Developing digital health interventions for falls prevention

An innovative user-centered design approach

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Chapter 1

General Introduction

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Developing digital health interventions to improve health care diagnosis, treatment, clinical decision support, care management, and delivery has become a key focus for many countries (Mathews et al., 2019). The term 'digital health interventions' covers a wide range of digital clinical tools including diagnostic tools, imaging tools, clinical decision support systems, health risk assessment tools, electronic health record systems, and monitoring devices (Gupta et al., 2022). A health care context in which digital health interventions could be of particular value in is in the context of falls prevention. Falls prevention in older adults relies on the collaboration between health care professionals (HCPs) from different disciplines and practice settings (Montero-Odasso et al., 2022). However, falls prevention interventions are often developed for use in a specific practice setting, resulting in several unintended barriers (e.g., poor communication and coordination between HCPs). These barriers may limit the use and, in turn, adoption of these interventions by HCPs in real-life practice settings, such as in a multidisciplinary care setting (McKay & Anderson, 2010). In the Netherlands, successful adoption of digital falls prevention interventions in real-life practice settings remains challenging. One way to improve the adoption of digital health interventions in real-life practice settings is by focusing on the needs of users during the development of these interventions, which is referred to as User-Centered Design (UCD; Norman & Draper, 1986). Within the scope of this dissertation, I explore digital falls prevention interventions that support HCPs in identifying individuals at risk of falling, and preventing falls incidences in these high risk individuals. In this dissertation, I apply an innovative UCD approach to inform the development of these digital health interventions for HCPs from different disciplines and practice settings. Specifically, this dissertation aims to (1) set new standards for examining the needs of prospective users of digital health interventions; (2) improve the development and refinement efforts of UCD developed digital health interventions; and (3) investigate the effectiveness, user experience, and implementation of UCD developed digital health interventions in real-life practice settings. Below, I introduce the main concepts discussed in this dissertation, as well as the aims of this dissertation in detail.

Impact and causes of falls

Falls are among the leading causes of injury and mortality in older adults aged 65 years and older (CDC, 2024; Salari et al., 2022; Santos-Lozada, 2023; WHO, 2021). In the past decades, the mortality rate from falls has increased worldwide, making falls a serious global health problem in our rapidly ageing population (CDC, 2024; Wang et al., 2021; WHO, 2024). In the Netherlands, with a population of more than 18 million inhabitants, falls in older adults resulted in 112.000 emergency department visits, 84.000 serious injuries (e.g., hip fracture), and 6723 deaths in 2023 (VeiligheidNL, 2023; WHO, n.d.). This ranks falls among the top ten causes of death in the Netherlands (WHO, n.d.). The consequences of falls can significantly reduce the quality of life of older adults as fall incidences are associated with a number of adverse health outcomes (e.g. functional, psychological, and cognitive decline; Giovannini et al., 2022). Furthermore, fall incidences can result in admission to hospital or long term care, placing a significant burden on the health care system. In the Netherlands, falls-related medical costs reached 1.4 million in 2023 (VeiligheidNL, 2023).

Falls are a result of several interacting risk factors, which makes determining the exact cause of falls difficult (Masud & Morris, 2001; Rubenstein, 2006). Therefore, an extensive amount of research has focused on identifying non-modifiable and modifiable risk factors that can increase an older adult's risk of falling (i.e., falls risk factors; Ambrose et al., 2013; Jehu et al., 2021; Li et al., 2023). While non-modifiable risk factors include factors such as female gender, age or a history of previous falls, modifiable risk factors include impaired balance and gait, medications, and visual impairments. These modifiable risk factors can be improved through targeted falls prevention (Ambrose et al., 2013; Montero-Odasso et al., 2022).

