Preventing Diabetic Foot Ulcers With eHealth

Jun 23rd, 9:00 AM - Jun 28th, 5:00 PM

Preventing Diabetic Foot Ulcers With eHealth: Rethinking Digital Care In Co-design

Deborah Pelders
Fontys University Of Applied Sciences

Roy Van Den Heuvel
Fontys University Of Applied Sciences; Eindhoven University of Technology

Mark Arts
Fontys University Of Applied Sciences

Ittay Mannheim
Ben Gurion University of the Negev

Rens Brankaert
Fontys University Of Applied Sciences; Eindhoven University of Technology

Citation

Pelders, D., Van Den Heuvel, R., Arts, M., Mannheim, I., and Brankaert, R. (2024) Preventing Diabetic Foot Ulcers With eHealth: Rethinking Digital Care In Co-design, in Gray, C., Ciliotta Chehade, E., Hekkert, P., Forlano, L., Ciuccarelli, P., Lloyd, P. (eds.), *DRS2024: Boston*, 23–28 June, Boston, USA. https://doi.org/10.21606/drs.2024.842

Preventing diabetic foot ulcers with eHealth: Rethinking digital care in co-design

Deborah Pelders[a,*], Roy van den Heuvel[a,b], Mark Arts[a], Ittay Mannheim[a,c], Rens Brankaert[a,b]

[a] Fontys University of Applied Sciences, The Netherlands
[b] Eindhoven University of Technology, The Netherlands
[c] Ben Gurion University of the Negev, Israel

*Corresponding e-mail: d.pelders@fontys.nl

doi.org/10.21606/drs.2024.842

Abstract: The number of people with diabetes is projected to increase over the upcoming years, putting pressure on care systems. Many patients with diabetes are at high risk of developing foot ulcers. These patients often struggle to relate to and monitor the health of their feet in everyday life. While eHealth technologies show promise in supporting self-management of diabetes, their use is still limited in the context of diabetic feet. By following a design process using co-design practices, we developed a suitable eHealth application that supports people in preventing diabetic foot complications. Through a participatory design approach, we uncovered 11 design requirements highlighting the importance of offering digital support when possible but enabling physical care when needed. We argue for a technology-supported culture of care through simplified self-monitoring and direct contact with care professionals. Finally, we discuss implications for designing eHealth solutions by involving all relevant stakeholders.

Keywords: co-design; ehealth; diabetic foot ulcers; design process

1. Introduction

Diabetes Mellitus is one of the most common chronic diseases worldwide and is expected to grow significantly over the coming years (Whiting et al., 2011). A prevalent and debilitating complication of diabetes is Diabetic Foot Ulceration (DFU), which is strongly associated with the presence of peripheral neuropathy, foot deformity, and different grades of ischemia (Jeffcoate et al., 1993). Diabetes-related foot ulcers significantly increase the risk for infection and are a leading cause of required lower extremity amputation, reduced quality of life, mortality, and healthcare costs (Matricali et al., 2007). Regular screening, education, and self-management are key recommendations to prevent diabetic foot development (IWGDF, 2023). In the Netherlands, foot care for people with Diabetes is mainly provided by specialized podiatrists. Because the availability of podiatrists will soon be insufficient to meet care

requirements for the rapidly growing population with Diabetes, preventative approaches like self-monitoring and remote care are urgently needed.

Diabetes self-monitoring has been shown to be successful, cost-effective and can reduce hospital admissions as well as diabetes-related complications (H. S. Brown et al., 2012; Healy et al., 2013). This includes awareness of complications such as DFU, self-management (Kebede & Pischke, 2019) and facilitating digital contact to cost-effectively provide insights into selfcare habits and the health status of a diabetic foot (Rinaldi et al., 2020). Ploderer et al. (2023) recently showed promising results with using a smartphone application to facilitate self-monitoring of the DFU healing process (Ploderer et al., 2023). A few studies show systems specifically developed for ulcer prevention purposes focusing on creating foot selfies for evaluation by podiatrists and to educate patients (Anthony et al., 2020; Swerdlow et al., 2021). Although patients see the benefit of using eHealth to monitor their feet and are generally willing to use such devices, there are often challenges concerning usability and long-term adoption.

During the COVID-19 pandemic, a large podiatry organization in The Netherlands wanted to maintain their culture of care which they describe as putting patients at the center of their care, and in personal contact with podiatrists. To facilitate this, an eHealth application called 'Voetencheck App' (English: FeetCheck App) was rapidly developed. The application sends notifications to people with diabetes to screen their feet, guided by questions and instruction videos. Patients take a picture of their feet, which is then inspected remotely by a specialized diabetes podiatrist. If required, the patient will be contacted by their own podiatrist for a consultation. An initial pilot during the first COVID-19 lockdown showed promising reactions from both patients and care professionals. Yet, it was recognized that the system lacked a solid understanding of patients' care journey and related experiences and podiatrist's usage of eHealth.

The user-driven and mobile nature of eHealth applications gives rise to novel challenges, where designers need to deeply understand the users' health context and experiences. This complexity arises from the many factors that impact a person's acceptance and use of technology (Zhang et al., 2019) and as such, designing eHealth systems requires frequent engagement with patients and domain-specific stakeholders (Schiller et al., 2013). Generally, user involvement of older persons is limited, may be biased by stereotypes, and may eventually influence the designed outcome (Mannheim et al., 2023). To tackle this, designers have increasingly looked towards participatory design methods (Eyles et al., 2016; Sanders & Stappers, 2008).

