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Personalised Micro-Intervention Technology for Diabetes Self-Management

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Summary

In this dissertation we investigate how personalised micro-intervention technology may be designed for use in Type 2 Diabetes Mellitus (T2DM) self-management. Micro-interventions are short momentary interventions aiming to have an immediate impact on targets. A proposed advantage of these interventions is that these reduce barriers associated with meaningful engagement by their short-term nature. However, micro-intervention technology is largely in its infancy and several unanswered questions remain regarding how the technology should be used and supported. Moreover, no unified terminology exists for what micro-interventions are nor what structures or types of systems facilitate their delivery. Our investigation of personalised micro-intervention technology for T2DM was carried out from three angles, firstly by looking at mobile health (mHealth) technology for diabetes, secondly by looking at the practical real-world use of micro-interventions and thirdly by exploring the theoretical constructs of what micro-interventions are, what components they are comprised of and what structures facilitate their delivery.

We initially, investigated through two studies what features or "components" of mHealth technology are desirable and useful for diabetes self-management. In our first study we formally looked at the literature on T2DM mHealth exploring and discussing a multitude of reported application components, barriers, facilitators, attrition rates and effects. However, we also uncovered significant gaps in reporting of attrition and rationale making it difficult to gauge which components and designs are truly useful for persons with diabetes. Our second study aimed to bridge this gap by engaging in a co-creation process with end-users and stakeholders. This co-creation process resulted in two user experience prototypes namely: an activity-based continuous glucose monitoring application and an online guide to diabetes. The study additionally explored the rationale and user experience over time for the created designs as well as exploring a number of diabetes thematic insights.

To generate knowledge about the real-world use of micro-interventions we investigated the use of "Episodic Future Thinking" as digital micro-interventions delivered through mHealth in two studies. Episodic Future Thinking is an intervention aiming to influence everyday decisions, promoting choices with long term benefits in this context health. The first of these studies focused on the design, implementation, and evaluation of a simple mHealth application delivering three micro-interventions. Our results showed that the use of episodic future thinking micro-interventions was feasible, but not always preferable to users. Our second study investigated the effectiveness of the developed micro-interventions and the mHealth technology, moreover aiming to explore the effects and user perceptions of two kinds of episodic future thinking. Results show that both kinds of episodic future thinking micro-interventions were effective but also that the version explicitly including goals was slight more effective while also providing additional benefits.

Finally, we returned to the more theoretical question of what a micro-intervention is, what components these consist of and what structures support their delivery. We developed the "Design for Micro-Intervention Software Technology" (D-MIST) framework based on a systematic review of the available literature on micro-interventions, prior definitions of the term and our own insights from the aforementioned studies. The framework formalises the role of the system in delivering micro-interventions, how these may be combined to create narratives and what exactly a micro-intervention is. The D-MIST framework provides researchers and designers with a unified way of understanding, classifying, designing, and evaluating micro-interventions as well as the systems that deliver them. Finally, we explore how this framework adds to our knowledge of how personalised micro-intervention technology can be created.

Resumé (Danish summary)

I denne afhandling undersøger vi hvordan personaliseret mikro-interventions teknologi kan designes til at støtte selvhåndtering af type 2 diabetes mellitus (T2DM). Mikro-interventioner er kortvarige indgreb der sigter efter at have en umiddelbar effekt. I modsætning til mere traditionelle interventioner har mikro-interventioner den fordel at de er kortvarige og derfor er nemmere at blive engageret i. Da mikro-interventioner er et forholdsvis nyt forskningsområde er der flere ubesvarede spørgsmål som f.eks. hvordan teknologien skal bruges og understøttes. Desuden findes ingen samlet terminologi for hvad mikro-interventioner er, eller hvilke strukturer og typer af systemer der understøtter den måde de leveres til brugeren. Den nuværende undersøgelse af personligt mikro-interventions teknologi gribes an fra tre vinkler: For det første gennem undersøgelse af hvilke mobile sundhedsteknologier (mHealth) der findes til at støtte diabetes selvhåndtering. For det andet ved at se på hvordan mikro-interventioner rent praktisk kan bruges i den virkelige verden og for det tredje ved at se på den teoretiske konstruktion af mikro-interventioner; hvad er disse praktisk er og hvilke strukturer understøtter deres levering.

I denne afhandling starter vi med at se på mHealth gennem to studier der undersøger hvilke komponenter og funktioner der er brugbare og ønskede af personer med diabetes. I det første studie ser vi på den videnskabelige litteratur om mHealth for T2DM og diskuterer de rapporterede komponenter, barrierer, facilitatorer, frafald af brugere og effekter. Konkret fandt vi større begrænsninger i litteraturen som gør det svært at bedømme hvor relevante de forskellige komponenter og design er for personer med diabetes f.eks. manglede begrundelse for tilvalg af komponenter og mangelfuld rapportering af frafald. Vores andet studie brugte en ”co-creation” proces til at undersøge hvilke komponenter og design personer med diabetes rent faktisk ønsker. Denne proces resulterede i udviklingen af to prototyper: en aktivitets-baseret applikation med tilknyttet kontinuerlig glukosemåler og en online guide til diabetes. Udover disse prototyper undersøgte studiet også rationalet bag prototyperne, brugeroplevelsen over tid og en række andre tematiske indsigter fra hverdagen med diabetes.

For at undersøge brugen af mikro-interventioner i den virkelige verden undersøgte vi brugen af episodisk fremtidstænkning (EFT) som digitale mikro-interventioner leveret gennem mHealth. EFT er en intervention som påvirker hverdagens beslutninger ved at fremhæve beslutninger med langtrækkende fordele; i dette tilfælde beslutninger der påvirker det fremtidige helbred. I det første af disse studier fokuserede vi på design, implementering og evaluering af en mHealth app der leverer tre mikro-interventioner. Resultaterne fra dette studie viste at det var muligt at bruge EFT som mikro-interventioner, men også at mikro-interventionerne ikke altid var fortrukket af deltagerne. I det andet studie undersøgte vi effekten og brugeropfattelse af to forskellige typer af EFT mikro-interventioner leveret gennem mHealth. Resultaterne viste at begge typer havde effekt, men også at EFT med klare helbredsmål direkte inkluderet var mere effektive og havde yderligere fordele.

For at svare de mere teoretiske spørgsmål om hvad en mikro-intervention er og hvilke strukturer der kan understøtte deres levering, har vi udviklet ”Design for Micro-Intervention Software Technology” (D-MIST) frameworket. Dette framework er baseret på eget arbejde og indsigter fra litteraturen fundet gennem et systematisk litteraturreview. Frameworket formaliserer digitale systemers rolle i leveringen af mikro-interventioner, hvordan disse kan kombineres, og præciserer hvad en mikro-intervention er. D-MIST gør det desuden nemmere for designere og forskere at forså, klassificere, udvikle og evaluere mikro-interventioner og systemer der leverer dem gennem en samlet beskrivelse. Til slut diskuteres hvordan dette framework bidrager til udviklingen af personaliseret mikro-interventions teknologi.

Preface

This PhD thesis titled: "Personalised micro-intervention technology for diabetes self-management" has been created and submitted to meet the requirements for obtaining a PhD degree at the Department of Applied Mathematics and Computer Science at the Technical University of Denmark. The main supervisor for the project was Associate Professor Per G. Bækgaard from the Department of Applied Mathematics and Computer Science, Section for Cognitive Systems. Co-supervisors for the project were Professor Jakob E Bardram from the Department of Health Technology and Chief Physician Kirsten Nørgaard from Steno Diabetes Center Copenhagen.

Kongens Lyngby, August 31, 2023

Dan Roland Persson

The format of the thesis is paper-based with the chapters listed in the tables of content summarising and expanding upon each of the following papers:

Paper I: Dan Roland Persson, Jakob E. Bardram, and Per Bækgaard. Exploring components, barriers, facilitators and attrition causes in type 2 diabetes mhealth: A scoping review. Manuscript, 2023

Paper II: Dan Roland Persson, Katiarina Zhukouskaya, Anne-Marie Karin Wegener, Lene Kølle Jørgensen, Jakob Eyvind Bardram, and Per Bækgaard. Exploring patient needs and designing concepts for digitally supported health solutions in managing type 2 diabetes: Cocreation study. JMIR Formative Research, 7:e49738, Aug 2023. ISSN 2561-326X. doi: 10.2196/49738.

Paper III: Dan Roland Persson, Soojeong Yoo, Jakob E. Bardram, Timothy C. Skinner, and Per Bækgaard. Episodic future thinking as digital micro-interventions. In Design, user experience and usability: The 12th international conference, DUXU, 2023, Held as Part of the 25th HCI International Conference, HCII 2023, Copenhagen, Denmark, July 23-28. In press: Late Breaking Work. Springer, 2023.

Paper IV: Dan Roland Persson, Jakob E. Bardram, and Per Bækgaard. Perceptions and effectiveness of episodic future thinking as digital micro-interventions based on mobile health technology. Sage Digital Health [Submitted], 2023.

Paper V: Dan Roland Persson, Mel Ramasawmy, Nushrat Khan, Amitava Banerjee, Ann Blandford, Jakob E. Bardram, and Per Bækgaard. A design framework for micro-interventions in mobile health technology. CHI 2024 [Submitted], 2023.

Not included in the thesis:

Paper 1: Dan Roland Persson, Valentino Servizi, Tanja Lind Hansen, and Per Bækgaard. Using augmented reality to mitigate blind spots in trucks. In HCI in Mobility, Transport, and Automotive Systems. Automated Driving and In-Vehicle Experience Design: Second International Conference, MobiTAS 2020, Held as Part of the 22nd HCI International Conference, HCII 2020, Copenhagen, Denmark, July 19–24, 2020, Proceedings, Part I 22, pages 379–392. Springer, 2020.

Paper 2: Valentino Servizi, Dan Roland Persson, Per Bækgaard, Hannah Villadsen, Inon Peled, Jeppe Rich, Francisco C Pereira, and Otto A Nielsen. Context-aware sensing and implicit ground truth collection: Building a foundation for event triggered surveys on autonomous shuttles: Artikel. In Proceedings from the Annual Transport Conference at Aalborg University, volume 28, 2021.

Paper 3: Valentino Servizi, Dan Roland Persson, Francisco Camara Pereira, Hannah Villadsen, Inon Peled, Otto Anker Nielsen, et al. "is not the truth the truth?": Analyzing the impact of user validations for bus in/out detection in smartphone-based surveys. IEEE Transactions on Intelligent Transportation Systems, 2023.

Paper 4: Valentino Servizi, Dan R Persson, Francisco C Pereira, Hannah Villadsen, Per Bækgaard, Jeppe Rich, and Otto A Nielsen. Large scale passenger detection with smartphone/bus implicit interaction and multisensory unsupervised cause-effect learning. arXiv preprint arXiv:2202.11962, 2022.

Paper 5: Jakob E Bardram, Claus Cramer-Petersen, Alban Maxhuni, Mads VS Christensen, Per Bækgaard, Dan R Persson, Nanna Lind, Merete B Christensen, Kirsten Nørgaard, Jayden Khakurel, et al. Diafocus: A personal health technology for adaptive assessment in long-term management of type 2 diabetes. ACM Transactions on Computing for Healthcare, 4(2):1–43, 2023.

Nomenclature

CAMS: CARP Mobile Sensing

CARP: CACHET Research Platform

CGM: Continuous Glucose Monitoring

D-MIST: Design for Micro-Intervention Software Technology

DDA: The Danish Diabetes Association

DTU: The Technical University of Denmark

EFT: Episodic Future Thinking

gEFT: Goal-oriented Episodic Future Thinking

GP: General Practitioner

HbA1c: Hemoglobin A1c

JIT: Just-in-Time

JITAI: Just-in-Time Adaptive Intervention

mHealth: Mobile Health

NIT: Non-Insulin Treated

PRISMA: Preferred Reporting Items for Systematic Reviews and Meta-Analyses

PSSUQ: Post-Study System Usability Questionnaire

PwD: Persons with Diabetes

SMBG: Self-monitoring of blood glucose

TSRQ: Treatment Self Regulation Questionnaire

T2DM: Type 2 Diabetes Mellitus

UX: User Experience

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In a PhD project comprising years of proverbially blood, sweat, and tears it is challenging to remember all the contributions and interactions that have helped carry this work to its completion. To all those unnamed that have in one way, or another contributed to this journey: you have my heartfelt thanks.

Contents

CHAPTER 1

Introduction

Throughout our lives we humans make countless decisions both consciously and unconsciously - large and small that influence our health. While these decisions made in discrete moments of time often seem trivial or unimportant the corresponding behaviours over time may have a significant impact on our health. E.g., we may decide to have a snack before dinner, avoid running because of the weather, take the elevator/bus out of convenience or simply enjoy some sedentary hours watching Netflix after a busy day. While these behaviours in isolation are not necessarily problematic the general discounting of future health they often represent is. Poor dietary behaviours together with sedentary behaviour are often factors associated with overweight and adverse long term health outcomes [1] presenting significant societal challenges. However, despite the known future consequences of our behaviours many choose to ignore these far away outcomes [2]. Consequently the prevalence of lifestyle related illnesses such as Type 2 diabetes with their adverse effects on health and quality of life continue to rise [3].

Type 2 Diabetes Mellitus (T2DM) is one such lifestyle related disease which from a global perspective is especially problematic given its prevalence. Risk factors for T2DM include a plethora of lifestyle behaviours: smoking, poor diet, overweight, lack of a physical activity and overeating [4]. Nevertheless, other factors such as genetic disposition has also been found to play a significant role [4]. While it is currently not possible to cure T2DM it is possible to achieve remission of the disease in many cases and to successfully manage in others e.g., through lifestyle changes, medications and in some cases through insulin injections [5]. Commonly lifestyle changes include diet, sedentary behaviour, and physical activity with these often aiming to facilitate a clinically relevant weight loss. Such lifestyle changes have been found effective not only in reducing risk of complications and comorbidities in T2DM for instance risk of cardiovascular disease [6] but have also been found effective in preventing or delaying the transition from prediabetes to T2DM [7]. A Recent trial further support the consensus that diabetes remission while difficult to achieve is feasible for many in the early stages of diabetes [8]. However, motivation to avoid complications remain an issue among those diagnosed with T2DM [9]. Even among persons with prediabetes lack of motivation to prevent the onset of T2DM is a common issue [7] with discounting of the future an associated factor [10]. One intervention proposed to combat this discounting of future health is Episodic Future Thinking (EFT) an intervention aiming to influence everyday decisions, promoting choices with long term benefits in this context health [11].

Unfortunately, global diabetes care efforts are often characterised by a lack of sufficient resources due to the rising global burden of chronic disease [12]. Well-known issues include limited availability of doctors and diabetes specialists as well as the time they have available for persons with diabetes (PwD) [13, 14]. Additionally, PwD often face decades of active self-management, with complications as an ever-possible consequence from mismanagement [15]. Given both the resource limitations and the relative time frame of diabetes PwD spend tremendous periods outside direct care with some estimates suggesting PwD spend as few as 5 hours annually with specialists [13]. As increasing time with specialists is rarely a practical/possible solution many have looked towards digital technologies to bridge the care gab. Digital technologies such as mobile health (mHealth) have several advantages compared to traditional care e.g., they are always available to users and highly scalable [16]. Such technologies are therefore seen as a reasonable and cost-effective alternative supplement to traditional care.

The idea of leveraging mHealth technology to affect momentary decisions and lifestyle is a topic of research that has seen significant scientific interest in recent years. Reflected in the development and research of hundreds if not thousands of apps. However, despite the research conducted and resources invested key challenges persist as seen by reports of low engagement, adherence and high real-world attrition for mHealth [17, 18]. Compounding these challenges is a general lack of rationale for decisions in the development of many mHealth solutions [19], lack of clinical evidence and the need for further validation of such solutions [20, 21]. While the root causes of these problems are an ongoing debate among researchers various proposed reasons include: lack of relevance [22], failure to address fluctuating needs [23], reduced autonomy to explore approaches to long term management [24] and mismatches between needs and intervention intensity overtime [25]. Several mHealth interventions and designs have been proposed to address these challenges such as gamification [26], personalisation [27] and Just-In-Time Adaptive Interventions (JITAI) [28]. A relatively new interpretation of these challenges is; that people are simply unable or unwilling to invest significant amounts of time and effort into designed interventions [29]. This line of thought argues that rather than attempting to change a person's inherent willingness to invest in interventions efforts should be directed towards matching users capacity for engagement while providing meaningful therapeutics [29].

Poetically, this can be exemplified by Van Goghs quote: *"Great things are not done by impulse, but by a series of small things brought together"*. Micro-interventions similarly aim to accomplish clinically relevant aims through a number of small momentary events. A micro-intervention is an intervention consisting of a number of events delivering short resources aiming to have an immediate positive impact on targeted attributes [30]. Micro-interventions compared to more traditional interventions are shorter, more narrowly scoped and emphasises short-term benefit through their events. Micro-interventions can also be ecological momentary interventions, just-in-time (JIT) and JITAI in nature [31].

Micro-interventions may thus be differentiated from more traditional interventions in that these are short, of limited depth and scope [31]. The short-term nature of each intervention has been argued as a way of not only reducing entry requirements but also the effort needed for purposeful engagement [29], e.g., by delivering resources at opportune moments while matching users often limited capacity or willingness for engagement [29]. However, in recognising the potential shortcoming of micro-interventions i.e., their short-term nature the idea of combining multiple different micro-interventions to facilitate behaviour change has been proposed [31, 29]. This combining different micro-interventions with limited scopes through narratives presents significant opportunities for personalisation of the delivered experience such as the micro-interventions used, their resources, the therapeutics leveraged, and the timing of events. Early research on combining micro-interventions have found encouraging indications [32, 33] but few studies have thus far explored combinatory effects in detail as is indicative of the early stage nature of most micro-intervention research. Thus most state-of-the-art research currently focuses on expanding the catalogue of available micro-interventions by designing and testing new interventions with smaller trials.

1.1 Project Background

This PhD is part of the integrated Personalised Diabetes Management (iPDM)-GO project: Aiming to innovate personalised digital health technology and encourage individualised diabetes care through digital tools. The project was funded by the European Institute of Innovation and Technology (EIT), a body of the European Union that receives support from the European Union's Horizon Europe research and innovation programme. The Copenhagen Center for Health Technologies' primary role in the project has been to develop personalised health technology able to adapt to the unique needs and challenges faced by PWD to identity appropriate technological solutions. This dissertation contributes to this work by exploring the idea of using personalised micro-interventions to support diabetes self-management.

1.2 Research questions

The main research objective of this PhD is to: *explore how personalised technology for micro-interventions can be effectively designed with a focus on diabetes self-management.* We initially approached this objective in two ways: by exploring diabetes technology and by exploring micro-intervention technology.

Throughout the course of this work a more fundamental problem emerged regarding the design of micro-interventions namely: *What exactly constitutes a micro-intervention?* Authors such as Paredes, Fuller, and Baumel all present various views on what a micro-intervention is with emerging literature often deviating further from these definitions [32, 31, 29]. These differences not only make it difficult to design micro-interventions but also makes it exceedingly difficult to productively leverage and compare existing works. An emerging opportunity in this PhD project was therefore to explore and better define what a micro-intervention is, what they consist of, and how these are delivered. Our resulting definition is based on both existing literature and the empirical work done as part of this dissertation.

This dissertation aims to address the research objective of exploring how technology can be designed for diabetes self-management in three ways. Firstly, by exploring which solutions, interventions, and application components ("features") are useful and preferable to users for self-management of T2DM. Secondly, by exploring how users perceive and engage with digital micro-interventions through two case studies. Thirdly, by defining what micro-interventions are as well as what components (or elements) and structures facilitate their delivery.

To address our first aim of exploring which diabetes technology is useful and preferable to PwD we started by exploring the diabetes workspace from both a theoretical and practical design angle. Initially, we formed a theoretical understanding of the diabetes mHealth workspace by exploring and comparing insights from the diabetes mHealth literature. Moreover, through this work we aimed to understand not only the effects of different application components but also how these facilitate or present barriers to usage and to understand how users interact with these solutions. To accomplish these goals we carried out a literature review aiming to answer the following research question:

- *RQ1: What application components, barriers, facilitators, attrition and effects are reported by the scientific literature on mHealth for T2DM?*

From an empirical standpoint, we also need to understand what makes for desirable and useful solutions for PwD in a Danish context. Considering the vastness of the problem and design spaces in diabetes as presented by the literature and considering the notion that clinical judgement may not necessarily always be aligned with user's needs [23] we employed a co-creation process aiming to answer:

- *RQ2: What are the needs, wishes and preferences for diabetes technology among persons with type 2?*

As for our second aim of exploring how users perceive and engage with digital micro-interventions we aimed to design an application delivering simple micro-interventions based on the established psychological intervention Episodic Future Thinking (EFT). We initially tested this application through a feasibility study aiming to determine:

- *RQ3: What is the feasibility of using Episodic Future Thinking as mHealth delivered micro-interventions?*

Following our initial feasibility study and based upon its results specifically that a variation to traditional EFT may be better suited for micro-interventions we created a larger randomised study aiming to explore:

- *RQ4: What are the effects and user perceptions of digital micro-interventions delivered as goal-oriented and traditional EFT?*

Lastly, returning to our final aim i.e., to define what micro-interventions are, what components these consist of and what structures support their delivery. To accomplish this we explored prior definitions of the term micro-interventions as well as its use in the scientific literature. Through a systematic review of available literature on micro-interventions and by applying insights from the empirical work described in this dissertation we aimed to synthesise an evidence-based framework of micro-interventions covering our final research question:

- *RQ5: What elements comprise a micro-intervention, what are their key components, and which constructs facilitate their delivery?*

1.3 Research methods

This section provides an overview of tasks performed in lieu of the previous section's research questions and the methods employed. Fig. 1.1 shows the triangulation model [34] of the work covered in this dissertation i.e., an overview of work within different work areas.

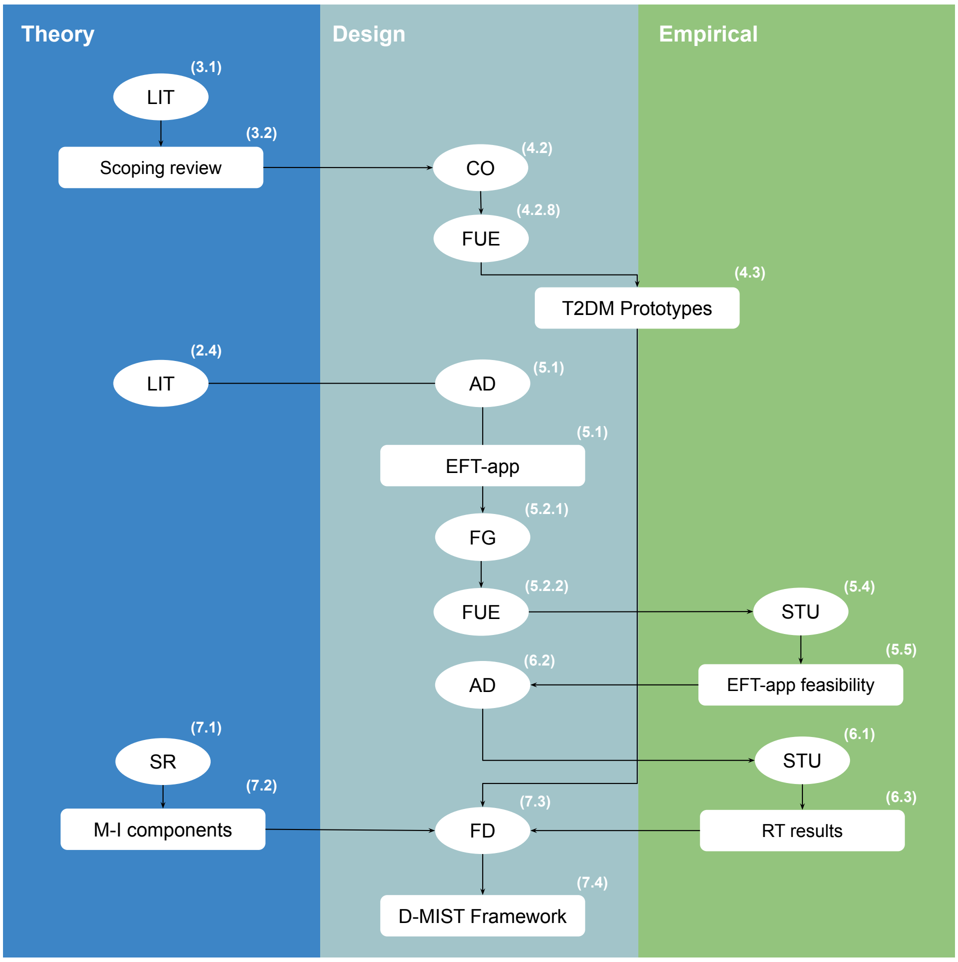


Figure 1.1: Triangulation model of content covered by this dissertation [34]. Abbreviations; LIT: literature review, SR: systematic review, CO: co-creation, AD: application development, FG: focus groups, FUE: formative usability evaluations, STU: study, FD: framework development.

1.3.1 Theoretical - Scoping review

To explore the literature on T2DM mHealth in line with RQ1 we systematically conducted a scoping review [35, 36] on 218 peer-reviewed articles collected from the Scopus database, with a total of 51 articles meeting inclusion criteria. The review was conducted in line with the method of Peters et al. [36] and the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) [37]. The review aimed to include studies at any stage of research to avoid potential biases in reporting and to ensure insights from early-stage research is included [38]. The detailed methodology and results being presented in chapter 3.

1.3.2 Design & Empirical - Co-creation

In order to answer RQ2 and to explore the formats and content of desirable solutions we need to thoroughly understand our user segment, their journeys and needs. However, most designers and researchers in lieu of themselves not being part of the target group are inherently biased and relatively minor but important nuances can easily be lost. We therefore needed a methodology which allows end-users a large degree of agency in the development process. Co-creation sometimes interchangeably referred to as co-design is an offshoot of the Scandinavian Participatory Design methodology [39] and is especially well suited to capture these user centric nuances. Co-creation broadly refers to any act of collective creativity shared by two or more people [40]. In this case we use the term to refer to the collaborative process seen in Fig. 1.2 involving end-users, designers, and stakeholders from the Danish Diabetes Association. Through this process we aimed to collaborative develop at least one desirable tool for T2DM while exploring user's journeys, needs and preferences to self-management over time. This study is covered in chapter 4.

Figure 1.2: Overall structure of the co-creation study - covered by chapter 4.

1.3.3 Empirical - Feasibility & randomised studies

In order to explore RQ3 & RQ4 we designed, implemented and studied an mHealth application supporting three micro-interventions based on an already established intervention in this case EFT [41, 42].

Based on extensive engagement with the existing literature on EFT an mHealth application was designed and implemented to deliver EFT as micro-interventions. The application design was matured through two user centred evaluations. Firstly in the form of focus groups with PwD and secondly through thinking aloud tests of the micro-interventions. The application was implemented in Flutter using an agile software development methodology. The EFT-application was subsequently used in a feasibility study carried out in line with the practices of early mHealth research aiming to address RQ3 [38]. The major phases of this work can be seen in Fig.1.3 with these covered in chapter 5.

Figure 1.3: Overall structure of the EFT feasibility study - covered by chapter 5.

Following the feasibility study a larger randomised study was planned to follow up on the results and limitations of the study. Specifically, how different variants of EFT micro-interventions affects delay discounting and how users perceive the experience of engaging with these variants. Resulting in a three arm pilot randomised study, the main phases of which can be seen in Fig. 1.4. This study is covered in chapter 6.

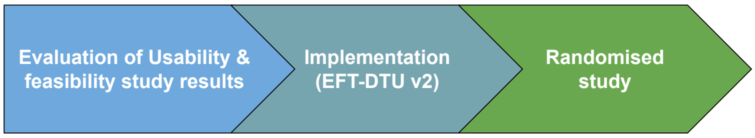


Figure 1.4: Overall structure of the randomised EFT study - covered by chapter 6.

1.3.4 Theoretical - Framework

Lastly, to explore RQ5 we needed to synthesise a broad number of insights from the literature and contextualise these to our own work and the previously established definitions of micro-interventions. The years 2020-2022, saw a significant surge in relevant publications presenting an opportunity for formalising micro-interventions. We therefore carried out a systematic review of literature focused on micro-interventions using PRISMA. A total of 205 articles were identified through 4 databases with 20 included in the review, 13 of which were published since 2020 [30]. Based on the insights provided by these we identified, organised, grouped, and modelled key components of micro-interventions and the constructs supporting their delivery into a unified framework. This work being covered by chapter 7.

1.4 Contributions

The contribution of this dissertation adds primarily to two areas of research 1) diabetes mHealth through papers I & II and 2) to micro-intervention research through papers III, IV & V. As part of our exploration of micro-interventions we additionally contribute to EFT research through papers III & IV by exploring the human-computer interaction of engaging with different EFT micro-interventions and by exploring the effects these have on delay discounting.

1) In terms of diabetes mHealth research we add a synthesised overview of existing diabetes mHealth technology literature by exploring: components, barriers, facilitators, reported effects and usage patterns. Based on this overview we raise and discuss a number of concerns and limitations about the development, rationale and reporting of mHealth research reducing designers ability to productively leverage existing literature. For instance which components or designs are useful and preferable to different users, and which are not.

Through our co-creation study we contribute by providing two specific co-created User Experience (UX) designs, the rationale for their creation and the imagined desirable user experiences provided. These designs are an activity based Continuous Glucose Monitoring (CGM) application and an online guide to diabetes. The user experience design and rationale for the co-created designs provide insights into the tools wanted by PwD to support self-management and how these tools can support self-management overtime as needs and situations change. Key insights include users acceptance and preference towards Self-Monitoring of Blood Glucose (SMBG)/CGM technology, need for agency and differing needs overtime. The latter insight is characterised by the discovery that a preferable outcome of successful engagement with mHealth may be future none-usage as goals have been reached. Moreover, through our co-creation work we generated a number of thematic insights relating to patients experiences with T2DM. These thematic insights add to knowledge about users journeys with diabetes, various issues faced and patients own solutions to these issues.

2) In terms of micro-intervention research we add to the growing literature on micro-interventions by exploring the creation of micro-interventions based on the concept of EFT. Through two studies we explored the user perceptions and the effects of these EFT micro-interventions delivered through a designed and implemented mHealth application. In addition to the proposed design and implementation, results from these studies contribute not only to the understanding of human-computer interaction of micro-interventions but also to the study of EFT by exploring real-world barriers, facilitators, and effects of future thinking. Specifically, we demonstrate that these micro-interventions are effective and

can be delivered through mHealth although these may not always be preferable to users, while also exploring the effects and user perception of different variants of future thinking.

Finally, we contribute to the understanding of micro-interventions by presenting the Design for Micro-Intervention Software Technology (D-MIST) evidence-based framework for micro-intervention systems. The framework unifies previous definitions by establishing a single taxonomy but also to ensures this framework covers explicit uses seen in the literature. The framework adds to the understanding of how micro-interventions can be used as building blocks by systems to create different narratives, how these can be personalised at different levels and how these achieve effects. The framework not only allows researchers to better understand micro-interventions but may also help designers create new micro-intervention systems and micro-interventions.

1.5 Thesis Outline

This dissertation is based on research conducted during the PhD study period and comprises five articles:

- Article I: ”Exploring Components, Barriers, Facilitators and Attrition Causes in Type 2 Diabetes mHealth: A Scoping Review”, explores the components, facilitators, barriers, attrition causes and effects reported by mHealth literature.
- Article II: ”Exploring Patient Needs and Designing Concepts for Digitally Supported Health Solutions in Managing Type 2 Diabetes: Cocreation Study”, explores the needs of persons with type 2 diabetes with end-users acting as experts in their own experience. Collaboratively, the work explores a broad collection of diabetes issues with the aim of co-creating solutions to user chosen issues in diabetes.
- Article III: ”Episodic Future Thinking as Digital Micro-interventions”, explores the design process, implementation, early feasibility and perceptions of EFT delivered as digital micro-interventions.
- Article IV: ”Perceptions and Effectiveness of Episodic Future Thinking as Digital Micro-Interventions Based on Mobile Health Technology”, explores, the perceptions and effectiveness of different types of EFT through a randomised study.
- Article V: ”A Design Framework for Micro-Interventions in Mobile Health Technology”, explores, the creation and rationale of a unified framework for micro-intervention systems based on the scientific literature and previous sometimes subtly differences in definitions and uses.

The thesis is organised into 8 chapters: Chapter 2 jointly describes background knowledge and the related works for key themes of this thesis. Chapters 3-7 presents and summarises the main objectives and subsequent findings of articles I - V in order. Chapter 3 thus covers insights from our scoping review on mHealth based interventions. Chapter 4 explores insights from the co-creation study aiming to develop new solutions to support T2DM self-management. Chapter 5 covers the design and implementation of EFT micro-interventions as well as the initial feasibility and usability findings with chapter 6 describing the randomised follow up study. Chapter 7 details the creation and rationale for our design framework for micro-intervention systems. Lastly, chapter 8/9 discusses the overall findings, work limitations, perspectives on future works and concludes upon the work.

CHAPTER 2
Background and related work

2.1 Diabetes

In the past 20 years a major contributor to growing global burden of chronic illness has been diabetes. Diabetes is generally characterised by an inability to properly regulate blood glucose leading to abnormal blood glucose levels. The three most common forms of diabetes are Type 1, Type 2 and gestational diabetes with Type 2 contributing the vast majority of cases, and roughly 90% of cases globally [43]. Type 1-diabetes is caused by an autoimmune disease destroying the body's ability to produce insulin [44], while Type 2 by contrast can be caused by both insufficient production of insulin or the inability to properly leverage insulin referred to as insulin resistance [43]. Gestational Diabetes sometimes referred to as "pregnancy diabetes" is caused by a form of insulin resistance caused by hormones during pregnancy but has also been associated with high risk of type 2 diabetes [45]. Global estimates suggests upwards of 9.3% (~463 million) of the global population are currently affected by diabetes with projections that this is likely to reach 10.9% (~578 million) by 2045 [46]. Nationally, (in Denmark) it is estimated that approximately 360.000 persons suffer from diabetes with another 480.000 estimated to have either undiagnosed diabetes or being at risk of developing Type 2 through prediabetes. Specific risk factors associated with the onset of prediabetes and subsequently progression to type 2 includes: family history, smoking, sleep quality/quantity, ethnicity, obesity, inactivity, age, and certain conditions such as hypertension [47].

T2DM by nature is considered a chronic lifelong illness, however recent works have found evidence that it is possible for many to achieve remission shortly after diagnosis through weight loss [8]. Traditionally these clinically relevant weight losses have been achieved through lifestyle modifications supported by various interventions and programs. While these programs have generally seen positive results, challenges remain in regard to adoption and maintenance of lifestyle changes [48]. However, recent advances in drug development may see drugs targeting obesity take a key role in facilitating these weight changes in coming years [49]. Nevertheless, lifestyle changes may include smoking cessation, modification of diet, increased physical activity and reduction of sedentary behaviour. Although, behaviour change is notoriously difficult [38] requiring maintenance of behaviours often for years, in the case of diabetes perhaps decades [15]. While many are successful in creating lasting habits there are also those falling back on negative habits through lapses and setbacks [38].

The long-term consequences of elevated glucose levels can be a number of problems such as: loss of senses, nerve damage, and other comorbidities e.g., increased risk of heart disease. In more severe or untreated cases, diabetes may cause blindness, kidney failure, heart attacks, strokes or lower limb amputation [50]. The World Health Organization estimates diabetes was the direct cause of 1.5 million deaths in 2019 with diabetes related comorbidities raising this figure considerably [50]. Initially, T2DM may be manageable by lifestyle changes and medications, in some cases by lifestyle alone referred to as Non-Insulin Treated (NIT) diabetes. In other cases however it may be necessary for persons to use insulin injections. Despite the potentially severe consequences, motivational and adherence issues are not uncommon [48]. The prevalence of depression among PwD also presents significant challenges due to its impact on person's ability to effectively self-manage diabetes [24]. A number of issues may also further complicate diabetes self-management such as the existence of comorbidity, pre-existing conditions, diabetes distress level, health or technical literacy and age.

The needs and challenges faced by PwD are often quite varied with changes occurring overtime based on personal circumstances, progression of the disease and previous experiences. A convenient albeit perhaps oversimplified view on the journey of a PwD can be found in the work by Klasnja et al. identifying four phases of this journey: 1) initial learning phase after diagnosis, 2) a stabilisation phase building confidence, 3) a relearning phase where adjustments are made in response to changes and 4) an expertise phase achieved through long term management [25]. However, this journey can be further complicated by the aforementioned issues and population differences e.g., lack of motivation, complications, or diabetes distress. Factors such as obtaining knowledge, taking responsibility, and receiving confirmation of lifestyle choices have previously been suggested as facilitating self-management. Factors supporting maintenance of behaviours includes support from others, experiencing effects, fear of complications and habitualisation of behaviours [51].

Glucose monitors are a commonly used tool among PwD enabling them to self-monitor blood glucose. The sophistication of these tools varies significantly ranging from one-use strips to devices providing continuous measurements through patches. A standard glucose monitor works by extracting a small blood sample which through a test strip allows a glucose monitor to provide a measurement. Flash glucose monitors and continuous glucose monitors (CGM) work by attaching a patch with a needle and sensor to a person enabling either on-demand or continuous readings of blood glucose levels. These measurements can have several purposes; they may e.g., enable PwD to assess how they are doing accurately [15] or enable PwD to reflect on how their actions affect glucose levels. Several studies have found these technologies to be perceived positively by a vast majority of users [52, 53]. Research has also associated SMBG measurements, especially structured SMBG and CGM measurements to be associated with improved blood glucose control [54].

Rather than momentary blood glucose the main outcome variable of interest in research is usually Hemoglobin A1c (HbA1c) or ”glycated haemoglobin”. A measure for average blood glucose levels for the last 2-3 months. Other common outcome measures include time-in-range [55], weight loss [56], lipids, blood pressure [57] and more focused measures for instance diabetes distress [24]. The first mentioned of these ”time-in-range” referring to proportion of time spent inside target blood glucose ranges which compared to the average blood glucose provides a more holistic view of daily variations. Quality of life and diabetes distress have also occasionally been used as a clinically relevant factors with both factors having previously been found to impact long term management behaviours [58]. E.g., with experience PwD may gradually begin to shift their focus from the disease itself to quality of life, effectively balancing self-management with other desires and activities [25].