Falls prevention

Falls prevention can include single-component interventions, such as an exercise program, or involve combinations of two or more intervention components, commonly referred to as multidomain falls prevention

interventions (Hopewell et al., 2018; Montero-Odasso et al., 2022). Multidomain falls prevention interventions start with a multifactorial falls risk assessment in older adults at high risk of falling. Following clinical guidelines for falls prevention, this assessment assesses the following modifiable risk factors; mobility, medication, dizziness/vestibular, vision, hearing, cognition, urinary incontinence, fear of falling, activities of daily living, environmental factors, footwear and foot problems, and nutritional status and vitamin D intake. Based on this assessment, appropriate intervention components for treating identified falls risk factors can be selected, resulting in individualized tailored interventions for high risk adults (Montero-Odasso et al., 2022). Compared to single component interventions, multidomain interventions based on multifactorial falls risk assessments have been shown to significantly reduce falls rates in older adults (Gillespie et al., 2012; Hopewell et al., 2018, 2020; S. H. Lee & Yu, 2020). In the Netherlands and internationally, a multidomain intervention based on a multifactorial falls risk assessment is therefore aimed for as standard practice for older adults at high risk of falling (Federatie Medisch Specialisten, 2024; Montero-Odasso et al., 2022). Therefore, in the Netherlands, a national multidomain falls prevention program has been set up that aims to reduce the burden of falls by improving the implementation of clinical guidelines regarding falls prevention into practice.

Barriers to falls prevention

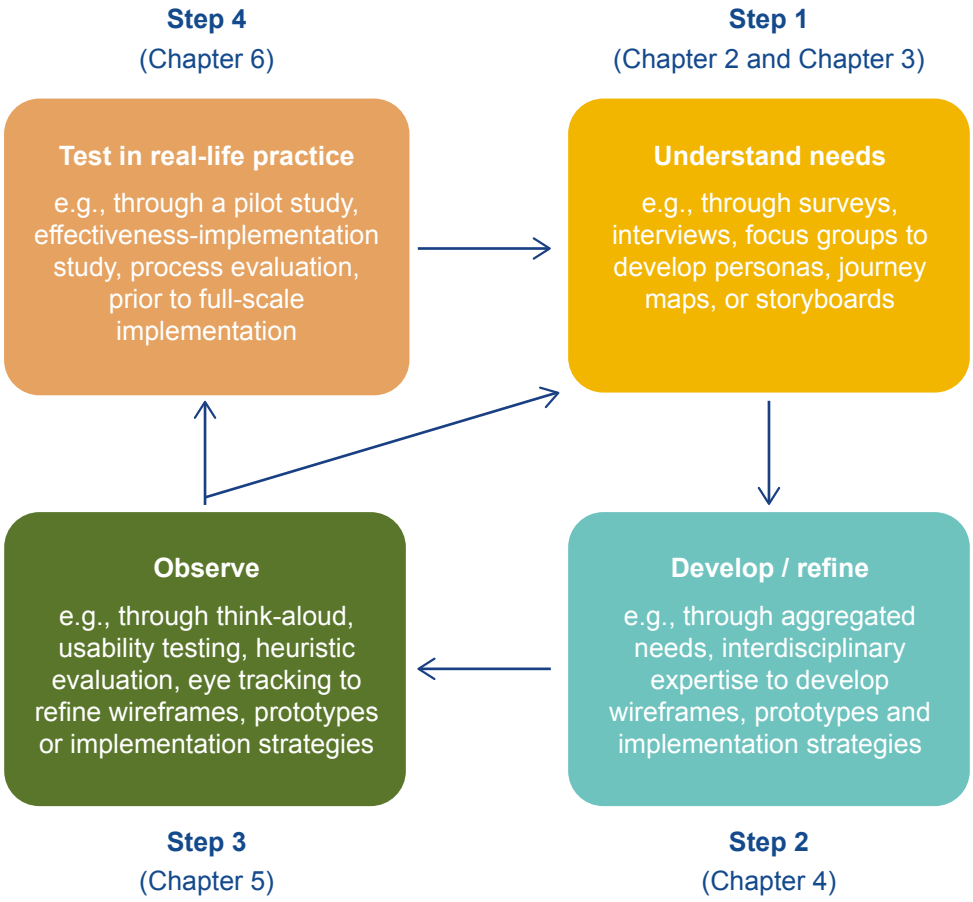
Multidomain falls prevention interventions require a multidisciplinary care approach, meaning that effective falls prevention involves the collaboration of a heterogeneous group of HCPs on a single patient case (Montero-Odasso et al., 2022). To support optimal delivery of these interventions, clinical decision support systems (CDSS) and multifactorial falls risk assessments have been developed but are often not designed for use in real-life practice settings, resulting in a number of unintended barriers. Systematic reviews highlight that these barriers include, but are not limited to time constraints, difficulty of use, lack of knowledge and skills, incompatibility with the workflow and context of use, poor communication and coordination, and unclear role distribution, which can result in low adoption rates among