In this study, we led a design process to improve and implement the design of the 'FeetCheck App' and redesigned the application from the ground up to better align with the needs of patients and the reality of podiatry practice. This co-design study had two goals: (1) To design a new version of the 'FeetCheck App' with emphasis on user's needs to help prevent DFU. (2) To share reflections on the co-design process leading towards this new design.

2. Related work

We first introduce the design space around diabetes-focused eHealth solutions and design processes. We then zoom in on self-monitoring technologies aimed at (the prevention of) Diabetic Foot Ulcers (DFU). The resulting insights and gaps form the basis of our participatory design approach, design activities, and outcomes.

2.1 Designing eHealth technologies for diabetes

Over the last two decades many eHealth technologies aimed at helping people with diabetes have emerged (Hood et al., 2016). Such eHealth systems help users in self-management of their disease and promote healthy behaviors, such as keeping track of glucose levels and improving nutrition or physical activity (Fico et al., 2020; Wang et al., 2020). While research into the usability and effectiveness of diabetes-related self-monitoring eHealth applications show promising results, researchers highlight the desire to investigate how app developers must fully consider users' needs in designing features for patients with diabetes (Sanz et al., 2021). Part of why this seems to be lacking might be because, traditionally, eHealth designs have used stand-alone usability metrics such as SUS (Broekhuis et al., 2019) and one-time focus group sessions. These might be useful tools to get a quick idea of ease of use, but they only provide a glimpse of the general usability, not the specifics of how users interact with the app in an everyday real-life context (Scheibe et al., 2015). Moreover, studies such as Khowaja & Al-Thani (2020) employ heuristics evaluation methods with users when the design is already completed, and it is often not clear whether resulting data will influence the redesign of the eHealth intervention (Khowaja & Al-Thani, 2020).

To engage stakeholders throughout the design process in eHealth, designers have increasingly used Participatory Design (PD) methods (Ayobi et al., 2021; Noorbergen et al., 2021). Castensøe-Seidenfaden et al. (2017) used an iterative PD approach to support designers in understanding the needs of end users (Castensøe-Seidenfaden et al., 2017). They found that it is critical to include all end user groups during all phases of a PD project and to work with a multidisciplinary team to include the range of expertise required to build a useful eHealth app. Following Sanders & Stappers et al. (2008), this type of design process can be described in phases in which different design activities take place (Sanders & Stappers, 2008). Noorbergen et al. (2021) highlight that the eHealth co-design research field is highly fragmented and mostly focuses on the early stages of the design process (pre-design & generative), and that few studies engage in a post-design phase (4.9%) (Noorbergen et al., 2021). Important for this study is the notion that “The tail end of the post-design phase [leads] to the front end of another design process.” (Sanders & Stappers, 2008). In this work, we use the pilot post-design phase results of the first ‘FeetCheck App’ as input for co-design activities in the pre-design phase.

2.2 Self-monitoring technologies for prevention of Diabetic Foot Ulcers (DFU)

To tackle the challenging task of monitoring people at risk of DFU, researchers experimented with imaging technology (Hazenberg et al., 2020), foot-scanners (Foltynski et al., 2011), and

wearable plantar pressure measurement systems for example incorporated in smart textiles (Orlando et al., 2021). While these technologies can deliver clinically accurate data, they are burdensome, often tested in a lab-based setting, and not meant for daily use at home (Najafi et al., 2020). Early explorations in using eHealth technologies for people at risk of DFU were often in the form of app-based diaries or data-tracking graphs. Such systems are simple in use and can give useful clinical input, but often fail to engage users over longer periods of time (R. Brown et al., 2017). To increase self-monitoring behaviors, nudging techniques delivered by mobile applications have been shown to increase the amount of daily foot inspections (Swerdlow, 2020). The rapidly increasing use of smartphones with good cameras is emerging as fertile ground for accessible, low-cost and data-rich self-monitoring designs. Work by Ploderer et al. (2023) has shown that letting people use the MyFootCare app is perceived to be valuable and shows promise towards promoting self-monitoring the health of their feet (Ploderer et al., 2023). While their study is limited to a sample of 12 participants, they identified that designers should consider working with patients comfortable with smartphones, and co-design for both patients and podiatrists dedicated to self-care. Finally, they highlight the need for patients and healthcare professionals to share data, experiences, and support. Since their design mostly allows monitoring existing ulcers, there is a need to focus such efforts on a more preventative approach. A co-design process seems well-suited to engage with the complexity of developing a prevention-focused eHealth solution for people at risk of developing DFU.

3. Methodological approach

In the following section we detail the methodological approach of the co-design process inspired by the co-design approach by Sanders & Stappers (2014). As such, a multi-disciplinary view was applied to include the perspectives of all relevant stakeholders, e.g., people with diabetes, podiatrists, other healthcare professionals and insurers. We started our design process with the initial prototype of the 'FeetCheck App', which was developed in 2020, and made available to patients via their care professional.

3.1 Ethical considerations

Participants in the design activities were provided with detailed information on the process and the activity and signed an accessible informed consent-form. Participants required no pre-existing experience or knowledge. Data was managed according to the standard privacy and ethical regulations. The Ethical Committee of the host institute gave approval for the research proposal.