Diabetes lifestyle changes can in practice be facilitated or supported in a number of ways such as physical classes, programs, health coaching or by implementation of specialised diets such as the Mediterranean diet. However, in the following section we will briefly cover those facilitated through mobile technologies before returning to more detailed descriptions of application components and implementations in chapter 3.

2.2 Mobile Health

Since Steve Jobs introduced the world to the wondrous possibilities of smartphones in 2007 the field of mobile health has grown explosively [59]. Suddenly people started carrying sensor rich devices with direct access to the internet around with them at all times. This development opened the door to new channels for patient/provider interactions but also passive collection of data which previously required specialised devices. These advances paved the way for near real time tracking of many health conditions, associated factors, and outcomes. These improved data sources have consequently led to a number of new intervention schemes such as JIT, JITAI and new affordances in patient-provider communication.

Although, this success, excitement and rapid growth has not occurred without presenting new challenges. While an untold number of apps have been presented over the years aiming to help PwD manage their condition these often lack underlying rationale and clinical evidence [20]. A consensus by the American Diabetes Association found significant problems caused by this wide variety of PwD, noting differences in education, age, socio-economic status, and digital literacy [20]. Additionally, while the accessibility of apps has increased exponentially, the discoverability of these has decreased obscured by the quantity available [60]. Equally, improved digital literacy has not universally kept pace with the adoption of smartphones presenting significant challenges to the aged portion of the T2DM population.

Applications also vary wildly in terms of both format and content. Some applications may aim simply to monitor, organise, and present data while others aim to facilitate a variety of interventions. Examples of such interventions include context aware message-based systems [61], gamified diabetes care [26] and systems aiming to streamline patient provider communication [15]. While some applications are more narrowly scoped focusing on for instance sedentary behaviours most mHealth interventions are multifaceted in nature containing components covering multiple aspects of diabetes such as diet, physical activity, blood glucose, etc.

Overall mobile health solutions have been found to have a moderate effect size in terms of improved HbA1c through behaviour change [62, 63]. However, many meta-analysis of these effect sizes cautions limitations regarding study designs and duration [64]. The multifaceted nature of most mHealth applications also present significant challenges in associating design choices and components with these effect sizes [65].

One staple of mHealth interventions targeting diabetes is the inclusion of educational elements aiming to increase health literacy and promote self-management behaviours [66]. These usually cover a broad variety of behaviours and topics such as diet, physical activity, blood glucose, and medications, but can extend to more domain specific areas, smoking, comorbidity etc. Recent meta-analysis also supports the usefulness of diabetes self-management education and support concluding it to have a small but significant effect on glycaemic control [67] with another review noting a reduced all-cause mortality risk [68].

Another common form of interventions focuses on increasing physical activity. These interventions have several formats ranging from alarms prompting users to break up sedentary time [69] to more intense day-to-day walking and exercise programs [26]. Various authors have also facilitated improved step counts as a measure for improved physical activity with various digital applications successfully supporting and facilitating these changes [26, 70, 71].

Lifestyle changes relating to diet and interventions aiming to assist these changes are also common in T2DM. Digital interventions relating to diet often involves collecting dietary information, counting calories or carbohydrates, or adhering to a recommended diet. One example being the Mediterranean diet which has been shown effective in reducing HbA1c levels [72]. Lifestyle interventions including nutritional education have also been found effective at reducing weight and glucose outcomes [73].

Many mHealth applications leverage forms of feedback through the mHealth system it-self, email or using short messaging services [74] with some systems employing forms of automated feedback [19, 75]. Topics covered in both automatic and manual feedback can e.g., include nutrition [76], physical activity [26], exercise intensity [77] and blood glucose readings [78].

However, in contrast to the positive results demonstrated by many studies, attrition remains a key issue with some studies reporting especially troubling usage trends. Baumel et al. e.g., found real word retention of popular mental health apps to be as low as 3.9% within 14 days [17]. Similar trends were reported by Meyerowitz-Katz et al.'s meta-analysis on attrition in chronic disease mHealth reporting pooled dropout rates of 43% across studies. But also noting indications of higher attrition rates across observational studies with further indications of both biased and dubious standards for reporting attrition implying real-world usage may be lower than reported [18]. While there is generally a paucity of information available on diabetes mHealth attrition one randomised controlled trial found 46.4% of users lost in 10 or less days and noting low utilisation of the app [79].

Several reasons have been proposed for this attrition, but little concrete evidence is available. In some instances authors have attributed these attrition rates to fundamental problems with the design and development of mHealth applications such as: too little emphasis on the user experience over time [25], failure to address changing needs [23] or that patient experiences and needs do not align strictly with clinical judgement [22]. Baumel et al. e.g., speculates that while people are interested in beneficial interventions, they are often unwilling or unable to invest the effort intended by developers leading to low engagement [29]. In a manner similar to micro-interventions JITAI have also been proposed as a means to increase relevant interactions while reducing friction: "The aim of these interventions aim to deliver the right component and the most effective dose and time to avoid delivering an intervention component when it is not necessary" - Miller [28].

2.3 Micro-interventions

The field of micro-interventions is one that has seen increasing interest in recent years. Archival evidence suggests the terminology has existed at least conceptually since the 1970ies [80], however the definition and origin for these early micro-interventions remain unclear. The modern reemergence of interest for micro-interventions in mHealth seems to have started in the early to mid-2010s. Early examples of these includes the work by Paredes et al. [32], Matthews et al. [81], and Meinlschmidt et al. [82] utilising mobile technologies to provide short beneficial therapeutics in discrete moments of time but with no author providing a concrete origin or definition for the term micro-interventions. However, it can also be conjectured that applications predating Paredes et al. could be considered to have utilised micro-interventions. The work of e.g., Quinn et al. is in many ways reminiscent of later definitions of micro-interventions using data collection and a feedback engine to deliver over 1000 different self-management messages [75]. Concurrently, with these developments the first large-scale introduction of what can be considered a micro-intervention occurred in 2016 with Apple releasing the "Breathe" app for the Apple Watch [83]. The Breathe-app provides short simple breathing exercises aiming to reduce momentary stress [84].

The earliest concrete evidence-based and explicit definition of the term appears to be from the work of Fuller-Tyszkiewicz et al. defining micro-interventions as: interventions designed to administer resources that can be quickly consumed and should have an immediately positive effect on target symptoms including JITAI and ecological momentary interventions [31]. Micro-interventions compared to traditional interventions are thought to have several advantages: Firstly, given their limited scope and duration micro-interventions are believed to lower the barriers associated with engagement. It has been argued this is because micro-interventions closely resemble the "interventions" people subconsciously engage with commonly, e.g., asking others for advice, watching a video, or playing an uplifting song [29]. Such similarities can also be seen reflected in the work by Paredes et al. with presented micro-interventions designed to closely resemble activities a person might already do for fun such as playing a small game, watching funny cats, or interacting with social media, but applied contextually to manage stress [32].

Micro-interventions have already seen use for a variety of purposes such as improving mood [82], promoting positive body image [31], and reducing the number of unpleasant dreams [85]. Fuller et al. for instance used 11 short videos delivering mindfulness and gratitude exercises over 21 days finding immediate improvements in body satisfaction post intervention [31]. Meinlschmidt et al. similarly used video clips to successfully elicit immediate mood changes over 13 days by allowing participants a choice of 4 interventions based on psychotherapeutic techniques [82]. Micro-interventions have also been used successfully to target the level of unpleasant dreams by proximal mood intervention prior to sleep [85]. Yet another micro-intervention successfully targeted users willingness and adherence for engaging in meditation suggesting micro-interventions are capable of affecting one another [33].

However, one limitation indicative of these studies on state-of-the-art micro-interventions is that they exclusively use one or few micro-interventions to accomplish limited goals. While several authors conceptually explored the idea of combining micro-interventions for greater effect and benefit [82, 32, 31, 33] the first attempt at conceptualising micro-interventions in a larger care/treatment context can be found in the work by Baumel et al. who coins the idea of "micro-intervention care" [17]. This conceptualisation differentiates between the micro-interventions themselves and the structures facilitating the delivery or "care" where individual micro-interventions are used as building blocks. Baumel et al. describes micro-interventions as consisting of events, the timing of which is determined by decision rules with proximal assessments gauging event effects and with each micro-intervention having an overall outcome. Micro-intervention care meanwhile consists of 1) a facilitating "hub", 2) a therapeutic narrative as a linking bridge between mico-interventions, 3) conceptual models describing possible uses in the therapeutic process and 4) the micro-interventions as building blocks. In this case the hub refers to any entity aiming to recognise an individual's state and context, recommend relevant interventions and create and maintain a coherent narrative [29]. The therapeutic narrative is seen as linking agent between micro-interventions supporting the move from one micro-intervention to another while consolidating the experience between interventions. The conceptual therapeutic process in this case being reminiscent of decision rules but detailing when and how each micro-intervention can be used to support clinical goals [29].

Overall there are several ways of designing micro-intervention systems and interactions with different levels of user agency and choice. E.g., Howe et al. describes three ways of interacting with micro-interventions namely: on-demand, pre-scheduled and JIT [86]. In on-demand users themselves are responsible for identifying need and choosing when to engage with micro-interventions as well as the choose the micro-intervention they wish to engage with. In pre-scheduling users choose a head of time opportune moments where they want to experience micro-interventions. JIT meanwhile uses various decision rules to determine need and attempts to suggest an optimal intervention for the user's needs. However, interactions can also combine elements these interaction schemes Howe et al. for instance uses both on-demand alongside JIT and pre-scheduling [86]. Users may choose when to engage micro-interventions based on a perceived need with the system recommending the interventions or the system may suggest opportune moments for interventions with the users choosing between a selection of micro-interventions.

Research on the user experience of micro-interventions have identified a number of factors impacting their use for instance: perceived benefits, perceived usefulness/effects, personal preference and novelty [32, 86]. Perceived rather than actual usefulness has been found to be an important factor for determining future usage [86]. Perceiving an effect from a micro-intervention has further been found to be a facilitator promoting engagement with future interventions. Personal preference has been found equally important for engagement with some users preferring lower intensity micro-interventions even if these are less effective [86]. Novelty has also been suggested as an important factor for maintaining engagement with users [32], that is users do not wish to engage with the same interventions indefinitely and may benefit from new micro-interventions.

2.4 Delay discounting & Episodic Future Thinking

A rather common saying relating to happiness in life is to "live for the moment" or to act without worry for the future. However, such biases in the present can have a significant impact on our long term health. Indeed these biases have been noticed in many problematic societal trends such as: smoking [2], poor dietary choices [87], obesity [88], lack of exercise, and sedentary behaviour [89]. All risk factors associated with development of diabetes [90, 91] and similarly poorer outcomes among those diagnosed with diabetes [92].

Delay discounting is a behavioural trans-disease measure for the tendency of humans to prefer immediate rewards over larger future ones [10]. High delay discounting has been associated with a number of these maladaptive behaviours such as overeating, preference towards calorie dense foods, obesity [93], smoking, sedentary behaviours, and forms of addiction [94]. Epstein et al. further suggests modification of delay discounting as a novel target for preventing prediabetes from transitioning to Type 2, given its association with changes in HbA1c and body mass index [10]. The study by Epstein et al. found evidence supporting the relationship between changes in delay discount and HbA1c with previous works associating delay discounting with obesity both significant risk factors in T2DM [10]. However, delay discounting is also a transdiagnostic process observed in many other disorders such as schizophrenia, bipolar disorder and eating disorders [95].

A variety of validated tools exist for measuring delay discounting [2]. These measures often consist of a number of monetary choices set at different time frames aiming to identify a person's discounting rate over time. Two notable tools are the Kirby Delay Discount Questionnaire [96] and the Adjusting Amounts Task [10]. The former consists of 27 questions with varying rewards to choose between at different points in times ranging from 7 to 186 days [96]. The Adjusting Amounts Task consists of 7 time periods each with 6 monetary adjustments i.e., ”Would you prefer $50 now or $100 in a week”. For each choice made the adjusted amount is adjusted by 50% depending on the choice e.g., if the ”now” amount is chosen it will be adjusted to ”$25 now” or if the future amount is chosen ”$75 now” with the next choice adjusted by +-$12.5 and so on until the indifference point is reached [10]. The discount rate k can then be determined by fitting the indifference points to Mazur’s hyperbolic model for delay discounting:

$$V = A/(1 + kD)$$

with V being the perceived subjective value, A the actual value, D the delay and k the discounting coefficient or rate [97, 10]. Higher values of k are thus indicative of faster discounting of future outcomes and distant outcomes being perceived as less valuable.

One intervention capable of affecting delay discounting is episodic future thinking (EFT) [94]. In EFT a person images a personal future event creating a detailed and vivid description of said event [95]. These descriptions of events are then recorded as audio and used to recall/pre-experience the future event [98]. Meta-analysis of the effects of engaging in EFT found that it significantly reduced delay discounting with positively phrased futures being found most effective [95]. EFT is believed to affect decision making by increasing the perceived value of delayed outcomes and by encouraging choices with long term benefits [99]. Although the underlying mechanism for EFTs ability to modify delay discounting is poorly understood there is a significant ongoing effort among neuroimaging researches to associate these effects with regions of the brain [100]. Nevertheless, EFT has consistently been shown effective in reducing delay discounting in experimental and real-world settings [10, 101, 102, 99, 103, 104]. For instance Hollis-Hansen et al. demonstrated that EFT can affect momentary behaviours associated with online grocery shopping [105]. Similarly, O’Niell et al. demonstrated that EFT used in a public food court encouraged healthier decision making resulting in a reduced caloric intake [106]. However, Voss et al. while observing no significant differences in delay discounting did find EFT effective in achieving a significant reduction in alcohol consumption among college students [107]. Recently, EFTs effects have also been demonstrated to improving diabetes self-management behaviours in this case medication adherence [102]. Epstein et al.’s recent 6-month trial further indicates that delay discounting could be modified on persons with prediabetes concurrently with changes to HbA1c, psychical activity and weight loss but notes that data does not suggest these changes occurred due to EFT [102].

A number of variations or alternatives to traditional EFT have also been suggested over the years with two particularly noteworthy ones being Goal-oriented Episodic Future Thinking (gEFT) and mental imagery. In gEFT goals are explicitly tied to the episodic futures [108]. Experimental results indicate that gEFT is at least equally effective in modifying discounting but may offer additional behavioural benefits [108, 109]. For instance, one study did not find the inclusion of health goals more effective in modifying discounting rate but did find it more effective in changing cravings and perceptions of unhealthy behaviours [109]. Mental imagery meanwhile aims to promote goal related behaviours by having users imagine through imagery attainment of a desired goal state [41]. While mental imagery is not directly related to EFT it is reminiscent of gEFT in that both methods involve pre-experiencing a vivid desirable future with the former utilising a mental image rather than audio recordings to imagine the future.

CHAPTER 3

Exploring Components, Barriers, Facilitators and Attrition Causes in Type 2 Diabetes mHealth: A Scoping Review

In this chapter we will explore the existing literature on T2DM mHealth with an emphasis on four thematic areas: 1) the components ("features") used by presented applications 2) their reported barriers & facilitators, 3) reported attrition and 4) effects. In order to explore these thematic areas and subsequently answer research question 1 we systematically carried out a scoping review of existing peer reviewed T2DM mHealth literature. This chapter presents the methodology and the principal findings of the review.

The following sections summarises and expand upon the paper:

Dan Roland Persson, Jakob Eyvind Bardram, Per Bækgaard. Exploring Components, Barriers, Facilitators and Attrition Causes in Type 2 Diabetes mHealth: A Scoping Review [Draft] 2023.

Please cite accordingly.

3.1 Scoping review

To conduct the scoping review on mHealth literature targeting T2DM we used the method outline by Peters et al. [36] and PRISMA [37]. We choose not to restrict the study types included beyond the exclusion of literature reviews in order to broadly capture perspectives and insights from early development as well as trials. We base this choice on the points presented by Klasnja et al. that even if definitive proof of behaviour change cannot be shown, early studies may add valuable insights to the understanding of how and why a technology works or does not for its users [38]. Consequently, to keep the scope of the review manageable we sought to limit it in three other ways: Firstly, by limiting the search to a single database of peer-reviewed literature in this case Scopus which has been found to contain a broad selection of literature [110] and found to be well-suited for evidence synthesis [111]. Secondly, by limiting research to the years after the emergence of modern smartphones in this case from 2008. Thirdly, by limiting included literature to research focused on mHealth rather than technologies using the umbrella term "telemedicine" which has previously been noted to create ambiguity and obscures insights from different platforms employed [112] i.e., smartphones, text-messaging, or web portals. Additionally, we will only include research papers focused on T2DM given the different needs presented by diabetes types [113]. Our final inclusion criteria are therefore: 1. peer-reviewed journal or conference papers, 2. published in English, 3. focused on type 2 diabetes mellitus, 4. leveraging smartphone technology, 5. that include descriptions of intervention, data collection, and software components used. After the study selection we extracted data from the included articles using three data collection forms in excel, previously developed based on a thematic analysis of the literature. These forms covered reported effects, components, and attrition in addition to more general study characteristics such as authors, title, study arms etc. To preserve nuances related to barriers and facilitators as presented in the included literature we summarise these in the style of a narrative review [114]. All articles were screened twice as part of the data extraction with discrepancies discussed between authors.

3.2 Principal findings

The literature search and record retrieval was conducted in mid-August 2020 and resulted in 218 records being identified (see Fig. 3.1). After removing duplicates 207 articles were screened initially by title and abstract with 66 articles moving on to full-text screening. A total of 51 articles were found to meet the inclusion criteria and were included in the review.

Of these 51 articles, 20 were pilot studies, 10 were random control trials, 8 feasibility studies with remaining papers including a variety of different study designs such as e.g., interview or cohort studies. In the following sections we will briefly provide an overview of the components found in these studies before looking at identified barriers, facilitators, and reported attrition. Finally, we will look at the reported effects and argumentation for clinical relevance presented by these studies. An overview of the literature can be seen in table 3.1.

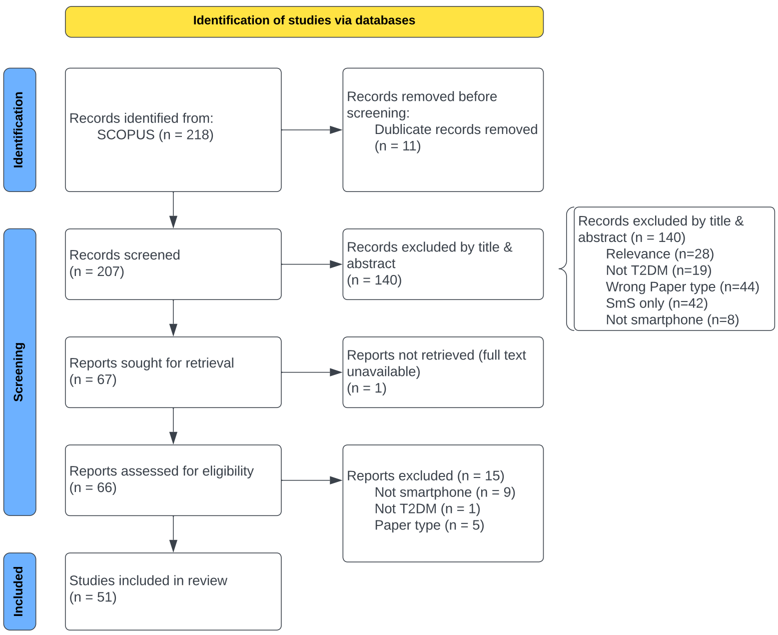


Figure 3.1: PRISMA flow diagram [37] showing the literature reviews inclusion process [115].

Table 3.1: Overview of the included literature including study characterises, mHealth approach (e.g., multifaceted, physical activity focus), study type and reported effects [115]. The abbreviations ”pos” and ”nr” standing for positive and not reported respectively.

Nr	Author	Year	Approach	Study type	Clinical	Other	Behavior	Psychological	Diet
1	Adu et al [19]	2020	Multifaceted	Usability	n/a	n/a	nr	nr	nr
2	Bailey et al [116]	2020	Sitting time	Feasability	n/a	pos	pos	pos	nr
3	Adu et al [117]	2020	Multifaceted	Pilot	n/a	pos	pos	nr	pos
4	Boels et al [27]	2019	Education	RCT	none	n/a	nr	nr	nr
5	Wilczynska et al [118]	2019	Physical activity	RCT	n/a	pos	pos	nr	nr
6	Huang et al [119]	2019	Medication	Feasability	none	pos	nr	nr	nr
7	Höchsmann et al [26]	2019	Physical activity	RCT	pos	pos	pos	nr	nr
8	Alonso-Domínguez et al [71]	2019	Multifaceted	Clinical trial	pos	n/a	pos	nr	nr
9	Koot et al [120]	2019	Multifaceted	Feasability	pos	n/a	none	nr	pos
10	Jeon et al [78]	2019	Multifaceted	Pilot	n/a	pos	none	nr	nr
11	Höchsmann et al [121]	2019	Physical activity	RCT	pos	pos	pos	pos	nr
12	Wang et al [122]	2019	Multifaceted	RCT	pos	n/a	pos	nr	nr
13	Sun et al [52]	2019	Multifaceted	RCT	pos	n/a	nr	nr	nr
14	Alonso-Domínguez et al [123]	2019	Multifaceted	Clinical trial	n/a	pos	nr	nr	pos
15	Yu et al [124]	2019	Multifaceted	Pilot	n/a	pos	nr	nr	nr
16	Valentiner et al [125]	2019	Physical activity	Pilot	n/a	none	pos	nr	nr
17	Yamaguchi et al [76]	2019	Multifaceted	Pilot	n/a	none	nr	nr	nr
18	Byrne et al [126]	2018	Physical activity	Feasability	n/a	pos	none	nr	nr
19	Torbjørnsen et al [127]	2018	Multifaceted	RCT	n/a	none	nr	nr	nr
20	Wang et al [128]	2018	Multifaceted	Pilot	n/a	pos	pos	nr	nr
21	Abidi et al [129]	2018	Multifaceted	Pilot	n/a	n/a	n/a	n/a	n/a
22	Berman et al [130]	2018	Diet	Cohort Study	pos	n/a	pos	nr	pos
23	Plotnikoff et al [70]	2017	Physical activity	Feasability	n/a	pos	pos	nr	nr
24	Yom-Tov et al [131]	2017	Physical activity	Pilot	n/a	pos	pos	nr	nr
25	Kleinman et al [112]	2017	BG and Feedback	Clinical trial	none	n/a	nr	nr	nr
26	Alexander et al [132]	2017	Multifaceted	Feasability	n/a	n/a	n/a	n/a	n/a
27	Kim et al [133]	2016	Multifaceted	Pilot	n/a	pos	pos	nr	pos
28	Pludwinski et al [134]	2016	Multifaceted	Qualitative	n/a	n/a	pos	pos	pos
29	Anzaldo-Campos et al [135]	2016	Multifaceted	RCT	pos	n/a	none	none	nr
30	Quinn et al [61]	2016	Multifaceted	RCT	pos	n/a	nr	nr	nr
31	Verwey et al [136]	2016	Physical activity	Mixed methods	n/a	n/a	nr	nr	nr
32	Pellegrini et al [69]	2015	Sitting time	Pilot	n/a	pos	pos	nr	nr
33	Quinn et al [137]	2015	Multifaceted	Pilot	n/a	pos	pos	pos	nr
34	Wayne et al [138]	2015	Multifaceted	RCT	pos	n/a	nr	none	nr
35	Goh et al [139]	2015	Multifaceted	Clinical trial	n/a	none	nr	nr	nr
36	Ghorai et al [140]	2014	Multifaceted	Development	n/a	n/a	n/a	n/a	n/a
37	Wayne et al [141]	2014	Multifaceted	Pilot	n/a	pos	nr	nr	nr
38	Strong et al [142]	2014	Multifaceted	Development	n/a	n/a	n/a	n/a	n/a
39	Quinn et al [143]	2014	Multifaceted	Randomized	n/a	n/a	nr	nr	nr
40	Verwey et al [144]	2014	Physical activity	Pilot	n/a	pos	pos	pos	n/a
41	Tatara et al [53]	2013	Multifaceted	Pilot	n/a	nr	nr	nr	nr
42	Ghorai et al [145]	2013	Multifaceted	Development	n/a	n/a	n/a	n/a	n/a
43	Tatara et al [53]	2013	Multifaceted	Pilot	n/a	nr	none	nr	none
44	Nes et al [146]	2012	Multifaceted	Feasability	n/a	pos	pos	nr	nr
45	Castelnuovo et al [147]	2011	Physical activity	RCT	none	n/a	nr	nr	nr
46	Quinn et al [75]	2011	Multifaceted	Cluster RT	pos	n/a	nr	nr	nr
47	Lyles et al [148]	2011	BG and Feedback	Pilot	n/a	none	nr	nr	nr
48	Stuckey et al [149]	2011	Multifaceted	Pilot	n/a	pos	pos	nr	nr
49	Årsand et al [150]	2010	Multifaceted	Pilot	n/a	none	pos	nr	pos
50	Quinn et al [151]	2008	Multifaceted	Pilot	pos	n/a	nr	pos	pos
51	Katz et al [152]	2008	Multifaceted	Pilot	n/a	pos	pos	nr	nr

3.2.1 Components

The most commonly observed components (”features”) seen in the literature on mHealth interventions can be seen in Fig. 3.2. The data collection in the studies include monitoring physical activity, diet, blood glucose and are the most common components. Educational elements, goal-setting, visualisation and different forms of feedback are prominently used in the literature.

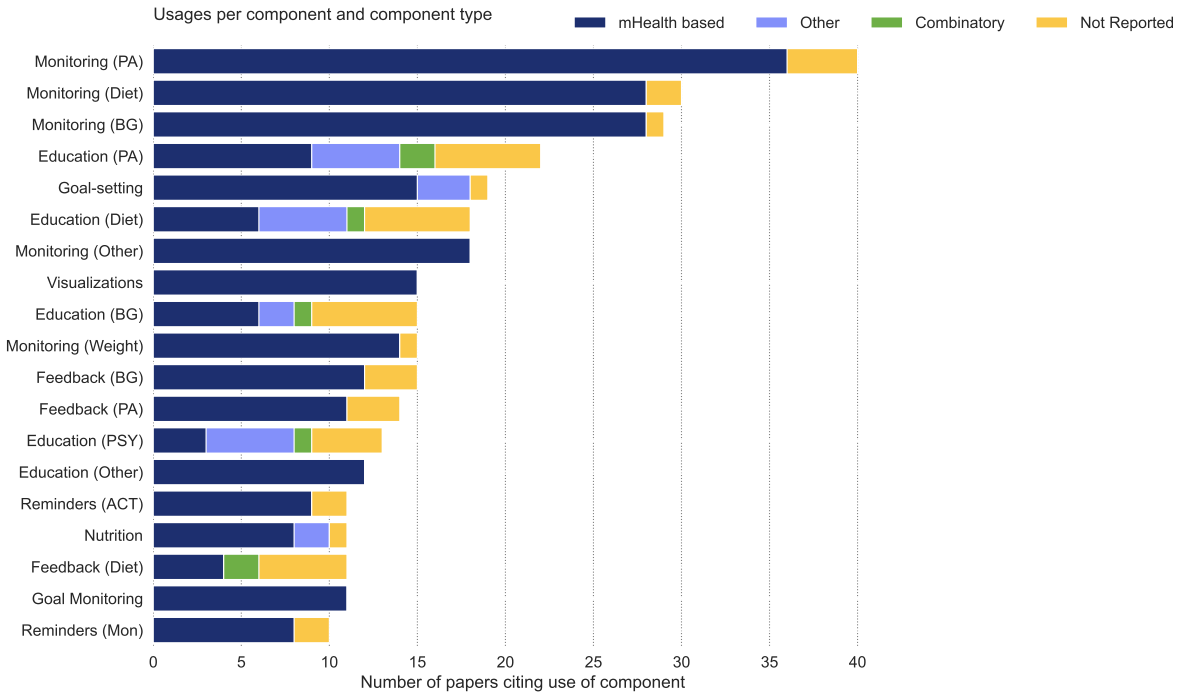


Figure 3.2: A barplot highlighting the inclusion of different components (”app features”) described by each study, colour coded according to whether these were facilitated through: 1) mHealth (Dark blue), 2) classes, workshops or other means (Light Blue), 3) by both (Green) or 4) with facilitation not disseminated (Yellow) [115].

Monitoring components: Data collection generally occurred through IOT devices, smartphone sensors and manual collection by users. Most applications feature forms of both user driven, system driven, and combinatory data collection [153] with collected data subsequently used as the basis for other interventions i.e., feedback, visualising trends etc. Table. 3.2 provides an overview of the different data types, their sources and means of collection.

Table 3.2: Summary of the different data types collected and their means collection as seen in the reviewed literature [115].

Data type:	Description	Sources	Means
Personalised data	Demographic data, goals, usage data.	Questionnaire / App dialogs	User driven
Location data	Users location / state (E.g. at home and work).	GPS / Beacons	System driven
Exercise data	Users activity, exercise and active lifestyle, fitness level.	Smartwatch sensors, accelerometer, GPS	Combinatory
Dietary data	Users food/drink intake, dietary habits.	IoT devices, image analysis or voice interfaces	Combinatory
Glucose data	Blood sugar level.	Bluetooth connection to glucose meter	Combinatory
Vitals data	Pulse, blood pressure, Weight, body mass index	Smartwatch, IoT devices, IoT weight	Combinatory
User state	Users mood, user pains.	Questionnaire / App dialogs	User driven
Wound images	Diabetes related wounds.	Image based dialog	User driven
Other	Cigarette use, medication use, food satisfaction.	Various prompts and dialogs	User driven

Data on physical activity was collected through a number of automatic means for instance through

IOT devices [7] and smartphones counting steps or tracking activity [154]. One particularly sophisticated system further tracked exercises through both the smartphones' camera when placed in front of users and through voice recognition by counting repetitions of an exercise [26]. Biometric indications of physical activity can also be seen used through smartwatches measuring blood pressure and heart rate [155]. Given the difficulty of recording certain exercises and reliability concerns some applications also support manual collection of physical activity data by allowing users to log data or use diary style documentation [154]. Some applications chose to represent the physical activity data as calories burned during exercise [139], by minutes of exercise [77] or by daily steps [121].

Dietary monitoring compared to physical activity relied more heavily on manual data collection such as calorie counting [133], intake recording [123], or logging meals through images [138]. Some applications had users record their diet through scanning barcodes [122], choosing items from a database [139] or picking from lists of meals [147].

Self-Monitoring of Blood Glucose (SMBG) was handled by a variety of devices featuring different levels of sophistication. Most of those described in the literature rely on users to measure SMBG and transfer results into the application [133] while other devices handle the latter automatically [52]. The use of more advanced technologies such as flash glucose or CGM was not observed in the reviewed literature.

Other types of data collected by applications included: mood [138], wound images [142], cigarette usage [140], beverage/snack conception [150], weight [130], food satisfaction [141], and pain [141].

Education: Most applications featured some form of educational component with many but not all of these facilitated through the mHealth application itself. The educational content presented by these covers a number of themes: self-management, physical activity, diet and more specialised topics specific to studies e.g., the Mediterranean diet [123]. Applications provide this educational material through simple messages [19], videos [145], quizzes [120] or personalised messages as educational elements [75]. Some applications further describe educational elements built into other features, such as the app by Wang et al. which provided health scores for dietary items reported [122]. Several papers also described educational components which were separate from the mHealth application e.g., Alonso et al. had nurse facilitated educational guided walks and a diet workshop [71]. Plotnikoff et al. likewise supplemented the mHealth intervention with 90 minute group mentoring with a psychologist and personal trainer aiming to motivate and teach [70]. Some authors also describe patient-provider feedback mechanisms that also aim to serve educational purposes [134].

Physical activity: Throughout the literature we see a number of components aiming to affect physical activity (seen by Fig. 3.2). Chief among these is monitoring of physical activity serving as the basis for other components i.e., visualisations [76], self-reflection [78], goal-setting [136] from either patient [150] or provider [144] with forms of manual [136] and automated feedback [131]. Some components aim to educate [70], while others attempt to motivate [131] with some trying to improve the effectiveness of physical activity [77]. E.g., Yom-Tov et al. used context-aware messages to motivate adherence to physical activity, discovering positive messages in particular increased next-day motivation to exercise [131]. Ried-Larsen et al. used smartphone sensors and an initial fitness test to facilitate JIT intervention of the intensity of interval walking ensuring the correct intensity of walks [77]. JIT components were also featured in Alexander et al.'s work leveraging an eco-system of sensors to identify meals and providing in-moment incentives for exercise shortly after identified meals [132]. Other authors use sensor data to identify periods of inactivity aiming to intervene by prompting users to engage in light physical activity [116, 69, 131]. Gamification elements were also successfully used to increase physical activity through a story driven game with aforementioned elements embedded included personalisation through a fitness test, education through instructions, in exercise intensity feedback, post-exercise feedback and various rewards [26, 121].

Diet: Many dietary intervention components resemble those seen in physical activity relying on data collection [53], visualisations [76], and goal-setting [127]. Nevertheless dietary data is often more complex in nature with applications considering portion size, nutrition, calories, and carbohydrates [76].

The aim of dietary interventions is generally to limit carbohydrates or to balance intake with the aim of facilitating a clinical weight loss [139]. In practice some applications attempt to balance intake with expenditure in the form of physical activity [133] with goal-setting being one way of achieve this balance [139]. Components aiming to support dietary behaviour change include daily recommendations [122], pre-planning of meals [147], and dietary prescription [147] for instance the Mediterranean diet [71]. Additionally, the use of manual feedback on dietary data from providers and health coach communication components were used to support users in adopting a diabetes friendly diet [52].

Blood glucose: Components related to blood glucose were generally centred around the measurements themselves either through reflection [154] or as alarms indicating a need for action [133]. Several of the applications described included threshold alarms as a component [122, 124], alerting users to abnormally high blood glucose readings with some suggesting medicinal dosages [133]. Many applications also feature feedback on blood glucose readings, for instance Kim et al. provided users with both general feedback on blood glucose and used alarms in case of hypoglycaemia among insulin dependent T2DM users [133]. Reflection on blood glucose data through visualisations [53] and feedback was also suggested as a way of educating and improving behavioural skills among PwD [78].

It is interesting to note that blood glucose including self-monitoring was only seen in little over half the included papers despite the fact that it is the most direct way for PwD to tell how they are doing [15]. In fact one study reported the SMBG module to be significantly more motivating than those relating to diet or physical activity [53]. Sun et al. also reported high acceptance of the use of SMBG with a post-study follow-up suggesting 89% of participants had continued using SMBG [52].

3.2.2 Barriers & facilitators

Throughout the literature two recurring categories of barriers can be observed i.e., those related to the diabetes treatment itself and those relating to the mHealth technology but with some overlap between the two. Treatment factors include: comorbidity, medicine, measurements, adherence [134], diabetes knowledge and motivation [19]. Lack of time and workplace flexibility [141] and lack of cultural tailoring to interventions [135] have also been identified as general barriers to self-management. Digital literacy has likewise been mentioned as a potential barrier to the adoption of mHealth for older PwD, noting the need for time, features, and support for such users to familiarise themselves with mHealth [52].

In terms of the mHealth barriers technical issues, cumbersome user interfaces [127] and burdens associated with data collection [156, 7] were reported. Lack of feedback mechanisms were also cited as a significant barrier to app usage [156], whereas its inclusion was noted as a facilitator for increasing self-awareness [134]. Application usability was likewise identified as both a potential barrier and facilitator affecting app satisfaction [119]. The importance of including users in the development process was noted as a facilitator for ensuring eventual solutions were valuable to users [154] while lack of user involvement was noted to have the opposite effect [27]. Users' perceptions of mHealth applications were reported as a facilitator for usage with perceived usefulness and benefits being associated with greater usage [53]. Encouragement rather than negative feedback was similarly suggested as a facilitator for continued usage [142]. Personalisation is likewise suggested as a major facilitator of engagement as it improves the overall experience and makes interventions more relevant to the individual [27]. Authors such as Höchemann et al. and Ried-Larsen et al. use fitness tests to adapt the intensity level of physical activity to the individual, reducing the likelihood of user frustration as goals are kept in line with users abilities [26, 77]. Various other forms of personalisation seen include: messaging [143, 131], goal-setting [78], and in feedback systems [147, 141, 144].

3.2.3 Attrition

In line with the findings of Meyerowitz-Katz et al. we found that many studies do not explicitly report attrition with only 8 out of 51 studies explicitly doing so with others reporting attrition partially or in piecemeal (28/51). We define partial reporting as omitting important details such as: exact numbers, reporting mHealth attrition synonymously with study attrition or as leaving out attrition causes. Moreover, few studies explicitly define what they consider to be attrition (3/51). Meyerowitz-Katz et al. for instance defines attrition as a point where users discontinue usage entirely or to a degree wherein derived benefit from mHealth is negligible [18]. Two methods commonly employed to disseminate attrition is to include this in an enrolment flowchart or through a brief summary of attrition in results. However, these methods of reporting leave much to be desired as they provide few details about "expected usage" vs "actual usage" for instance users may have continued usage of the application but to a degree wherein benefit is negligible. Moreover, summary reporting of attrition does not allow us to determine if or when such trends occurred or how much users actually used the presented applications.

The attrition reported across studies varies greatly ranging from as low as 0% and upwards of 90% as seen in table 3.3. Among the few studies that disseminates detailed usage patterns we observe higher attrition than among studies summarising usage and attrition. Yamaguchi et al. e.g., noted an attrition rate of roughly 78% of participants in 12 weeks, with roughly one-third lost to attrition by the second day of the study [76]. Goh et al. comparably found that 78.6% of users were lost within 2 weeks, with only 9.5% of users retained by the end of study (week 8) [139]. Boels et al.'s findings similarly shows 79% attrition, adding that general usage of the application was lower than expected [27]. Boels et al. further speculates that a one-size-fits-all intervention approach does work in practice with many participants stating they were uninterested in mHealth reflected by 2/3 participants choosing the lowest possible intervention intensity with engagement lower than expected [27].

The above examples of detailed reporting underline particularly well how important detailed dissemination of attrition is in interpreting study results. Based on studies which provided detailed usage patterns we indeed find it highly unlikely that most mHealth applications in the wild can achieve retention rates in excess of 80% long term in particular given the results of Meyerowitz-Katz et al.'s systematic review and meta-analysis [18]. Another real-world study of popular mental health apps seemingly supports this point as it found that just 2.9% of users were retained past the second week [17]. Interestingly, Yamaguchi et al. attributes their attrition partly to their study not reminding participants to use the application unlike some contemporary studies [76]. However, this raises a question of whether it is appropriate to facilitate and report usage motivated by external factors such as pressure from researchers or monetary compensation rather than autonomous motivation to use such solutions, a question that is beyond the scope of this dissertation.