HCPs (Gemmeke et al., 2022; Meekes et al., 2022; Muusse et al., 2023; Van Rhyn & Barwick, 2019; Vandervelde et al., 2024; Westerbeek et al., 2021). With the falls rate projected to rise sharply in the Netherlands, there is a need to explore how interventions for falls prevention can be improved for HCPs from different disciplines and practice settings (i.e., primary care, patient home, or hospital setting) to enhance adoption and consequently, realize the promising effects of these interventions in older adults (Van Der Naald et al., 2024; VeiligheidNL, 2023).

User-Centered Design

UCD has been shown to enhance the user experience, user satisfaction, and quality of digital health interventions (Ferrucci et al., 2021; Walden et al., 2020). UCD is an iterative design approach that places users at the forefront of the development process of digital health interventions through prospective user involvement, thereby enhancing the usefulness and usability of interventions for users in real-life practice settings (Abras et al., 2005; Kujala, 2003; Mao et al., 2005; Norman & Draper, 1986). In UCD, prospective users should be consulted early on and continuously during the development of an intervention following an iterative cycle (Abras, et al., 2005; Witteman et al., 2015, 2021). This iterative cycle comprises of three steps: (1) understanding the needs of prospective users; (2) developing and/or refining interventions based on these needs; and (3) observing prospective users interactions for further refinement of interventions (Witteman et al., 2015, 2021). In each step, data from prospective users is collected using quantitative or qualitative methods to produce different UCD outcomes. For the development of digital health interventions, these outcomes support researchers and designers in making design decisions that are more likely to meet the needs of users (Salinas et al., 2020). However, research has called for improvements in UCD in an attempt to encourage wider adoption of digital health interventions by users (Van Velsen et al., 2022). In the below sections, I introduce improvements to UCD outcomes specifically and the iterative cycle as a whole. This enhanced iterative cycle is illustrated in Fig. 1 and is applied in this dissertation to develop digital health interventions for falls prevention.

Fig 1. An enhanced iterative cycle for UCD (Witteman et al., 2015, 2021).



Step 1: Understand the needs of users

In the first step of the iterative cycle, the aim is to understand the needs of prospective users (Witteman et al., 2015, 2021). Examples of early-stage UCD outcomes that are useful for uncovering these needs are personas and journey maps. Personas are data-driven user descriptions that represent fictional users of an intervention whose user characteristics are based on a distinct group of prospective users of an intervention (Adlin & Pruitt, 2010). While the use of personas has been extensively applied in the field of product marketing, a growing body of research has explored the use of personas in informing the development of digital health interventions (Adlin & Pruitt, 2010; Holden et al., 2017; Jansen et al., 2017; Ledel Solem et al.,

2020; LeRouge et al., 2013; Miaskiewicz & Kozar, 2011; Pollack et al., 2019). Engaging with personas during the development process of these interventions can foster user-focused thinking and decision-making, increasing the user-centeredness of interventions which is vital for successful adoption (Witteman et al., 2015, 2021).