3.2 Methodological overview & Co-Design Activities

We hereby summarize the general approach and the co-design activities that were conducted during an 18-month co-design project. The design process comprises of 4 main phases: the Pre-Design, Generative, Evaluative and Post-Design phase. The co-design activities included focus groups, interviews, expert sessions and co-creation workshops to help

understand participants' needs and empower participants to co-design their own ideas and solutions. Table 1 provides an overview of all design activities and participant information.

Table 1 An overview of the design activities leading up to the final design of the 'FeetCheck App'.

Phase	Activity	Aim	Participants	Data Collection	Result
Pre-Design	Patient Focus Groups	Deepen understanding of needs and wants of patients with Diabetes.	13 patients (4 sessions)	Field Notes, Transcripts, Empathy Map, Thematic analysis	11 Design Requirements
	Stakeholder Interviews	Deepen understanding of experiences from relevant stakeholders.	5 podiatrists, 4 healthcare professionals, 4 insurers	Summary with member check, Field notes, Thematic analysis	
	Patient Focus Groups	Deepen Understanding of user experience of patients that used the App.	12 patients (3 sessions)	Transcripts, field notes, Thematic analysis	
Generative	Multistakeholder Co-creation Session	Ideation of features.	8 participants (Designers, developers, podiatrists)	Field Notes, Annotated Paper Prototypes	First Digital Prototype
	Podiatrist Co-creation Session	Use input from Multistakeholder session for improving features.	5 podiatrists	Paper Prototypes, List of Features	
Evaluative	Iterative Development	Evaluation and Development of App prototype.	8 participants (Designers, developers, podiatrists)	Feedback on Digital prototypes	Working FeetCheck App Design
	User Testing	Gain feedback about App prototype.	6 patients	Field notes, Video recordings, Improvements list	
Post-Design	Longitudinal Evaluation Study	Understand whether the intervention and process achieved its goals.	30-50 patients. 10 healthcare professionals	Ongoing	Feedback for future modifications

The *Pre-Design Phase* included 7 focus groups and 13 interviews. Firstly, four focus groups with people with diabetes were organized to better understand their latent needs and experiences. Recordings were transcribed, coded and analyzed using a thematic analysis method with an inductive approach. Secondly, interviews were conducted with podiatrists, other healthcare professionals (e.g., MD and General practice-based nurse) and healthcare insurers to get an understanding of their experiences with eHealth. Additionally, three focus group sessions with patients with experience with the initial version of the 'FeetCheck App' were conducted. These focus groups formed our initial Post-Design data leading into the Pre-Design phase. The output of these design activities led to a collection of 11 design requirements for using eHealth in Diabetic Foot Ulcer (DFU) care (Table 2).

In the *Generative Phase*, the main goal was to redesign the prototype of the app. We organized 2 co-creation sessions in which a paper prototyping method (Rubin & Chisnell, 2008)

was used to co-create implementations of the design requirements. One was a multistakeholder co-creation session in which features were ideated on empty paper screens using a brainwriting method. These empty paper screens were entitled with the design requirements retrieved from the Pre-design phase to inspire participants in their ideation of new features. Then, the output of ideas was used by podiatrists who improved these ideas and generated new ideas using a similar method. The podiatrists during the second co-creation session were all experienced in assessing 'FeetCheck App' images, which supported them to look at generated ideas from a practical user-perspective. Also, we chose for a second session with only podiatrists to overcome dependency barriers between participants from the multi-stakeholder session which could possibly hinder ideation of new ideas. Combined with insights gathered from the Pre-Design Phase patient focus groups, the generated ideas allowed us to reimagine the application and develop (Rubin & Chisnell, 2008) new features based on the 11 design requirements.

The *Evaluative Phase* consisted of a cycle of design iterations with stakeholder feedback. After the first version of the digital prototype was finalized, the prototypes were user-tested in Think-out-loud sessions. Six patients evaluated the application in terms of usability, accessibility and functionality. The collected field notes were used to improve the final 'FeetCheck App' design. A working 'FeetCheck App' was then developed using an iterative cycle of software development and evaluation.

The *Post-Design Phase* started after launching the App to the App Stores (Rondom Podotherapeuten, 2024). A longitudinal evaluation study was started to gain insights into how well the intended goals of the design were being met. This study is ongoing, and outside the scope of this paper.

4. Results

Based on the data collected in the design activities in the four design phases, we have gathered a rich picture of the needs and wants of patients and healthcare professionals. By putting our stakeholders at the center of the co-design process, we identified design opportunities and reimagined a new version of the 'FeetCheck App'. A total of 31 patients (P), 12 podiatrists (PD) and 8 other healthcare professionals (Medical Doctor: MD, Nurse Practitioner: POH, Insurer: I) participated.

4.1 Pre-design phase: Development of design requirements

We were interested in understanding participants' latent needs and attitudes towards eHealth. The focus groups formed the basis for the resulting themes presented below. Within each theme, important topics are illustrated by representative quotes.