A number of factors were reported in the literature for their association with attrition. For instance, Tatara et al. noted higher perceived usefulness was associated with a higher degree of usage while also noting a possible reason for none-usage is mastery of the applications content [53]. The study by Berman et al. is interesting in this context as the study: "promised to treat and reverse diabetes short term" [130] which from users perspective can be seen as a particularly attractive value proposition. Berman et al. indeed also reported a relatively low attrition rate of 13% noting greater usage was associated with increased HbA1c improvements ending with 28% of participants achieving below diabetes HbA1c levels [130]. Another study's findings moreover suggest that once formed the perception of usefulness changes very little in an intermediate time frame of 2-3 months [144]. In contrast another study found user engagement dropped below 33% despite almost 80% of participants rating the application as highly useful [120].

Positively phrased content [142], personalisation [125, 26], gamification[121] and face to face elements [76] were generally noted as having positive effects on attrition. The study by Höchmann for instance reported relatively low attrition from inclusion of gamification elements. However as noted by other authors such "one-size-fits-all" solutions may not be preferable [27] suggesting potentially that no single solution can address all user needs and preferences.

Demographic differences in usage and attrition were also reported across a number of studies. One Danish study for instance found men to have a lower response rate than women suggesting that feedback should be tailored to sex but also that these results are counter to previous findings [125]. Another study found that significantly more men had signed up for the study and were more likely to be robust users compared with women, the study contextualised this as being due to a higher diabetes prevalence among Japanese men but also a more positive attitude towards technology [76]. While, a third study

Table 3.3: Overview of study attrition characteristics for literature included in the review. Abbreviations: CDA = clearly described attrition, AD = attrition defined, AC = attrition causes discussed, x = included, (x) = partially included, and nr = not reported [115].

Author	Arms	Days	Total (n)	Attrition (%)	CDA	AD	AC
Adu et al	0	7	18	33.34	x	nr	nr
Bailey et al	2	56	20	10	x	nr	nr
Adu et al	1	21	50	18	(x)	nr	nr
Boels et al	2	~182	230	79.14	(x)	nr	x
Wilczynska et al	2	140	85	~ 71	(x)	nr	nr
Huang et al	2	84	51	12	x	nr	(x)
Höchsmann et al	2	168	36	0	x	nr	nr
Alonso-Domínguez et al	2	365	204	7.85	(x)	nr	nr
Koot et al	1	168	100	67	x	(x)	nr
Jeon et al	1	28	38	0	nr	nr	nr
Höchsmann et al	2	168	36	5.56	x	nr	nr
Wang et al	2	~182	120	nr	nr	nr	nr
Sun et al	2	~182	91	nr	nr	nr	nr
Alonso-Domínguez et al	2	365	204	7.85	(x)	nr	nr
Yu et al	4	168	185	10.4/15.5	(x)	nr	nr
Valentiner et al	2	84	37	0	(x)	nr	nr
Yamaguchi et al	1	382	522	85.06	x	x	x
Byrne et al	1	112	7	42.86	(x)	nr	nr
Torbjørnsen et al	3	365	nr	25.75	(x)	x	nr
Wang et al	3	~182	26	~8	(x)	nr	nr
Abidi et al	1	nr	7	nr	nr	nr	nr
Berman et al	1	84	109	13.77	(x)	nr	nr
Plotnikoff et al	2	140	84	54.77	(x)	nr	(x)
Yom-Tov et al	1	182	27	nr	(x)	nr	nr
Kleinman et al	2	182	91	20.46	(x)	nr	nr
Alexander et al	1	nr	4	nr	nr	nr	nr
Kim et al	1	84	30	3.34	nr	nr	nr
Pludwinski et al	1	nr	11	nr	nr	nr	nr
Anzaldo-Campos et al	3	304	301	13.14	(x)	nr	nr
Quinn et al	4	365	118	13	(x)	nr	nr
Verwey et al	3	~121-182	240	23.08	(x)	nr	nr
Pellegrini et al	1	30	9	11.12	(x)	nr	nr
Quinn et al	1	28	8	12.5	(x)	nr	nr
Wayne et al	2	182	131	28.36	(x)	nr	nr
Goh et al	1	56	84	90.48	x	x	x
Ghorai et al	nr	nr	nr	nr	nr	nr	nr
Wayne et al	1	182	21	9.53	(x)	nr	nr
Strong et al	nr	nr	nr	nr	nr	nr	nr
Quinn et al	2	365	117	nr	nr	nr	nr
Verwey et al	1	91	20	15	(x)	nr	x
Tatara et al	1	365	12	nr	(x)	nr	x
Ghorai et al	nr	nr	nr	nr	nr	nr	nr
Tatara et al	1	152	11	0	(x)	nr	nr
Nes et al	1	91	15	26.67	(x)	nr	(x)
Castelnuovo et al	2	365	nr	nr	nr	nr	nr
Quinn et al	4	365	163	33/22.5	(x)	nr	nr
Lyles et al	1	91	8	25	(x)	nr	nr
Stuckey et al	1	56	24	nr	nr	nr	nr
Årsand et al	1	182	12	0	x	nr	nr
Quinn et al	2	91	30	13.34	(x)	nr	nr
Katz et al	2	91	30	nr	nr	nr	nr

found women to have a higher chance of being robust users [139].

3.2.4 Evidence of Effects

Clinical effectiveness is often measured in T2DM by a reduced HbA1c or weight loss. We nevertheless decided to look at effects in a more holistic fashion in line with the points of Klasnja et al. [38] as illustrated by Fig. 3.3. We divided effects between several categories to create a more nuanced picture of effects in addition to those considered strictly clinically relevant, additionally allowing the inclusion of none clinical trials arguing for the relevance of their findings.

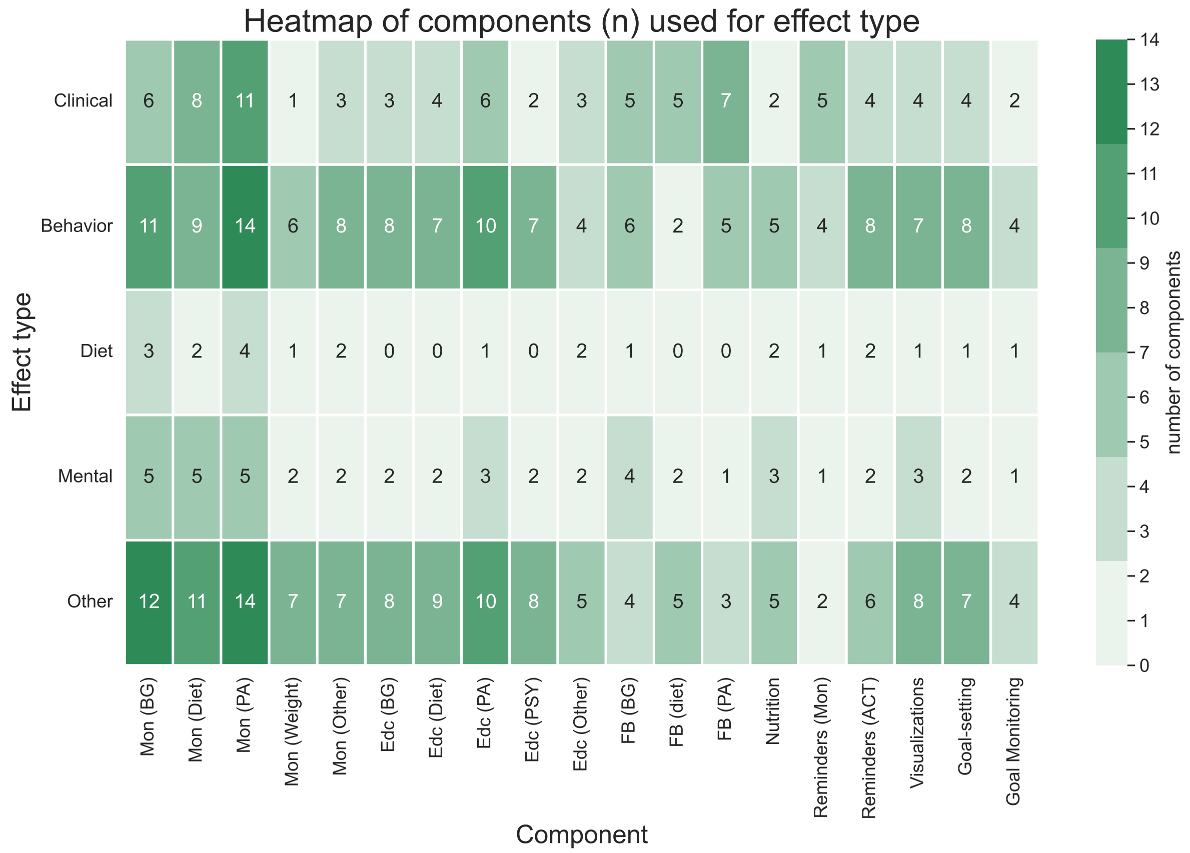


Figure 3.3: Heatmap showing the number of studies reporting positive effects in relation to different component utilised with each study usually consisting of multiple components further sub divided by the effect type reported [115].

From Fig. 3.3 we see that studies including self-monitoring of diabetes factors are often reported with positive clinical, behavioural and other effects. Several papers also report positive effects from interventions including different educational and feedback components. Many articles report positive behavioural changes in relation to goal-setting. Prior works found goal-setting to be a widely used component of many mHealth applications [157] with systematic reviews backing the positive effect [157, 158, 159]. Previous research also suggest personalised messages have positive effects on outcomes [160, 161], but also notes patients prefer personal communication but not necessarily two-way communication or overtly frequent messages [161]. Remote feedback has also been found to have small to moderate effects [162] in line with the findings reported in literature included in this our review [163, 130]. Components such as self-monitoring [158], physical activity [164], and dietary [165] modification have also been found effective in improving HbA1c outcomes. Moreover, Höchsmann et al. and Alonso-Dominguez et al. both argue for clinically relevant improvements to daily step counts reporting 3000 and 1852 steps extra on average respectively [121, 71].

Sun et al. argued that observed HbA1c reductions (1% vs 0.66% control) were associated with improved patient-provider communication, and improved patient compliance through monitoring [52]. Quinn et al. on the other hand reported a 1.2% improvement over the control from personalised messages [75] with Yom-Tov et al. having similar findings [131]. Another study (single arm) reported a reduction of 1.3% HbA1c from components such as monitoring, education, and feedback from health coaches [120]. One application leveraging mHealth based health coaching with meal-planning, self-monitoring, educational materials and meal-planning noted comparable clinically significant improvements (0.8%) [130].

In terms of overall effects reported by the randomised control trials included in our review these generally show HbA1c reductions of between 0.3% [163] and 1.2% [75] compared to control. With one paper tentatively suggesting improvements in HbA1c seems to occur faster when using mHealth compared to traditional care with significant differences between mHealth and control arms at 3 months favouring mHealth but not at 6 months [138].

3.3 Implications

A major issue with much of the presented literature is that it is exceedingly difficult to productively leverage. This is partly caused by limited descriptions of the mHealth interventions utilised but also the limited rationalisation provided for these i.e., the relevance of components, their intended target users and their expected usage patterns. These points are especially well emphasised by two quotes from the included literature:

- "*There remains paucity of information in relation to the description of the development processes and design of smartphone apps interventions, leaving unanswered questions about how to productively leverage apps for diabetes self-management*" - Adu et al. [19]
- "*To be effective, apps should optimally incorporate the needs of end-users. While in our trial participants could choose the frequency of and topics of the intervention, future interventions should target specific populations taking into account their needs and expectations*" - Boels et al. [27]

We similarly observe the dissemination of larger trials often place very little emphasis on detailed descriptions of the technology used. This not only obscures which components were used, but also the rationale for their inclusion and subsequently which components actually contributed to observed effects. This being especially problematic in diabetes mHealth where interventions are multifaceted in nature i.e., HbA1c changes can occur from a number of components targeting diet, physical activity or weight. Consequently, we are often unaware of whether components contributed to observed effects and whether certain components contribute enough to reimburse users effort [65]. As highlighted by Boels et al. the lack of specific user targets also further obscures when and where different designs and components may be useful and preferable to users. For instance contemporary work suggests that the gamification approach presented by Höchsmann et al. [121] may be most effective among a younger user demographic. Suggesting the need for further emphasis on users and exploration their experiences over time [166].

Among the papers providing detailed usage patterns we see evidence of profound differences in the uptake of components. Koot et al. for instance found significant differences in expected usage of components from the first week of the study e.g.,$\approx$ 25% of users engaged with health lessons, $\approx$ 75% with SMBG and $\approx$ 100% with body weight [120]. Yamaguchi et al. and Tatara similarly noted significant differences in engagement with and attitude towards components [76, 53]. These observations suggest there are significant differences in engagement between components and thus proverbially that different "doses" of the interventions are experienced. Worsening these issues is the lack of clearly defined usage expectations for components; for instance many papers describe the inclusion of an SMBG element but not the intended ”doses” of these i.e., the frequency of measurements. Previous works have established this as an important detail not only because the use of SMBG among NIT T2DM is a highly debated topic with divergent viewpoints [167, 168, 169, 170] but also because SMBG can be used in contrasting ways. SMBG can simply be used to enable PwD to measure their momentary blood glucose at opportune moments [127] but can also be used as part of structured SMBG facilitating self-learning [168]. However, we expect these uses to have different engagement patterns in the latter case in the range of 5 measurements per day in a structured manner rather than say a few sporadic measurements per week [168]. Indeed some research backs this point by suggesting high frequency of measurement is associated with larger effect sizes in terms of HbA1c [168]. This example thus shows the importance of not only properly describing the components employed but also the importance of rationalising their intended usage. Given these points we argue the inclusion of usage patterns and attrition in dissemination is vital in not just our interpretation of results but also our ability to productively leverage previous research.

While our findings also support those by Meyerowitz-Katz et al. regarding poor practices in reporting attrition we add to these that not all attrition is necessary bad as otherwise implied by its negative connotation in literature. The attrition causes identified by Tatara et al. for instance showed that one reason for attrition was users having achieved a sense of master of diabetes activities included in the applications [53]. Thus as PwD gradually gain experience and become more proficient at self-management they may outgrow the need for continuous app-usage [25]. This consequently implies the need for more nuances in attrition reporting it-self as none-usage as a result of mastery of app content could be seen as a success criteria.

3.4 Chapter summary

In this chapter we explored the literature on T2DM mHealth interventions from four points of view: 1) the components used 2) the barriers and facilitators imposed by these components, 3) the resulting attrition and 4) the effects. Based on a scoping review we synthesised and summarised insights from 51 articles presenting a plethora of approaches to interventions, application designs, components and combinations of these. Moreover we presented and discussed the reported barriers, facilitators, usage patterns, attrition and the effects reported by these applications.

However, a number of major limitations were also found in the literature, for instance: limited depth of attrition reporting, unclear rationale for including components, and their expected usage patterns. These limitations not only make it exceedingly difficult to judge the effective contribution of different components in relation to overall outcomes but also make it difficult to assess which components and designs are preferable based exclusively on the literature. This calls for extra care and consideration to be put into the design and dissemination of future works with e.g., increased emphasis on user-centred factors such as component rationale, component/mHealth uptake, clearly defined and reported attrition in addition to discussion of factors affecting these, like the user experience over time. In summary we have:

- Carried out a scoping review to explore the literature on T2DM mHealth interventions.
- Explored the different components utilised by mHealth interventions and how these act as either barriers or facilitators for the experience, and moreover looked at resulting usage patterns, attrition, and effects of reported applications.
- Lastly, we discussed the implications of certain limitations discovered in this scoping review; specifically that the dissemination and reporting practices make it difficult to productively leverage existing mHealth research for example when choosing between designs.

CHAPTER 4 Exploring Patient Needs and Designing Concepts for Digitally Supported Health Solutions in Managing Type 2 Diabetes: Co-creation Study

In the previous chapter we established that the literature on diabetes mHealth contains a plethora of interventions, components and different designs aiming to support PwD. However, few studies actually quantify the contribution of different components, rationalise aspects of the design or explore users' perceptions of these over time. These findings consequently leave significant gaps in the reasoning and benefits of choosing one particular component or design over another for use in mHealth applications. In this chapter we aim to bridge this gap by engaging in a user driven innovation process aiming to explore the needs, wishes and preferences for diabetes technology among those with type 2 diabetes. This chapter summarises the planning, execution and results of a user driven co-creation process involving PwD and other stakeholders aiming to explore and develop technology sought by the end-users.

The following sections summarises and expand upon the paper:

Dan Roland Persson, Katiarina Zhukouskaya, Anne-Marie K Wegener, Lene Kølle Jørgensen, Jakob E Bardram & Per Bækgaard. (2023). Exploring Patient Needs and Designing Concepts for Digitally Supported Health Solutions in Managing Type 2 Diabetes: Cocreation Study. In JMIR Formative Research 7 (Aug. 2023).

Please cite accordingly.

4.1 Co-creation

The term co-creation broadly refers to acts of creativity involving multiple persons [40]. Over the years the term has seen varied uses [39], but we take it to refer to acts of creativity wherein end-users have broad influence on the design process which occurs collaboratively with stakeholders. Compared to traditional user centred design with the 'user as subject' co-creation proverbially aims to include the 'user as partner' [40]. Including the user in this way has several benefits: Firstly, it aims to challenge assumptions and biases of those traditionally involved in the design process such as designers in lieu of themselves not being end-users [171]. Secondly, co-creation aims to actualise the knowledge and know-how of "experts of their own experiences" i.e., the end-users [40]. And thirdly, to incubate new ideas and insights through knowledge sharing and a collaborate effort [172].

Important factors in successful facilitation include bringing together a diverse group of participants with domain knowledge or knowledge garnered through experiences. It is equally important to foster a creative atmosphere wherein participants feel comfortable and safe, where they can freely express their thoughts [173]. To facilitate such an atmosphere it is also vital for participants to feel equal in a sense to avoid diminished creativity due to the emergence or inclusion of an authority or dominant expert [174]. It is likewise important for the facilitators to practice proactive neutrality to ensure equality in the process and to guide the creative process without exerting influence on the process [175].

4.2 Methods

Workshop planning was it-self a collaborative effort between researchers at The Technical University of Denmark (DTU) and the Danish Diabetes Association (DDA). Researchers at DTU were primarily responsible for the detailed planning and execution of the workshops while the DDA contributed domain expertise and opportunities for recruitment. The overall structure of the workshops were planned by Dan Roland Persson and Katiarina Zhukouskaya prior to the first workshop (see Fig. 4.1). Workshops drafts were reviewed by stakeholders at both DTU and DDA with adjustments made according to the feedback and stakeholder experiences. Each workshop was planned to be approximately 3 hours in duration with breaks every 45 minutes to reduce the likelihood of participant fatigue.

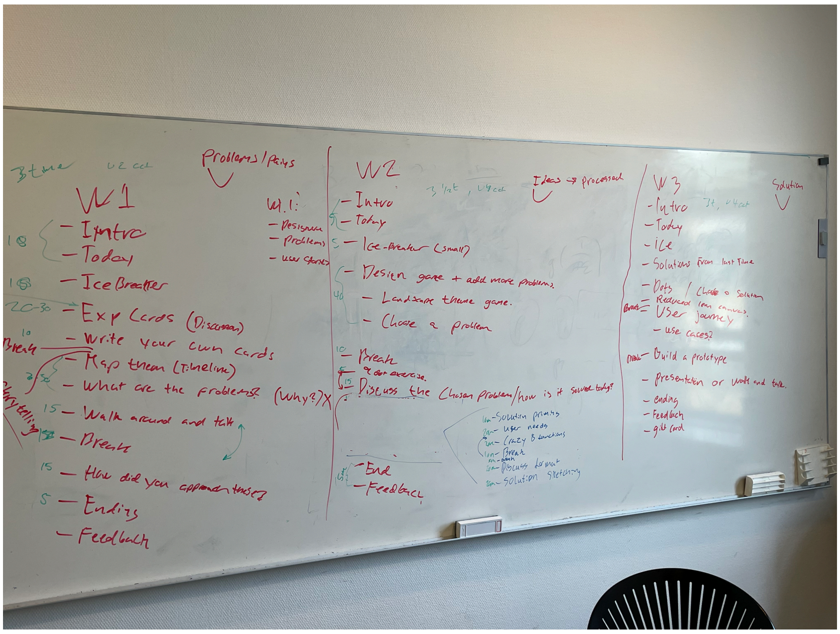


Figure 4.1: Early workshop planning done collaboratively on whiteboards.

Between workshops results were processed and adjustments were made to the subsequent workshop based on observations and feedback. E.g., some exercises were lengthened, shortened, or replaced based on the experiences of the prior workshop.

The workshops were planned according to the Double Design Diamond [176] seen in Fig. 4.1 with the content of the workshops covering all four design phases of the diamond: 1) A discovery phase: aiming to explore the problem space, opportunities and needs using divergent thinking. 2) A definition phase: aiming to narrow down the problem space opportunities and needs through convergent thinking. 3) A development phase: aiming to create and explore solutions through divergent thinking. 4) A delivery phase: aiming to evaluate, choose favourable solutions and improve those solutions.

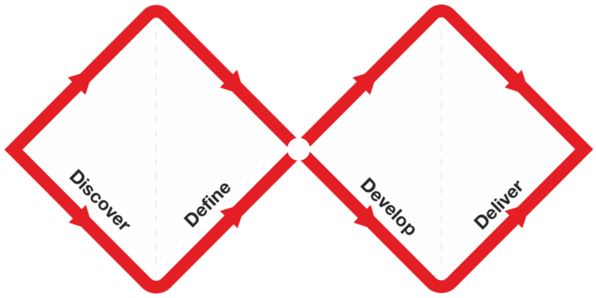


Figure 4.2: The Design Council's Double Diamond model [176].

We planned 3 workshops to facilitate this design process, the first workshop primarily aiming to look at the problem space in line with point 1). The second workshop picking up from the first aims to narrow-down the problem space and facilitate ideation of those problems aligned with 2) and 3). The final workshop in line with point 4) aimed to have participants choose and develop favourable solutions.

While the workshops managed to achieve their aims the final prototypes developed were not fully matured due to time constraints. Consequently, past the final workshop we aimed to further develop these prototypes by initially creating high-fidelity prototypes [177] and by validating these prototypes with workshop participants. A total of 7 formative usability evaluations were conducted with workshop participants post workshop 3 using semi-structured interview questions and thinking out loud.

4.2.1 Overall workshop procedure

Each workshop had a single facilitator and one assistant who primarily acted as a documenter making notes of different discussions and events. In practice the workshop and exercises were facilitated through a slideshow presentation introduced by the facilitator. Slides stayed visible throughout exercises and contained descriptions of each task, time frames and the goals of the exercise.

Each workshop started by welcoming participants and providing a structured walk-through of the agenda including the overall research and workshop aims. Afterwards participants were introduced to one another through an icebreaker exercise aiming to familiarise participants with one another and to create a comfortable atmosphere for expressing thoughts and opinions without fearing repercussions [173]. Towards the end of each workshop participants were provided feedback forms where they could anonymously suggest improvements to the workshops or provide other feedback.

Informed consent to participate was obtained from participants through email correspondence and orally via phone calls as part of the sign-up process. All workshops started with a detailed walkthrough of the workshop and the opportunity to ask questions about the workshop. Participants were also reminded that they were free to ask questions at any time and could withdraw from the workshop/study at any time without providing a reason.

4.2.2 Facilitation style

The facilitation style was primarily based on the principles and framework of Wróbel et al. on proactive neutrality [175]. Fundamentally, the role of the facilitator in the design process is one that is neutral, has no substantial decision making authority, providing structure and process so that groups can make high quality decisions, while acting as a third party [175]. Proactive neutrality according to this framework supports the creative process by promoting 1) impartiality, 2) equidistance and 3) fairness. Impartiality, in this case referring to the facilitator not expressing judgement about opinions, concepts or ideas. Equidistance being the promotion and facilitation of symmetry in the processing such as assisting participants equally and encouraging sharing of information. Lastly, fairness aims to keep the facilitation process transparent and honest, supporting two way communication between facilitators and participants allowing them influence on the process.

4.2.3 Recruitment

To achieve our aims of bringing together diverse expertise for the co-creation workshops we needed to recruit both a diverse group of stakeholders and a similarly diverse group of participants in this case persons with T2DM.

Inclusion criteria for PwD was having non-insulin treated T2DM and experience with blood glucose measurements. The inclusion criteria were added to keep participant needs more uniform and to keep emphasis on issues not related to insulin treatment. We added the blood glucose measurements requirement in order to ensure participants were ”experts” of their own experiences given previously emphasised points that PwD are unable to tell how they are actually doing unless they actively monitor blood glucose [15].

Distributed recruitment materials included flyers, newsletters, email lists and social media posts provided prospective participants information about the study's purpose and linked to the study website. Throughout the study the website was updated to reflect the upcoming workshop, but also contained more general information about the study and its research aims. Participants signed up for one workshop at a time but were encouraged to participate in future workshops and were provided with 200DKK (30$) to cover workshop associated transport costs. After the final workshop participants across all workshops were invited to participate in the formative usability evaluations.

Stakeholders were recruited from the DDA and DTU and included: researchers (both diabetes & UX), a diabetes nurse and other experts. Stakeholders were generally expected to have experience working with PwD and knowledge of clinically relevant parameters.

4.2.4 Locations

The meeting location for each workshop was chosen based on the workshop's content. The first workshop was held at the DDA offices in Copenhagen. This space was chosen given the DDA's history of being a place where many different everyday issues concerning diabetes are discussed, which was well aligned with the topic of current issues faced by PwD. We imagined that this space would be comfortable for such discussions and could facilitate a sense of familiarity and security.

The second and third workshops, focusing on ideation and exploring the solution space, were held at the DTU's innovation hub: DTU Skylab. This space, unlike that of the previous workshop, has special facilities built for the purpose of innovation, including practical equipment like whiteboard walls, as well as supplies for prototyping.

4.2.5 Workshop 1

Prior to the first workshop a deck of cards was created containing 28 experience cards (see Fig. 4.3) describing situations in diabetes. The topics of these cards included: blood glucose, diabetes knowledge, psychology, diet, physical activity, and more personal issues a person may face in diabetes. The cards were created collaboratively with the DDA based on their expertise and on prior works by DTU researchers e.g., interviews.

The first exercise leveraged the aforementioned experience cards to facilitate an initial discussion about problems faced by PwD. Some of the cards included blank spaces where participants could add their own contextual features or interpretation of the problem. Participants were also provided a number of completely blank cards where they could add their own problems. Participants were instructed to discuss the cards and sort them for relevance based on their experiences. Exercise two consisted of choosing a single card as the basis for telling a story to provide more real-world context to the chosen experience card. The third exercise aimed to populate a timeline with the experience cards using

Figure 4.3: Examples of the experience cards employed in the first workshop - translated from Danish [178].

a template which was made explicitly vague with no clear starting point or endpoint with "diagnosis" being the only present landmark. Exercise four consisted of each group presenting their created timeline with other groups discussing and providing feedback to the timelines aiming to facilitate group creativity. Exercise five had participants use the timeline to create their own problem/issues/pain statements based on topics discussed in the workshop. Lastly, participants brainstormed and discussed possible ideas to solving their problem statements including how participants currently dealt with such issues and how they would prefer these to be dealt with in the future.

4.2.6 Workshop 2

The first exercise was aimed to allow both new and previous participants to (re-)familiarise themselves with the results of the last workshop while allowing participants the possibility of adding new problems to those discovered in the previous workshop. Exercise one consisted of a "landscape game" [179] wherein participants placed problem statements from the previous workshops on a game-board in accordance to how personally or generally relevant they found different problems. Participants were asked to discuss each issue and choose whether it was a universal problem or a more individual problem in-case of differing opinions. Exercise two consisted of participants choosing the most important problem and contextualising it through a template e.g., when it occurs, where it occurs, and for whom it occurs. Exercise three used this detailed problem definition to brainstorm possible solutions using solution templates aiming to sketch/describe each possible solution briefly. The fourth and final exercise had participants present the chosen problem and possible solution in plenum such that other participants could provide feedback, feature suggestions or other comments to the presented ideas.

4.2.7 Workshop 3

In preparing the third workshop the possible solutions described in workshop 2 were processed into solution concepts. Concepts remained true to the descriptions made in the previous workshop but with added details such as feedback from the final exercise of workshop as well as a unified drawing and description. These solution concepts were used for the first exercise to allow participants to (re-)familiarise themselves with the results of the previous workshop. Exercise one consisted of ”brainwriting” [180] for each solution with the aim of generating features, ideas, requirements for each of the solution concepts. Brainwriting is a technique used to rapidly generate ideas for a given topic without production blocking from needing to vocalise ideas i.e., usually only one person in a group can vocalise an idea at a time blocking others from doing so. Groups were provided 9 pieces of paper each reflecting one solution concept for a problem space; Fig 4.4 showing a concept example. Participants each started with one solution concept and started writing ideas for the solution concept before passing it on to another participant after some minutes. Participants kept passing the templates around until everyone had been through them all once.

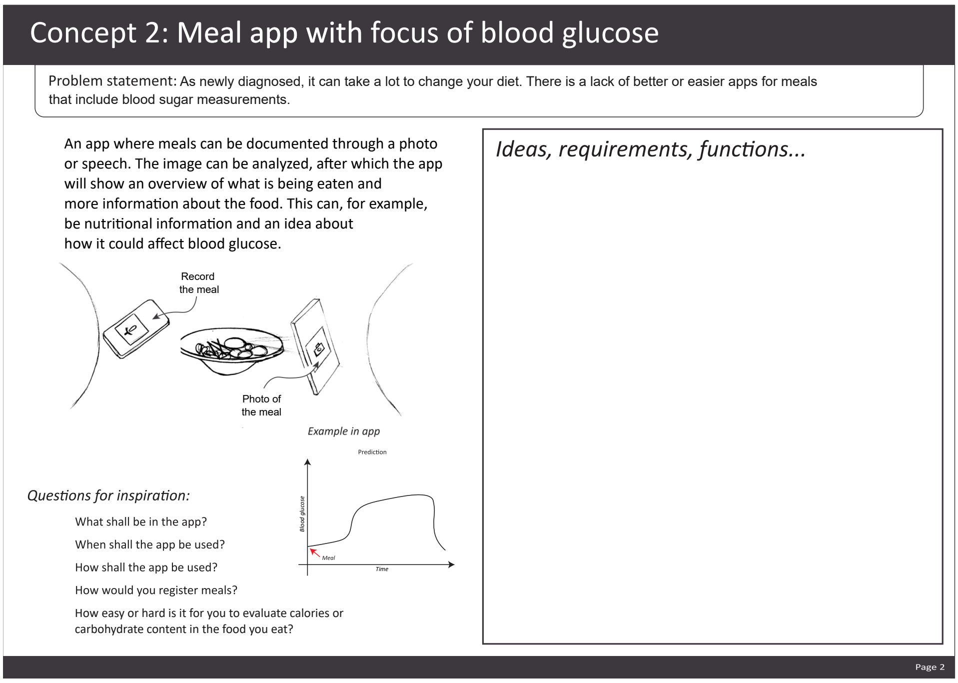


Figure 4.4: Solution concept 2 as presented to participants in workshop 3 - translated from Danish [178].

Exercise two consisted of a plenum discussion about the different solution concepts and which should be developed further. After the discussion participants were instructed to vote on the concepts, they found the most promising. In exercise three participants were split into two almost equal groups with designers and other stakeholders aiming to jointly develop a prototype based on the templates from exercise one. Given the variety of possible solutions both digital and non-digital participants were provided a number of different templates and tools for this process, to facilitate the creation of prototypes with formats ranging from digital concepts to devices and other possible solutions.

4.2.8 Formative usability evaluation

Following the third workshop high-fidelity prototypes [177] were developed based on low fidelity prototype sketches, documented discussions, and requirements. The resulting high-fidelity prototypes were further made interactive using Figma and HTML for testing purposes. We aimed to validate these high-fidelity prototypes through formative usability evaluations [181] in order to improve the prototypes, ensure they remained aligned with participants wishes and to ensure minute but important details were not left out.

Each formative usability evaluation lasted one hour and was facilitated online using Zoom. Each evaluation started with an introduction by investigators followed by testing of the two high-fidelity prototypes. As a part of the introduction participants were instructed to carry out "thinking aloud" while testing the prototypes. Participants were allowed to test the prototypes at their own pace. At certain predetermined points investigators asked participants questions related to their actions or asked for their perceptions of completed tasks. E.g., after completing the app setup or introduction module. After approximately 30 minutes testing transitioned to the second prototype facilitated similarly to the first.

4.3 Principal findings

The workshops were held in November/December 2021 with formative usability evaluation conducted in January 2022. A total of 20 PwD participated across our 3 workshops with 7 of these participating in formative usability evaluations. 11 stakeholders additionally participated across workshops including UX designers, diabetes researchers and a diabetes nurse.

The primary results of the workshops included the development, rationale, and user experience of two prototypes. The first prototype being an activity-based CGM application and the other being an online guide to diabetes. Participants choose to work on two different prototypes rather than one noting these complimented each other nicely in serving different needs. Additionally, discussions and insights provided by participants in the form of timelines and other artefacts provide us with a number of thematic insights relating to different diabetes activities. In the following sections we will explore the designs of the two prototypes, their rationale and user experience. Afterwards we will explore the thematic insights generated by the workshops.

4.3.1 Prototype 1: Activity-based CGM application

The primary aim of prototype one was to support PwD in learning from their own data in particular how they affect their blood glucose and in turn how it affects them. The prototype was built around the use of CGM and was imagined as providing a timeline of diabetes related activities (see Fig. 4.5). The types of activities or events featured on this timeline would depend on users current goals and was imaged to feature a wide variety of different data through "modules". Each module was imagined to represent an aspect affecting diabetes e.g., diet, physical activity, sleep etc. Once enabled a module would add events to the timeline based on data collection by both system and user depending on the data type and the module. Clicking a corresponding event on the timeline would allow users to see collected information about the event in addition to passively collected data, for instance the location where it occurred.

The look of the timeline was also imaged as being dynamic such that users could change the time period shown, see old data, or change how data is displayed. Various filters and overlays changing the looks of the timeline was also imaged such that participants could e.g., see different data such as step counts in relation to CGM data. Explored changes to the timeline included various forms of aggregated data, time-in-range, average blood glucose and progress towards users' goals.

The user experience developed by participants was imaged to have three unique phases of use. These phases were imaged specifically to keep the application relevant over time and to address different needs over time. The phases identified being a "learning" phase, "active measurement" phase and "support tool" phase. These phases can be seen reflected in Fig. 4.6 showing how the prototype works in the form of a UX storyboard.

The learning phase was imagined specifically to address the needs of newly diagnosed PwD by providing a short but structured introduction to various factors affecting diabetes. The learning phase

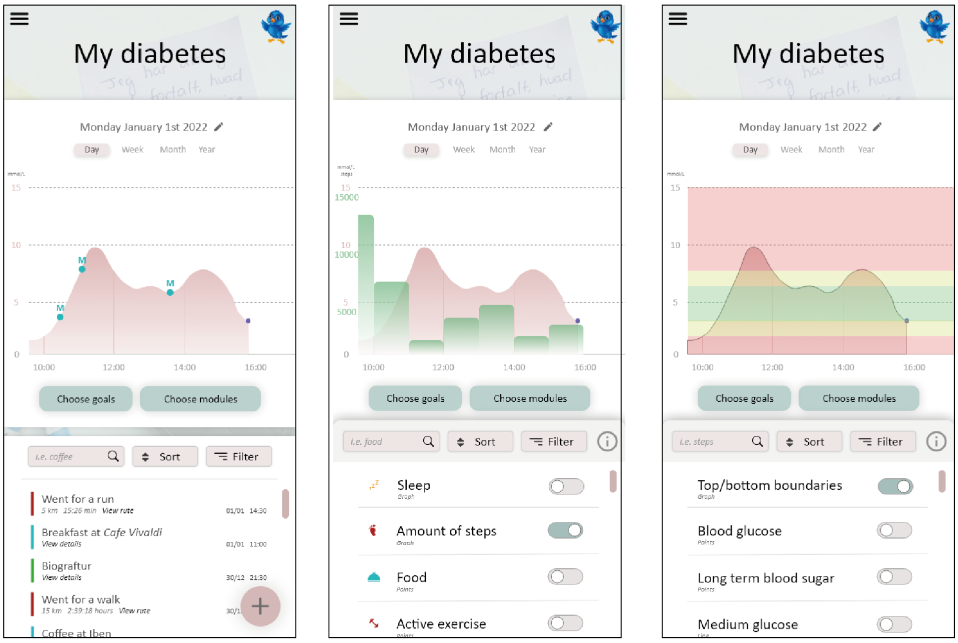


Figure 4.5: Prototype one. The left-most screen represents the homescreen and timeline metaphorically representing "my diabetes" with several logged meals. The middlemost screen shows an example of personalisation of the homescreen with recorded activity data, and the right-most screen shows the overview with glucose top/bottom boundaries [178].

itself was broken into different sub phases partly to reduce fatigue from burdensome data collection but also to keep learnings focused on each individual factor. As such participants would start with learning about their blood glucose overtime with one added factor at a time for instance diet, physical activity, sleep. The initial focus would therefore be on diets' effects on blood glucose followed by physical activity and so on, allowing participants to learn about each factor individually.

In the active measurement phase users were imaged to have full freedom in the modules they enable and how they wish to use these for self-management. In this phase the application provides supporting suggestions such as highlighting trends and providing simple feedback. Users would additionally through different features and filters be able to substantially personalise the look and purpose of the timeline to suit their individual needs and goals.

Lastly, the support tool phase was imagined as a more passive low-usage phase where users do not have an explicit need for using the app actively, characterised by stable blood glucose. The phase from a UX perspective thus consists of infrequent usage and with less data being collected apart from automated collection occurring in the background. Users in the phase primarily use the app to review old data, notes or to for instance log occasional SMBG or HbA1c readings from their doctor.