Different types of user characteristics in personas, such as external and intrinsic user characteristics, can be used to guide the development of different intervention components. External user characteristics (e.g., context of use) can inform the user experience of interventions. In turn, intrinsic user characteristics (e.g., behavioral beliefs) can inform the targeting of behavioral determinants in interventions (i.e., factors that influence the behavior of prospective users). However, for the development of digital health interventions, personas-construction is regularly centered around either external (e.g., needs, contexts of use, intuitive processes) or intrinsic user characteristics (e.g., beliefs, perceived barriers, perceptions; Bierbooms et al., 2021; Holden et al., 2017; Jansen et al., 2017; Ledel Solem et al., 2020; LeRouge et al., 2013; Pollack et al., 2019). This could inhibit the successful adoption of UCD developed interventions by users, as the development of these interventions is centered around either influential external or intrinsic user characteristics to adoption, but excludes their combined influence on adoption (Garavand et al., 2016; Jacob et al., 2020). In this dissertation, I aim to address this limitation by exploring how both types of user characteristics can be successfully elicited in personas to gain a holistic understanding into the needs of users. Specifically, I illustrate an improved personas-construction approach in which I combined UCD with the Integrated Model of Behavioral Prediction (IMBP) framework to gain insight into both the external and intrinsic user characteristics of prospective users of a digital health intervention. For background, the IMBP framework is a behavioral theory that suggests that an individual's intention to perform a given behavior is positively or negatively influenced by certain beliefs and barriers about the given behavior (Fishbein & Ajzen, 2011). Compared to personas, journey maps are visual pathways representing the overall experience of an intervention by users based on the perspectives of prospective users of an intervention (McCarthy et al., 2016). Journey maps are beneficial in the development of health interventions as they can be used

to visualize desired future states of a service that are aligned with the needs of users and pinpoint areas for improvement in current practice (Flood et al., 2021). While personas provide insight into who users of a digital intervention are, journey maps depict how these users may engage with the digital intervention in practice as they move through a series of touch points (i.e., points during which users interact with the intervention; McCarthy et al., 2016). Therefore, integrating personas-construction and journey mapping into the development process of digital health interventions could be beneficial, as it can foster a comprehensive understanding of user needs. In this dissertation, I explore whether using both a personas-construction approach embedded in behavioral theory and journey mapping can facilitate a comprehensive understanding into the needs of prospective users, setting new standards for examining user needs to inform the development of digital health interventions **(chapter 2 and chapter 3).**

Steps 2 and 3: Develop, observe user interactions, and refine interventions

The second and third step of the UCD iterative cycle aims 1) to aggregate and translate the needs of prospective users into design requirements and use these requirements to develop a prototype of the intervention (i.e., simplified version of the intervention) and 2) to observe prospective users interactions for further refinement of interventions (Witteman et al., 2015, 2021) First, when aligning the design requirements to the needs of the user, this step can increase the prototype's fidelity among prospective users (Witteman et al., 2015, 2021). However, in the context of UCD developed digital health interventions, a trade-off exists whereby researchers need to make decisions about satisfying the needs of users versus developing technologically possible interventions (Van Velsen et al., 2022). This can make translating user needs into tangible design requirements for UCD developed digital health interventions difficult, suggesting that effective development of these interventions may benefit from an umbrella view to problem solving. Interdisciplinary expertise relies on the knowledge and perspectives of researchers from several different disciplines to solve complex problems (Witteman et al., 2013). Thus, one way to harness an umbrella view in UCD

developed digital health interventions is by involving interdisciplinary expertise in the development process of such interventions. In this dissertation, I illustrate how interdisciplinary expertise from communication science, medical informatics, geriatrics, and epidemiology were involved to inform the user interface, software, clinical guidelines, and clinical risk prediction in a UCD developed digital falls prevention intervention, respectively **(chapter 4).**