Theme 1: Patient-specific monitoring to provide personalized care

Patient-specific monitoring emerged as an important theme in the focus groups**,** in which patients described the need for a more personalized approach to their care trajectory. In the existing care pathway for diabetic foot ulceration, there are hardly any (eHealth) products,

services, or healthcare processes where people's personalized health needs are being taken into account. A podiatrist argues for such an approach: "*We want insights into what this (eHealth, red.) does for the patient; (to be) quicker and more patient-centered.*" (PD). Focus group participants describe their need for digital solutions that allow patients and healthcare professionals to provide care that fits their specific health results and daily life agendas. As one MD said: "*Sometimes it would be so much more patient-friendly to let them just send a picture."* (MD). A general practice-based nurse specialist agrees with an ambitious outlook: "*I am a big proponent of enabling patients to collect their own data, such as blood pressure, and share this with a system connected to the GP-systems*." (POH). An important point in supporting such personalized monitoring is the balance between digital and physical care. As a podiatrist succinctly put it: "*Digital remote care should happen in combination with physical care, not replace it."* (PD). This balance was also illustrated by a general practice-based nurse specialist: "*We still should see the feet once a year. What can be monitored earlier is a benefit. Saving time there allows you to help people who need it. Digital where possible, physical where needed*." (POH).

Theme 2: Self-management in line with ability

Taking charge of your own health and wellbeing is a complex undertaking and not everyone is able to completely self-manage. The ability to self-manage is a spectrum, where patients want to be supported to the extent they feel is feasible. As one patient summarizes: "*You try to live your life as good as you can, taking into account the possibilities you have; these possibilities are good if they fit in your life well." (*P). Overall, patients have a need to direct their own healthcare process, as one GP says: "*I think people like to have control, to have accessible communication and to receive answers quickly*." (MD). Reflecting on using the application to let people self-manage their monitoring a podiatrist says; "*With the [FeetCheck App] we can take the patients' schedule into account*." (PD). Which is a desired idea among the patients of the focus groups: *"I no longer have to go to the podiatrist unnecessarily. I only go there when necessary, just like with the doctor."* (P). All patients agreed that information about the follow-up after sharing data is necessary to use and maintain trust in the app.

Theme 3: Information and Education is often insufficient

From the moment of diagnosis people with diabetes experience a lack of information regarding care- and self-management opportunities. Even though healthcare professionals name the educational aspect of care as one of their main tasks; *"Education is key"* (PD), there seems to be a desire for more personalized and practical information. As a patient says: "*There are many opportunities, but you have to figure it out yourself. A lot of things aren't being told."* (P). Next to patients' education, the interviews also brought into light the need for educative support in digitalization among the healthcare professionals: "*Success factors are the digital skills of caregivers and patients"* (PD). This can be in its functionality, but also in the information given: "*Not too much or too elaborate information for either patient or caregiver*." (POH). Also, the aim of the design should be explained: *"We want insight into what it means for the patient; faster, more person-oriented".* (PD).

Theme 4: Patient-Caregiver Communication facilitates use of eHealth

Scaffolding empathic and quick communication between patients and care professionals emerged as a key theme from our focus groups. Patients require podiatrists that understand their needs: "*It's like a warm bath, someone who really understands. And knows how hard it is.*" (P). While eHealth solutions often offer textual information or chatbots, patients highlighted the need for human contact: "*When I ask a question, she really listens."* (P). This need for contact is also described from the side of the insurers: "*Possibilities for interaction (with the podiatrist, red.) are important when talking about the digitalization of care.*" (I). This sentiment is illustrated more practically in relation to the experiences of patients with the first version of the FeetCheck App: "*People don't mind uploading something 10 times, like a picture of the foot, if there's a response from the caregiver saying that they saw it and that it looks good. Really that personal note*." (P). Important is that this communication is required as a personal feedback mechanism, driving sustained engagement: "*Only uploading pictures but getting no response is useless, then you don't keep doing it."* (P). To maintain engagement, podiatrists recognized that eHealth systems should be introduced and repeatedly evaluated in-person.

Theme 5: Usability and Accessibility are crucial for wide adoption

Since our target group is mostly comprised of older adults, there's a tendency to ascribe a lack of digital literacy to the entire group (i.e., ageism). While it's certainly true that not everybody is capable of adopting eHealth without issues, a significant part of the older generation has learned to deal with digital systems in their everyday life: "*It's not (anymore) true that older persons are less digitally literate. For example, since COVID-19, they have started facetiming with their grandkids a lot more."* (POH). Still, patients with experiences with the first prototype of the application highly value an easy-to-use interface, for instance through feedback mechanisms and menus. eHealth approaches should not only take digital skills into account, but also the physical realities of patients at risk of Diabetic Foot Ulcer (DFU): "*We have people that are not so mobile, so it would be useful to continue appointments online, sharing information and perhaps pictures*." (MD).

The themes that emerged in this phase allowed us to formulate a set of design requirements for the development of the next iteration of the application, summarized in Table 2.

Table 2 An overview of the design requirements derived from the Pre-Design Phase.