The switch between the latter two phases was imaged as being rather dynamic. Users may initially have a need for a prolonged active usage phase when newly diagnosed with diabetes to support stabilisation of blood glucose and self-management. Stability once obtained can in essence be seen as achieving a form of mastery of diabetes self-management activities causing users to see less value in maintaining extensive data collection on established habits and behaviours resulting in a transition to the support tool phase. Participants themselves cited a variety of other reasons adding to motivation for transitioning phases such as the monetary costs, associated discomforts and the time consumption or other data collection concerns. Participants also noted there could be several reasons why one might transition back into an active phase, such as shifting goals, modification of lifestyle changes, or in response to the progressive nature of diabetes. Users may therefore over the course of many years with diabetes transition between intermittent active measurement periods with high app use and potentially

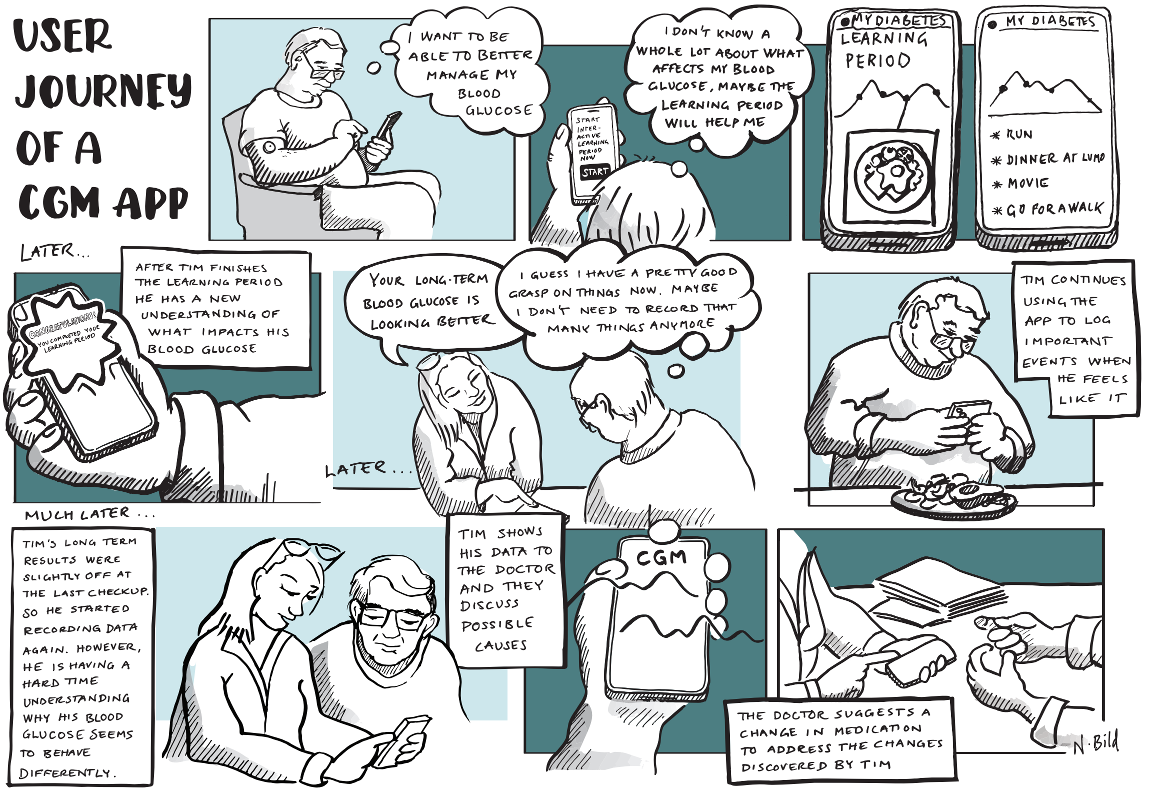


Figure 4.6: User experience storyboard for the activity-based CGM-app highlighting its intended phases of use [178].

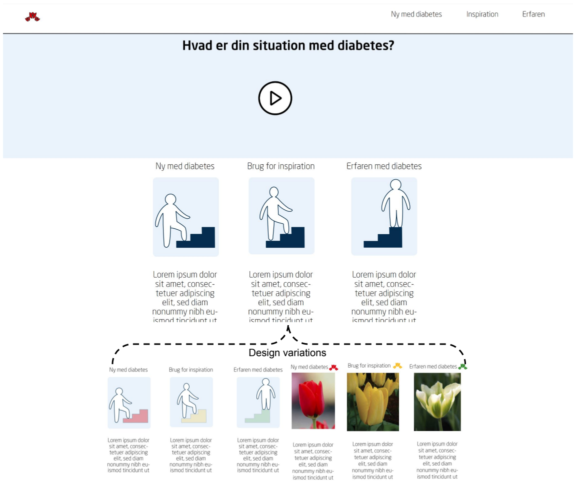
long periods of relative inactivity or none-usage.

It is worth noting that the design of this prototype and how it is aims to support users is reminiscent of Li et al.'s stage-based model of personal informatics systems [153]. Li et al.'s model consists of an iterative learning process wherein users undergo 5 stages: 1) preparation, 2) collection, 3) integration, 4) reflection and 5) action. In this case our prototype allows users to choose goals and determine what they want to track through the modular design in line with the preparation and collection phases of Li et al.'s model. Data is then processed, combined, transformed, and visualised on the CGM timeline similar to the integration/reflection stages. Finally, data can be reflected upon by the user supported by visualisation and suggestions from the app aiming to prompt users themselves to take action. Consequently, our findings seem to support the validity of Li et al.'s model while also showing indications that the model is desirable and positively perceived by users.

A notable insight from the design of prototype one was the rationale provided for its multi-phase design: Participants specifically noted that none-usage of the application i.e., the support tool phase was a desirable outcome for successful app engagement. This presents a contrary way of thinking to that traditionally seen in much of the literature on mHealth [18, 182, 183] wherein users retention and engagement are core focuses. Perceived usefulness has also been suggested as an important factor leading to increased usage and engagement [184]. However, the developed experience and its underlying rationale suggests long term active use may not be a positive or even preferable outcome as seen from the users perspective.

4.3.2 Prototype 2: An online guide to diabetes

A common problem shared by many workshop participants was the lack of a unified evidence-based introduction to diabetes. Prototype two (see Fig 4.7) was envisioned to mitigate this problem by providing a comprehensive online guide to diabetes aiming to impart knowledge and to support discovery of individualised approaches to self-management. Similar to the first prototype the guide was also imagined to heavily feature through its content the value of structured SMBG.



(a) Entry points to the guide.

(b) Conceptual depiction of the guide's content.

Figure 4.7: Prototype depiction of the online guide (in Danish). (a) Shows the initial page of the guide presenting users to the guide's structure and content through both video and text - including alternate designs of this menu. (b) Exemplifies the content of the guide through video, text and curated links [178].

The guide itself was imagined to focus on short high-quality videos with supporting text, links to supplementary materials and websites with verified information e.g., containing more detailed or medical information. The key idea behind this approach was that users themselves could choose the level of depth provided i.e., whether a brief overview or a more in-depth exploration of a topic was preferable. This approach was chosen to provide users with both a low barrier entry point in the form of videos providing sufficient working information with more comprehensive literature available for those interested. The main categories of content discussed were: the disease it-self, blood glucose, physical activity, diet, motivation, and inspiration.

A key feature of the guide was its different entry or navigation points allowing users to access the guide's content. These were initially imaged as three different perceived situations a PwD could choose from. E.g., "new to diabetes", "in need of inspiration" or "experienced with diabetes". Choosing one of these situations would provide the users with guide content relevant to their perceived situation. The subsequent formative usability evaluations however revealed the necessity of conceptualising additional perceived situations to allow users to find the most relevant entry point. Newly diagnosed for instance are introduced broadly to diabetes, blood glucose measurements and the factors that affects one's blood glucose. Those further along in the diabetes self-management journey may need inspiration on the practical implementation of lifestyle changes such as different diets, approaches to exercise etc. While those with more experience may be more interested in new content, perspectives, research or approaches to management. Users may also be interested in being able to go back to previously seen content easily or find new relevant content related to their situation i.e., personalised suggestions for content. Consequently leading to discussions about the potential role of accounts, content history and receiving more personal recommendations for content. Significant emphasis was also placed on the guide providing evidence based curated links to resources, communities or local initiatives providing PwD with an overview of available help and resources acting as a diabetes information hub.

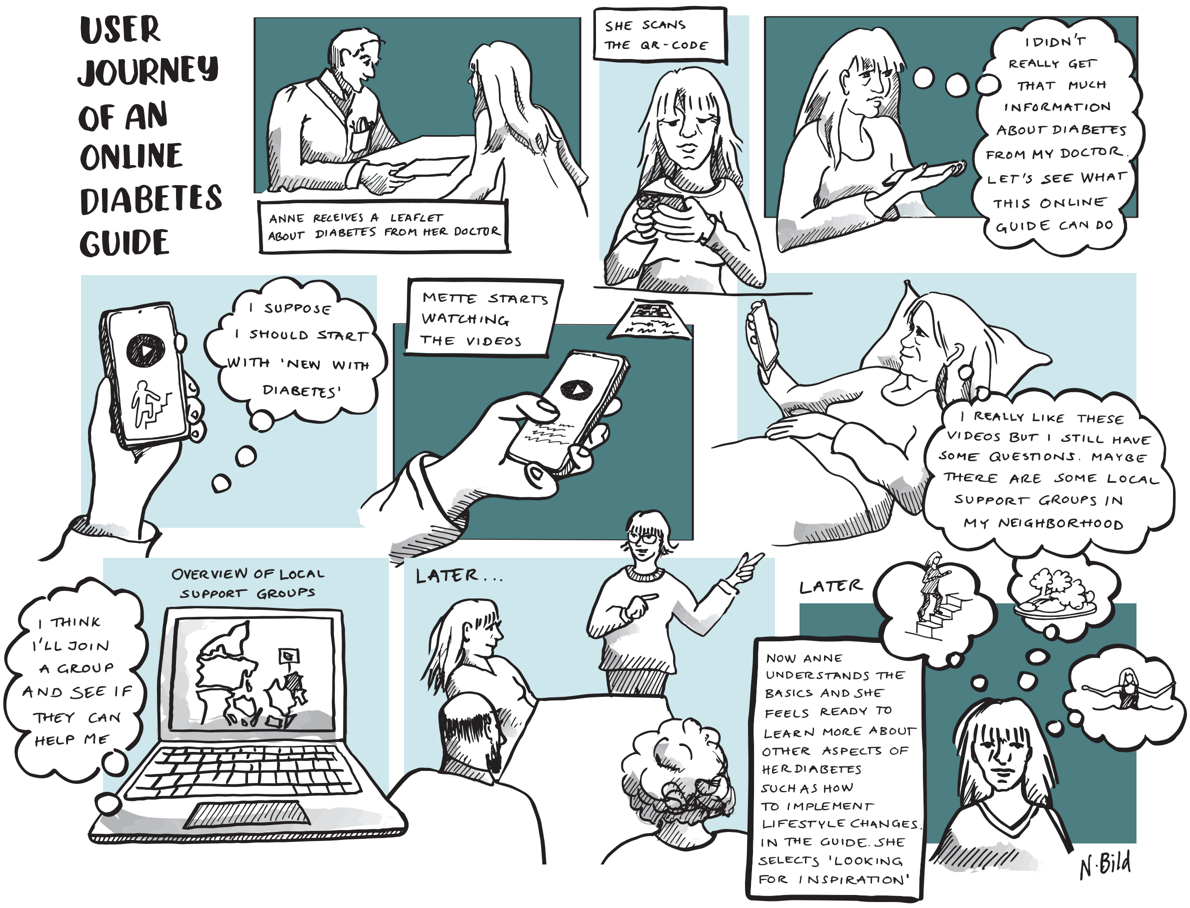


Figure 4.8: User experience storyboard for the online diabetes guide showing its intended use over time [178].

The user journey of prototype two can be seen in Fig. 4.8. Use of the guide was imaged to start directly upon diagnosis with the General Practitioner (GP)s providing PwD with a folder containing brief information on diabetes and linking to the guide via QR code. When first accessing the guide a video plays explaining the purpose and structure of the guide. Users can then, based on the video or the description of each situation choose the one most relevant to their current situation. If newly diagnosed this might include a general introduction to diabetes, associated factors and suggestions for getting started with various lifestyle changes through a number of videos. As users engage with the guide's content they may change their perceived situation and use the guide to navigate to more relevant content e.g., various ways of implementing lifestyle changes. The guide's content while imagined to be especially useful for newly diagnosed, was likewise seen as useful to those with more diabetes experience given that it could be used to find detailed information and links for more specialised information.

An especially interesting aspect of prototype two's design is the idea that the guide could facilitate self-exploration on how to best manage diabetes by presenting different approaches to lifestyle changes. Rather than providing an one-size-fits all intervention the inspiration part of the guide could show various different methods or interventions for dealing with diabetes behaviours. Participants were quite adamantly against the idea of one-size-fits-all solutions nothing that these simply would not work for everyone given differences in motivation, approaches, and preferences. Thus the guide was imagined to present and link multiple different options to for instance diabetes friendly diets or by providing users with a choice of diverse motivational techniques. Through this approach to presenting information the guide could effectively support self-exploration of how to best manage diabetes long-term by allowing users to choose between options. However, as pointed out by participants not every PwD will necessary be interested in purely digital tools making it useful if the guide provides an overview of non-digital options such as classes, workshops, and other local initiatives.

4.3.3 Thematic insights

Workshop participants' experiences with diabetes were quite diverse in terms of the problems faced, their journey with diabetes and with respect to how they approached challenges. One of the timelines created during the workshops showing diabetes experiences can be seen in Fig. 4.9. Participants generally agreed that lack of knowledge was a significant challenge at time of diagnosis with various degrees of pains derived from dietary and physical activity changes. E.g., some participants stated having changed diets quite substantially while others noted much smaller changes. In practice increasing physical activity was handled in a variety of ways: some for the gratification of activity itself, others seeking and sharing motivation among peers. Prominent themes featured heavily in the workshops include: diabetes care, diabetes knowledge, blood glucose, diet, physical activity, and social aspects of diabetes. More minor themes include positive phrasing, medications, screening, and quality of life.

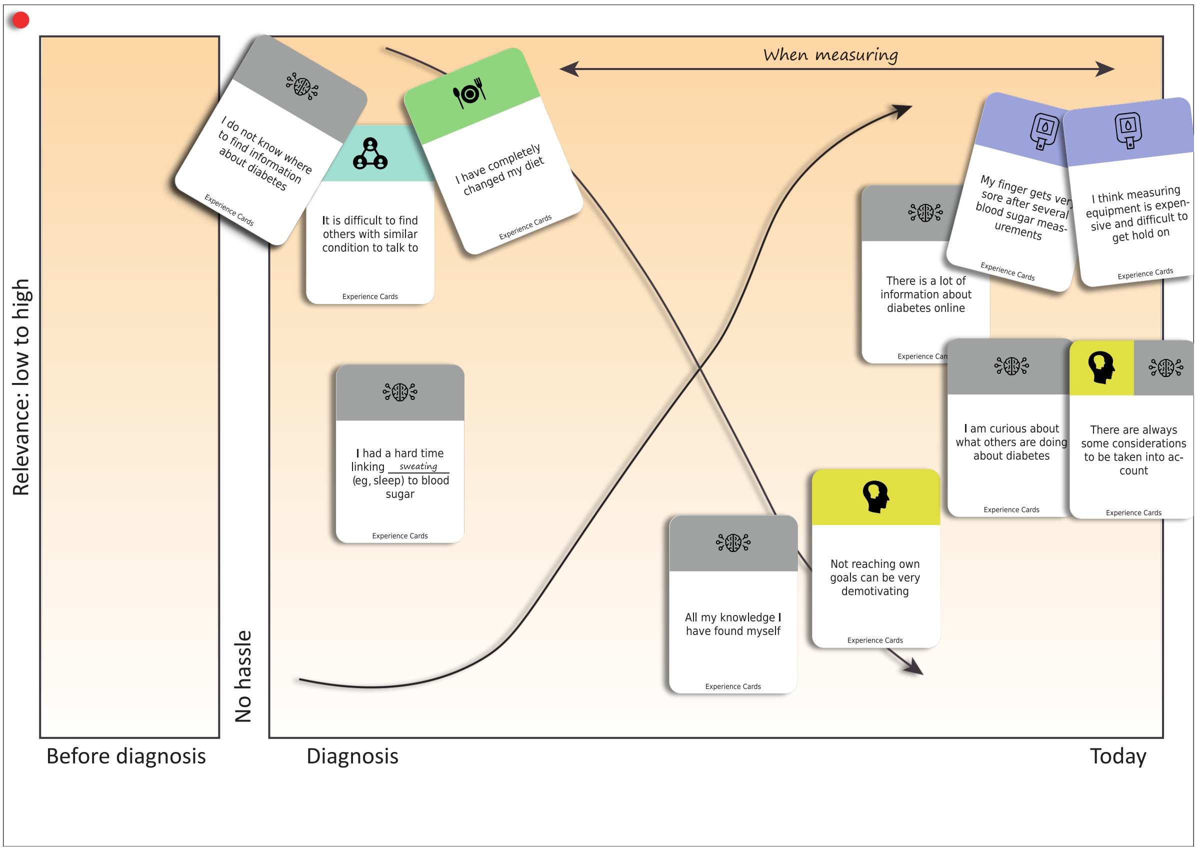


Figure 4.9: Example of a timeline created by participants of the first workshop showing how experiences change over time [178].

Diabetes care: For many the journey with diabetes started at the GPs office having received the diagnosis, sometimes in relation to unrelated health tests. Given that the healthcare system can be seen as the starting point for many it is no surprise diabetes care was a frequently discussed topic of the first workshop. Here a variety of issues were noted such as lack of adequate time for consultation, availability/accessibility of specialists and the perceived diabetes knowledge of GPs. PwDs relationship with their GP was brought up and discussed with divergent viewpoints. Some participants noted having a good relationship with the GP or with the clinics attached nurse. However, many also noted a challenging relationship to GPs relating to a perceived lack of knowledge, feedback or interest. These poorer relationships and interactions were generally cited as detrimental and in contrast also highlights the importance of a good relationship with GPs.

National policy was brought up as troubling in the context of initiatives offered by various municipalities. While some municipalities offered quite intricate support in the form of various initiatives such as classes others offered fewer or different opportunities. Municipalities and GPs support in helping PwD get access to glucose monitoring equipment was also noted as a significant source of frustration. This related both to national policy[1] as well as different GPs and municipalities willingness to provide glucose monitors. The perceived differences in care offered by municipalities and GPs created the perception of a "treatment gap" between GPs/municipalities causing frustration and annoyance among participants - who noted glucose monitors should be easily available to all PwD.

Diabetes knowledge: As was highlighted by the timeline (Fig. 4.9) a significant initial challenge for many PwD is the lack of diabetes knowledge. Participants noted acquiring knowledge from a variety of sources: Healthcare professionals, the DDA, Google, Facebook groups, blogs, videos, books, and from peers. Facebook communities were cited as especially useful given the large collective knowledge base of members. However, a consensus among participants was that there was usually not enough information from the GPs requiring PwD themselves to find reliable sources of information, providing a significant burden. Related issues to this process included too much, too little, overly negative, incorrect, and incomplete information. Information discovered may also lack context, be in-actionable, or unproportionately emphasise negative future aspects of diabetes. Given the challenges associated with procuring knowledge many participants wished they had been provided access to a more structured holistic introduction to diabetes.

Of particular note was negative information which was seen as problematic given that it could instil a sense of hopelessness, discourage or overwhelm e.g., through fear of comorbidities. These insights are supported by previous works suggesting these as risk factors for diabetes distress and depression, moreover noting that leveraging the threat of comorbidities may not be beneficial [24].

However, an important source of actionable diabetes knowledge was found through glucose measurements allowing participants to learn about diabetes in a practical personal sense. Participants noted this enabled them to make informed choices to keep blood glucose stable. These findings also support Bardram et al.'s point that PwD cannot tell how they are doing without measurements [15].

Blood glucose: Measuring blood glucose was universally cited by participants as being an irreplaceable tool for diabetes. Devices were not only used to provide momentary insights but were actively used to generate knowledge on how diabetes affects a person and vice versa. Some participants had even associated different symptoms such as feeling ill or too warm to high blood glucose allowing them to "instinctively" tell when their blood glucose was elevated without testing. This knowledge in turn enabled them to more readily take action in such situations. The intensity of SMBG was noted to vary over time initially as part of structured SMBG participants measured blood glucose often to facilitate learning with most participants noting an eventual transition to more sporadic use to for instance check hunches.

Based on past experiences, structured SMBG and CGM were especially well liked by participants. Structured measurements were considered useful in facilitating the self-learning process and associating chances in blood glucose to actions or symptoms. Thus empowering them to make their own insights into diabetes and how it affects them personally. Nevertheless participants noted preferring CGM over structured SMBG given the higher data fidelity and reduced discomforts. However, participants again

[1] Policy in this case requires the municipality to approve of equipment requisitions by GPs for patients.

noted significant challenges in procuring CGM devices with some participants sourcing CGM devices from abroad due to their unavailability in Denmark.

Despite the different approaches and preferences to lifestyle changes all participants agreed that SMBG and other derivatives were vital tools for T2DM. This indicates a generally high acceptance of SMBG/CGM technology in line with those previously observed [169, 52, 185] and shows PwD sees these as an integral part of self-management.

While occasional SMBG was found useful for checking hunches it was also perceived as less useful in many contexts i.e., having to carry a device, contextual appropriateness of testing, discomforts, and the lack of insights between measurements. Participants found periods of high frequency measurement through structured SMBG or CGM especially useful in generating diabetes knowledge. The idea of a high frequency structured SMBG or CGM period was also seen as something that should be implemented as a standardised treatment after diagnosis. Participants' preferences for higher frequency of measurements is tentatively supported by Tomah et al.'s findings that higher frequency 4-8 times/per day yielded the best results in clinical factors [168]. Participants perceptions of CGM being more useful given higher data fidelity is likewise supported by related works for instance Taylor et al. found CGM to achieve a 0.4-0.7% larger reduction in HbA1c than SMBG with NIT T2DM [169]. These findings support user preference for technology with high data fidelity such as CGM. However, it is important to highlight that the use of glucose monitoring technologies is a topic that has seen significant debate in the scientific community. These debates are centred around not only around associated costs, benefits and risks but also the clinical value it-self with highly diverging viewpoints presented by different authors [167, 168, 169, 170].

Diet: The scope of dietary change was quite varied with some participants noting significant changes and challenges with others noting relatively minor ones. Dietary change was noted by some as taking significant effort shortly after diagnosis but was perceived as less problematic over time as working habits were established. Dietary insights were generally sought from aforementioned sources supported by insights from SMBG allowing a trial and error approach to dietary tailoring and foods. In terms of keeping blood glucose stable, diet was perceived as highly interconnected with physical activity with some participants creating rules for balancing the two with SMBG again underlined as an important tool for decision making.

Physical Activity: The main challenges associated with physical activity were perceived as motivational in nature. Participants own motivational solutions included gym memberships, joining sports teams, competition, or finding enjoyment while exercising. Commitments to others, one-self or groups such as in team sports were by many perceived positively. However, individual motivation was generally varied with significantly differences in what actually motivates between people. Other issues include correlating exercise with longer term blood glucose improvements and domain knowledge such as the impact of different exercises or the required intensity levels.

Social: Social aspects of diabetes were also brought up frequently in the form of both local groups and online communities for sharing knowledge, expertise and to support motivation. The collective knowledge base of large online communities was perceived as useful. Posting questions even if relating to very specific topics was noted to usually garner some useful responses or clues making large Facebook groups a valuable source for information and past experiences.

Local groups and initiatives were liked by some but not all participants for the opportunities they provide, such as meeting others, sharing experiences, discussing topics or for other activities provided by such groups. Activities such as exercise groups or diabetes cooking classes were liked by some participants but were also noted to contain challenges. Given the broad demographic segment affected by T2DM it can be difficult to find groups of like minded individuals with similar goals, situation, and commitment level - which was considered important for such groups to work. Participants placed significant emphasis on the importance of comfort in such diabetes groups in addition to the need for sharing goals etc. An important point made by participants was that while some find significant motivation from group commitments other do not or do so to varying degrees reflecting the individual needs and preferences of PwD.

Other themes A total of six other themes were regularly brought up in the workshops but were not featured as prominently: positivity, diagnosis/early screening, diabetes medication, weight loss, healthcare integration and quality of life.

Participants placed significant emphasis on positive and encouraging solutions and components rather than ones attempting to leverage more negative emotions. Participants in the first workshop honed in on the fact that many materials and interventions were not necessarily focused on positive empowerment. Online materials could e.g., attempt to use the fear of complications or worse outcomes [24] as a motivator but this was not universally supported by participants. Interestingly, these observations are in contrast to previous works such as that by Rise et al. which concluded knowledge did not lead to behaviour change if diabetes was not perceived as scary [51]. Similarly, participants did not like the idea of scolding or negative responses from the prototypes to actions and indeed found these problematic. A view pointed supported by some recent works from psychology which suggests an association between instilling fear and negative factors such as anxiety and diabetes fatigue [186]. This negative tone also extended to GPs and may be indicative of a poor relationship between patient and provider [187]. Participants mentioned e.g., overly pessimistic projections for the future and course of the disease. Interestingly, some participants did note this to be a significant motivator in the form of proving the GP wrong, but to others it presented a discouraging barrier. These observations support Skinner et al.'s point that instilling fear as a motivator may not be beneficial in many cases and at worst may contribute to the development of diabetes distress/depression [24]. Lastly, we see positivity reflected in features and phrasing chosen by participants in the development of both prototypes. In prototype one participants e.g., wanted the feedback provided by the system to be phrased positively, and encourage but also noted it should not scold users for not using it for periods of time. In prototype two significant emphasis was placed on ensuring content was generally positive and encouraging even when talking about comorbidity e.g., that these with effort could be avoided, while still highlighting the potential downsides of inaction.

Many participants felt an important factor in diabetes was getting the diagnosis as early as possible to reduce the chance of complications. Some participants experienced receiving the diagnosis per chance in connection with other medical tests. The general consensus was that early screening especially among high prediabetes risk groups could make a large difference in preventing the onset of T2DM. These concerns were reflected in our only non-digital solution concept which was imagined as a home-test kit for diabetes inspired by other Danish screening programs aiming to promote awareness and catch risk factors or cases much earlier.

Diabetes medication was also discussed albeit briefly and in relation to other topics. Medication was brought up in relation to the CGM prototype as the prototype could show or highlight encouraging trends with the medication. Likewise, the prototype was imagined as a tool which might enable PwD to communicate better with their GPs or even help the GPs adjust medication. Moreover, some participants found the prospects of avoiding medication through self-management and lifestyle a desirable and motivating goal.

Interestingly, the theme: weight loss despite being a highly relevant clinical factor was mostly entirely absent from our workshops. Discussions among participants in connection with the development of prototype one seems to suggest this was a conscious choice as the idea of a weight-loss module was quickly discounted. The reasoning for this decision being that it would inadvertently lean focus too heavily towards a "weight-loss" culture with its negative connotations and thereby also shift the focus from the blood glucose. While it is debatable whether this choice was truly informed or caused by underlying participant biases was not explored. On one hand it could be argued there may not be an explicit need for focus on weight as related works found indications of this occurring naturally as a consequence self-management [169]. On the other hand, it can equally be argued participants simply did not fully understand the clinical benefits of such weight loss [188]. This discovery is however, aligned with the idea that users experiences and needs are not always aligned with clinical judgement [23] and may indicate that weight loss despite the benefits should not overtly be made a focus but should rather be facilitated through the interventions passively.

Another area where the wishes of participants deviated from a purely clinical perspective was in regard to prototype one's use in healthcare. Previous research has suggested that an app such prototype one can have several benefits when integrated into existing healthcare such as more timely treatment changes [189, 190]. Nevertheless, participants specifically choose to keep the app separate from clinical practices preferring to retain agency over when and where data is shared with GPs if shared at all.

Finally, quality of life was briefly discussed in several of the workshops with participants noting that while self-management was important it could sometimes be necessary to take small breaks [25]. Emphasis was especially placed on finding an approach to self-management that a person could live with comfortably. Thus, again supporting Skinner et al.'s point about the importance of supporting self-exploration [24]. This idea of supporting self-exploration was especially profound in prototype two by its emphasis on providing users with many different approaches to various activities.

4.4 A broader view of micro-intervention systems

Both developed prototypes can be seen as interesting in the larger context of what a micro-intervention system is. Firstly, because it can be argued that both prototypes resemble the micro-intervention hubs described by Baumel et al. [29] in that the developed systems/interactions i) aim to recognise an individual's state and context, ii) recommend relevant interventions and iii) create and maintain the right narrative linked to the larger therapeutic process [29]. Secondly, in that both prototypes aim to serve forms of short contextually relevant interventions. Prototype one for instance does this by providing users with trends and short feedback messages in the active phase and by the imagined passive data collection in the support tool phase. Prototype two meanwhile does this by serving short educational videos reminiscent of those employed by various micro-intervention systems [31, 32, 191] and by suggesting a variety of different larger interventions and approaches to diabetes self-management. Participant discussions of the guide linking to both other technical solutions, tools or in-person local offers is reminiscent of the micro-interventions used by Parades et al. with the intervention it-self consisting of a prompt and a URL for an external resource [32]. In these ways participants discussed the inclusion of micro-interventions as a natural part of the prototypes.

The online guide in particular is well aligned with our definition of a micro-interventions system. The online guide through its interaction model does three things: i) The guide helps PwD recognise their situation, context and needs through its "perceived situations" and structure. ii) the guide serves a number of relevant micro-interventions in the form of educational videos and by presenting different approaches to self-management. iii) the guide allows the users to create and maintain a narrative through the guides content and structure.

However, unlike the hub entity described by Baumel et al. we observe real-world scenarios are unlike to rely solely on a single actor to facilitate the aims of the hub. While both of our prototypes can be seen as serving micro-interventions neither relies solely on user nor system to do so. In the first prototype's case the system recognises a persons state and context, but leaves the choice of intervention to the user in line with Li et al.'s stage-based model. Nevertheless it could be argued the act of providing feedback or trends itself could be an educational micro-intervention as both cases could have an immediate positive behavioural impact in line with Fuller et al.'s definition [31]. In prototype two's case we see users themselves act to recognise state and context supported by the guide in line with point i), however while the system provides users with recommended and relevant interventions in line with ii) users are free to choose whichever order content is consumed and which approach to follow. These cases therefore suggest that system and user are symbiotically responsible for fulfilling the aims of the hub. Consequently, also suggesting Baumel et al.'s conceptualisation may not adequately consider the interactions between actors and the system in micro-intervention care, implying it may be necessary to adopt a more holistic view on the role of the micro-intervention system.

4.5 Chapter summary

In this chapter we explored the results of a co-creation study involving researchers, designers, stakeholders and end-users. Through the study two prototypes were co-created aiming to address end-users' most critically perceived needs. The two prototypes designed were: an activity-based CGM app and an online guide to diabetes. Additionally, through the workshops a number of insights were generated around core activities in diabetes management including participants' own approaches to different lifestyle changes, the value of different tools, and the users' preferences. In summary in this chapter we have:

- Explored the study design, methods and results of a co-creation study aiming to create technology for T2DM which is both preferable and desirable to intended end-users.
- Co-created two prototypes: an activity-based CGM application and an online guide to diabetes. Moreover, we have explored the rationale for their creation, the intended user journey, and the solutions envisioned user experience over time.
- Through the co-creation process we have additionally generated a number of insights in thematic areas related to diabetes e.g., how the needs or motivators of PwD may differ, change over time and how these may not be aligned with clinical judgement.
- Lastly, we contextualised these results to micro-intervention technology discussing how the two prototypes add to our understanding of micro-intervention systems.

CHAPTER 5

Episodic Future Thinking as Digital Micro-interventions

A well-known issue with lifestyle changes is that they are difficult to initiate and moreover to maintain with a lack of motivation an often cited problem. However, as briefly touched upon in the introduction, this lack of motivation may be affected by users' biases towards preferring immediate gratification over future health. In related works we further covered the concepts of delay discounting and EFT which has the ability to reduce delay discounting with the former suggested as a potential target for improving outcomes in a range of health conditions. In this case we are particularly interested in EFT's ability to reduce delay discounting in a diabetes context given the established association between delay discounting and poorer outcomes in both T2DM and prediabetes. This chapter summarises the initial design process, the resulting mHealth app implementation, and a feasibility study of EFT as digitally mHealth delivered micro-interventions.

The following sections summarises and expand upon the paper:

Dan Roland Persson, Soojeong Yoo, Jakob E. Bardram, Timothy C. Skinner & Per Bækgaard. (2023). Episodic Future Thinking as Digital Micro-interventions. Design, user experience and usability: The 12th international conference, DUXU, 2023, Held as Part of the 25th HCI International Conference, HCII 2023, Copenhagen, Denmark, July 2328. In press: Late Breaking Work.

Please cite accordingly.

5.1 Initial design

The idea of creating EFT micro-interventions were originally conceived in a number of meetings and discussions with Timothy Charles Skinner from the University of Copenhagen given EFTs potential application in T2DM [192] and prediabetes [10]. These discussions eventually culminated in an mHealth application for facilitating the delivery of EFT micro-interventions and the requirements of such an application. Based on these discussions and the existing literature on EFT an early prototype was developed (see Fig. 5.1). At this stage of the design process 3 micro-intervention components were identified, namely 2 micro-interventions and an assessment task:

- MI-1: A self-guided generation task for creating audio cues - wherein users imagine a vivid event in the future creating an audio description of said event as vividly as possible.
- MI-2: An audio based projection (or reflection) session - where generated cues are reviewed by users (or "pre-experienced") aiming to prompt reflection about the future.
- A1: A delay discounting task - where a person's inherent delay discounting is measured through a number of questions aiming to determine a person's discounting coefficient k (see section 2.4).

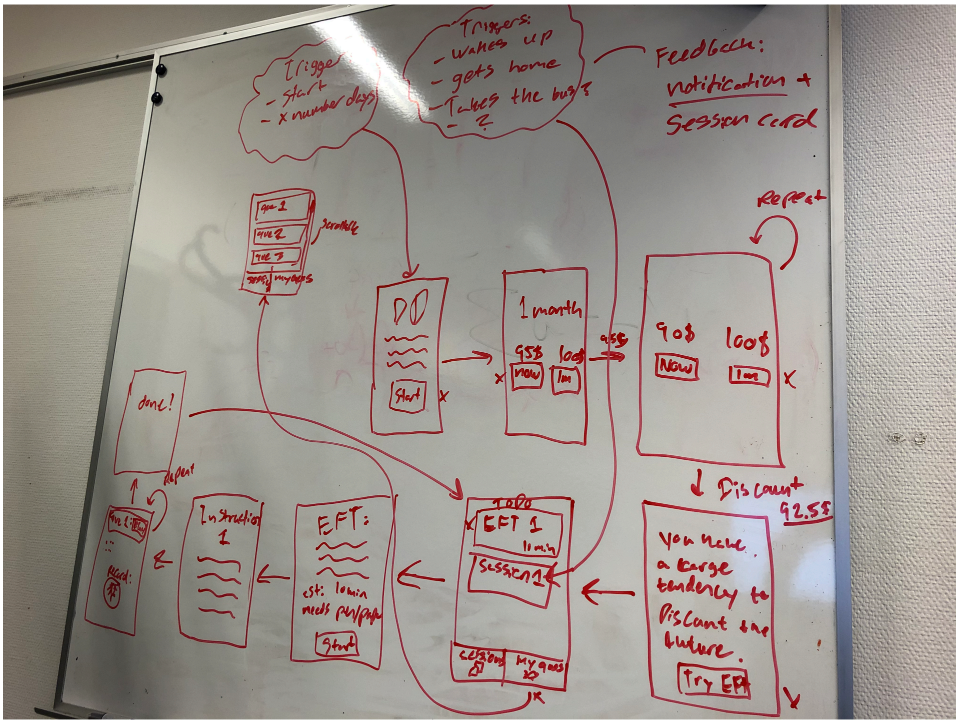


Figure 5.1: Early low-fidelity prototype sketches on a whiteboard used for discussion.

5.1.1 Micro-intervention components

MI-1: We initially based our self-guided generation task on the task described by Stein et al. [104] and on the results of Ye et al.'s meta-analysis emphasising that positively framed futures are more effective at affecting delay discounting [95]. The resulting micro-intervention resource was a textual task description instructing users on how they create vivid episodic futures.

As previous research suggests the effectiveness of EFT is dependent on the number of generated futures and the time frames of those futures [103] we designed the self-guided generation task to iterate and support the creation of cues through different time frames. The task was designed to be repeatable asking users to imagine events at different times in the future in this case: 1 day, 7 days, 1 month, 3 months, 1 year, 5 years and 25 years. While the task description was based on previous works [104, 103, 95] none at the time included a detailed and explicit task description. Based on the implicit descriptions available we created a three part task description instructing users to: 1) image a future event that they are positively looking towards, 2) to imagine what it feels like to experience the event, who is present, what they are doing and how they are feeling. 3) writing a script about the event describing it and recording it as a short 20-30 audio clip. The resulting task description is reminiscent of that published by Epstein et al. [101] in 2022 after the completion of this study.

MI-2: The audio-based projection session in line with previous works was imagined to take place twice per day i.e., before the first and last meal of the day [98]. Rather than reviewing all episodic futures participants would review a subset of their created cues with the reflection task designed to take up only a few minutes. Participants were encouraged to engage with these sessions at least twice per day through the app and with reminders sent if sessions were not completed.

A1: An assessment component was also designed to measure delay discounting through the 100$ adjusting amounts delay discounting task [10] adjusted to local currency ~1000DKK following the procedure described in related works (section 2.4). The task was designed as an app-based questionnaire prompting users to decide between two amounts until reaching an indifference point, with the adjustments repeating for various time frames in this case matching the time frames used in the self-guided generation task.

5.2 User experience research

To rapidly improve the design of our theory-based application we decided to adopt a human-centred design process aimed at enhancing the prototype design. However, the emergence of the global COVID pandemic and associated societal restrictions presented various barriers to the user experience design research. Due to these restrictions, it was only possible to carry out two formal rounds of user experience research with the additional restriction that these had to be facilitated online. In the following sections we will briefly go over the prototypes created through the design process as well as the two major rounds of user experience research, their methods, and results. In this case focus groups [193] with persons with T2DM and the formative usability evaluations [181] of the mHealth application.