Second, with regards to observing prospective users interactions for further refinement of interventions, this step can be achieved by means of usability testing (Abras et al., 2005). Usability testing can improve the user experience, efficiency, and satisfaction of an intervention by analyzing prospective users interactions with the prototype after they have been asked to complete a set of specified tasks using the prototype (Dumas et al., 1994). Several methods can be used during usability testing including think-aloud methods and observations via video recordings (Abras et al., 2005). Video recordings can help uncover potential usability problems as the researcher can review a prospective users steps during task completion. In turn, think-aloud methods such as concurrent think-aloud can help deepen the resarchers understanding of identified usability problems as prospective users are asked to articulate their thought process during task completion (Abras, Maloney-Krichmar, et al., 2005; Ericsson & Simon, 1984). Furthermore, next to video recordings and think-aloud methods, usability evaluation methods have been developed to support researchers in classifying and prioritizing identified usability problems based on the problem's severity rating. Such a classification approach can guide the refinement efforts of digital health interventions as the most severe problems are prioritized first by developers (Khajouei et al., 2011; Nielsen, 1993). However, a limitation of current practices to prioritizing usability problems is that the severity rating does not take into account the secondary user experience, which could lead to suboptimal prioritization of usability problems during refinement efforts. In health care, users of digital interventions can be divided into primary users, such as HCPs using the intervention, and secondary users, such as patients benefiting from the intervention (Alsos & Svanæs, 2011; Angell et al., 2016). Therefore, usability problems experienced by HCPs (i.e., primary users) could have a

severe negative effect on patients (i.e., secondary users), and solving these usability problems in digital health interventions is crucial for improving patient care (i.e., secondary user experience). This dissertation explores a severity rating based on the potential negative impact of usability problems on the secondary instead of primary user experience to improve the refinement efforts of a UCD developed digital health intervention in a falls prevention context **(chapter 5).**

Step 4: Testing UCD driven interventions in real-life practice

As described above in step three, usability testing of digital health interventions is conducted in a controlled environment, with a small number of prospective users, in which the examination of the user interface is limited to specified tasks (Abras, Maloney-Krichmar, et al., 2005; Witteman et al., 2015, 2021). While this step is vital for enhancing the usability of interventions for prospective users prior to implementation, investigating the efficacy of UCD developed digital health interventions in real-life practice settings is crucial for ensuring its successful adoption by prospective users after implementation. Therefore, I propose a fourth step in the iterative cycle in which the near final version of the digital health intervention is tested in real-life practice settings. Specifically, since UCD is considered to be an effective development strategy for improving the user experience of digital health interventions for HCPs and older adults, I explore whether this enhanced user experience can facilitate a change in behavior in these users (Czuber et al., 2024; Harte et al., 2017; Hsieh et al., 2021; Nimmanterdwong et al., 2022; Rice et al., 2022; Tejeda et al., 2023). This can improve current understandings of the effectiveness of UCD driven digital health interventions for improving health care. In this dissertation, I test the effectiveness, user experience, and implementation of a UCD developed digital health intervention for falls prevention in Dutch primary care prior to full-scale development and national implementation (**chapter 6**).

OVAST and AD*F*ICE_IT

This dissertation is part of two funded digital health intervention projects for

falls prevention, **'OVAST'** ('**O**ptimizing, implementing, and evaluating the **V**alanalyse screening and **A**sse**S**sment **T**ool') and **'AD*F*ICE_IT'** ('**A**ltering on adverse **D**rug reactions: **F**alls prevention **I**mprovement through developing a **C**omputerized clinical support system: **E**ffectiveness of **I**ndividualized medica**T**ion withdrawal').

Due to low adoption rates in real-life practice settings, the **'OVAST'** project focused on enhancing the user experience of an existing paper-based multifactorial falls risk assessment tool for HCPs in Dutch primary care, namely the Fall Analysis 1.0 (in Dutch: 'Valanalyse'). Developed by the Dutch National Expert Center on Injury Prevention (in Dutch: VeiligheidNL), the Fall Analysis 1.0 makes use of evidence-based functional tests and questionnaires to guide HCPs through the assessment of 13 (modifiable) falls risk factors to inform a multidomain intervention in high risk older adults (i.e., history of falls, mobility, medication, dizziness/vestibular, fear of falling, vision, hearing, activities of daily living, cognition, urinary incontinence, environmental factors, footwear and foot problems, nutritional status and vitamin D intake; VeiligheidNL, n.d.). In this project, I collaborated on the development and testing of the improved version of the Fall Analysis 1.0 and corresponding training, namely the Fall Analysis 2.0 (in Dutch: 'Valanalyse 2.0'). Specifically, the content of the Fall Analysis 2.0 and corresponding training are based on the content of the Fall Analysis 1.0 and corresponding training. However, the user experience of the Fall Analysis 2.0 and corresponding training are based on UCD outcomes which included the development of personas, journey map, prototype and usability testing of the prototype, as well as investigating the effectiveness, user experience, and implementation of a near final version of the Fall Analysis 2.0 and corresponding training in primary care. The entire OVAST project is described in this dissertation.