Theme	**Design Requirements**
Patient-specific monitoring	1.1 Have the ability for patients to share health data such as pictures showing critical spots with their podiatrist and other care givers, linked to Electronical Health Record (EHR). 1.2 Offer a personalized balance in digital and physical care. For example, depending on the patients' health situation, the number of screenings complemented to physical consults can differ.
The ability to Self-manage	2.1 Include adherence features based on patients' preferences and needs, recognizing their ability to self-manage. Such as personalized notifications for patients to screen their feet. 2.2 Provide features to manage patients' and podiatrists' expectations on the procedure of the health data assessment. Such as information on what patients can expect after sharing health data.
Information & Education	3.1 Include educational features based on the patients' specific needs and abilities. Such as informative videos and explaining feet photos with textual description. 3.2 Provide purposeful and practical information for both patient and caregiver. Such as an introduction video explaining the goal of feet screening and expected actions that come along.
Patient – Care-Professional communication	4.1 Offer empathic and quick communication with care professionals. Such as a personal telephone call for follow-up based on shared health data. 4.2 Support physical consultations by showing health data collected by patients. Such as a timeline feature providing an overview of executed feet screenings and watched informative videos. 4.3 Use a single point of contact. The same care professional explains the app and also does the evaluations during physical consultations. For example, helping to log-in and to set notifications.
Usability & Accessibility of eHealth	5.1 Provide patients with immediate feedback after each action. Such as a textual confirmation that profile settings have been adjusted. 5.2 Take into account the differences in digital skills. Simplifying login steps, use audiovisual support, multiple languages, and provide advice on taking photos together with informal caregivers.

4.2 The generative phase: Co-designing the application

This section describes the desired application functions based on the design requirements (DR). Paper prototypes of app screens were first co-designed through a session with a group of 8 various stakeholders and subsequently improved upon in a co-creation session with 5 podiatrists specialized in diabetes. The result of this Generative Phase was an interactive, co-designed prototype (Figure 1).

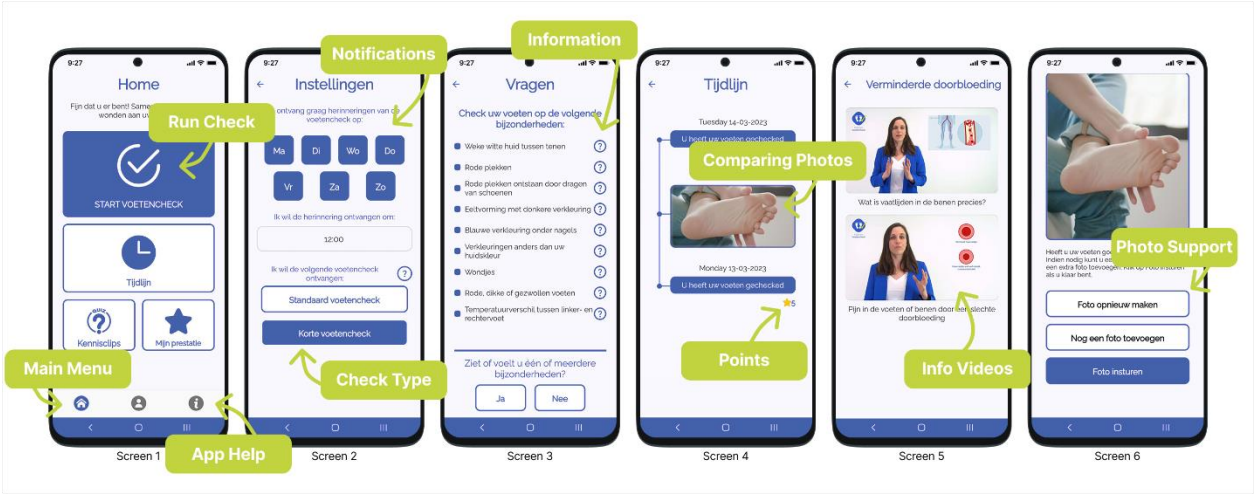

Figure 1 The translation of design requirements into a new design. FLTR: Screen 1-6.

The newly co-designed application is improved by supportive and educative features to help patients screen their feet regularly, providing care professionals with patient-specific, high-quality health data, and considering differences in people's self-management abilities.

To redesign the photo-sharing feature to consider the patients' digital and physical abilities (**DR 5.2, 5.3**) and improve data quality for therapists (**DR 1.1**), participants proposed features to share multiple photo's instead of one and allow retakes (Screen-6).

The application should provide patients with a clear overview of their personal health results (**DR 1.1**) and self-monitoring efforts (**DR 2.1**). As a podiatrist says: *"It is interesting to obtain information about the patient's adherence with self-care. For example: To what extent did they watch the video, and how many foot checks did they perform." (PD).* Participants co-designed a timeline feature, visualizing FeetCheck data chronologically (Screen-4).

To support patients in monitoring their feet throughout their everyday routines (**DR 1.2**, **2.1**) the profile settings within the application were redesigned (Screen-2). This improved feature could include personalization options such as the ability of scheduling when to receive reminders. According to podiatrists, another feature that would contribute to patients' adherence was a reward feature; patients receive points for each self-management activity such as screening their feet (**DR 2.1**).

Patients have a desire to receive tailored information about the assessment procedure of shared health data (**DR 2.2**) and Diabetic Foot Ulcer (DFU) care (**DR 3.1, 3.2**). Podiatrists found it important to check if that information is understood by patients. Therefore, educational features such as informative, curated, videos with practical advice and follow-up questions were developed (Screen-5). Sharing new videos over time was suggested to motivate patients to keep learning about self-management. The timeline can be used to show the watched videos and answered questions (Screen-4).

In the co-design process towards desired *patient – care-professional communication,* podiatrists strived for time-saving mechanisms while maintaining trust in quality triage (**DR 4.1,**

4.2): *"If there is no need to visit the clinic based on shared health information; answers to questions and feet photo, an assistant could call or automatic feedback could be sent to the patient. This way, waiting time could be reduced"* (PD). To implement this idea, a clear text or video of what to expect after having done a screening was suggested.