5.2.1 Prototypes

Throughout the design process several prototypes were created with different fidelity levels [177]. Initially, a paper prototype (using a whiteboard in this case) was made to provide an overview of different functionalities, screens and components seen in Fig. 5.1. This prototype was subsequently expanded several times, firstly by developing the initial low-fidelity prototype into a high-fidelity prototype covering the entirety of the app, including screens, interactions, error messages and notifications. An exert of the full wireframes can be seen in Fig. 5.2 showing the early design of the self-guided generation task. Throughout the design process described in the following sections this high-fidelity prototype was iteratively updated to reflect insights generated throughout testing and was eventually used as the basis for implementing the application.

More specialised interactive prototypes were also created for different purposes such as testing the adjusting amounts task and micro-interventions. These included: a fully interactive HTML and JavaScript prototype of the adjusting amounts task which was used as part of the focus groups described in the next section. An interactive prototype was similarly made covering the self-guided generation task and reflection session aiming to validate the micro-interventions, their instructions and assess potential usability problems.

5.2.2 T2DM Focus groups

To explore initial perceptions of core concepts such as delay discounting and EFT and to discover what users would want [194] from an EFT micro-intervention system we conducted three focus group sessions with 11 persons with T2DM. The focus groups were facilitated online using the meeting platform Zoom. Participants were initially asked broad questions about their decision process when carrying out diabetes self-management related behaviours followed by an introduction to delay discounting and EFT. During the introduction participants were also invited to try the interactive HTML adjusting amounts task where they could see their delay discounting. The length of the task was perceived as relatively quick and easy to complete, with participants suggesting various improvements such as a progress bar and more visual feedback when time frames or monetary values are updated between decisions. While the adjusting amounts task description and resulting delay discounting results were perceived positively, challenges were noted in translating these results to diabetes behaviours.

Participants generally perceived EFT as an interesting concept but noted that it was difficult to conceptually relate to diabetes and their own behaviours. Discussions among participants leaned towards the intervention adding little to those already managing diabetes successfully which they perceived themselves as doing. Although, participants also noted the micro-interventions would be interesting and potentially useful for persons initiating lifestyle changes as it could help motivate them. EFT was

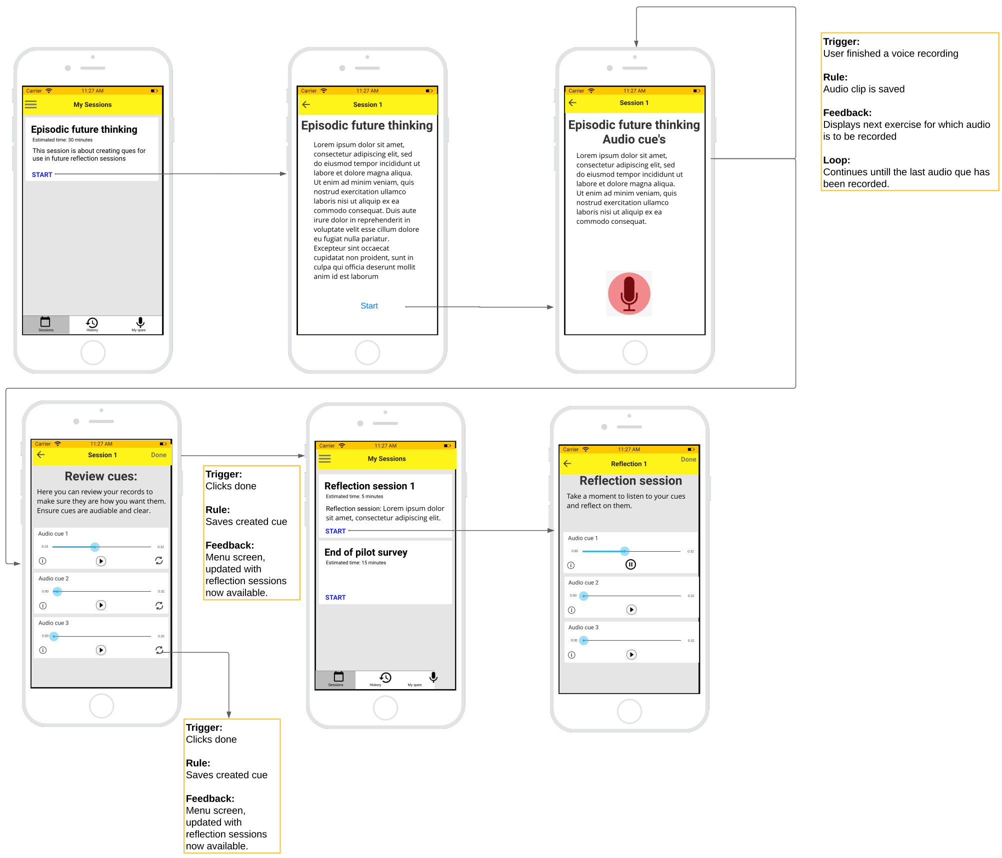


Figure 5.2: A small portion of the full wireframes showing the initial design of the self-guided generation task and reflection session.

discussed as a tool which might help newly diagnosed PwD to come to terms with the disease and getting them to take it seriously. E.g., by providing newly diagnosed with an understanding of the seriousness of future consequences and by emphasising the value of acting i.e., by reducing the delay discounting. Participants speculated that EFT as a concept might be useful to highlight the potential consequences of certain behaviour such as the potential consequences of inactivity in diabetes. On the other hand participants generally leaned towards positive reinforcement rather than attempting to leverage fear of complications. Noting the need for a positively framed message regarding the consequences i.e., that these can be avoided by action. In lieu of that point participants also discussed the idea of combining EFT with other techniques such as goal-setting.

5.2.3 Formative usability evaluation

To ensure the design of our micro-interventions and that of the system were acceptable usability evaluations were conducted with students at the Technical University of Denmark. These evaluations aimed to identifying problems with the design of our self-guided generation task and reflection session, uncovering opportunities for improvements and to validate that participants could generate sufficiently vivid audio cues based on the task description. A total of 6 persons were recruited for online evaluations through Zoom using an interactive prototype which covered the self-guided generation task and reflection sessions.

Participants found the provided self-guided generation task easy to complete with all participants successfully creating a future event within a relatively short time period. Several participants noted that the self-guided generation task was generally pleasant and that the task made them feel emotions such as happiness and joy in anticipation of the created episodic futures. Prior to this observation there had been significant debate among project collaborators on whether the self-guided generation task should it-self be considered a micro-intervention. This being primarily due to the sessions role in setting up EFT micro-interventions and thereby seemingly not having an effect of its own counter to Fuller et al.'s definition of a micro-intervention [31]. However, our usability evaluations tentatively confirmed the hypothesis that the self-guided generation task should be considered a micro-intervention given its immediate effect of providing a positive lookout on the future. An effect which may be useful in promoting intervention value given prior works association between an initial positive exposure and the perceived value of interventions [33].

5.2.4 Final Design

Discussions among focus group participants indicated that while the 1000DKK adjusting amounts task was easy to complete the amounts included in decisions were too low, i.e., the amounts used were perceived as not facilitating meaningful choices. Participants noted being rather indifferent towards most of the choice e.g., 1000DKK now or 750DKK in a month. These observations are in line with Epstein et al.'s suggestion that if amounts are too small many participants seem to automatically discount choices [42]. The adjusting amounts task was subsequently changed to a 10.000DKK adjusting amounts task similar to the 1000$ task described by Epstein et al. aiming to make choices feel more impactful and prompt deeper reflection on choices [42].

While participants through the formative usability evaluation indicated the task description itself was sufficient for completing the self-guided generation task, they also noted some difficulties imaging futures in certain time frames. Based on these observations and participants own suggestions several changes and additions were made to the self-guided generation task: 1) the examples provided as part of the task description were made to reflect the time period participants were asked to imagine. 2) a tab of additional examples was added aiming to inspire participants to get started. 3) participants could choose provided examples as a template to help them get started with their first cue. 4) the application would initially prompt users to imagine futures relatively close to the present starting with one month in the future to leverage a hypothesised learning curve effect.

An emerging concern from the design and validation of the two micro-interventions created was that these were both centred around audio, potentially limiting the contextual settings where they could be used. To alleviate this potential short-coming we looked at works similar to EFT. The work by Chan and Cameron on mental imaging [41] was chosen as the basis for the creation of another micro-intervention focused on an image-based representation of the future, aiming to remind users of their created episodic futures.

- MI-3: An imaged-based projection task - aiming to quickly remind a person of a created episodic future through an image representation of that future.

MI-3: The third micro-intervention based on mental imagery was designed to randomly occur throughout the day as to bridge the gap between scheduled reflection sessions. A consequence of this was the addition of a new step to the self-guided generation task (see Fig. 5.3) asking users to associate an image with their created episodic futures.

5.3 Implementation

Implementation of the EFT-application was carried out using Flutter an open-source framework by Google for building natively compiled multi-platform applications with a single codebase through the Dart programming language[1]. The use of Flutter was largely motivated by two factors firstly the single

[1] https://flutter.dev/

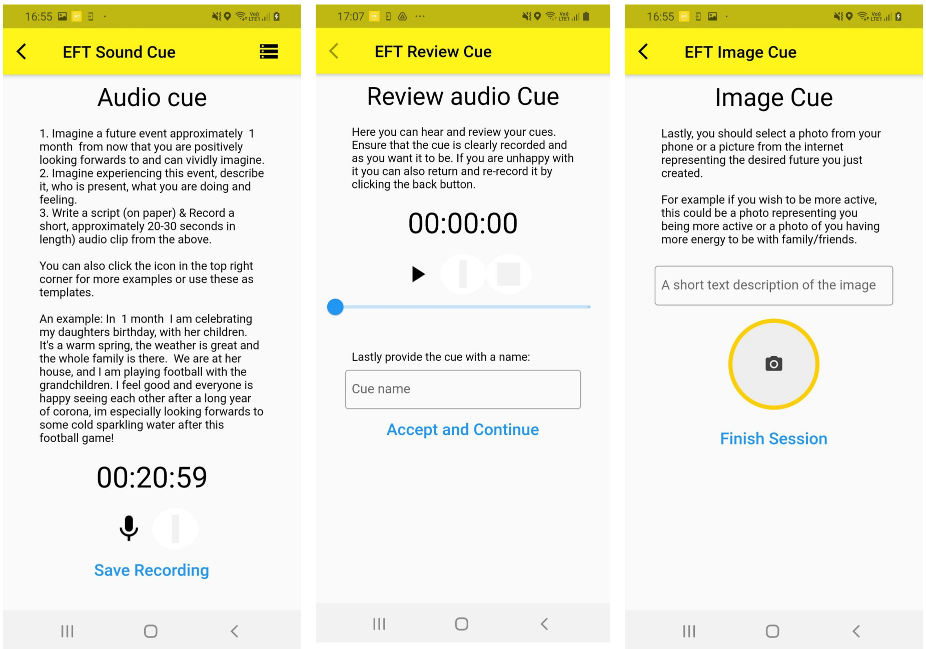


Figure 5.3: The final design of the self-guided generation task as implemented in the application [195].

code base facilitating the deployment of both iOS and Android apps, and secondly the availability of the CACHET Research Platform (CARP) and the CARP Mobile Sensing (CAMS) framework. CARP is an open-source research platform for digital phenotyping [2] with a number of open-source components such as web-services, surveys and background processes allowing more rapid development of the application.

5.3.1 Architecture

The application relies on CARP mobile sensing for handling background processes and passive data collection through the various sensing packages controlled by the CAMS Study controller. An overview of the application architecture can be seen in Fig. 5.5. Sampling packages can in this case be seen as plugins to CAMS responsible for handling data sampling such as step counts [15]. The application used the sensor and context packages in addition to an application specific sampling package which included support for measures such as delay discounting, usage events, and Bluetooth Beacon events. Beacon events were originally intended to enable JIT delivery of image-based projection but had to be dropped for the feasibility study due to issues with Flutters native support for this feature. Data collected by the application is uploaded to the CARP Web Services a secure Cloud-based Data Management infrastructure compliant with GDPR. The system also used the CARP research package to facilitate the collection and recording of informed consent. The application was additionally built using a number of notable Flutter packages for included features such as "Flutter Sound" for recording/playback, "Local Notifications" for notifications and the "Flutter Localization" package supporting Danish and English versions of the application.

5.3.2 Background processes & notifications

Background processes are useful for a variety of tasks, such as for sending JIT notifications in response to user actions, passive data collection and for scheduling future tasks. However, these processes have

[2] http://carp.cachet.dk/

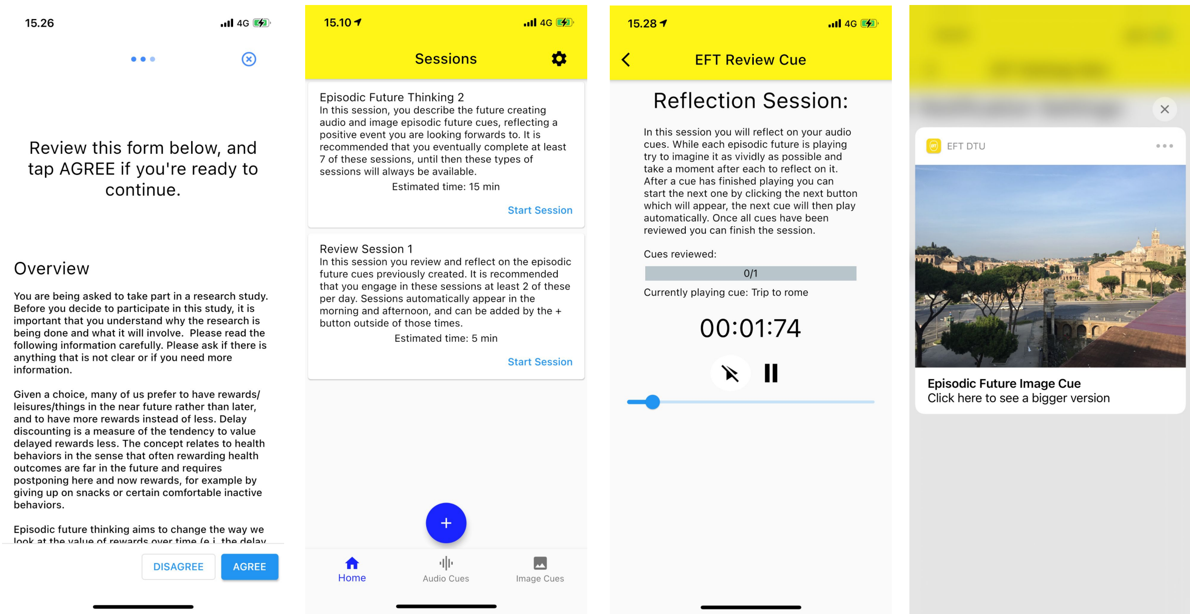


Figure 5.4: Screenshots of various features of the app, the left-most image shows the app-embedded consent form. The left middle screen shows the app homescreen with active session and the right middle screen shows the audio-based projection session. The right-most screen showing an example of an image-based projection notification. [195]

also become increasingly challenging to support and to keep alive on modern smartphones [196]. In the last few years in particular there have been several updates to smartphone operating systems trying to curb the power consumption of background processes. While these changes are largely beneficial to users by improving battery life these changes are more problematic for researchers needing to rely on them. A significant amount of time was therefore spent implementing, testing, and improving the background processes.

In the EFT applications case, we rely on background processes for a multitude of tasks such as delivery of notifications, scheduling of different sessions, and collecting passive data. CARP mobile sensing is primarily responsible for keeping these background processes alive supporting other services by trigger them with appropriate intervals. Fig 5.6 provides an overview of the logic behind sessions appearing in the application and notifications showing up facilitated by background processes.

5.4 Feasibility study

Following the practices of early stage mHealth research we conducted a single arm feasibility study to understand how and why the system is or isn't used by its users [38]. In line with research question 3 (section 1.2) we want to know if it is feasible to use EFT as mHealth delivered micro-interventions.

Given our aim of making the EFT micro-interventions broadly usable we did not place any restrictions on recruitment for the study. Recruitment occurred at DTU from early January to February 2022 through announcements, board messages, email lists and through word of mouth. Recruitment materials presented interested subjects with general study information including links to the subject information letter and sign up page, with interested participants invited to participate in the study through email.

The overall structure of the study can be seen in Fig. 5.7 including the timing of surveys and the expected levels of engagement with different micro-intervention. The primary outcome measure for the study was delay discounting measured through the apps adjusting amounts task. The secondary

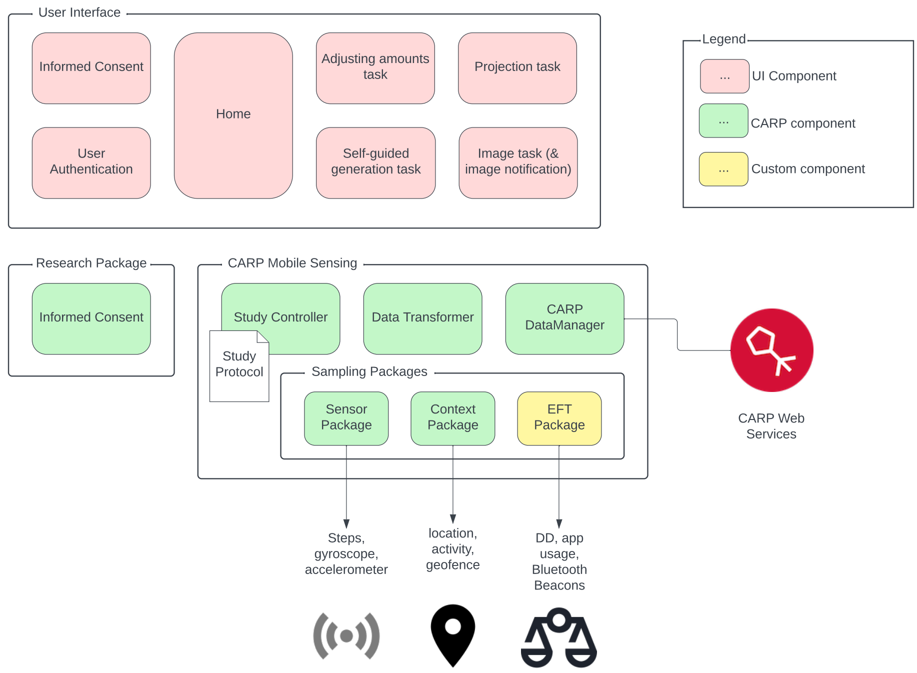


Figure 5.5: Overall architecture of the EFT mHealth application [195].

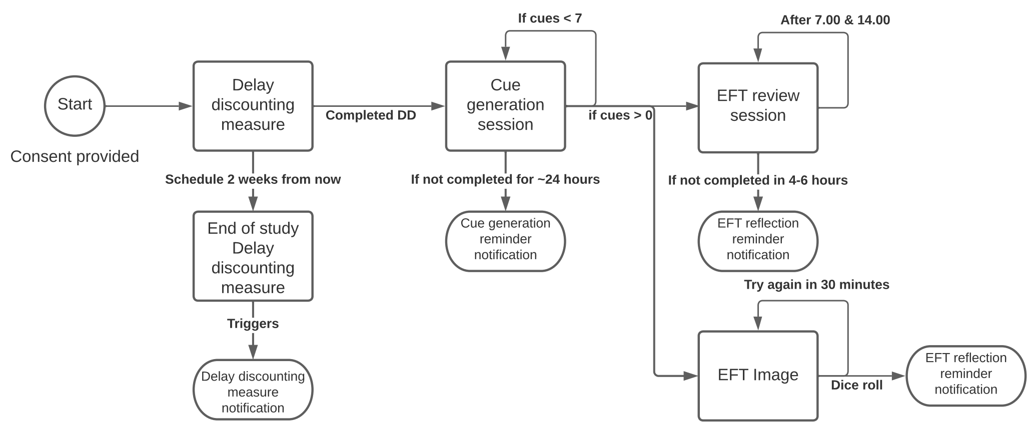


Figure 5.6: Flowchart showing the logic behind new sessions appearing and the timing of notifications in relation to sessions. Rectangular boxes representing the sessions themselves with rounded boxes representing notifications.

outcome was motivation to engage in healthy behaviours in this case physical activity and diet and was measured through the Treatment Self Regulation Questionnaire (TSRQ). Perceived usability was measured using the Post-Study System Usability Questionnaire (PSSUQ) at the end of the study with additional supplementary questions added to contextualise PSSUQ answers and to explore well-liked or poorly perceived features. User's experiences with different micro-interventions were sampled along with the TSRQ questionnaires at the start and end of the study through a number of supplementary questions centred around the different micro-interventions. These included questions about the experience of engaging with the self-guided generation task and reflection sessions, barriers to these, and approaches

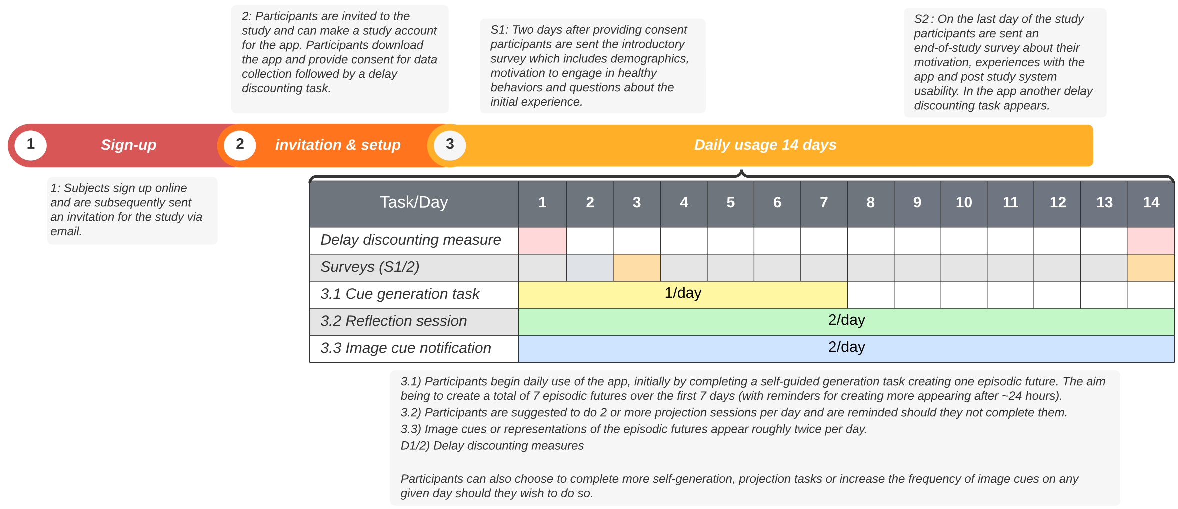


Figure 5.7: Timeline of the feasibility study showing different phases, as well as expected usage and the timing of surveys/measures [195].

to task completion. Participants were encouraged to engage in audio-based reflection sessions at least twice per day with approximately 2 image cues appearing randomly throughout the day. Participants were also encouraged to create 7 cues throughout the first 7 days i.e., one per day but participants could choose to complete all self-guided generation tasks faster if they preferred.

5.5 Principal findings

In total 24 persons signed up for the study with 14 accepting the study invitation, downloading the app, and provided consent to participate. Out of those 14, 12 participants completed the initial survey and 9 the end of study survey. 83% of participants where between the ages of 20-30, half were female, and a quarter of participants identified themselves as being from a minority group.

5.5.1 Primary & secondary outcome

We observed no statistically significant changes in delay discounting between participants largely due to lower than expected completion rate of the final in-app delay discount measure. Within subject statistical analysis of TSRQ (using python 3.7.0, scipy 1.7.3) revealed no statistically significant changes in TSRQ scoring for neither physical activity nor diet between the start and end of study surveys. However, at end-of-study there was a noticeable albeit insignificant difference to question 14: ”Because I want others to see I can do it” (Physical Activity) showing a mean change of 1.65 (Likert scale, $p=0.31$).

5.5.2 PSSUQ

The EFT-applications usability assessed through PSSUQ (see Fig. 5.8) revealed that a majority of users were satisfied with the system with supplementary questions adding suggestions for improvements to the system/UI. Questions 3 and 4 further suggest users could effectively and quickly complete tasks and scenarios presented by the system i.e., the micro-interventions. Two exceptions to the overall positive feedback was in response to PSSUQ questions 6 (I felt comfortable using this system) and 8 (I believe I could become productive quickly using this system). Looking to our supplementary experience questions

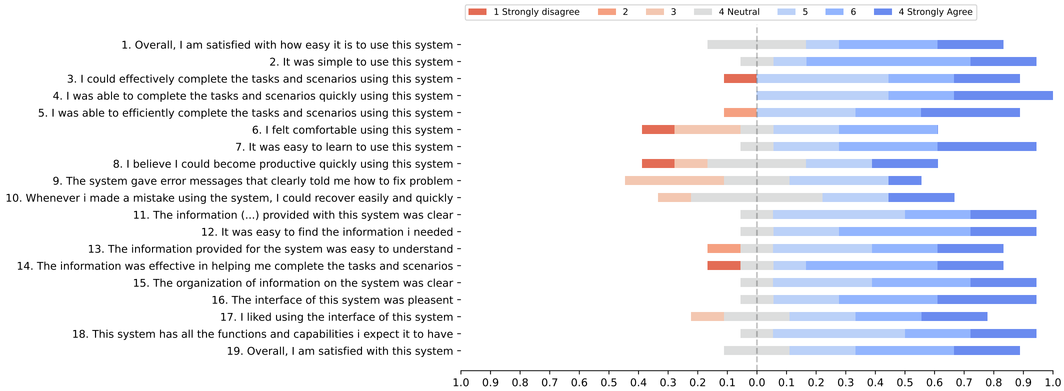


Figure 5.8: Diverging stacked bar chart of the EFT-applications PSSUQ scores [195].

for nuance to these we found that users perceived varying degrees of discomfort from listen to their own voice in relation to question 6. We also observed in relation to question 8 that some participants perceived a disconnect between the aims of EFT micro-interventions and that of the study which worked with idea of becoming healthier. i.e., the EFT micro-interventions did not aim to directly affect health as expected by some participants.

5.5.3 Qualitative analysis

Thematic analysis of the qualitative experience questions revealed 5 recurring themes: 1) listening to one's own voice, 2) contextual appropriateness of interventions, 3) imaging distant futures, 4) perceived value, and 5) the facilitating system.

Listening to one's own voice was generally cited as uncomfortable with many participants reporting mild or severe annoyance, with approximately half of participants mentioning their own voice. Consequently, suggesting that listening to one's own voice presents a significant barrier to engaging in EFT. Participants suggested various ways of alleviating this barrier such as keeping cues textual and letting users read them during projection sessions, letting others record the cues or having the cues read out loud by a voicebot.

The contextual appropriateness of different micro-interventions was also brought up by participants. The need for recording in a quiet setting as part of the self-guided generation task presented a barrier to some users in everyday life with others commenting on having difficulties finding a quiet place to listen to their audio cues.

Some participants noted significant difficulties in imagining distant futures due to them being outside the scope of time they usually think about. Despite the provided examples being noted as helpful in this regard some participants requested more examples covering a greater variety of episodic futures with increased focus on examples in the distant future.

The perceived value of the micro-interventions was another frequently mentioned topic with divergent viewpoints. Some participants noted that the experience of reflecting on the future was pleasant and encouraging serving as a reminder of things to look towards with others less optimistic. Some found the micro-interventions inconsistent with the overall aims of improving distal health outcomes and questioned how engaging in EFT would actively help them tangibly achieve health goals. However, it is worth noting that EFT by the intervention's nature may not provide directly tangible effects through a reduced delay discounting. Instead a reduced delay discounting may provide subtle benefits by reducing impulsiveness and shifting decision making to favour future outcomes, yet such changes may be difficult to perceive from users perspective.

In terms of the EFT-application participants perceived some areas of the system positively with others seen as less favourable. On one hand participants found the system to be easy to use and found provided micro-intervention task deceptions sufficient to quickly complete the interventions. Similarly, the image cue notifications were well liked. On the other hand, participants noted that some interactions in the design could be improved and more broadly complained about issues relating to the mobile sensing. For one the mobile sensing was perceived negatively due to the observed battery drain in addition to stability issues caused by background processes causing notifications to occur irregularly on some phones especially on iOS phones.

5.5.4 Usage and attrition

The EFT-application saw lower usage than expected and relatively high attrition with an accumulated attrition of: 21.4% by day 3, 43% by day 7 and 78.6% by the end of study (see Fig. 5.9). These rates are seemingly in line with those found by Baumel et al. for real-world usage of mental health app [17]. Participant feedback and experiences suggests this attrition was related primarily to the perceived value and voice barriers described previously. Participant comments especially those relating to the perceived

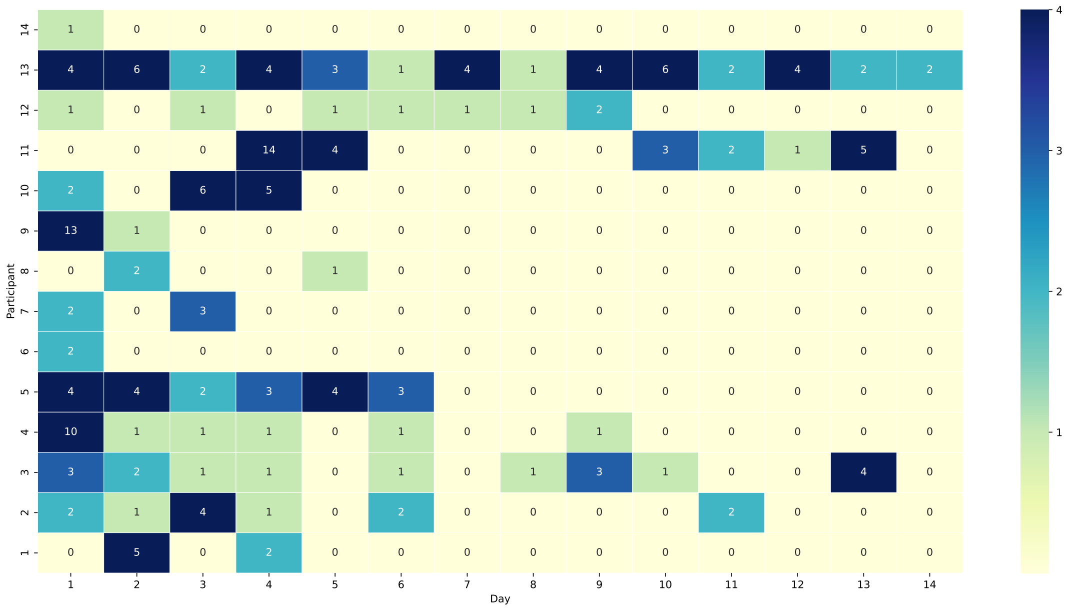


Figure 5.9: Heatmap showing different participants daily completion of self-guided generation task and audio-based projection sessions throughout the study [195].

value point to the need for a strengthened value proposition of the EFT-application and its micro-interventions. Previous research likewise seems to support this hypothesis as perceived value has been positively associated with increased usage [31]. Interestingly, comments pertaining to the self-guided generation task indicates some participants adopted a goal-oriented EFT approach to creating cues perhaps to bridge the perceived gap between health and the interventions. Users unprompted adoption of this approach could indicate that goal-oriented EFT may be better suited for micro-interventions given some users implicit association between the two. Goal-oriented EFT as briefly mentioned in related works being a variant where goals in this case health goals are explicitly tied to the episodic futures.

5.6 Implications for micro-interventions

This feasibility study contributed several insights into how users perceive the operation of micro-interventions. In terms of the resources delivered participants had various preferences: some preferred textual reminders, reading the cue themselves, while others noted the image cue was enough to prompt reflection of the episodic future or liked the audio format but preferred it to not be in their own voice. While these variations to classical EFT have not been tested, they represent interesting possibilities for personalising EFT micro-interventions. More broadly, suggesting the resources delivered by micro-interventions can be a more dynamic and personalised component.

The relatively short duration of intervention usage in line with those observed by Baumel et al. [17] also indicates it may be necessary for micro-intervention systems to suggest/deploy supplementary or other micro-interventions within a relatively short time frame to alleviate fatigue. However, this could also indicate that EFT micro-interventions should be served alongside other micro-interventions to maintain interest consistent with previous notions that novelty may be an important factor to maintaining interest [32, 86]. Low engagement with an active micro-intervention may also serve as a decision rule for triggering new more relevant or preferable interventions through mobile sensing. There are thus indications that while EFT micro-interventions are feasible, they may not be preferable in complete isolation but should rather be used as a component of larger micro-intervention systems.

5.7 Chapter summary

In this chapter we explored the design, implementation and initial feasibility study of the EFT-application. Our results i.e., PSSUQ, automatic data collection and experience sampling indicates that our architecture and mHealth system worked as expected and was capable of delivering the EFT micro-interventions. While users overall perceived the app usability favourably and the micro-interventions as easy to complete, we also discovered significant barriers to their use. These barriers include the perceived value of the micro-interventions, contextual appropriateness of resources and listening to one's own voice. Despite the barriers and relatively low usage observed we tentatively find the use of EFT as digital micro-interventions feasible. In summary we highlight the following from this chapter:

- The EFT-application was generally perceived as acceptable with users able to complete different micro-interventions with relatively ease. Despite this we did not manage to identify any significant changes to our primary measure (discounting rate) nor any changes to our secondary measures i.e., motivation to engage in healthy physical activity and dietary behaviours.

- Usage of the application was more sparse than expected with high attrition reassembling previous findings for real-world use [17]. Associated with this high attrition was a number of barriers to use such as the contextual appropriateness of resources, the perceived value of the micro-interventions and listening to one's own voice.

- We observed indications that goal-oriented EFT may be preferable as the basis for EFT micro-interventions with some users seemingly adopting an unprompted goal-oriented approach to generating episodic futures. Results from the focus groups included in the design process tentatively support this hypothesis as participants discussed the embedding of goals into EFT.

- However, given limitations in terms of study duration, app user retention and participants a larger scale study is necessary to further explore the effectiveness of these micro-interventions.

CHAPTER 6

Perceptions and Effectiveness of Episodic Future Thinking as Digital Micro-Interventions Based on Mobile Health Technology

Based on the results of the feasibility study covered in the previous chapter a follow-up study was planned to address shortcomings. In particular we wanted to explore the effectiveness of EFT micro-interventions in modifying delay discounting in a larger study with more participants. Moreover, based on observations that goal-oriented EFT (gEFT) may be preferable to traditional EFT for use in micro-interventions we also aimed to explore how perceptions and effects differ between these types of future thinking. Consequently, a randomised study was planned and executed with three study arms: gEFT, EFT and a control arm. The aim of the study was to explore the effects and user perceptions of micro-interventions based on gEFT and EFT in line with research question 4.

The following sections summarises and expand upon the paper:

Dan Roland Persson, Jakob E. Bardram & Per Bækgaard. (2023). Perceptions and Effectiveness of Episodic Future Thinking as Digital Micro-Interventions Based on Mobile Health Technology. [Submitted] Sage Digital Health.

Please cite accordingly.

6.1 Methods - Randomised trail

A three armed randomised study design was chosen for this exploration, partly to minimise biases but also in order to ensure results were readily comparable. As such the study consists of two intervention arms i.e., gEFT and EFT with the third arm acting as a control. Both intervention arms received EFT micro-interventions enhanced with mental imagery, with one arm engaging in gEFT where goals are explicitly tied to the episodic futures. Aiming to keep the control group comparable to the intervention arms we opted for a ”Best-Available-Therapy” approach [197] wherein the control group received a commonly used intervention. In this case the control group was given generic motivational materials on goal-setting, similar to those discoverable on search engines such as Google. In line with other early stage works on micro-interventions [32, 82, 31, 86] we opted for a relatively short study duration of 3 weeks. To explore the effects and perceptions between intervention arms we employed a number of measures and surveys, the timing of which can be seen in Table 6.1.

Day	Demographic	DD	TSRQ	Other	PSSUQ
1	x	x	x		
7		x	x	x*	
14		x	x	x*	
21		x	x	x*	x**

Table 6.1: Overview of surveys and their delivery throughout the study. * marks a step that is different for control group compared to intervention groups and ** marks a step skipped by the control group. [198]

The studies primary outcome measure was delay discounting measured through our app-based delay discounting adjusting amounts task. The secondary outcome was motivation to engage in healthy behaviours measured through TSRQ. In this case we used a none-disease specific version of TSRQ which allowed participants themselves to choose a behaviour to focus on with provided suggestions such as: physical activity, diet, smoking cessation, reduced alcohol consumption or improved sleep habits. If a participant for instance had chosen to work with improved diet the TSRQ would cover motivation to engage in healthy dietary behaviours. TSRQ was used in this manner to allow users to work with their own goals through the EFT-application while keeping motivation to engage in a variety of health related behaviours comparable. Variants of TSRQ have already been used to measure motivation in settings equivalent to those researched in EFT studies, e.g., smoking cessation, physical activity and diet [199].

The systems usability was assessed using PSSUQ version 3 [200] with additional exploratory questions added aiming to contextualise PSSUQ answers such as good or bad aspects of the system.

Lastly, we aimed to capture perceptions of future thinking through weekly questionnaires pertaining to the different experience of engaging with EFT or in the control groups case the educational materials provided. The aim of this data being to compare how seemingly minor changes in the design affects user perceptions [201]. As such each study arm received weekly surveys asking questions about different sessions i.e., the self-guided generation task, reflection sessions for instance how participants approached these, their perceptions, perceived barriers etc.

6.1.1 Procedures

Recruitment occurred at DTU between January 4th and the 11th 2023 through university course announcements, messages, and email lists. Promotional materials included a general description of the study purpose and a link to the study website which contained more detailed information including the full subject information letter. Interested subjects could sign-up for the study through the website and subsequently received an email invitation to the study with instructions on creating a study account, downloading the app, and providing consent through the application.

Upon signing up participants were randomly assigned to one of the three study arms using a python script to block randomise participants [202]. We randomised in blocks of 6 participants (reflecting our 3 arms doubled) at a time to ensure groups remained equal throughout the sign-up and allocation process with a total of 90 possible allocation blocks.

Upon providing consent through the EFT-applications participants were presented with a brief welcome/introduction page for the app followed by initial measurements i.e., a demographic survey, baseline delay discounting measurement and the TSRQ measure. Once the measurements were completed participants were presented with the first self-guided generation task. After the creation of the first audio cue and associated image regular reflection sessions started showing up twice per day with image notifications appearing randomly twice throughout the day. Each week participants would additionally, receive a delay discounting and TSRQ measure along with the supplementary experience questions. On the final day of the study participants additionally received the PSSUQ.

