while ensuring high levels of privacy and security of sensitive health data and enabling effective support for users and the development of policy.	While mHealth systems primarily focus on the data stream between the user and the mHealth device, mHealth systems also need to consider additional data-integration levels to ensure that the mHealth system uses biosensor data in an effective and responsible way. mHealth systems require data streams of biosensor recordings to remote systems to increase users' psychological capability (P2) by facilitating information exchange, for creating opportunities (P3) by including stakeholders in the goal setting and data assessment process, and for increasing motivation (P4) by facilitating social interactions and identifying the motivational factors of the individual user. We identify four additional data-integration levels: the immediate biosensor data gathering for individual feedback (level A), biosensor data aggregation and analysis (level B), and interfaces with information systems of healthcare providers (level C) and health insurance providers (level D).
Guideline 6: ensure effective stakeholder involvement in all design phases to account for the complexities associated with using mobile biosensor measurements for behaviour change and to reconcile the diverging backgrounds, interests, and perspectives of all relevant stakeholders.	While mobile biosensor recordings offer important insights into a person's health status, designing systems to use these recordings for behaviour change is a challenging task that involves complexities associated with the long-term consequences of unhealthy lifestyle behaviors, multiple direct and indirect stakeholders with diverse backgrounds and interests, and a complex landscape of remote systems. Actively involving stakeholders already in the contextual and conceptual design phases contributes to reconciling different stakeholder perspectives early and ensures that the mHealth artifact adequately reflects the intricacies of increasing individual users' capability (P2; e.g., convey biosensor information in a way that is *intuitive* for the target cohort), opportunity (P3; e.g., ensure seamless integration of biosensor data with the healthcare provider IS), and motivation (P4; target *meaningful* motivational factors for a particular cohort) to engage in targeted behaviors.

Appendix B.

B.1. Using Co-design in mHealth Systems Development: A Qualitative Study

This appendix lists the interview guide and further background information on the participants for Chapter 4.

B.1.1. Interview Guide

The semi-structured interviews in this research were guided by the well-established co-design framework by Sanders and Stappers (2014), which was iteratively contextualized throughout the interviews (i.e. from Figure 4.1 to Figure 4.2 in the Chapter 4). Questions were structured around:

> **RQ3:** *How can one contextualize existing co-design frameworks to the mHealth setting?*
>
> **RQ4:** *What are guidelines to address common challenges in using co-design in mHealth systems development?*

Through the interviews, the researcher attempted to expand and refine this contextualized framework by uncovering emergent and additional themes as well as furthering the understanding of existing themes. Questioning was of a general nature and semi-open ended in the context of co-design and mHealth system design. More specifically, the focus of the interviews was to solicit responses, insights, and suggestions regarding the following areas:

- The value of using co-design in mHealth systems development
- The contribution of co-design methods to mHealth systems development
- The disadvantages/risks of using co-design methods in mHealth systems development

- The value added by co-design methods in specific phases of mHealth systems development
- The important lessons to be learned when using co-design methods in mHealth systems development
- The use and misuse of the term co-design in research and practice

Examples of Questions for Co-design Method Experts (CMEs)

- From our literature search we found that co-design has recently receive increased research attention. Based on your expertise and reading of the literature, do you feel that co-design methods are adequately applied in practice?
- Based on your expertise, do you feel that the term co-design is adequately used in research and practice? Is the term potentially misused to label research co-design that would not be truly classified as co-design based on your expertise?
- What do you think would be the barriers and challenges of applying co-design methods in a mHealth context? What advice would you give to researchers for overcoming these barriers and challenges?
- In the application of co-design, are there specific methods that are underused or misused?
- Do you think that co-design methods are adequately applied across the whole design process or are there certain aspects over/underrepresented?

Examples of Questions for mHealth System Developers (MSDs)

- Why did you choose to employ co-design methods in your study?
- What were the co-design phases you went through in your study? What is the purpose of each phase? Does the level of involvement with stakeholders differ from phase to phase?
- What was your rationale for the specific co-design methods you chose to employ in your study? What co-design phase were these methods used in and why?
- What was the added value of using co-design methods in your study?
- What were the barriers and challenges of using co-design methods in your study?
- How did you evaluate your designs and when did this occur?
- What advice would you give to mHealth system developers that are looking to use co-design in their project?

B.1.2. Background of Interview Participants

Table B1.2. Background of interview participants

Stakeholder	ID	Background	Gender
Co-design Method Expert (CME)	CME1	Researcher at a North American university with over 40 years of publication experience in design	Female
	CME2	User experience designer at a private company in Australasia for more than 2 years	Female
	CME3	Researcher at a European university with over 10 years of experience in design	Female
	CME4	Researcher at an Australasian university with experience in co-design spanning 10 years	Male
	CME5	Researcher at a European university with experience in co-design spanning 20 years	Female
	CME6	PhD and freelance designer in Australasia with over 3 years of experience in co-design	Female
	CME7	Researcher at an Australasian university with over 20 years of experience in design	Male
	CME8	Researcher at an Australasian university with over 7 years of experience in design	Female
mHealth System Developers (MSD)	MSD1	Researcher at an Australasian university with over 4 years of experience in stroke rehabilitation	Female
	MSD2	PhD graduate at a private company in Australasia with over 10 years of experience in mHealth for disease management	Female
	MSD3	Principle designer at a private company in Australasia with over 5 years of experience in mHealth for disease management	Female
	MSD4	Researcher at a European university with over 20 years of experience in design of health information technology	Female

	MSD5	Researcher at an Australasian university with over 3 years of experience in mHealth	Male
	MSD6	Researcher at an Australasian university with over 7 years of experience in human-computer interaction	Female
	MSD7	Researcher from an Australasian university with over 4 years of experience in mHealth	Female
	MSD8	Researcher from an Australasian university with experience in e-health for health promotion	Female

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