The feeling of single-point caregiver contact (**DR 4.3**) could be supported by conducting telephone calls to schedule follow-up consults by patients' own podiatrists.

A clear menu structure (Screen-1) has been mentioned repeatedly to overcome different digital abilities (**DR 5.1, 5.2**). Also, audiovisual support and feedback was appraised by the participating care professionals (Screen-4).

4.3 The evaluative phase: Iteratively evaluating and improving the application

In this phase, a prototype based on the results of the Generative phase was evaluated in usability-tests with six patients.

The most frequent feedback from the participants emerged from the implementation of a short foot-screening option, which is an overall question to confirm that the feet have been checked. Participants found the short screening option less time consuming and supportive to make feet screening a routine: "It's nice that you don't have to click ten times when you already know that your feet did not change" (P). Podiatrists expressed their concerns with regards to the less elaborate feet screening. They mentioned that some patients need step-by-step guidance to screen their feet properly: "The ability in self-management differs a lot among patients" (PD). Therefore, both options were implemented via a choice option in profile settings.

Interestingly, most participants mentioned that they expect others to appreciate the reward feature but not themselves: "Those points, personally I am not motivated by it, but others might like it" (P). Especially because the rewards could not be exchanged for something of value. Therefore, an idea was suggested to bring real rewards, such as discounts on soles, however this was not implemented in the current version.

Other features such as the timeline, the informative videos, and the profile settings were positively received. Patients mentioned their wishes for informative video topics; new care opportunities and other patients' stories. The ability to personalize the reminders, set a profile picture and compare shared feet pictures via the timeline feature was appreciated. One patient says: "It is nice to feel that it is a free choice when you like to screen your feet and receive reminders" (P).

Regarding usability, scrolling pages confused many participants. Fixed buttons and easy guidance to the main menu were helpful suggestions and consequently implemented. Also, a progress bar during the screening process seemed desired as mentioned multiple times.

After a period of continuous iterations and evaluations between the design of the application and software development, a fully working version of the 'FeetCheck App' was completed in line with (most of) the features that came out of the co-design process.

4.4 The post-design phase

The aim of the Post-Design phase is to evaluate the 'FeetCheck App' on how well it has achieved its intended goals. Preliminary findings based on talks with podiatrists and patients indicate that the redesigned 'FeetCheck App' is being received well and that patients appreciate the clear interface and ability to screen their feet with quick response. One patient said: "*I sent a picture because I didn't trust a pressure point. I quickly received an answer and was reassured."* (P). While some patients can manage to manually screen their feet, others said that: "E*ven with explanations aof the screening questions, it wasn't always easy to choose yes or no. Sending in a picture every once in a while works very well, and often there's a rapid response.*" (P). A longitudinal evaluation study is currently underway to gain insights into how well the intended goals of the redesign are being met and to facilitate future modifications – this is outside the scope of this article.

This work reimagined the design process by means of implementing a co-design process to redesign the 'FeetCheck App'. The engagement of patients in the process was received positively by all patients, as one patient mentioned: "*You know, I think it's such a shame that so many clear-cut solutions have been devised that haven't been thought through. That is why I am happy with this kind of event, that more attention will be paid to what it is like from the point of view of a diabetes patient*." (P). Other stakeholders in the process agreed that reimagining the design process was a positive contribution to the aim of the research. One GP says: "*I think it is nice and special that you say that you are taking a step back and looking more broadly. Embracing everyone involved increases the chance of success*." (MD).

5. Discussion

The 'FeetCheck App' was initially designed as a prototype without conducting a co-design process due to rapid need for the app during the COVID-19 pandemic. This study aimed to rethink the application following a participatory design process and consequently, redesign the application from the ground up, emphasizing higher usability and long-term adoption. The four phases used in this study, including patients and various healthcare professionals, helped to understand how the stakeholders perceive their role and experiences in the process of Diabetic Foot Ulcer (DFU) care. The co-design process considers users as experts in their own experience (Sanders & Stappers, 2008), allowing us to observe how primary users, like people living diabetes and podiatrists, engaged with the FeetCheck App in their everyday practice. Including ways that we did not imagine or intend, such as involvement of patient' partners in taking pictures. We recognize that user involvement at a higher level is quite demanding, specifically for the heterogenous group of patients, who have different characteristics and needs (Fischer et al., 2020). As described by Noorbergen et al. (2021), there are no de facto standards in the field so we tailored the activities to the capabilities of the different stakeholder groups, considering abilities and dependencies between patients and therapists. Highlighting the notion that "no designed system is ever complete" (Sanders & Stappers, 2014), we emphasize that using the tail end of the Post-Design phase from the first prototype is valuable, as stakeholders, including patients, had a clear understanding of the main

concept and goals. This helped to give more direction to their input in our subsequent co-design activities.