6.2 Implementation

6.2.1 Overall changes

Between the first study and that described in this chapter a number of modifications were made to the EFT-application in order to improve the stability and fix various bugs reported in the feasibility study. A significant number of changes were also made to the application to comply with Flutter null safety introduced in between studies, potentially introducing new bugs. A number of improvements were also made to the application based on user feedback from the previous study e.g., progress bars were added to the self-guided generation task and an improved progress bar to the delay discounting adjusting amounts task to highlight progress.

A number of changes were also made aiming to improve the stability of background services. For instance the CARP mobile sensing framework was modified to allow automatic triggering of code tasks, whereas previously these were triggered indirectly by data collection events. Improved stability was also sought through improvements to the logic triggering notifications however, these improvements did not work consistently due to library conflicts between the original notification system and that supported by CARP in the latest versions of the framework. Consequently, the entire notification system had to be redesigned from the ground up centred around pre-scheduling of notifications whereas previously the notification system had only partially relied on pre-scheduling.

Lastly, all study surveys were coded and embedded directly into the EFT-application through the CARP research package in this case: TSRQ, PSSUQ and surveys on user's experiences were thus delivered through the application rather than through separate means.

6.2.2 Supporting study arms

To accommodate the study design a number of changes were made to the EFT-application the foremost of which was the support for the three study arms. Rather than creating and supporting multiple different versions of the EFT-application we choose to update it to support automatic assignment to study arms upon providing consent through CARP. This allowed each instance of the application to know its assigned study arm and to serve content specific to that condition i.e., gEFT, EFT or motivational materials. In the following paragraphs we will briefly highlight the major differences between study arms.

EFT: The EFT arm was largely unchanged from that described in the previous chapter 5, albeit with overall improvements to the application covered in the previous section.

gEFT: The main differences of the gEFT condition were that textual references to EFT were changed to include goals with the self-guided generation task likewise changed to support the creation of goal-oriented cues. The self-guided generation task asked users to explicitly tie goals to their episodic futures with provided examples updated to reflect this tie-in. Similarly, the image representation of the future event was changed to reflect goal-oriented imaging rather than reflecting the event it-self in a fashion more akin to its original use [41]. The text introducing users to the app was also modified to more explicitly link health goals and the future thinking.

Control: Compared with the intervention arms (gEFT & EFT) the control group did not receive any form of future thinking from the application. Instead the control group received a different introduction to the application reflecting general health goal-setting and two new sessions created for the control group. The first session covered general educational materials on goal-setting, how to get started with health-related goal-setting and how to apply it in practice. The first session further urged participants to use goal-setting and to use the educational materials as a basis for finding more techniques to support goals. The second session timed a few days after the first once again urged participants to use goal-setting or another self-discovered technique to support their goals if that had not already done so. Condition specific surveys were also added to reflect the materials provided rather than those of the EFT arms.

6.3 Principal findings

A total of 208 participants were enrolled in the study and randomised, of those 175 participants completed the in-app demographic questionnaire with 61.7% being male and 34.3% being from a none-majority group. A detailed overview of participant demographics can be found in table 6.2. Using one-way ANOVA we observed no significant differences between baseline characteristics gender (p=0.51), ethnicity (p=0.20) and income (p=0.10). We similarly, observed no group differences between baseline delay discounting, but did observe one difference between baseline TSRQ scores to question 12: "Because it is easier to do what I am told than think about it" (p=0.01). However, this difference was not observed in subsequent measures, the cause of the initial difference is not known.

Characteristics	Goal-Oriented	Classical EFT	Control
n	59	53	63
Age mean(SD)	25.22 (4.32)	24.66 (3.26)	24.41 (4.05)
Gender			
% Male (n)	66.1 (39)	56.6 (30)	61.9 (39)
% Female (n)	32.2 (19)	41.5 (22)	36.5 (23)
% Prefer not to say	1.7 (1)	1.9 (1)	1.6 (1)
Race/ethnicity			
% Non-minority (n)	62.7 (37)	60.4 (32)	73.0 (46)
% Minority (n)	30.5 (18)	33 (18)	25.4 (16)
% Prefer not to say (n)	6.8 (4)	5.7 (3)	1.6 (1)
Household income			
% <190.000dkk (n)	50.8 (30)	45.3 (24)	49.2 (31)
% >190.000dkk (n)	20.4 (12)	26.4 (14)	34.9 (22)
% Prefer not to say (n)	28.8 (17)	28.3 (15)	15.9 (10)

Table 6.2: Baseline characteristics of participants that completed the demographic survey for all study arms [198].

A total of 31 participants completed all measures across conditions specifically: 8 in goal-oriented, 9 in EFT and 14 in the control group. The study flow can be seen in Fig. 6.1, data from all participants whom provided consent have been included in our analysis.

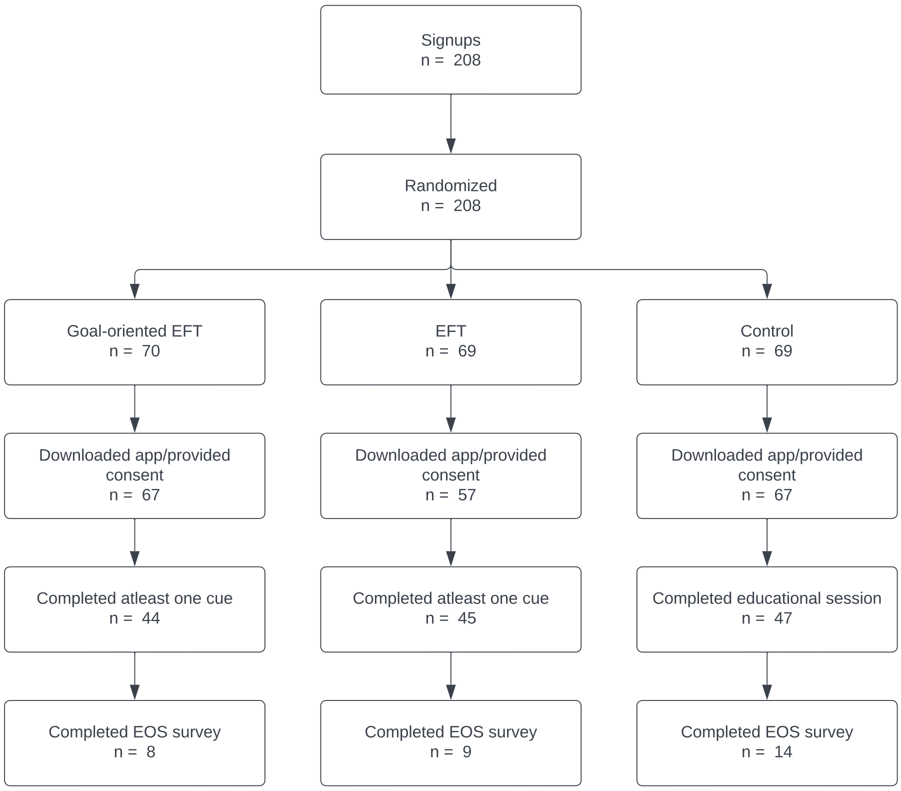


Figure 6.1: Overview of the participant flow, randomisation and retention through different phases of the study [198].

6.3.1 Primary & secondary outcomes

The discounting rate k was calculated based on individual discounting rates recorded through the indifference points reached in the adjusting amounts task. The mean discounting rate overtime between conditions throughout the study can be seen in Fig. 6.2. All discounting rates were manually checked for inconsistencies e.g., instances where participants always preferred the larger amount etc. Nonlinear regression (through SciPy v1.9.1) was used to fit the difference points across the delays and calculate the discounting rate. Differences between groups where compared with repeated measures ANOVA on log(k).

Analysis of the discounting rates revealed that a significant difference in discounting rate k was achieved by gEFT at the end of study compared to baseline (see Fig. 6.3) with the EFT condition showing a similar albeit not significant trend; likewise the control group did not show any significant change compared to the baseline. The end-of-study overall mean logarithmic delay discounting for gEFT was -7.33 compared to a baseline of -6.34; the difference of -0.99 $\pm$0.51 being statistically significant ($t=2.31$, $p=0.02$). The end-of-study overall mean logarithmic delay discounting for EFT was -7.37 at compared to a baseline of -6.52, with the difference of -0.85 $\pm$0.68 not being statistically significant ($t= 1.26$, $p=0.21$). Comparable yet not significant results were likewise observed when including only participants completing all 4 discounting measures, with gEFT showing a reduction of -0.84 $\pm$1.10 and EFT a reduction of -0.6 $\pm$0.93. The control group comparatively showed an increased discounting rate at 0.51 $\pm$0.56 and 0.66 $\pm$0.67, when including only participants having completed all discounting measures. Comparing different study arms at end of study shows statistically significant differences between gEFT and the control group ($t=-2.39$; $p = 0.02$) but not between EFT and the gEFT groups

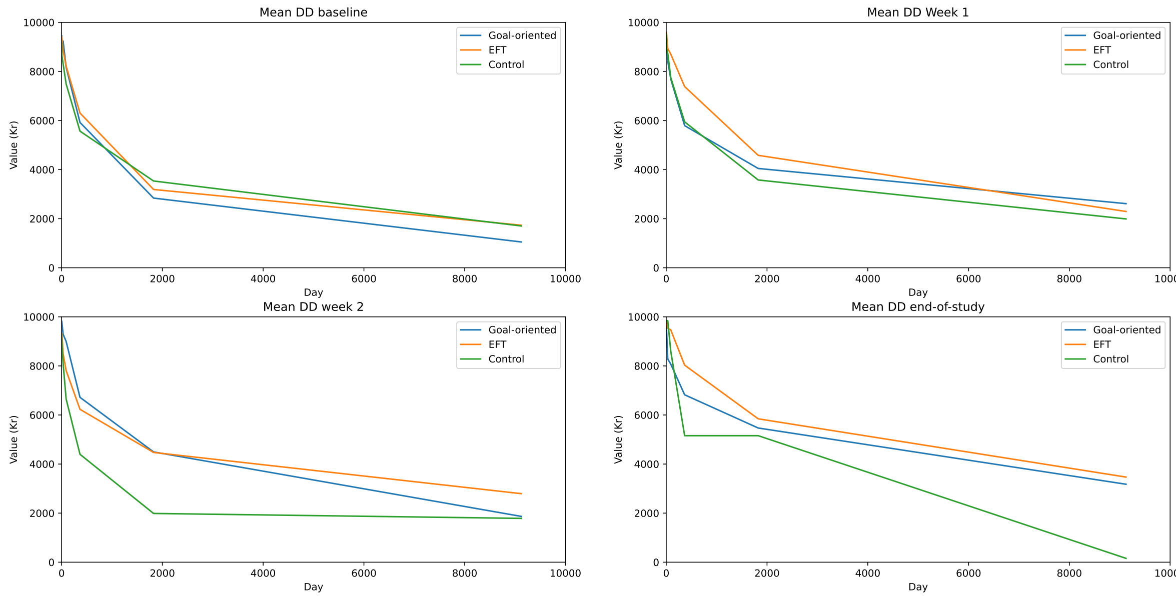


Figure 6.2: Weekly mean discounting for all three study conditions [198].

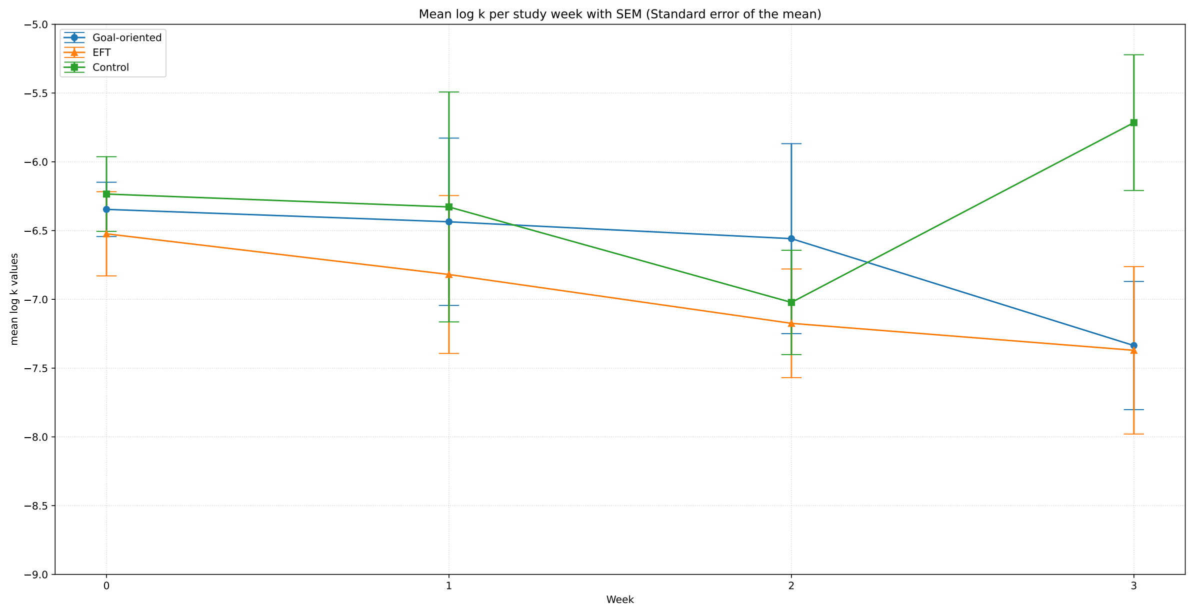


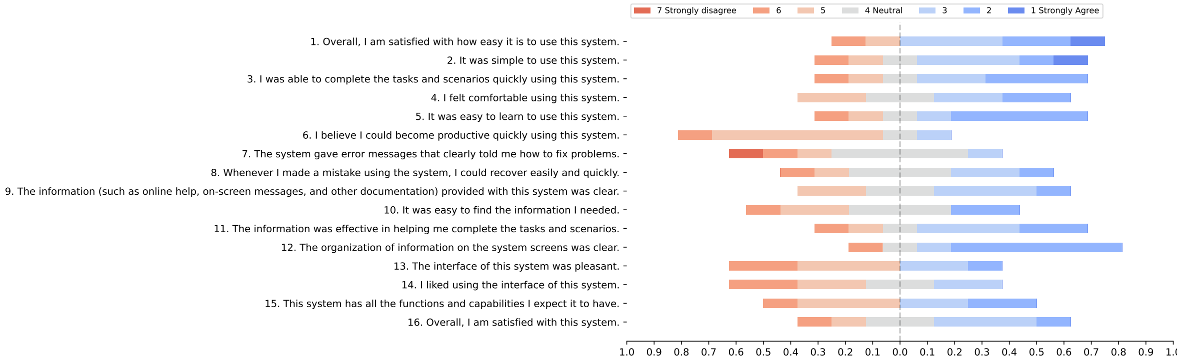
Figure 6.3: Log(k) discounting rate per condition throughout the course of the study [198].

(t=0.04; p = 0.96) and borderline significance between EFT and the control group (t=-2.04, p = 0.05).

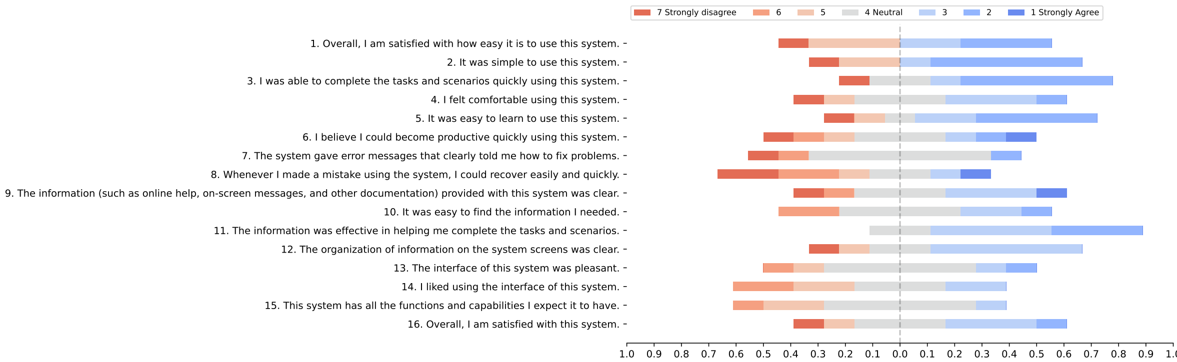
While the analysis of TSRQ scores showed some statistically significant changes had occurred, these changes were not consistent between weeks and thus no direct increases in motivation were observed. The TSRQ results can be seen in appendix D.

6.3.2 PSSUQ

The PSSUQ results for both intervention arms can be seen in Fig.6.4a and Fig.6.4b. The usability of the system measured through the PSSUQ generally showed positive perceptions through questions 1, 2, 3, 4, 5, 16 suggesting most participants found the system satisfactory, comfortable to use, learn and that tasks could be completed relatively easily and quickly. Additionally, questions such as 9, 11, 12 indicate that the information provided, task descriptions and organisation of information was generally perceived as sufficient. However, participants were more divided on questions (7,8,10) such as error messages, error recovery and the ease of finding information suggesting these to be areas that can be improved. Lastly participants were generally more negative towards questions 13, 14, 15 dealing with the user interface and system capabilities. The score of gEFT for question 6: "I believe I could become productive quickly



(a) PSSUQ scoring for gEFT.



(b) PSSUQ scoring for EFT.

Figure 6.4: Diverging stacked bar charts of gEFT (a) and EFT (b) PSSUQ scoring [198].

using this system" was lower than for EFT. Experience sampling suggests this to have been caused by the perception that the system did very little to directly support the goals embedded in gEFT and thus that the overall system was not conductive in fulfilling these goals. However, experience sampling also indicates that gEFT participants generally had an increased goal-awareness and a reduced number of statements indicating scepticism towards future thinking.

6.3.3 Attrition

The total study attrition was 83.58% for gEFT, 87.72% for EFT and 79% for the control group. The retention rate and active daily users can be seen in Fig. 6.5 with active users defined as those having completed one or more self-guided generation task or reflection session per day. Analysis of usage data shows that few users actually engaged with the system consistently and less still at the recommended frequency. For instance some users completed more sessions than recommended on some days and less or none other days. We note these usage patterns to be less than "ideal" given our previously recommended session frequency (as described in chapter 5.4) with few users engaging consistently with 2 audio-based projection sessions per day.

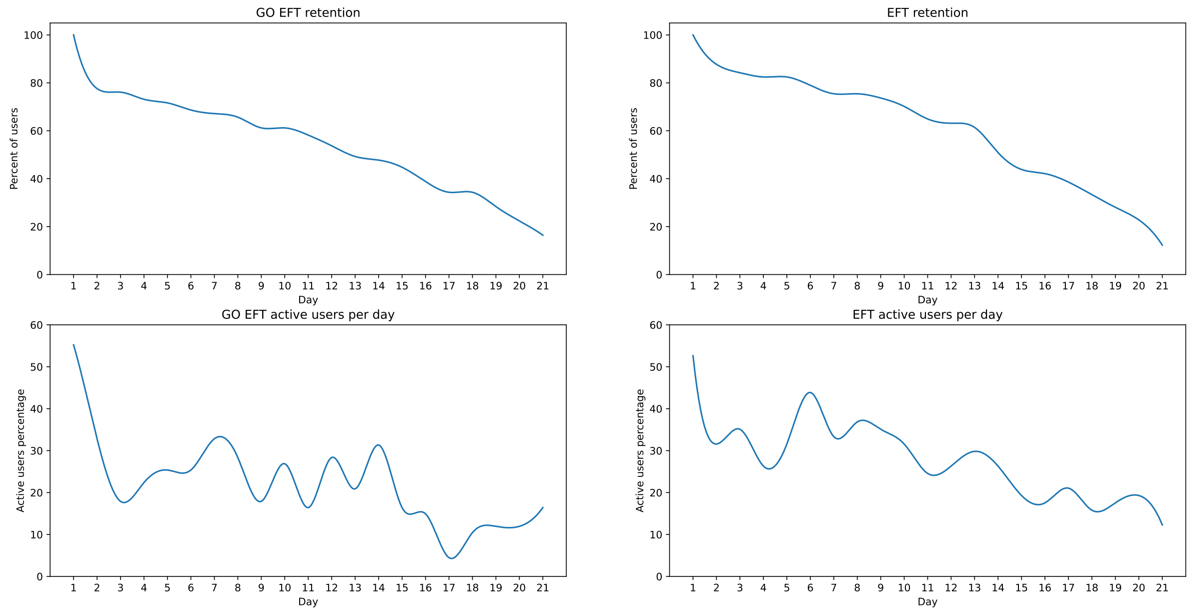


Figure 6.5: An overview of engagement with self-guided generation tasks and audio-based projection sessions. The left-most figures showing retention and active users for gEFT and the right-most figures the retention and active users for EFT. The top-most retention figures show overall retention and app attrition with the bottom-most figures showing the percent of users completing at least one session per day [198].

6.3.4 Qualitative data

A thematic analysis of experiences reported by participants revealed 2 domains with 9 themes, the first of these domains relating to the micro-interventions while the second relates to the system. Micro-intervention related themes include: tasks, one's own voice, contextual challenges, notifications, perceived effects, perceived usefulness and UX over time. In the system domain themes include: the interface, bugs and suggestions for improvement.

Tasks: While participants broadly expressed surprise and satisfaction with the micro-intervention duration's i.e., that these were quick they also noted that the self-guided generation task was more challenging. Two types of challenges are reflected in these comments: getting started on your first cue and imagining far away futures. In the former case participants noted that while the instructions and examples were useful, more examples and tips for creating your first cue would be useful. In the latter case and in line with the results of the previous study far-away futures were cited as being the most challenging to imagine. However, we also found some evidence supporting the hypothesis that the self-guided generation task has a learning curve effect as some participants noted quickly becoming unsatisfied with the quality of their cues opting to change/update them. Other participants noted that the self-guided generation task generally became easier over time especially when imagining events closer to the present.

One's own voice: Listening to one's own voice was likewise brought up by participants similar to the feasibility study. Accordingly, some participants expressed significant discomfort from listening to their own voice while others did not comment on the topic. Interestingly, some participants opted to mitigate this barrier in an unexpected way by simply not using the audio-based projection sessions and instead relying purely on image cues.

While comments about one's own voice persisted throughout the weekly experience questions, these generally lessened in quantity towards the end of the study. One possible reason for this could be that participants simply became more accustomed to their own voices as the study progressed. Alternatively, it could also be argued that participants retained towards the end of the study were simply more resilient to this barrier while those that were not dropped out adding to attrition. Both of these explanations seem tentatively supported by available data with some participants noting they became more accustomed to the sound of their voice. However, based on the quantity of comments and level of annoyance expressed the observed attrition is better explained by retained participants being more resilient to their own voice.

Contextual challenges: The contextual appropriateness of different micro-interventions were also cited as a barrier to some participants. E.g., needing a quiet place for recording, and similarly a quiet place for reviewing cues. However, contextual challenges were not mentioned in relation to image cues perhaps due to their use of an image resource and comparatively much shorter nature i.e., these can be consumed at a glance of the phone.

Notifications: The notifications provided by the application were also well-liked with the volume and relatively low intensity cited as a positive. Participants seemed universally satisfied with the image-based cues relative to the audio-based ones. Statements by some participants seem to indicate that the notification reminders of reflection sessions could themselves also serve as a form of EFT micro-intervention with some participants stating that the notification reminder of audio sessions was enough to prompt them to start thinking about their episodic futures.

Perceived effects: While most participants reported that they did not perceive any noticeable changes to their behaviours and decision a few actually did perceive a difference. Some participants described changing their in-moment behaviours positively due to thinking about the episodic futures and their embedded health goal. Those in the goal-oriented condition moreover perceived an increased awareness of health goals in everyday life and that they spent more time thinking about the future. The embedding of goals was well perceived with some participants noting that the future goals also prompted reflection on how one actually reaches these goals. Participants in the EFT condition similarly reported increased awareness of the future, but these expressions were comparatively more scarce. Although, some participants in both conditions noted scepticism of future thinking in general citing the perception that the micro-interventions did not seem to: "work for them personally".

Perceived usefulness: Generally, participants found the experience of engaging in future thinking pleasant, with image cues receiving favourable comments. Participants in the EFT condition were generally the most vocal in expressing doubt or scepticism of the EFTs effects while such comments were more scarce in the goal-oriented condition. Experiences seem to indicate that a variety of factors affected this perception, some participants cited personal preference, others noting lack of a particular need, and some noting the lack of perceived effects. A few participants further added that the EFT micro-interventions in isolation were not interesting enough to warrant continued engagement with the mHealth system and moreover that the system lacked feedback on for instance users goals.

UX over time: Throughout the course of the study several observations on the user experience over time was made by participants. For instance that created cues especially those closer to the present came to pass, making participants update their cues so these were once again future events. Another cause of updating cues over time came in the form of users growing tired or unsatisfied with their episodic futures prompting them to create new ones or update the existing ones. Interest in the micro-interventions was also noted to vary with some users noting decreasing interest in the interventions towards the latter half of the study supporting previous observations that there is a need for novelty in micro-intervention systems [32, 86].

Interface: As previously noted participants were generally more negative to PSSUQ questions 14 and 15 with participant comments contextualising this as: not liking the colour scheme of the application, the design of certain screens and the general polish of some user interfaces.

Bugs: Technical issues were brought up by participants as a general barrier to use. Several of the issues mentioned being traceable to background processes not working as intended especially on iOS. One notable example being an issue on iOS were putting the application into the background during the self-guided generation task could result in users having to re-record their audio cue.

Improvements: Various improvements were suggested by users, including the use of textual cues rather than audio-based ones and further splitting the cue-generation task in to different parts such as separating audio cue generation and mental imagery. Tailoring of intervention timing based on context, preferences and other multimedia were also suggested by participants. E.g., textual, audio or image cues may be contextually preferable and better suited to prompt future thinking at different times. Likewise different types of multimedia such as image or text may be better suited for facilitating future thinking in some users.

6.4 Implications for micro-interventions

The results of this study has several broad implications on the use of micro-interventions. Given micro-interventions short-term nature it is important for these to be both effective and preferable to users or as emphasised by JITAI: ”to use the right intervention at the right time” [28]. Despite our results showing that low intensity EFT micro-interventions can effectively modify delay discounting these micro-interventions may not be preferable to a majority of users. We see this reflected in both the observed attrition across conditions but also in user comments and in relation to mental imagery being notably preferred. Limiting user frustrations by personalising the delivered micro-intervention resources to match individual preferences may be key to achieving micro-interventions aim of matching users willingness or ability to engage. Thus while other multimedia formats may be less effective in reducing delay discounting these may engage users otherwise unwilling or unable to engage in audio-based EFT.

Similarly, the experiences sampled in this study support those previously observed in the feasibility study covered in chapter 5. In particular that EFT micro-interventions should be leveraged as a building block for larger narratives supported by other micro-interventions rather than used in isolation. Even though both intervention arms achieved their aims of reducing delay discounting interest in the micro-interventions were not enough to maintain engagement. Even among retained users expressions of monotony occurred relatively quickly i.e., within the 3 week study period. This implies that micro-intervention systems may need to account for a need for variation or novelty to maintain interest even short term.

Our findings are also in line with those previously reported in the micro-intervention workspace. For instance our findings support those of Howe et al. in that users prefer lower intensity interventions even if these are less effective [86] in this case reflected by users preference for image-based projection. Moreover, our findings also support both Howe et al. and Paredes et al.'s findings regarding the need for novelty [86, 32], and by extension the notion that micro-interventions should preferably be combined into narratives [29].

6.5 Chapter summary

In this chapter we presented the study design and results of a randomised study aiming to measure and compare the effects and perceptions of two types of EFT micro-interventions delivered through our updated mHealth application. While both intervention arms saw a mean reduction in participants' delay discounting, only gEFT achieved a statistically significant reduction. These results show that low intensity EFT micro-interventions may be able to effectively modify delay discounting within a relatively short time frame.

Despite the positive effects found, key issues and barriers remain reflected by high attrition across conditions. Chief among these barriers are: listening to one's own voice and the perceived value of EFT micro-interventions. Results of our thematic analysis indicate that gEFT does provide a clearer value proposition for future thinking through the inclusion of tangible goals, but not enough to offset barriers to future thinking in itself. Thus to summarise our main findings were:

- Both intervention arms successfully modified delay discounting rates observed among participants but with only gEFT achieving a statistically significant discounting rate at end-of-study.
- Insights from experience sampling further suggest gEFT may offer additional benefits for instance through goal-awareness, goal reflection and a clearer value of future thinking in general.
- However, despite the positive findings attrition remains a key issue, with associated factors in line with our previous findings. Our results indicate that there may be a need for enhancing the user experience of our system by serving additional micro-interventions as a more coherent narrative. These micro-interventions could for example address the need for personalising the EFT resources delivered to better suit users' preferences, or address the need for novelty or the lack of motivation from EFT micro-interventions served in isolation.

CHAPTER 7

A Design Framework for Micro-interventions in Mobile Health Technology

A recurring issue seen and experienced throughout much of the work covered by the previous chapters is the lack of a unified definition of what a single micro-intervention is and what components, structures and mechanisms support their delivery. While two definitions have been presented by Fuller et al. and Baumel et al. respectively these are not immediately reconcilable, nor are they sufficiently developed to encompass the uses seen in the broader literature. The term ”micro-intervention” thus differs sometimes subtly between definitions and observed usage. This lack of precise terminology makes it exceedingly difficult to not only design micro-interventions but also assess, evaluate, and compare previous micro-interventions. In this chapter we look at this issue through a systematic review and the theoretical work carried out in developing the ”D-MIST” framework for micro-intervention systems. Moreover, we look at the potential effects of different framework components and discuss the implications of the framework.

The following sections summarises and expand upon the paper:

Dan Roland Persson, Mel Ramasawmy, Nushrat Khan, Amitava Banerjee, Ann Blandford, Jakob E. Bardram & Per Bækgaard. A Design Framework for Micro-Interventions in Mobile Health Technology. [Submitted] CHI 2024.

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7.1 Systematic review

In order to comprehensively gather insights from the literature on micro-interventions we used four databases: ACM, Scopus, Pubmed, and Web of Science. The same search terms were employed across database, in this case: “micro-intervention” OR ”micro intervention” OR ”micro-interventions” OR ”micro interventions”. We choose these search terms to limit results to research which identifies it-self as employing micro-interventions rather than using more generic search terms. Particularly, to avoid results which resemble micro-interventions but were not imagined as such. Moreover, we have chosen to include all usage contexts targeting adults and include both non-digital and digital micro-interventions served on any platform. Our overall inclusion criteria are thus: 1) A peer-reviewed journal article or conference paper, 2) written in English, 3) describing the implementation of at least one micro-intervention or their key components, 4) working with adults, 5) targeting mental or physical health or well-being. The database search and retrieval process for the review was carried out in early to middle May 2022.

7.2 Principal findings

A total of 205 records were identified through included databases, 81 from Scopus, 27 from ACM and 58 from Web of Science and 39 from PubMed. After accounting for and removing 75 duplicates between databases 131 articles were screened by title and abstract. After this screening 107 articles were excluded leaving 24 articles that were sought retrieved for full-text eligibility review with 20 meeting our inclusion criteria. In the final round of screening two articles were removed based on the targeted users and two being removed due to being inaccessible. Fig. 7.1 shows the PRISMA flowchart representing this process.

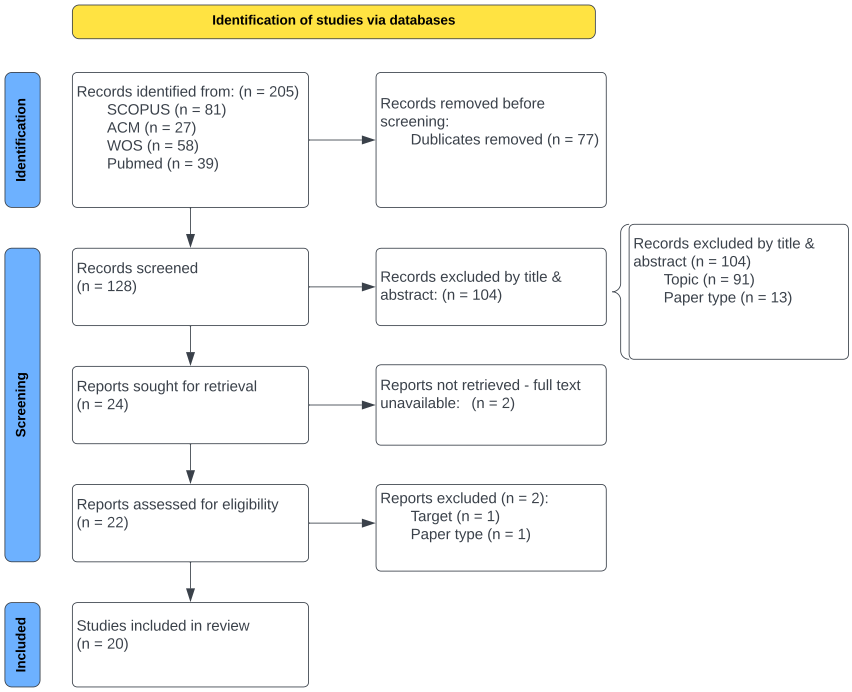

Figure 7.1: PRISMA flow diagram showing the article selection process [30].

An overview of the included literature can be found in table 7.1. The majority of included literature (n = 13) was published between 2020 and 2022 with remaining articles published between 2014-2020. The included studies are generally characterised by short intervention periods (7-28 days) with approximately half the literature reporting on early stage research such as development, pilot or feasibility studies. The other half describing various forms of randomised studies with between 2 and 4 arms. Study participants range from 0 to 838, with the study containing 0 participants working with experts rather than potential users. The number of micro-intervention events used were generally between 1-18. Notable exceptions include one study working contextual event detection rather than interventions [203] and the other working with a large variety of short messages [204]. In the following sections we will explore the literature on micro-interventions through the major components outlined by Baumel et al. (see section 2.3). Starting with the micro-intervention system or the hub as outlined by Baumel et al., followed by the "conceptual model" of the therapeutic process i.e., how micro-interventions in practice are chosen as steps in the therapeutic process, followed by the narrative presented. Afterwards, we will cover the micro-interventions, their events and the decision rules used to trigger these events.

Table 7.1: Key study characteristics of articles included, ordered by micro-intervention (M-I) target and year of publication [30].

Author	Year	Paper type	M-I target(s)	M-I Users	n user	t (M-I) days	M-I outcome	Digital (platform)
Howe E. et al. [86]	2022	Pilot (3 groups)	Stress	Information workers (All)	86	28	Positive	Yes (desktop/smartphone)
de Witte M. et al. [205]	2022	Development	Stress	All	0	0	N/A	No
Gummidela V.N.C. et al. [206]	2021	Mixed methods	Shallow breathing (stress/anxiety)	Adults	66	1	Positive	Yes (Smartphone)
Peeters, M.C.W. et al. [207]	2020	Pilot	Stress (cognitive appraisal of combining multiple roles)	Working mothers	240	7	Partly Positive	Yes (Smartphone)
Clarke S. et al. [208]	2017	Design	Stress	Adults	0	0	Positive	Yes (Smartphone)
Paredes P. et al. [32]	2014	Pilot (2x2 groups)	Stress	All	20	28	Positive	Yes (Smartphone)
Kim E. et al. [209]	2022	RT	Mood, motivation	Adults	838	1	Positive	Yes (Online)
Everitt N. et al. [210]	2021	RT (4 groups)	Mood	All	235	31	Positive	Yes (Smartphone)
Meinlschmidt G. et al. [211]	2020	Pilot	Mood	Adults	27	13	Positive	Yes (Smartphone)
Meinlschmidt G. et al. [82]	2016	Pilot	QoL (Mood)	All	27	13	Positive	Yes (Smartphone)
Matthews M. et al. [81]	2014	Pilot	Mood, well-being	Bipolar disorder	3	21-28	Positive	Yes (Smartphone)
Fraser E. et al. [212]	2022	RT (3 groups)	Body dissatisfaction	Young Women	176	1	Positive	Yes (Online)
Gobin K.C. et al. [213]	2022	RT	Body dissatisfaction	Young Women	230	1	Positive	Yes
Fuller-Tyszkiewicz M. et al. [31]	2019	RT	Body satisfaction	Women	247	21	Positive	Yes (Smartphone/PC)
Wahl K. et al. [203]	2022	Feasibility	Compulsive handwashing	OCD	21	1	Feasible	Yes (Smartwatch)
Vandesande S. et al. [191]	2022	Pilot	Parent self-efficacy	Parents of children with disabilities	16	21	Partly Positive	Yes (Online)
Malouff J.M. et al. [85]	2020	RT (2 groups)	Unpleasant dreams	Adults	126	1	Positive	Yes (Online)
Van Cappellen P. et al. [33]	2020	RT (2x2)	Increasing enjoyment and motivation to engage in meditation	Adults (midlife)	240	21	Positive	Partly (Ipod)
Conroy D.E. et al. [204]	2019	Pilot	Promote PA, reduce sedentary time	Adults	11	112	Positive	Yes (Phone)
Kivity Y. et al. [214]	2016	Diary Study	Social anxiety	Adults with high social anxiety	83	7	Positive	Parly (Online)

7.2.1 Micro-intervention systems

The micro-interventions seen in the included literature are almost exclusively delivered through various digital systems with one exception, music therapy, which is facilitated in person by a clinician using a dedicated space and musical instruments aiming to lower stress [205].

Howe et al. describes three ways of delivering micro-interventions namely, JIT, pre-scheduled and on-demand [86]. JIT as suggested by the name attempts to identify opportune moments of need to serve interventions automatically, while pre-scheduling allows users to choose future time periods to receive interventions with on-demand allowing users to choose when to engage on an as needed basis [86]. It is however worth noting these ways of interacting are not mutually exclusive as Howe et al. uses JIT and pre-scheduling in combination with on-demand. The paper by Meinlschmidt et al. similarly, describes a combinatory approach to delivering smartphone-based micro-interventions as these are pre-scheduled in the sense that daily engagement is expected, but with the timing left up to users i.e., on-demand [82]. Fuller et al. used on-demand micro-intervention videos with embedded before and after assessments through an online portal and app instructing participants to use the system as often or whenever they like [31]. On-demand systems can thus be characterised both by allowing users a choice of when to engage with micro-interventions but also which micro-interventions they engage in.