The second project '**AD*F*ICE_IT**' focused on personalized medication management for falls prevention in older adults by (1) developing and validating a falls risk prediction model to identify an older adult's risk of falling; (2) developing and testing the CDSS to facilitate deprescribing of falls risk increasing medications in older adults; and (3) developing and testing a patient portal to facilitate shared decision-making and joint

medication management between HCPs and older adults. CDSS are computerized systems that transfer knowledge from guidelines to support HCPs in the treatment of patients (Goud et al., 2010; Sim et al., 2001). In the context of falls prevention, CDSS can be useful for the treatment of complex risk factors within a multidomain intervention, such as considering deprescribing of falls risk increasing drugs (Van de Loo et al., 2024). As part of this project, I collaborated on the development of the CDSS which included the development of the user interface, knowledge base, reasoning engine and software, as well as the integration of the falls risk prediction model. In this dissertation, the development of the CDSS is described in which UCD was complemented with interdisciplinary expertise.

Fig 2. Overview of the research outlined in this dissertation.

1 Aim and outline of the dissertation

Figure 2 provides a visual overview of the contents of this dissertation, which is divided into three parts. **Part 1** (aim 1) of this dissertation sets new standards for examining the needs of prospective users to inform the effective development of digital health interventions. This part comprises of chapters 2 and 3 of this dissertation. In **chapter 2**, I conducted a quantitative study to gain insight into the holistic needs of prospective users by combining UCD with behavioral theory (i.e., the IMBP framework) to construct personas representing fictitious users of the Fall Analysis 2.0. In **chapter 3**, I carried out a qualitative study to gain a deeper understanding into the needs of prospective users of the Fall Analysis 2.0 by visualizing the desired future state of the digital health intervention in a journey map. Together, this comprehensive approach to understanding user needs informed the design and implementation requirements for the Fall Analysis 2.0 prototype and corresponding training, respectively.

Part 2 (aim 2) of this dissertation was to improve the development and refinement efforts of UCD developed digital health interventions. This part includes chapters 4 and 5 of this dissertation. In **chapter 4**, I demonstrated how the AD*F*ICE_IT CDSS was developed by harnessing an umbrella view including interdisciplinary expertise from communication science, medical informatics, geriatrics, and epidemiology. In **chapter 5**, I test the usability of the Fall Analysis 2.0 prototype among prospective users. Additionally, I explore how the prioritization of identified usability problems in UCD developed digital health interventions can be enhanced to improve refinement efforts of these interventions. The results of this study were used to inform refinements to the Fall Analysis 2.0 to be evaluated in part 3.

To examine the potential influence of UCD on behavior and determinants of behavior, **part 3** (aim 3) of this dissertation was to investigate a UCD developed digital health intervention in real-life practice settings. This part includes chapter 6. In **chapter 6**, I describe a hybrid type 2 effectiveness-implementation study in which I tested the effectiveness, user experience, and implementation of the Fall Analysis 2.0 on the falls risk management behavior of HCPs and the adherence-related motivation of older adults in primary care in the Netherlands.

In chapter 7, the final chapter of this dissertation, I summarize the main results of chapters 2 through 6. Additionally, I discuss the implications of the integrated results in practice, as well as this dissertation's strengths and limitations. Lastly, I provide directions for future research and share my final conclusions.