Engagement in using eHealth applications is often low (Islam et al., 2022). Although there always will be patients that are not willing or able to engage in self-monitoring their health (Ploderer et al., 2023). Nevertheless, it has been emphasized that no or low involvement of users in the design could also hamper acceptance (Fischer et al., 2020; Greenhalgh et al., 2017; Mannheim et al., 2023). We believe that the renewed app design, developed in co-design with stakeholders, will better suit the users' needs and improve adherence to prevention-stimulating practices. We found that letting patients share data in their own way and maintain good contact with care professionals supported **patient-specific monitoring.** Where Van Ploderer et al. (2023) used a computer-vision model to track ulcer healing (Ploderer et al., 2023), rather than preventing them, the need for patients to share data with a podiatrist was perceived as important to engagement. The simplicity of the 'FeetCheck App' and the reminder features were helpful in enabling **self-management**. Still, personalization efforts can be improved. Wang et al. suggest to further investigate optimal formats and the frequency of engaging patients as well as build better tailoring of messages (Wang et al., 2020). **Information and education,** provided via technology, is found to be effective in the performance of foot self-care (Lira et al., 2023; Moreira et al., 2020). Our informative video clips and texts were highly appreciated to convey information. Future work can explore how information can be personalized to the needs of the patient, for instance through virtual consultation. **Patient - Care-Professional communication** is a core concept of the 'FeetCheck App'. Enabling a means of communication within regulatory and practical considerations requires organizational efforts such as using dedicated diabetes podiatrists who inspect the health data and subsequently have the patient's podiatrist call for an appointment. While we see the advances of AI-powered screening systems (Pappachan et al., 2022), we mustn't forget to lose sight of having a human-in-the-loop to make sure people are being listened to. Many people with, or at risk of DFU have difficulties with the **usability** of mobile applications (Arnhold et al., 2014). While the 'FeetCheck App' had initially similar problems, the co-design activities were successful in identifying and subsequently redesign the most important usability problems such as readability and navigation. The inclusive design process was positively received by all stakeholders and seems to successfully contribute to usability and long-term adoption, differing from eHealth designed with a lack of user involvement in which (older) patients are often excluded (Mannheim et al., 2023).

This study had certain **limitations**. The participants in this study mostly consisted of enthusiastic patients willing to engage in co-design activities and had experience with digital apps. This might not be representative of the heterogeneity of the target population, and people with lower motivation to self-monitor the health of their feet might have different requirements. Additionally, taking photos of feet is sometimes difficult for people with decreased mobility. Future work could explore options to provide support, for instance by asking the

informal caregiver to support. While preliminary test results seem promising, a robust evaluation study is required to gauge the effect of our co-design process on the effectives of the intervention.

6. Conclusion

A Participatory Design approach helped us to re-think a technology-supported culture of preventive Diabetic Foot Ulcer (DFU) care, in which patients with diabetes are supported to monitor the health of their feet in everyday life. This study demonstrated that co-design practices are highly recommended to understand patient and therapist needs and desired app features in developing digital preventive eHealth interventions for people at risk of DFU. Generating insights that might apply broader. We believe that monitoring patient-specific health results remotely, via co-designed eHealth such as the 'FeetCheck App', could reduce pressure on our care system. Future research should investigate the long-term engagement and effectiveness of the 'FeetCheck App' on preventing diabetic foot complications.

Acknowledgements: This study was part of the Technology Support for Diabetes project, which is subsidized by SIA RAAK EXZ.EXZ.01.004. The authors would like to thank RondOm Podotherapeuten for their support in co-designing the app. Additionally, we would like to thank all participants and podiatrists for their knowledge and insights. We also thank the developers of Stofloos.

7. References

Anthony, C. A., Femino, J. E., Miller, A. C., Polgreen, L. A., Rojas, E. O., Francis, S. L., Segre, A. M., & Polgreen, P. M. (2020). Diabetic Foot Surveillance Using Mobile Phones and Automated Software Messaging, a Randomized Observational Trial. The Iowa Orthopaedic Journal, 40(1), 35–42. https://www.ncbi.nlm.nih.gov/pubmed/32742206

Ayobi, A., Stawarz, K., Katz, D., Marshall, P., Yamagata, T., Santos-Rodriguez, R., Flach, P., & O'Kane, A. A. (2021). Co-Designing Personal Health? Multidisciplinary Benefits and Challenges in Informing Diabetes Self-Care Technologies. Proceedings of the ACM on Human-Computer Interaction, 5(CSCW2). https://doi.org/10.1145/3479601

Broekhuis, M., van Velsen, L., & Hermens, H. (2019). Assessing usability of eHealth technology: A comparison of usability benchmarking instruments. International Journal of Medical Informatics, 128, 24–31. https://doi.org/10.1016/J.IJMEDINF.2019.05.001

Brown, H. S., Wilson, K. J., Pagán, J. A., Arcari, C. M., Martinez, M., Smith, K., & Reininger, B. (2012). Cost-Effectiveness Analysis of a Community Health Worker Intervention for Low-Income Hispanic Adults with Diabetes. Preventing Chronic Disease, 9, 120074. https://doi.org/10.5888/pcd9.120074

Brown, R., Ploderer, B., Da Seng, L. S., Lazzarini, P., & Van Netten, J. (2017). Myfootcare: A mobile self-tracking tool to promote self-care amongst people with diabetic foot ulcers. ACM International Conference Proceeding Series, 5, 462–466. https://doi.org/10.1145/3152771.3156158

Castensøe-Seidenfaden, P., Reventlov Husted, G., Teilmann, G., Hommel, E., Olsen, B. S., & Kensing, F. (2017). Designing a Self-Management App for Young People With Type 1 Diabetes: Methodological Challenges, Experiences, and Recommendations. JMIR MHealth and UHealth, 5(10). https://doi.org/10.2196/mhealth.8137