Pre-scheduled micro-intervention systems meanwhile allow users to choose times in advance where they believe they will be open to engagement. In Howe et al.'s system this is handled by users choosing the intervention at the time of scheduling while Meinlschmidt et al. allows users to choose in moment [82]. Malouff et al. also uses pre-scheduling to affect unpleasant dreams in the sense that the micro-intervention must be used just before going to bed [85].

Lastly, JIT micro-intervention systems may choose the micro-intervention most appropriate for users in a given circumstance or choose when users are most likely to need an intervention. The system described by Paredes et al. for instance aimed to match interventions with user's contextual needs, finding that machine learning could be used to improve engagement and efficacy [32]. Howe et al.'s system meanwhile prompted users to choose between one in three micro-interventions when the system detected a stress reduction was needed [86]. Micro-intervention systems delivering JIT additionally contain various features for data collection used to determine when, where and which micro-interventions to deliver. Some systems rely on subjective assessments such as questionnaires [211], short surveys [213] or other forms of data collection such as biometric [208, 86]. One application for instance used a "Microsoft Band" (Smartwatch) to identify moments of stress through embedded heart rate and activity recognition sensors [208]. Another application leveraged: email volume, calendar saturation, time of day, facial expression, heart rate, and ecological momentary stress assessments to determine a stress score used to decide when to deliver interventions [86].

7.2.2 Conceptual model

Throughout the literature we see a number of different factors used to determine which micro-intervention should be deployed in the current context, an overview of which is shown in Fig. 7.2. Common factors for deciding between interventions are targets (e.g., stress [208], mood [209]), user needs [210], user traits [32] and preferences [86]. It is worth noting however, that the current literature generally does not explicitly detail how and when individual micro-interventions can or should be used as steps in a therapeutic process. Moreover, many systems allow users themselves to determine when and which interventions they engage with [31, 82].

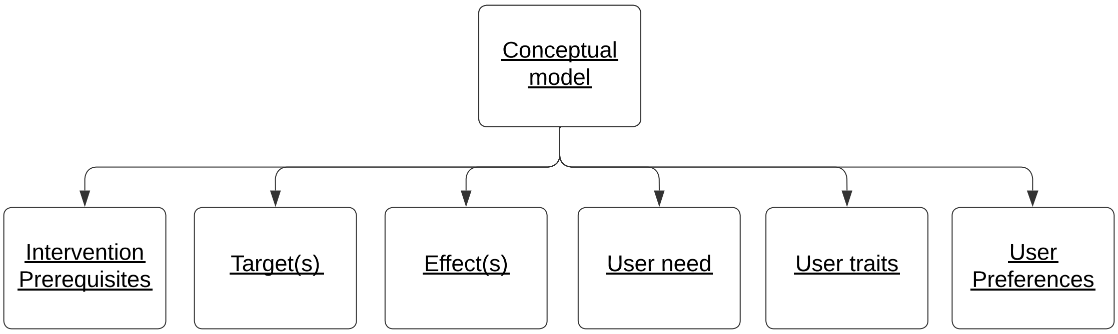

Figure 7.2: Overview of factors that could affect when and where micro-interventions are deployed through conceptual models of the therapeutic process [30].

The user's role in micro-intervention systems can be both as a recipient or active partaker in the decision process. Micro-interventions systems therefore fall into one of three categories: 1) instances where users predominantly act as primary decision makers [82, 31, 211], 2) instances wherein the system acts as the primary decision maker [210, 86] and 3) hybrid approaches where both user and system collaboratively decides [32, 207, 86]. The relationship between these decision makers can be imagined as a form of continuum as visualised in Fig. 7.3, with user and system on opposite ends of said continuum.

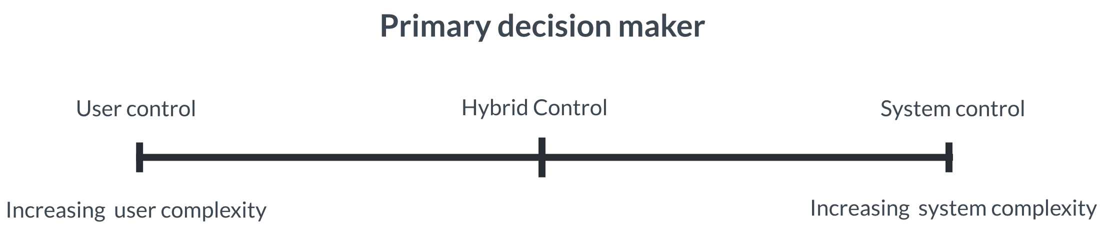

Figure 7.3: The decision-making continuum seen in micro-intervention systems, with most systems belonging to the hybrid category [30].

It can also be said that Fig.7.3 is a simplified submodel of the general interactions between users and systems as previously contextualised [215]. The work of Parasuraman et al. for instance describes the relationship between system and user as being on one of 10 levels, where the highest level (10) largely ignores the human [215]. Contrary to the model presented Parasuraman et al. we note that the micro-intervention systems cannot operate without humans that consume interventions and so the micro-intervention continuum operates only within the lower-end subset of Parasuraman et al.'s automation levels (1-5) i.e., between 5. executes that suggestion if the human approves and 1. the computer offers no assistance: human must take all decisions and actions [215].

Given the aforementioned problems with the terminology used by different authors relating to what is considered a micro-intervention and an event, it is likewise difficult to distinguish between conceptual models and decision rules. In the upcoming section on decision rules we will go over these jointly rather than separately.

7.2.3 Narratives

While only three of the included studies explicitly detail longer term narrative considerations, most literature (n = 10) did utilise simple forms of narratives through their designs with either system [210], event ordering [191], random chance [32], or user choice [82] dictating the flow of the narrative. While we use the phrase ”longer term narrative” to denote long term engagement through serving multiple micro-interventions over time it is important to contextualise this to current research. That is to say a limitation of the current literature is the short-term nature of studies especially when compared with the scope of more traditional behaviour change which may require years of maintenance [38]. Thus when discussing long term, we generally refer to the scope of current research i.e., beyond 14-21 days. In this case we take the terminology ”simple narratives” to describe narratives that do not expressly consider the broader application or combination of micro-interventions.

For instance Meinlschmidt et al. allows users themselves to choose a micro-intervention in moment [82] with user choice thus dictating the narrative structure. Similarly, Fuller et al. despite providing arguably semi-sequential micro-interventions (i.e., order dependent) also allows users to more or less freely use these in any order [31]. The system by Paredes et al. on the other hand uses a recommender system to match micro-interventions with context and users personality, subsequently discussing longer term narrative implications such as the need for novelty [32].

In terms of longer narrative considerations one paper speculates that micro-intervention systems modifying mood through its micro-interventions may be used as a long term early warning system for changes in mental well-being [81]. Noting such systems could be used in care settings by both patients and clinicians to facilitate long term management of serious mental illness by providing context aware micro-interventions based on users needs [81]. De Witte et al. similarly considers that a narrative value of their micro-interventions lies in reducing stress which impacts both concentration and learning allowing potentially improved uptake of educational interventions or other interventions that may benefit from a reduction in stress [205]. Van Capellen et al. meanwhile demonstrated that a micro-intervention could be used to increase the enjoyment of and motivation to engage with another micro-intervention [33].

7.2.4 Micro-interventions

Most of the micro-interventions included in the review targeted three symptoms: stress (n = 6), mood (n = 5) and body satisfaction (n = 3). The remaining literature targeted more abstract concepts such as quantity of unpleasant dreams [85], parent self-efficacy [191], compulsive handwashing [203], social anxiety [214] or promoted physical activity [204]. An overview of the micro-interventions can be found in table 7.2.

Micro-interventions targeting stress use various techniques to reduce symptoms, for instance de Witte et al. uses short music therapy sessions to mitigate stress [205]. Paredes et al. uses 4 therapy groups as the basis for their micro-interventions: 1) Positive psychology, 2) cognitive behavioural, 3) meta-cognitive, 4) somatic with each intervention delivered as a prompt and resource URL (linking to e.g., a game) [32]. Clarke et al. based on the work of Paredes et al. used similar therapy groups, but with micro-interventions linking to other separate applications [208]. Other means of affecting stress include various exercises for instance ”feel calm and present” [86] and a game using biofeedback to reduce shallow breathing as a proxy for stress [206].

Table 7.2: Study characteristics of the micro-interventions, events and resources employed [30].

Author	M-I intervention(s)	Event type	Events	Resource(s)
Howe E. et al. [86]	”Get my mind off work”, ”Feel calm and present”. ”Think through my stress”	Variations/Repetitions	3	Videos, chatbot conversation, activity suggestion
de Witte M. et al. [205]	Music therapy	Variations	2	Therapist facilitation
Gummidela V.N.C. et al. [206]	Game Biofeedback, visual feedback, game with Pacing, pacing	Repetitions	4	Game, visual or audio feedback
Peeters, M.C.W. et al. [207]	”Use your resources” & ”Count your blessings”	Repetitions	2	Email, text
Clarke S. et al. [208]	Positive psychology, cognitive behavioural, meta-cognitive, and somatic	Repetitions	18	Applications
Paredes P. et al. [32]	Positive psychology, cognitive behavioural, meta-cognitive, and somatic	Repetitions/Single	16	Text/URL to web apps
Kim E. et al. [209]	Behavioral activation (scheduling exercise)	Single	1	Text, Exercise
Everitt N. et al. [210]	Mindfulness exercise, relaxation exercise	Repetition	4	Audio exercise
Meinlschmidt G. et al.(2020) [211]	Viscerosensory attention, emotional imagery, facial expression, contemplative repetition	Single/Repetition	4	Short video clip
Meinlschmidt G. et al.(2016) [82]	Viscerosensory attention, emotional imagery, facial expression, and contemplative repetition	Repetitions	4	Text, Videos, audio
Matthews M. et al. [81]	Visualised digest	Repetitions	1(+)	Visualisation
Fraser E. et al. [212]	Gratitude meditation, mindfulness meditation	Single	2	Audio guide
Gobin K.C. et al. [213]	Self-compassion	Single	1	Written task
Fuller-Tyszkiewicz M. et al. [31]	Gratitude task, breathing, and relaxation	Variations/Repetitions	11	Videos (Education/Exercises)
Wahl K. et al. [203]	N/A	Single	0	N/A
Vandesande S. et al. [191]	Psychoeducation	Sequence	4	Video series
Malouff J.M. et al. [85]	Vivid recall of positive events	Single	1	Text
Van Cappellen P. et al. [33]	Loving-kindness meditation or mindfulness and educational passage (positivity plus vs control passage)	Single/Sequence/Repetitions	4	Text (Educational), Audio (Exercise)
Conroy D.E. et al. [204]	Motivational, educational, or action messages	Variations	456	Text
Kivity Y. et al. [214]	Reappraisal	Repetitions	2	Reappraisal training (in-person)

Modification of mood is handled by various exercises [210], visualised digests [81], behavioural activation [209], viscerosensory attention, emotional imagery, facial expression, and contemplative exercises [82, 211]. Everitt et al. for instance uses mindfulness and relaxation exercises to positively affect mood [210], while Kim et al. used a combination of psychoeducation and scheduling exercises to facilitate behavioural activation [209].

Modification of body image is similarly handled by a number of exercises e.g., meditation [212], self-compassion [213], or various tasks such as gratitude and breathing [31].

In terms of other aims Malouff et al. uses vivid recall of positive events to reduce the number of unpleasant dreams [85] while Vandesande et al. uses psychoeducation to increase parent self-efficacy [191]. Kivity et al. uses reappraisal techniques to reduce anxiety [214] and Conroy et al. uses messages to promote and increase physical activity [204].

It is once more necessary to highlight the problem arising from the lack of a unified terminology in the literature and especially the nuances presented by Baumel et al. between micro-interventions and events [29]. For instance Paredes et al.'s wording clearly indicates that each instance of a prompt and URL should be considered a unique micro-intervention [32] whereas by Baumel et al.'s conceptualisation it could/should be argued that these are events [29]. The 11 videos used by Fuller et al. could similarly be considered as 11 micro-interventions given each videos unique content [31] or could be considered one or more micro-intervention covering 11 semi-sequential events [29]. In this case we say these are semi-sequential given that the video descriptions allude to a relationship between some videos e.g., ”10 Gratitude exercise” and ”11 Gratitude additional examples” [31]. The psychoeducational videos used by Vandesande et al. are in ways reminiscent of those by Fuller et al. but differentiates themselves in that these are explicitly to be consumed in a certain order [191]. Consequently, there are potential biases in our interpretations of various authors works given the connotation used by the various authors. In the following sections we will mostly ignore these discrepancies and go over events as we interpret them according to Baumel et al.'s definition: with each event acting as the in-moment attempt for change [29]. However, we will return to and attempt to resolve these discrepancies when presenting our framework later in this chapter.

7.2.5 Events

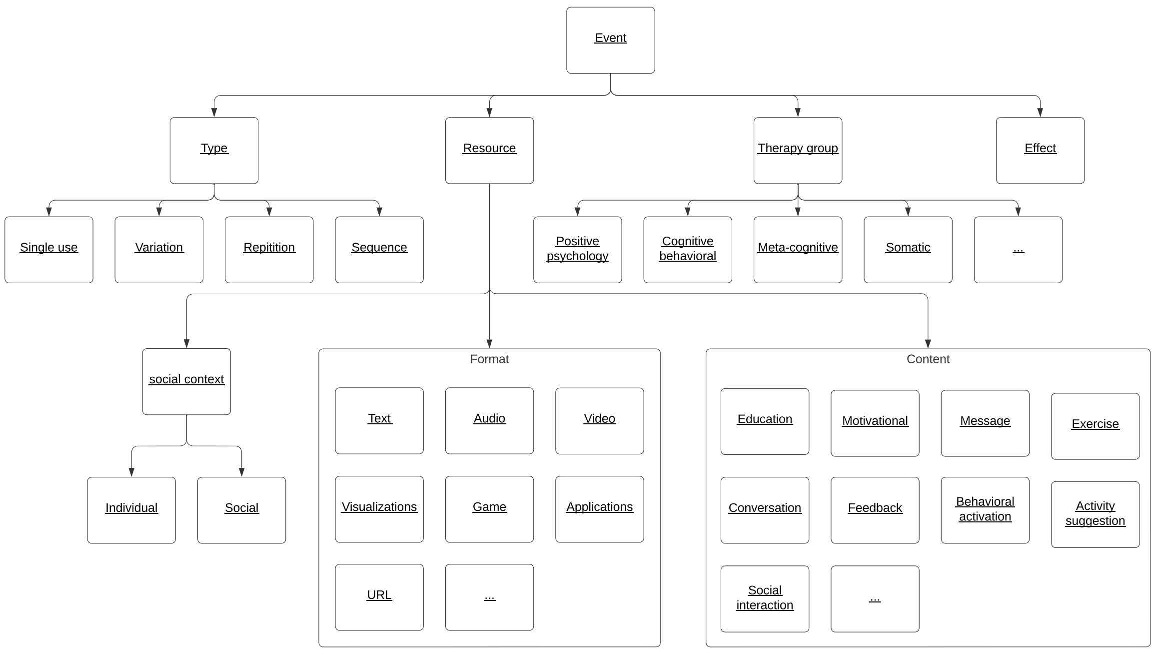

Figure 7.4: Synthesised overview of events seen throughout the reviewed literature [30].

The number of events i.e., unique attempts at momentary change presented by each study generally varies greatly in the included literature between 0 and 456, with most papers including 1-18 unique events. As previously mentioned, the two outliers 0 and 456 are related to a paper working with JIT detection for micro-interventions [203] and one using various messages to increase physical activity [204]. A synthesised overview of events and their components can be seen in Fig. 7.4. An event is characterised by delivering a resource containing a piece of content responsible for achieving a momentary change resulting in an event effect which can be measured by proximal outcome assessments. By Fuller et al.'s definition of micro-interventions the resources delivered by events pertain to one of three types: single use, variation or repetition [31], to which we add the type "sequential" as observed in the work by Vandesande et al [191]. Moreover, each event can be further classified by which therapy group they belong to in line with the work of Paredes et al., however the classification of events included in this review is beyond the scope of this work.

As previously described, the events used by Vandesande et al. and Fuller et al. both utilise video resources with employed content aiming to educate or serve exercises [31, 191]. The work by Paredes et al. likewise makes use of videos but to a lesser extend with URL linked resources including games, news, social media, exercises, or funny cats and moreover distinguishes between individual or social micro-interventions (in this case events) [32]. Clarke et al. also delivers events by linking to resources in this case applications with provided examples including reflection, guided meditation and breathing exercise applications [208]. Exercises are delivered by a variety of formats such as audio [210], manually by a clinician [205] or by text [82, 211, 86]. For instance, Howe et al. delivers textual resources describing momentary exercises but delivers these through pre-scheduling or through interactions with a chatbot [86]. We therefore see event resources utilise a number of formats: text [86], audio [33], video [191], games [206], applications [208], prompts [210], or combinations of these. Most commonly we see these deliver exercises [210], education [191], or various therapeutic techniques such as behavioural activation [209].

7.2.6 Decision rules

Decision rules are used to determine when and where an event should be deployed [29]. Literature on JITAIs adds that decision rules should be seen as a way of operationalising the delivery of interventions as well as for options tailoring the intervention [216]. Fig. 7.5 shows an overview of synthesised decision rules.

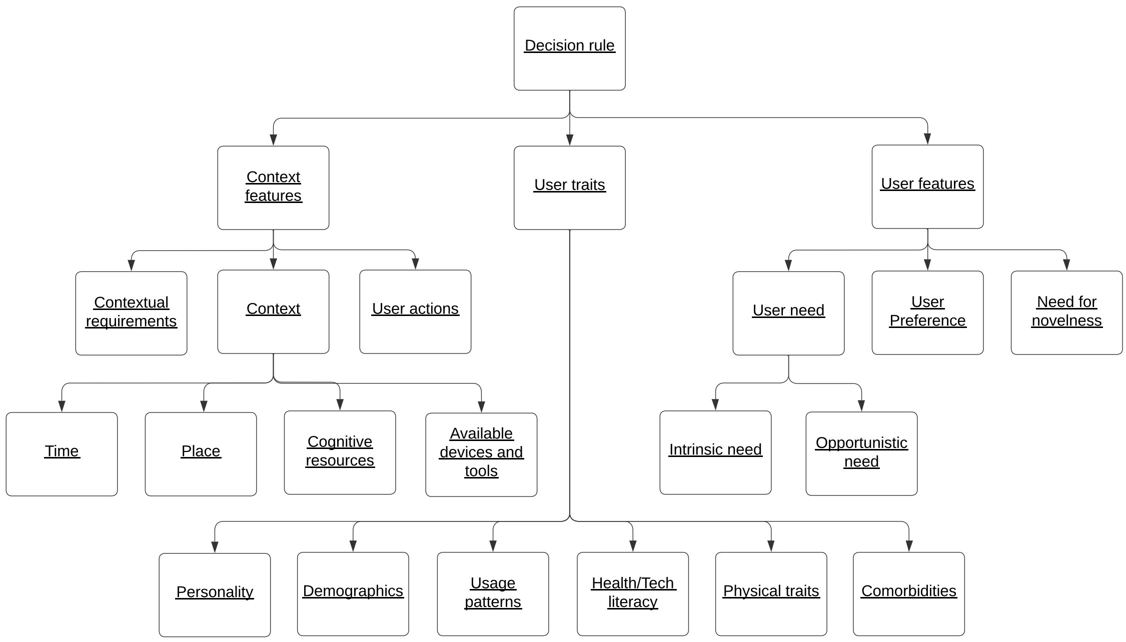

Figure 7.5: Synthesised overview of decision rules seen throughout the reviewed literature [30].

The work of Clarke et al. describes the use of a stress detection module and a recommender module aiming to deliver JITAI micro-interventions to affect stress identifying moments of high heart rates and using these as a decision rule for when to deliver events chosen by the recommender module [208]. Howe et al. similarly aims to target stress but which provides a more comprehensive description of decision rules [86]: with 6 decision rules employed: 1) a computed stress score, 2) it being a weekday and within working hours, 3) no other interventions scheduled later, 4) the user not having completed an intervention in the past hour, 5) the user having not been sent a nudge within 2 hours, 6) and the total nudges not having exceeded four today [86]. In this case the computed stress score is based on work parameters such as email volume, calendar saturation, time of day, facial expression, heart rate and ecological momentary assessments. Other applications have used both smartwatches [208] and a bioharness chest strap to measure breathing as a proxy for stress [206]. Paredes et al. describes the use of a recommendation system that leverages a large variety of data: personality, demographic, comorbidity (depression, coping), reported mood/energy, global positioning system, calendar, time, accelerometer, and screen lock [32]. Proximal effect assessments are likewise used as a data source for improving the relevance of intervention as seen in Clark et al.'s work, but other assessments employed in the literature could likely be used for similar purposes such as: Multidimensional Mood State Questionnaire [211] or ”State body image (Visual analogue scales)” [213].

Users themselves often have significant agency over the delivery of events either in terms of timing or the event/micro-intervention used. In the literature we see users decide timing based on an identified need or through identifying an opportune moment e.g., in between meetings rather than in the meetings where the need may technically be greater. Studies indicate factors such as perceived usefulness [210], perceived effort [86], preference [82] and novelty all play key roles in users' decision making process [32]. However, the mechanisms and consequently the ”decision rules” employed by users themselves to determine event timing and which intervention to engage in is generally an under explored topic in current micro-intervention literature.

7.3 Developing the framework

Our reasoning for creating the D-MIST framework (”Design of Micro-Intervention System Technology” Framework) is manyfold: Firstly, we believe the lack of a clear conceptual understanding and definition of what a micro-intervention is hampers the development of new micro-interventions. Secondly, the lack of an adequate understanding of micro-interventions components and the structures facilitating their delivery makes these difficult to assess, evaluate and moreover makes it difficult to compare micro-interventions previously presented especially when these rely on differing definitions often implicitly described. Thirdly, for micro-interventions to be effective we need to understand how these operate both short term and long term with appropriate means of evaluating their effects. Finally, we believe a unified framework may enhance the quality of future research by adding to the transparency of that research and to ensure reproducibility in the description of micro-interventions and their systems.

7.3.1 Methods

Within the space of software engineering Ralph Johnson described an ”ideal” way of developing frameworks: First analyse the problem, abstractions and collect examples, then model abstractions that cover identified examples and finally test the framework by using it to resolve those examples [217]. Accordingly, in the previous sections we have collected examples of micro-interventions, their supporting structures, various definitions and identified problems brought about by these differences.

The development of the framework continued by synthesising and modelling the components of micro-interventions; examples of this modelling work can be seen in the figures showing components of events and decision rules (Fig. 7.4 and 7.5). Discrepancies between previous definitions and uses were further identified and discussed among collaborators. Finally, components were incorporated and fitted into a unified framework, which we checked against the existing literature and our prior works to ensure the framework encompassed these.

7.4 The D-MIST Framework

The Design for Micro-Intervention Software Technology (D-MIST) framework can be seen in Fig. 7.6 with table 7.3 containing the definitions of the framework's components.

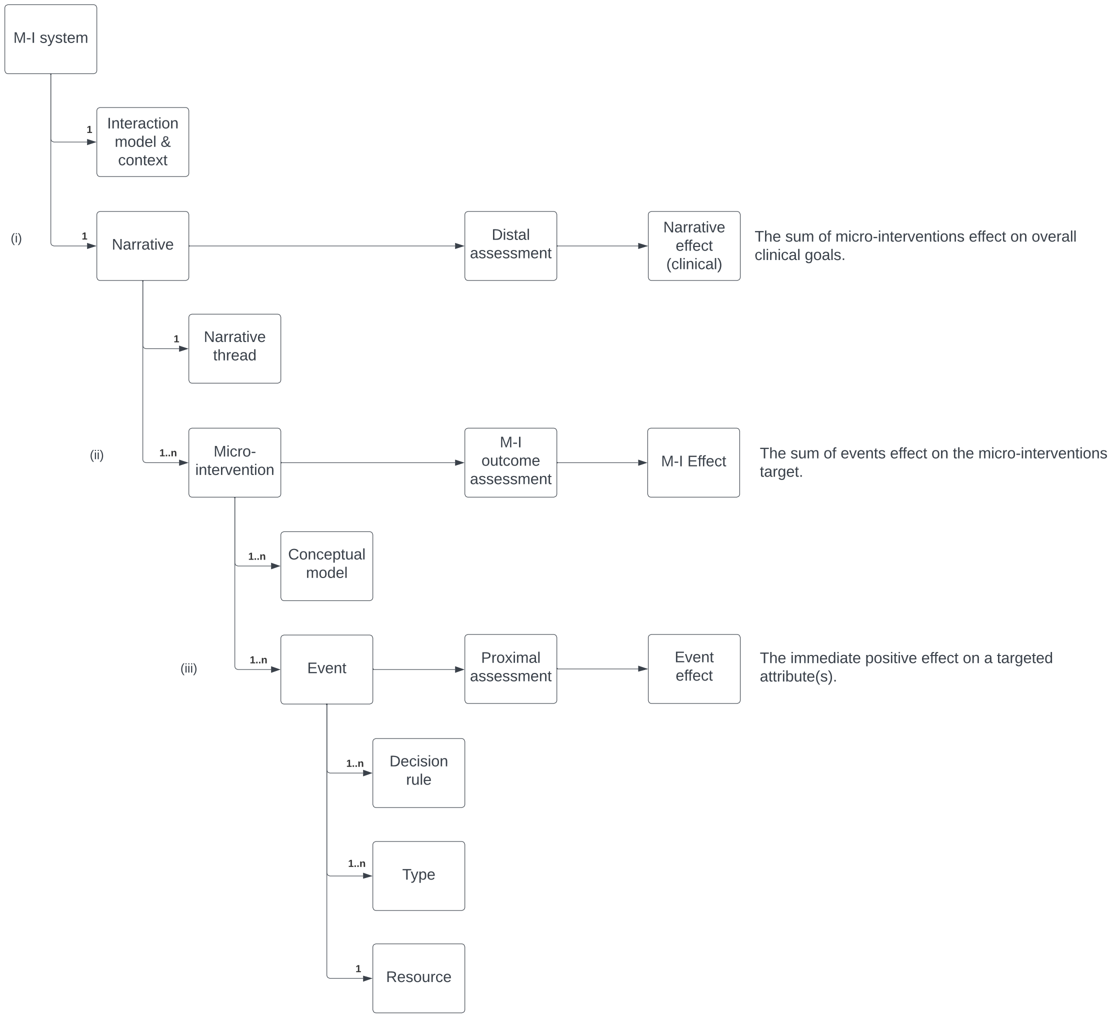

Figure 7.6: Overview of the D-MIST framework showing the major components of a micro-intervention system including how such systems achieve different effects. These components include (i) the narrative, (ii) micro-interventions, and (iii) events. [30] The abbreviation M-I standing for micro-intervention.

The framework defines a micro-intervention system as operating on three different levels: (i) the **narrative**, (ii) the **micro-intervention**, and (iii) the **event** level. The effects of each of these levels can be seen as interconnected in the sense that the micro-intervention effect is the sum of its events' effects and the overall narrative effect is the sum of its employed micro-interventions.

We see the aims of the system as a) creating and maintaining a narrative, by b) serving relevant micro-interventions c) through recognition of the user's situation, context, and needs, similar to Baumel et al.'s hub [29]. In practice the system achieves this through its design and interaction model. For instance an on-demand system in line with that of Paredes et al. could recommend micro-interventions based on context [32] or other actors e.g., healthcare providers to fulfil the aims of the system.

The narrative itself is told through the micro-interventions employed and the momentary events utilised by these. The role of the narrative is to synergise effects between individual micro-interventions and consolidate the experience in support of the narrative goal (e.g., a clinical or treatment goal). We refer to the created narrative as the "narrative tread" representing the events experienced of which overall each step is determined by the best fitting conceptual model.

M-I system	The micro-intervention system through its design and interaction model aims to facilitate (i) the creation and maintenance of a narrative, (ii) by serving relevant micro-interventions, (iii) through recognition of the users' situation, context, and needs
Interaction model	The interaction model formalises how the aims of the system are achieved through the user's interactions with the system (e.g., JIT, on-demand) and other actors (e.g., health coaches, relatives).
Narrative	A narrative aims to create a meaningful story through its micro-interventions and the events as experienced by the user through a narrative thread aiming to synergise individual micro-interventions effects towards the goal of the narrative.
Narrative thread	The narrative thread is the list of experienced micro-interventions through their corresponding events, where each step is determined by the user's circumstances and the best fitting conceptual model.
Micro-intervention	A micro-intervention is a highly focused type of therapy relying on one or more events of a given type, each attempting some momentary change.
Conceptual model(s)	Conceptual model(s) describe the conditions for when and where a micro-intervention is relevant and can be used as part of a narrative.
Event	An event provides a resource based on its intended type and therapeutic group with an immediate positive effect on target attribute(s).
Decision rules	Decision rules determine which events should be triggered, the intensity of the event, and the condition under which they should be triggered (e.g., contextual factors, time of day, or user's state).
Type	The event type refers to the way the event is used. Events can be classified as single-use, repeated, varied, sequential or adaptive.
Resource	Each resource provides a piece of content (e.g., a video, exercise, or call to action) in various formats aiming to facilitate an immediate positive effect

Table 7.3: Key terms and definitions of the D-MIST framework [30].

The micro-intervention is a highly focused therapy relying on one or more events aiming to facilitate momentary change. Each micro-intervention may serve different roles in different narratives based on e.g., user need or preference with the roles represented by each micro-intervention's intended conceptual model(s). The conceptual models describe the conditions for when and where a micro-intervention is relevant in a narrative, such as excluding audio-based EFT in situations where it may not be personally or contextually preferable to users even if they could benefit from reduced delay discounting.

The event contains a resource, which intends to have an immediate impact on targeted attributes with the delivery of these events determined by decision rules. The resource serves a piece of content responsible for achieving the immediate effect with the type referring to how each intervention is used, e.g., single use, repeated or sequential. In the following sections we will go over each of the frameworks components and delve into their rationale.

7.4.1 Micro-intervention system

In previous works the role of the system has only been loosely defined, for instance in Baumel et al.'s conceptualisation of digital micro-intervention care a "hub" is described which may or may not be fulfilled by a digital system [29]. The aims of the hub as described by Baumel et al. is to create an integrated experience by "...(1) recognising an individual's state and context, (2) recommending interventions that are relevant, and (3) helping create and maintain the right narrative, meaning, and values that derive from each intervention and linking it to the larger therapeutic process"- Baumel et al. [29]. Thus any entity fulfilling these aims could be considered a micro-intervention hub with provided examples suggesting it could be: "a digital application, a human technology coach, a consumer who self-manages his or her state, or a psychotherapist" - Baumel et al. [29]. However, we find this definition problematic for two reasons: firstly, by the fact that the role of the system is not adequately described and secondly, that the interactions between actors is not expressly considered e.g., user, system, and care provider. Moreover as seen in section 7.2.1 we see cases from the literature wherein no single entity completely fulfils the aims of Baumel et al.'s hub in practice [32, 82, 211, 86, 210]. Rather we see the aims collectively fulfilled by the interactions between user and system. In real-world care settings such as the one described by Matthews et al. other actors such as care providers could also be included in these interactions adding to the complexity [81]. For instance systems may recognise the need for an intervention JIT in line with point (1) but where the system allows users to choose the intervention in line with (2) [86]. For example, the system presented by Paredes et al. allows the users to choose when to request an intervention with the system recommending an intervention based on users needs [32]. This system thus fulfils the aims presented by 1) having users recognise state and context for when to request an intervention, 2) having the system recommend an intervention based on user's state through assessment, and 3) by creating and maintaining a narrative collaboratively decided by user and system. We therefore formalise the role of the micro-intervention system as being:

- *The micro-intervention system through its design and interaction model aims to facilitate 1) the creation and maintenance of a narrative 2) by serving relevant micro-interventions 3) through recognition of users' situation, context and needs.*

In this case we use the terminology "aims to facilitate" as we see the system it-self as not necessarily accomplishing these aims on its own but rather through the interactions it facilitates. We also highlight the "by serving relevant micro-interventions" part of our definition as we believe it to be a universal trait of micro-intervention systems to be the entity serving micro-intervention event resources.

From a design perspective we see several exciting ways of blending these aims to suit users that might have different needs or preferences for agency. JIT systems could for instance present users with options to choose from freely or recommend interventions deemed especially well-suited for the user by either system or care provider. Pre-scheduled micro-intervention systems could likewise both recommend times helping the user schedule interventions or provide users with suggested micro-interventions for those times.

7.4.2 Interaction model

Our idea of explaining how a micro-intervention system practically achieves the aims of the system through an interaction model was inspired by classical flow modelling from UX research [218]. We refer to this as an interaction model rather than flow model as we believe it necessary to not only formalise the actor's role in achieving the systems aims but also to describe the interactions themselves i.e., JIT, pre-scheduling, on-demand or combinations of these. For these reasons we define the interaction model as:

- *The interaction model formalises how the aims of the system are achieved through users' interactions with the system (e.g., JIT, on-demand) and other actors (e.g., GP, health coaches, other users).*

7.4.3 Narrative

Baumel et al. previously described the therapeutic narrative as: the linking agent that consolidates the experience between micro-interventions [29]. In a more literary sense of the word we see a micro-intervention narrative as: "a particular way of explaining or understanding events" - Cambridge dictionary [219]. The role of the narrative as we see it is therefore not only to serve as a linking agent between micro-interventions but also a concrete way of understanding the micro-interventions and events deployed. Thus the narrative tells a story through its micro-interventions and the events experienced by users with the aim of achieving larger treatment goals.

A micro-intervention system may provide a number of different possible *narratives* through its available *micro-intervention catalogue* and the *conceptual models* presented by these. We dub the created narrative the *narrative thread* with each step determined by the alignment of goal and user needs. In this way each micro-intervention can be seen as a self-contained limited "program" of sorts aiming to achieve concrete goals for the larger narrative.

For instance in the diabetes workspace a narrative goal may be to reduce long term blood glucose (HbA1c), however depending on the available catalogue of micro-interventions this aim could be achieved in a number of different ways. As noted by both Paredes et al. and de Witte et al. stress may be a factor with a concrete impact on person's abilities to engage in other interventions [32, 205] with depression and diabetes distress both prevalent risk factors in diabetes [24]. A narrative could therefore, aim to reduce these before transitioning to interventions with more direct impacts on long term blood glucose. Similarly, a high delay discounting rate could be targeted by events as a proxy for poorer self-management behaviours which at the narrative level serves to improve HbA1c. The observed correlation between perceived effect and low effort [86] could also be exploited to provide users with a low barrier entry point supporting future usages association with future usage [33]. These examples serve to highlight the potential of tailoring a narrative using different micro-interventions based on user needs. Overall we define the narrative as:

- *A narrative aims to create a meaningful story through its micro-interventions and the events as experienced by the user through a narrative thread aiming to synergise individual micro-interventions effects towards the goal of the narrative.*

7.4.4 Narrative thread

The narrative thread i.e., the series of micro-interventions leveraged and the events experienced by users is defined as:

- *The narrative thread is the list of experienced micro-interventions through their corresponding events, where each step is determined by the user's circumstances and the best fitting conceptual model.*

The narrative thread is in practice determined by the interaction model with either system, user or both tailoring its flow. The system may e.g., based on mobile sensing determine the users circumstances and choose between available micro-interventions based on an interpretation of the user's current circumstances and the conceptual models. In systems where users have agency over the narrative the thread may be determined by the users' perceived circumstances and subjective understanding of available micro-intervention.

7.4.5 Micro-intervention

Returning to our previous point about what constitutes a "single" micro-intervention and what should be considered an event: Primarily we believe this to be a design choice related to the micro-intervention and its intended aim. In this case we emphasise the "highly focused" part of our definition of micro-interventions in that these should ideally operate within a limited duration and scope. Studies such as those by Howe et al. and Paredes et al. both emphasise the need for novelty [32, 86] despite the relatively short study duration's supporting the notion that micro-interventions should not aim to operate indefinitely. Indeed we believe this to be directly against their basic nature and what makes them different to traditional interventions i.e., highly focused, low intensity, short and focused on momentary change [31, 29]. Rather, we argue longevity should be achieved through micro-intervention narratives aiming to maintain interest, provide variation, and synergise effects between shorter micro-interventions.

For instance, in the work by Vandesande et al. it could be argued that each video on its own should be considered a micro-intervention [191]. However, given that each video's content may be necessary for understanding that of subsequent ones and that they are expressly designed to be consumed in sequence, these should not be considered four micro-interventions but rather one micro-intervention with four events. Thus sequential events, variations and repetitions can depending on their design be considered one micro-intervention with multiple events and not several single event self-encompassed micro-interventions. We therefore define each micro-intervention as being:

- *A micro-intervention is a highly focused type of therapy relying on one or more events of a given type, each attempting some momentary change.*

While our definition does not fully resolve the ambiguity presented, it does provide designers and researchers with a way of formalising choices related to the scope of each micro-intervention. In this way several micro-interventions may be designed to target the same attributes or symptoms but may do so with different numbers of events. Consequently, each design may have different advantages/disadvantages which make them preferable to different users in various contexts reflected by each design's conceptual model(s) for when they may be best leveraged in narratives.

While we think the micro-intervention per our definition is a convenient design unit for creating small, focused programs of events and for creating personalised narratives, we also note the micro-intervention is not necessarily something users should always be presented with or interact with directly. For instance systems leaning more heavily towards automation could serve events without informing users explicitly about the designed micro-interventions they interact with.

Finally, we also wish to highlight the "each attempting some momentary change" part of our definition as it reflects the fact that micro-interventions may contain events aiming to accomplish different things in lieu of its overall goal. Van Capellen et al. for example uses a form of psychoeducation to improve the uptake and enjoyment of medication it-self a micro-intervention [33], nonetheless this psychoeducation would not make sense without a subsequent event suggesting meditation. Hence, we consider these sequential events with two distinctive aims, with the first aiming to increase the effectiveness of subsequent events.

7.4.6 Conceptual model(s)

Baumel et al. previously defined the conceptual model as how a micro-intervention can address steps within the therapeutic process and to determine which intervention should be used in a given context [29]. We add to this definition that each micro-intervention may have one or indeed more possible models for when a micro-intervention may be used in a narrative. For instance meditation may be used to target a variety of different symptoms [220, 221], with recent works having shown behavioural activation while having an effect on depression could likewise be used to increase physical activity suggesting potential dual purposes [222]. The latter example is especially interesting as we could see three potential narrative use cases or models for when behavioural activation could be used: 1) targeting depression 2) targeting lack of exercise or 3) targeting both in combination. We therefore describe the conceptual models as:

- *Conceptual model(s) describe the conditions for when and where a micro-intervention is relevant and can be used as part of a narrative.*

In practical terms the conceptual models and decision rules have significant similarities and are likely to rely on many of the same data sources. The primary difference being in how data is employed, in the case of decision rules these are used to determine the specific timing or variation of event delivered while the conceptual models aims to determine which program i.e., micro-intervention is best used to achieve narrative goals. In this way we can consider the difference as macro-rules that determine the flow of the narrative vs micro-rules that determine how micro-interventions work in-moment. In instances where the user has significant agency over the narrative thread the conceptual model(s) may be an implicit part of the system reflected by how micro-interventions are presented to users.

7.4.7 Event

Baumel et al. described the event as the smallest component of the micro-intervention attempting to achieve momentary change or impact in lieu of the intervention target [29]. However, we argue that rather than the event it-self being the cause for momentary change it is the resource described by Fuller et al. which facilitates the effects of the event [31]. Consequently, we describe the event as being:

- *An event provides a resource based on its intended type and therapeutic group with an immediate positive effect on target attribute(s).*

We choose the term attributes rather than symptoms to denote that the resources provided by events may have multiple effects and thereby also possible targets. We also use the term to denote that targets may be more abstract in nature for instance enjoyment and motivation of subsequent events or EFT targeting delay discounting as a proxy for behaviours.

7.4.8 Decision rules

Baumel et at. previously defined decision rules as guiding which and when events are deployed [29] with Fuller et al. noting that micro-interventions can be JITAI [31]. Works on JITAI such as that by Nahum et al. describe decisions rules as being: a way of operationalising intervention delivery and adaptation which options to offer, to whom and when [216]. As such micro-interventions can be adaptive in two ways, either through the events chosen and the duration between them or by adapting delivered resources to better suit users. For instance a system suggesting short physical activity exercises could theoretically also adapt exercise intensity to suit users based on fitness level as previously seen in some mHealth systems [26, 162]. As such:

- *Decision rules determine which events should be triggered, the intensity of the event, and the condition under which they should be triggered (e.g., contextual factors, time of day, or user's state).*

7.4.9 Type

The event type refers to the way the event is intended to be used. Fuller et al. previously described three types of micro-interventions by our definition applicable to events i.e., single use, repetition, and variations. Moreover, we add to these the types: sequential and adaptive events. As previously argued the work by vandesande et al. highlights that some events might occur in logical sequence or have prerequisites meaning these must occur in order [191]. Likewise, in line with Fuller et al.'s definition that some micro-interventions may have a JITAI nature [31] we imagine that event resources can also be adaptive in nature. For instance in a physical activity micro-intervention the event resources could be adapted to match user exercise levels. We thus define the event type as:

- *The event type refers to the way the event is used. Events can be classified as single-use, repeated, varied, sequential or adaptive.*

Depending on the design of each micro-intervention we note an event may be a combination of types. In the context of our EFT micro-interventions we see the cue-generation and reflection sessions as both sequential as one is required to engage in the other and repetitions as both tasks are repeated several times.

7.4.10 Resource

The idea of resources delivering momentary change stems from Fuller et al.'s definition which emphasises that micro-interventions are designed to administer quickly consumable resources that should have an immediate positive effect. Whereas in the work by Baumel et al. this trait is attributed to the event and not the delivered resource. Arguably it can be stated the resource and event are interdependent in nature, an event must occur for a resource to be consumed and consequently a resource must be delivered for an event to have an effect. Resources per our definition thus aim to provide the content consumed by users to facilitate the immediate positive effect sought by micro-interventions. As previously explored, these may leverage a variety of formats or combinations to deliver similarly varied content. The defining feature of the resource is therefore:

- *The resource provides a quick piece of content in an appropriate format aiming to facilitate the immediate positive effect.*

7.5 Implications

In the previous section we have unified, specified, and explored the rationale of the D-MIST framework. In this section we will briefly discuss the implications of this framework and how it contributes to our understanding of micro-interventions.

Foremost our framework presents three levels of effects across components: Narrative effects, Micro-intervention effects and Event effects. Importantly we note these to be interconnected in the sense that each level may attempt different things from the others, but ultimately aim to serve the narrative effect i.e., treatment goals. Thus the narrative effect can be said to be the sum of effects from the micro-interventions and their events. However, as shown by Van Capellen et al. effects may synergise [33] i.e., effect each other in this case one event may increase effectiveness and uptake of subsequent ones. For instance as previously highlighted a stress/depression micro-intervention could have a direct impact on not only self-management behaviours but also uptake on subsequent micro-interventions. Thus suggesting synergies exist not only between events but the benefits provided by micro-interventions.

Furthermore, the framework adds to the clarity of disseminated research by providing a set of concrete definitions for the components comprising micro-intervention systems. For instance, the framework can be used to describe narrative considerations, how the design facilitates the creation of the narrative through interactions between actors. As well as how micro-interventions along with their events are designed to be used through conceptual models and decision rules. A significant benefit of describing the systems this way is that it makes it easier to leverage previous research and thus improves the reusability and reproducibility of future research - with the latter being a topic of significant concern and interest in the scientific community [223]. As an example we find the decision rules provided by Howe et al. especially useful in this regard as they clearly detail the conditions for triggering events [86]. This clarity in reporting consequently makes it possible to accurately reproduce Howe et al.'s micro-intervention in other contexts and to more readily leverage these in future micro-intervention systems.

A potential limitation to the framework is that not every valid micro-intervention system may necessarily have to use each component directly. While we believe micro-intervention systems always provide a narrative and thus also a narrative thread we note some designers may prefer not directly work with these components. For instance, by our interaction model a valid on-demand system could leave these in the hands of the user with users who will be able to freely choose between which micro-intervention and events they wish to engage with. Arguably, in such cases the conceptual usage models are an implicit part of the users decision making process which is affected by how users are introduced to and allowed to choose between interventions. From a research perspective such instances present a form of "black box" micro-intervention system wherein the narrative, conceptual usage models and decision rules are largely undefined and unknown to researchers. In such cases experience sampling or proximal assessments may be prudent to generate knowledge on user's preferences and reasons for engaging with certain micro-interventions and events at different times.

7.5.1 Personalised micro-intervention technology

One implication of our framework is that it allows us to look at different ways micro-intervention systems can be personalised to better suit users in line with the original aims of the PhD study, namely the personalisation of micro-intervention technology. Based on our framework and the results of the review presented earlier in this chapter we proposed the hierarchical micro-intervention technology personalisation pyramid presented by Fig.7.7. We see that micro-intervention technology can be personalised in a number of ways providing increased personalisation with the speculated cost of increasing complexity.

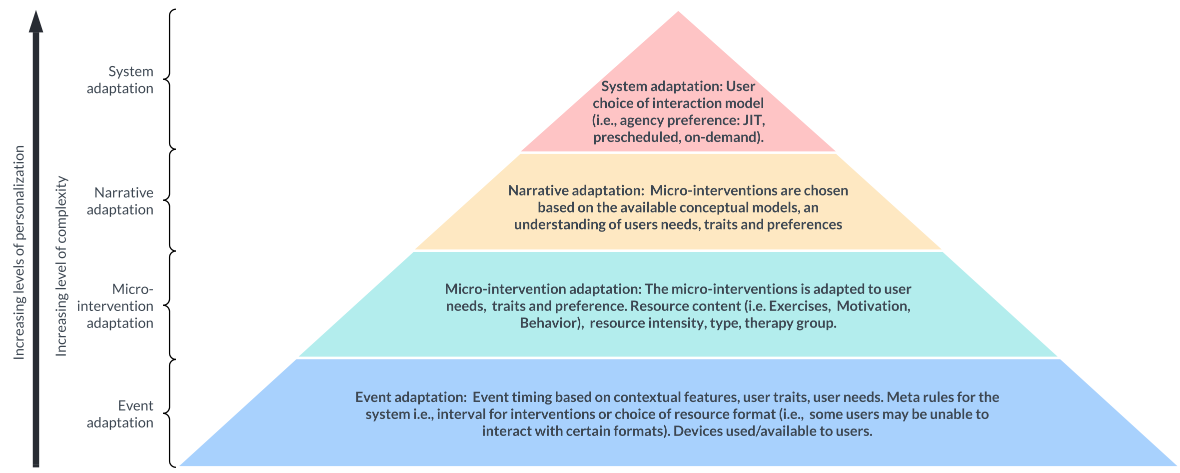

Figure 7.7: Micro-intervention system personalisation pyramid showing the different levels of personalisation micro-intervention technology can leverage [30].

This personalisation can take the form of event, micro-intervention, narrative, or system adaptation. We see the lowest level of adaptation as being related to the events served [82, 31, 86], their timing [32] through meta rules, decision rules [86], the resource formats employed and the devices used for data collection or delivery [208, 206]. Micro-intervention adaptation refers to the resource content served, the intensity and timing of events. Micro-intervention adaptation may include attempts to maximise engagement through the therapy group, type, number, combination, and intensity of events aiming to match users needs and capacity for engagement. Narrative adaptation refers to how micro-interventions [33] are combined overtime into the narrative thread through the conceptual models again aiming to meet users' different and evolving needs. The final level of adaptation involves users' abilities to affect the operation of the system or more specifically the interaction model employed, such that the interactions and actors involved in achieving the overall goal of micro-intervention systems are personalised to suit the user.

7.6 Chapter summary

In this chapter we have explored the literature on micro-interventions highlighting insights and the designs comprising micro-intervention systems and their components. Based on these we have synthesised, rationalised, and created the D-MIST framework for micro-intervention systems. The framework formalises the role of the micro-intervention system in delivering narratives of micro-interventions through the interaction between user, system, and other actors. Moreover we have briefly discussed the implications of this framework and how it contributes to our understanding of personalised micro-intervention technology. To summarise in this chapter we have:

- Presented an overview (or catalogue) of micro-interventions, the systems delivering them, and their components as seen in the literature through a systematic review.

- Based on the systematic review, previous definitions of the term micro-interventions and our prior works (chapter 3-6) we have created the D-MIST framework formalising the role of a micro-intervention system and its components.
- Created a hierarchical micro-intervention technology personalisation pyramid based on the D-MIST framework describing different ways and levels of personalisation possible for micro-intervention systems.

CHAPTER 8

Discussion

In this dissertation, we have aimed to explore micro-intervention technology for type 2 diabetes self-management from three angles. Initially we explored which mHealth application components and designs exist and are preferable for T2DM self-management in a Danish context. Through our empirical studies, we have explored how EFT micro-interventions can be designed, how users perceive them, and what usage patterns arise from such technology. Lastly, we returned to the more fundamental issue of what a micro-intervention truly is and what components and structures are used in their delivery. In this chapter, we aim to revisit the initial research questions and discuss our findings.

8.1 Mobile Health Technology for Diabetes

Through the initial exploration of mHealth technology literature, we aimed to answer the research question:

- *RQ1: What components, barriers, facilitators, attrition and effects are reported by the scientific literature on mHealth for type 2 diabetes?*

Overall, we see application components (or "features") pertaining to different forms of monitoring used most frequently for instance: physical activity, diet, blood glucose. Other common components utilise data collected to deliver: visualisations, feedback, and goal-setting. However, the design and use of these components varies greatly between applications, for instance some applications provide simple automated feedback on measurements [19], others leverage larger libraries of feedback messages [61] and others still have healthcare providers provide manual feedback [147, 141]. There are thus significant differences not only in how components are designed but also the depth these provide.

Through our review we identified a number of barriers to T2DM mHealth such as bugs [127], cumbersome interfaces, over reliance on user driven data collection [7], lack of immediate feedback [156], lack of personalisation [27], comorbidities [134], and more person specific barriers such as workplace flexibility [141] and digital literacy in the elderly population [52]. Several of the barriers and facilitators reported are also interconnected, for instance higher automation of data collection has been suggested as a facilitator while the opposite has been suggested as a barrier. However, higher automation may likewise have the unintended consequence of making some users uncomfortable with the system due to privacy concerns [224]. In general reported facilitators are: personalisation [27, 143, 131], adaptive goals [77], positive feedback [142], instilling a sense of achievement [116], gamification [26, 121], and content tailoring [145, 143].

Reported attrition and usage patterns were generally varied across studies with great disparity between reporting practises and the reported attrition. Among studies providing detailed usage and attrition we generally saw much higher attrition [139, 76, 27] than among studies summarising attrition or usage briefly. Our finding support those by Meyerowitz-Katz et al. in that we found very few studies that quantify what should be considered attrition [18] or otherwise justify expected engagement with proposed mHealth apps. A number of studies further associated usage/attrition with a number of factors such as: usefulness [53], positivity [142], app acceptability [127], personalisation [27] and the inclusion of "face-to-face" sessions in addition to mHealth [76, 128].

The effects of included mHealth applications are generally positive with most studies reporting some form of positive outcome. Clinically relevant factors reported include: improvements to HbA1c [52], step counts [121, 71] and body weight [120]. Other reported effects included various behavioural [26], dietary [130], mental health [144] or other effects for instance medication adherence [112]. However, as also noted by some authors there are significant challenges in attributing these improvements to specific components of the multifactorial interventions [123, 124].

A number of limitations to these works were also uncovered in the form of limited descriptions of the mHealth interventions, their rationale and usage patterns. These limitations consequently make it difficult to productively leverage existing works and to choose between various components/designs as usage patterns and insights related to these are often omitted. Thus, while we had originally planned to utilise the literature review as the basis for creating micro-interventions it quickly became evident that a more user centred approach was necessary. Especially considering the breadth and scope of possible problems faced by PwD and the multitude of possible solutions available to solve these.

We therefore adopted a methodology that would allow the end-users as great an influence as possible on what solutions and components should be included in diabetes systems. Moreover, through this methodology we also wanted to know whether digital solutions and micro-interventions would even be interesting technologies from the end-user's point of view. Our resulting co-creation process thus aimed to answer:

- *RQ2: What are the needs, wishes and preferences for diabetes technology among persons with type 2?*

Results from the co-creation study show that the needs of PwD are diverse and changing over time with motivations and preferences towards self-management equally varied between PwD. Overall, we found that PwD have a general need for solutions that provide curated information about diabetes, provide insights into blood glucose and facilitates the exploration of how to best manage diabetes long term. Other important needs for instance in relation to dietary change or motivation to engage in physical activity were noted to vary between PwD and over time making these less universal. Based on the co-creation design process, two prototypes were designed and evaluated. The first prototype being an activity-based CGM application and the second an online guide to diabetes. The results of our co-creation study overall suggest the need for solutions centred around glucose monitoring technology which allows users to see how they are doing [15]. mHealth technology should likewise not aim to be "one-size-fits-all" but rather embrace a philosophy of supporting users in self-exploring on how to best manage diabetes long term [24]. Personalisation of solutions to match users needs over time, preferences and unique motivators seem key to this philosophy. Moreover, as indicated by our design's expectation for changing needs future mHealth solutions should carefully consider the user experience over time [166] rather than expecting uniform engagement over time.

Through the co-creation study we found that PwD are interested in (or "wish" for) solutions that can be used in a variety of ways and ones that supports self-exploration of approaches to long-term self-management. We see these needs reflected in both prototypes (see section 4.3): In prototypes one's case through its modular design and different usage phases allowing users themselves to decide how they use the application. In prototype two's case by allowing users different ways of engaging with content, its depth and by aiming to present users with broad opportunities, approaches, and interventions that they themselves can choose from. Both prototypes thus support users in creating a personalised approach to diabetes self-management empowering the users to make decisions for themselves on an informed basis.

Oppositely participants showed animosity towards the idea of "one-size-fits-all" [27] solutions citing differences between PwD including motivational factors and solution preferences as also found in previous research [225, 134]. This observation supports earlier micro-intervention research by Paredes et al. who argued there are no one-size-fits-all interventions and that interventions should instead be matched to individuals based on their personalities and current needs [32].

Despite participants insistence on avoiding "one-size-fits-all" [27] solutions it could reasonably be argued that the presented prototypes have become exactly that. However, we would argue this is not the case in a traditional sense. In prototype one's case participants themselves are given significant agency over how they use the application and how they utilise results. In this way prototype one's design closely resembles Li et al.'s stage-based model for behaviour change with users actualising and translating insights to action [153]. Prototype two meanwhile could be said to present users with the choice between multiple interventions through its content, supporting Skinner et al.'s point about facilitating self-exploration of how to manage diabetes long term [24]. Participants themselves also emphasised that not everyone would necessarily be interested in digital solutions prompting the idea of embedded an overview of local initiatives into the online guide. Both prototypes thus provide users plenty of agency in how these are used and in the case of the online guide which content is consumed. We highlight this example as it shows aspects of personalisation built into the solutions more fundamentally than for instance simply delivering variations to messages [61] or simple personalised feedback [144]. Our results also suggest solutions such as those by Höchemann et al. and Alonso-Domínguez et al. utilising gamification and the Mediterranean diet respectively [26, 71] while potentially useful for many - may not be universally preferable to PwD and may again limit self-exploration on how to best manage diabetes long term [24].

SMBG and CGM components were perceived preferably by workshop participants and was noted as an important tool for self-management providing significant value which aligns well with previous findings [168, 54]. Counter to this, participants generally wished and preferred to keep solutions from focusing on weight loss and to keep these separate from GP work practices. These observations are interesting as they align with the aforementioned notion: that the needs and preferences of patients may not always align with clinical judgement [22]. In this case weight loss has been shown highly relevant to glycaemic improvements, with its omission going against clinical judgement [226, 227, 228]. However, it has also previously been argued that glycaemic changes through weight loss can be achieved without an overt focus on weight loss [169]. Participants also preferred to keep the solutions separate from GP's work practices, instead choosing the option to share data with the GP on an as-needed basis. A likely culprit for this choice seems to be tensions between GPs and PwD [229] indicated by many participants showing some animosity towards GPs/municipalities/practices and by extension their handling of diabetes care.

Prototype one with its emphasis on different usage phases i.e., initial usage/learning, active measurement, and support tool periods is especially interesting in the greater context of mHealth as it suggests none-usage to be a desirable outcome of successful engagement. This consequently stands in contrast to traditional mHealth wherein high retention has previously been used as a measure of success [18, 182, 183]. Likewise, this supports the notion that some attrition may be caused by users achieving a sense of mastery over diabetes or at the very least the content of the application [154].

Comparing our results to those reported by Klasnja et al. we see significant overlap in our findings [38]. Firstly, our two developed prototypes strongly resemble aspects of the four areas where technology may support diabetes self-management as described by Klasnja et al., with our prototypes also including many of the features described. The four areas described by Klasnja et al. being: 1) understanding diabetes, 2) responding to change in times of stability, 3) improving communication and 4) tailoring to individual needs and motivations [25]. We see point 1), 2) and 4) prominently aligned with prototype two through its emphasis on knowledge and different approaches. Likewise we see all four points align with the features of prototype one through its intended usage phases, for instance in line with 1) the prototype aims to help PwD understand the disease and supports users in responding to changes in times of stability in line with 2) through its intermittent active phases. The solution moreover can be used to support 3) as reflected in the UX storyboard by improving communication with GPs and allows users to tailor the application (or intervention) to their needs similar to 4). Numerous other findings overlap, such as rationale, the role of SMBG, desired user experience and intensity over time. Further supporting the validity and generalisability of these insights is the fact that our study and that of Klasnja et al. used different methods (Co-creation vs interviews & a focus group) to arrive at these results and moreover that these were found in different contextual settings (Denmark vs the United States) [25].

8.2 EFT as micro-interventions

To explore how users perceive and engage with digital micro-interventions in the real world we created new mHealth-delivered micro-interventions based on the established intervention Episodic Future Thinking. Our first aim was therefore to determine:

- *RQ3: What is the feasibility of using Episodic Future Thinking as digital micro-interventions?*

To test micro-interventions in the wild we designed, implemented, and evaluated an mHealth system delivering EFT and mental imagery based digital micro-interventions. Our design process explored the use of these micro-interventions in T2DM self-management through focus groups with indications that they are conceptually interesting shortly after diagnosis. Through formative usability evaluations we further found the designed micro-interventions usable with test users completing sessions and tasks with relative ease. PSSUQ scoring and data collected by the application further shows that the implemented mHealth system was capable of delivering the EFT micro-interventions. The PSSUQ scoring indicates that users found our implemented mHealth application and the tasks it presents i.e., micro-interventions acceptable with both formative usability testing and experience sampling backing this finding. Based on the results of our study, user experience research, PSSUQ scoring and experience sampling we find the use of EFT as micro-interventions feasible. However, we also found that not all of the micro-interventions were perceived preferably by the users.

While we overall find the use of these micro-interventions feasible a number of barriers also makes them less feasible. For instance we see indications that users do not necessarily find these interventions preferable or acceptable e.g., persons with significant apprehension towards listening to their own voice may be poorly served by the traditionally audio-based format EFT reflected in this case by poor uptake and high attrition. Some comments from participants further suggest users generally preferred the image-based projection sessions over the audio-based ones. Moreover, we found a number of barriers related to traditional EFT aside from listening to one's own voice including perceiving more distant futures and the contextual appropriateness of engaging with the different micro-interventions. Experience sampling also indicates that users generally had a hard time seeing the value of EFT as an intervention in general.

One way of improving the EFT micro-interventions identified through participant suggestions is the embedding of concrete goals in the episodic futures. An approach which is supported both by our focus groups and prior works on gEFT [109, 108]. A limitation to our feasibility study was the limited number of participants which did not allow us to detect any meaningful changes to delay discounting made worse by low app usage towards end-of-study and subsequently a low competition rate the of end-of-study delay discounting measures.

The finding that gEFT may be better suited for micro-interventions and the limited number of participants led us to the second larger EFT study aiming to identify effects and to compare the effects of engaging with gEFT and EFT. Specifically, looking at the discounting rates and the user perceptions between gEFT and EFT. This resulted in a three-arm study consisting of gEFT, traditional EFT and a control group aiming to explore:

- *RQ4: What are the effects and user perceptions of digital micro-interventions delivered as goal-oriented and traditional EFT?*

In terms of effects both intervention arms managed to achieve noticeable reductions in delay discounting when compared to the control group. However, gEFT was the only condition to achieve a statistically significant reduction in delay discounting relative to baseline measures. Nevertheless, the effects on delay discounting between intervention arms were relatively comparable with goal-oriented achieving a logarithmic mean reduction of -0.99 vs -0.85 for traditional EFT which could indicate that gEFT is more effective in reducing delay discounting.

Overall, we cautiously conclude gEFT has small but noticeable benefits over traditional EFT which makes it more suitable for micro-interventions. Firstly in terms of reducing delay discounting, secondly in that gEFT in addition to emphasising the future outcomes also increased goal-awareness, and thirdly in that users more clearly perceived the benefits of future thinking through the addition of tangible goals as indicated by users experiences. These results are both in contrast to and in line with prior results, our results tentatively support O'Donnel et al. in noting goal-oriented seems to be slightly more effective [108]. Athamneh et al. contrary to this study found no differences between the effects of gEFT and traditional EFT, but our findings support the insight that goal-oriented may offer benefits beyond effects on delay discounting [109]. In particular we see signs that users perceived the value and effects of future thinking more clearly in the gEFT group. For instance a few participants perceived through experience sampling that gEFT had swayed decision making towards healthier choices in this case exercising when motivation was otherwise lacking. Relative to the 6-month trial by Epstein et al. which observed an effect size of -1.95 (week 12) and -1.99 (week 24) our study observed roughly half the effect size for gEFT in a quarter of that time [101]. Overall we find it unlikely that our implementation alone would be more effective than that of Epstein et al., but our results could indicate the addition of mental imagery has enhanced the speed at which changes to discounting occur. These results are in contrast to Voss et al.'s similarly scoped 1 month study which despite observing behavioural modifications did not observe changes in delay discounting [107]. However, a key difference between our study and that by Voss et al. was again our inclusion of a mental imagery micro-intervention. Consequently, it is possible that mental imagery may have enhanced the overall effectiveness of EFT or that mental imagery it-self may be a primary contributor to observed effects. Alternatively the addition of image-based projection may have caused effects to occur faster than traditional EFT as indicated by the lack of observed changes to delay discounting reported in Voss et al.'s study [107]. Future work is necessary to explore the relationship between the micro-interventions and their observed effects.

Despite the observed benefits of gEFT study attrition remained high and comparable across all 3 conditions. While the control group had the lowest relative attrition the retention did not differ by a significant margin (87.72%-79%) in spite of the comparatively lower intensity of the control group in the latter weeks of the study. We also observed lower than expected daily usage among participants with a relatively low number of participants completing the recommended reflection session frequency. Nevertheless, observed usage patterns seems to support those previously found in real-world usage [17]. This observation supports Fuller et al.'s finding that micro-intervention attrition remains largely in line with that of traditional real-world mHealth interventions [31] and contrasts the idea that micro-interventions on their own reduce barriers related to engagement [17]. One potential cause for the observed usage patterns could be that participants simply did not have a particular need for the micro-interventions. However, another possibility is that while users found the studies content and interventions interesting this may not be indicative of a genuine desire for behaviour change [31]. In line with real-world usage participants could within minutes access the interventions with little prior thought about whether they were truly interested in the study's content. The observed usage patterns likewise support the notion that "...a high portion of those interested in digital behavioural and mental health interventions in the real-world are not investing as much effort in these interventions as intended by intervention developers" - Baumel et al. [29]. In this case reflected by our high sign-up rate and comparatively low engagement with the micro-interventions.

Throughout the two EFT case studies our view on micro-interventions have shifted quite considerably. Originally in our feasibility study we in line with the definitions by Paredes et al. and Fuller et al. considered the self-guided generation task, audio projection sessions and image projections as three separate micro-interventions [32, 31]. Rather we now consider the self-guided generation task, audio-based reflection sessions, and image-based projections as one micro-intervention in line with the D-MIST framework with these using different events and resources that are both sequential and repetitive. Participant preferences towards our implemented micro-intervention design however implies that image-based projection may be better used as a separate micro-intervention i.e., decoupled from the audio sessions.

Our findings overall emphasise 5 design recommendations for future mHealth systems wanting to utilise EFT based micro-interventions. Firstly, that these should be based on gEFT given the slightly larger discounting reduction and the additional benefits provided by increased goal-awareness. Secondly, that micro-interventions should ideally avoid using recordings made in the user's own voice. Indeed we find it difficult to imagine most users can overcome this barrier given that micro-interventions should not aim to operate indefinitely and are generally characterised by low intensity. Moreover, the frustration itself could negatively affect usage of the micro-intervention system and as such should using the users own voice should generally be avoided. Thirdly, EFT micro-interventions should ideally facilitate future thinking using event resources consisting of various multimedia based on users' preference such that users generally engage with the format suiting them best. Fourthly, future thinking should be facilitated through context aware events through decision rules such that events are facilitated at opportune or contextually relevant moments with the deployed resource being contextually appropriate. Finally, EFT micro-interventions should ideally not be used in isolation but rather as part of larger micro-intervention narratives to maintain user interest with other micro-interventions potentially benefiting from a reduced discounting.

In the context of our current mHealth system we believe these recommendations could be implemented by supporting future thinking in different formats i.e., computer generated reading of episodic futures, textual representations and by using image-based projection as separate micro-interventions with different narrative uses. However, more work is necessary to determine whether these are best served as separate micro-interventions with different conceptual models or as one JITAI micro-intervention utilising different events that engage users at contextually relevant points of time and aim to match the resource served to user preferences. Future work should investigate how these different micro-intervention designs perform and moreover what conceptual models such designs present.

8.3 Defining micro-interventions

Over the last decade the terminology for micro-interventions and their components have been continuously refined in terms of depth and coverage [32, 31, 29]. However, this also introduces problems in interpreting previous research as many of these definitions are not immediately reconcilable. For instance, the work by Paredes et al. seems to suggest each in-moment intervention should be considered its own micro-intervention [32] whereas Baumel et al. notes each micro-intervention may have several "events" [29]. Fuller et al.'s description similarly alludes to the idea of each micro-intervention having one or more events albeit without the "event" terminology [31]. Consequently, in order to determine how micro-interventions as a technology should ideally be designed, we need to answer:

- *RQ5: What elements comprises a micro-intervention, what are their key components and which constructs facilitate their delivery?*

Based on the literature of micro-interventions and our own findings we developed the D-MIST framework for micro-intervention systems by which we define a micro-intervention as being: "*A micro-intervention is a highly focused type of therapy relying on one or more events of a given type, each attempting some momentary change*". A micro-intervention is comprised of elements such as events delivering resources using decision rules to determine the timing and type of events presented. Per this definition each micro-interventions can be seen as a miniature "intervention program" with a number of events serving resources that aim to facilitate momentary changes in lieu of the micro-intervention's goal. The micro-intervention system through its interactions aim to deliver a narrative supporting longer term distal goals by combining several micro-interventions in response to users context, needs, and other factors for instance the need for novelty [86, 32]. The constructs that support the delivery of micro-interventions in digital systems are: 1) The interaction model detailing how the general aims of micro-intervention systems are accomplished through interactions between actors. 2) The narrative proverbially telling a meaningful story through micro-interventions employed and the events used by these. 3) Each step of the narrative thread being determined by which micro-intervention is the best fit to the current narrative based on the conceptual models presented by available interventions. 4) The conceptual models detailing how, when and where each micro-intervention can be used narratively. Each micro-intervention can thus also be seen as a unit of design with a set number of events, the type and decision rules of which determines their use and timing e.g., sequential or repetition. Micro-interventions targeting the same attributes may be differentiated from one another by the number of events, types and resources employed by these making them preferable in different narrative contexts reflected by different conceptual models.

Contrary to Baumel et al. we found the topmost construct that directly facilitates micro-interventions to be the system rather than micro-intervention care [29]. We did this partly to limit ourselves to constructs which directly affect the user experience with such systems i.e., human-computer interaction but also to distance micro-intervention systems from the broader clinical and therapeutic contexts. In part motivated by the aforementioned finding that clinical judgement and patient needs may not always align, but also because we associate ”care” with factors outside of the scope of current stage research which may include considerations such as: policies, politics, costs vs benefit and social inequality [5].

When comparing the D-MIST framework to the key components of JITAIs we see several areas of overlap. Regarding tailoring previous JITAI research has noted: intervention engagement, fatigue, and states of vulnerability/opportunities as key components [216], while our framework does not explicitly include these as components, they are implicitly part of both conceptual models and decision rules. The term decision rule in JITAIs is used to denote when and where intervention/adaptation options should be used. A key difference between decision rules in JITAI and those of micro-interventions is that the latter is not necessarily adaptive by design. Indeed most of the micro-interventions seen in the literature so far presents very little dynamic variation [31, 191, 82, 213] with some JIT micro-interventions presented [208, 210, 86] but without direct tailoring of the event/resources intensity. Based on the personalisation pyramid, micro-interventions may adapt to user needs in 4 ways: event, micro-intervention, narrative, and system adaptation. Individualisation in micro-intervention system can thus occur through the event themselves, the micro-interventions, how these are combined or how a system serves these through its interactions and actors.

Looking more broadly at micro-interventions it has previously been argued that micro-interventions closely resemble the ”interventions” people subconsciously engage with such as asking others for advice, watching a short video, or listening to an uplifting song [29]. Engagement with short forms of multimedia have become more common place in recent years demonstrated by the popularity of applications such as Snapchat and TikTok [230], with other platforms emulating their style of content e.g., YouTube shorts and Facebook's stories. It can be argued micro-interventions have also found their way into this new content reflected by various catchy videos aiming to entertain with knowledge, lifestyle tips or to spread mental health information [231]. These types of content indeed fit well into the ”single” event micro-intervention category, however much of the content presented in this manner emphasise catching interest and going viral more so than being factual [232, 233]. Yet these examples still highlight the popularity, outreach and potential of content served in this manner. In a sense the paper by Paredes et al. can be said to have predicted this development to a degree given its topic of popular culture therapy [32]. This shift in content expectations is also being seen in this work reflected by user's preferences for the online diabetes guide focusing on short high-quality videos. A few contemporary works have also started looking into the effectiveness of delivering content in these manners [234, 235] underlining Paredes et al.'s point that there is significant potential for developing micro-interventions based around popular culture [32].

8.4 Limitations & future directions

Overall there are several noteworthy limitations to our work of exploring personalised micro-intervention technology for self-management of T2DM.

A major limitation to this work is the limited number of participants in both the EFT studies and the co-creation study which may impact the generalisability of findings. Future work is therefore necessary to explore the robustness of results.

In terms of the co-created prototypes for instance more work is needed to ensure these are broadly usable for the T2DM population including those unfamiliar with glucose monitoring. A future study aiming to test functional prototypes is also necessary to follow-up on the results of the co-creation study. Moreover more work is needed in defining the final content of the guide and the potential micro-interventions both designs should include. For instance in prototype one it was imagined that the system should intervene using messages about patterns etc. but the exact scope of these messages was not explored. In the case of prototype two the resources provided by the online guide were not explored beyond overall topics and more work is necessary to determine the exact content that should be provided.

Regarding the EFT studies limitations can also be noted, for instance more work is necessary to confirm the generalisability of results, with additional efforts likely necessary to improve uptake of these interventions. The perceived value of the micro-interventions in particular may have caused these to underperform as many users stopped using them before achieving any noticeable effects. Future works should also investigate if perceived value and attrition can be improved e.g., by using different forms of multimedia.

In terms of the reviews conducted there are limitations in the number of databases and search terms employed for chapters three and seven respectively. In our review of mHealth technology it may be prudent to extend the review to more databases to include a broader selection of the literature. The search terms used for our review of micro-interventions could likewise have been expanded to cover research not explicitly stated as micro-interventions.

Additional work may also be necessary to refine the D-MIST framework. For instance we have done our utmost to ensure that the use cases seen in the literature and in our own work are included and adequately explained by the D-MIST framework, however, this may not be all-encompassing given the limited research available and the early stage nature of most state-of-the-art micro-intervention research. Thus while our framework covers the trends seen in the literature more work is necessary to determine the validity and rigidness of the framework. Moreover, future works should include the development of tools supporting the development of systems and micro-interventions based on the framework actualising its usefulness in design and development.

CHAPTER 9

Conclusions

The objective of this PhD dissertation was to explore how technology for micro-interventions can be effectively designed with a focus on diabetes self-management. Through our work we have explored i) what makes for desirable mHealth solutions in T2DM, ii) what users' perceptions of micro-interventions are and what factors affect them, and iii) created a more precise definition of what micro-intervention are through the D-MIST framework for micro-intervention systems.

Through the review of state-of-the-art literature on micro-interventions and the implications from studies conducted we have developed the D-MIST framework of micro-intervention systems. Through this framework we have gained a conceptual understanding of what a micro-intervention is, how they can be combined narratively, and how systems might deliver these interventions. These insights consequently formalise how micro-intervention systems may beyond momentary effects support larger intermediate and distal goals. Moreover, the D-MIST framework provides us with insights into how micro-intervention systems as well as micro-interventions themselves may be designed.

Through the literature review and co-creation study we explored which systems, components and interventions are desirable for self-management of T2DM, resulting in two co-created prototypes: An activity-based CGM application and an online guide to diabetes with emphasis on content matching users perceived situation, both of which are potential micro-intervention systems. Through the development process of these prototypes we observed that PwD are particularly interested in technologies leveraging structured SMBG/CGM and technology that supports users by providing a large degree of choice and agency which facilitate self-exploration of how to best manage T2DM long term.

Additionally, we designed a smartphone mHealth application delivering EFT as micro-interventions aiming to test these "in the wild" to better understand their uptake and real-world usage. Through this work we have produced a number of insights regarding factors that affect the usage of micro-interventions: micro-intervention duration, event/resource length, novelty, perceived usefulness, perceived effects, personal preference and contextual preference in terms of both the timing of events and the resources delivered by those events. Beyond demonstrating the feasibility of using EFT as micro-interventions we moreover looked at the perceptions and effects of two different types of episodic future thinking (gEFT vs EFT) as micro-interventions. Despite less-than-ideal usage patterns both types of future thinking successfully reduced the discounting rate among participants, with gEFT achieving statistically significant results by the end-of-study. Our results and experience sampling indicate gEFT might be slightly more effective than traditional EFT with the former providing additional benefits such as a clearer perceived value of future thinking, increased goal-awareness and goal reflection.

Overall, through our studies, we have gained an understanding of what types of systems and micro-interventions can support T2DM self-management. Moreover, we have explored what factors affect micro-intervention uptake and usage, such as the need for novelty, personal preference, and contextual resource appropriateness. Based on these insights and contemporary works we have conceptualised a design framework for micro-intervention systems which includes the major components of such systems and how these components may be used for personalisation in different ways to create truly personalised micro-intervention technology.

APPENDIX A

Article I: Exploring Components, Barriers, Facilitators and Attrition Causes in Type 2 Diabetes mHealth: A Scoping Review

Authors: Dan Roland Persson, Jakob Eyvind Bardram, Per Bækgaard.

Manuscript draft.

APPENDIX B

Article II: Exploring Patient Needs and Designing Concepts for Digitally Supported Health Solutions in Managing Type 2 Diabetes: Cocreation Study

Authors: Dan Roland Persson, Katiarina Zhukouskaya, Anne-Marie K Wegener, Lene Kølle Jørgensen, Jakob E Bardram & Per Bækgaard.

Journal of Medical Internet Research Formative Research 2023.

DOI: https://doi.org/10.2196/49738

APPENDIX C

Article III: Episodic Future Thinking as Digital Micro-interventions.

Authors: Dan Roland Persson, Soojeong Yoo, Jakob E. Bardram, Timothy C. Skinner & Per Bækgaard.

Design, user experience and usability: The 12th international conference, DUXU, 2023, Held as Part of the 25th HCI International Conference, HCII 2023, Copenhagen, Denmark, July 2328. Published 25 November 2023.

DOI: https://doi.org/10.1007/978-3-031-48038-6_14

APPENDIX D

Article IV: Perceptions and Effectiveness of Episodic Future Thinking as Digital Micro-Interventions Based on Mobile Health Technology.

Authors: Dan Roland Persson, Jakob E. Bardram & Per Bækgaard.

Manuscript submitted to Sage Digital Health.

APPENDIX E

Article V: A Design Framework for Micro-interventions in Mobile Health Technology.

Authors: Dan Roland Persson, Mel Ramasawmy, Nushrat Khan, Amitava Banerjee, Ann Blandford, Jakob E. Bardram & Per Bækgaard.

Manuscript submitted to the Conference on Human Factors in Computing Systems (CHI) 2024.

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