Eyles, H., Jull, A., Dobson, R., Firestone, R., Whittaker, R., Te Morenga, L., Goodwin, D., & Mhurchu, C. N. (2016). Co-design of mHealth Delivered Interventions: A Systematic Review to Assess Key Methods and Processes. Current Nutrition Reports, 5(3), 160–167. https://doi.org/10.1007/s13668-016-0165-7

Fico, G., Martinez-Millana, A., Leuteritz, J. P., Fioravanti, A., Beltrán-Jaunsarás, M. E., Traver, V., & Arredondo, M. T. (2020). User Centered Design to Improve Information Exchange in Diabetes Care Through eHealth: Results from a Small Scale Exploratory Study. Journal of Medical Systems, 44(1), 1–12. https://doi.org/10.1007/S10916-019-1472-5/

Fischer, B., Peine, A., & Östlund, B. (2020). The Importance of User Involvement: A Systematic Review of Involving Older Users in Technology Design. The Gerontologist, 60(7), e513–e523. https://doi.org/10.1093/geront/gnz163

Foltynski, P., Ladyzynski, P., Migalska-Musial, K., Sabalinska, S., Ciechanowska, A., & Wojcicki, J. (2011). A new imaging and data transmitting device for telemonitoring of diabetic foot syndrome patients. Diabetes Technology and Therapeutics, 13(8), 861–867. https://doi.org/10.1089/dia.2011.0004

Greenhalgh, T., Wherton, J., Papoutsi, C., Lynch, J., Hughes, G., A'Court, C., Hinder, S., Fahy, N., Procter, R., & Shaw, S. (2017). Beyond adoption: A new framework for theorizing and evaluating nonadoption, abandonment, and challenges to the scale-up, spread, and sustainability of health and care technologies. Journal of Medical Internet Research, 19(11), e8775. https://doi.org/10.2196/jmir.8775

Hazenberg, C. E. V. B., aan de Stegge, W. B., Van Baal, S. G., Moll, F. L., & Bus, S. A. (2020). Telehealth and telemedicine applications for the diabetic foot: A systematic review. Diabetes/Metabolism Research and Reviews, 36(3), e3247. https://doi.org/10.1002/DMRR.3247

Healy, S. J., Black, D., Harris, C., Lorenz, A., & Dungan, K. M. (2013). Inpatient diabetes education is associated with less frequent hospital readmission among patients with poor glycemic control. Diabetes Care, 36(10), 2960–2967. https://doi.org/10.2337/dc13-0108

Hood, M., Wilson, R., Corsica, J., Bradley, L., Chirinos, D., & Vivo, A. (2016). What do we know about mobile applications for diabetes self-management? A review of reviews. Journal of Behavioral Medicine, 39(6), 981–994. https://doi.org/10.1007/S10865-016-9765-3

Islam, S. M. S., Mishra, V., Siddiqui, M. U., Moses, J. C., Adibi, S., Nguyen, L., & Wickramasinghe, N. (2022). Smartphone Apps for Diabetes Medication Adherence: Systematic Review. JMIR Diabetes, 7(2), e33264. https://doi.org/10.2196/33264

IWGDF. (2023). IWGDF Guidelines (2023 update). Www.Iwgdfguidelines.Org. https://iwgdfguidelines.org/guidelines-2023/

Jeffcoate, W. J., Macfarlane, R. M., & Fletcher, E. M. (1993). The Description and Classification of Diabetic Foot Lesions. Diabetic Medicine, 10(7), 676–679. https://doi.org/10.1111/j.1464-5491.1993.tb00144.x

Kebede, M. M., & Pischke, C. R. (2019). Popular Diabetes Apps and the Impact of Diabetes App Use on Self-Care Behaviour: A Survey Among the Digital Community of Persons With Diabetes on Social Media. Frontiers in Endocrinology, 10, 135. https://doi.org/10.3389/fendo.2019.00135

Khowaja, K., & Al-Thani, D. (2020). New checklist for the heuristic evaluation of mHealth apps (HE4EH): Development and usability study. JMIR MHealth and UHealth, 8(10), e20353. https://doi.org/10.2196/20353

Lira, J. A. C., Rocha, Á. S. C., Bezerra, S. M. G., Nogueira, P. C., Dos Santos, A. M. R., & Nogueira, L. T. (2023). Effects of educational technologies on the prevention and treatment of diabetic ulcers: A systematic review and meta-analysis. Revista Latino-Americana de Enfermagem, 31, e3944. https://doi.org/10.1590/1518-8345.6628.3945

Mannheim, I., Wouters, E. J. M., Köttl, H., van Boekel, L. C., Brankaert, R., & van Zaalen, Y. (2023). Ageism in the Discourse and Practice of Designing Digital Technology for Older Persons: A Scoping Review. The Gerontologist, 63(7), 1188–1200. https://doi.org/10.1093/geront/gnac144

Matricali, G. A., Dereymaeker, G., Muls, E., Flour, M., & Mathieu, C. (2007). Economic aspects of diabetic foot care in a multidisciplinary setting: a review. Diabetes/Metabolism Research and Reviews, 23(5), 339–347. https://doi.org/10.1002/dmrr.706

Moreira, J. B., Muro, E. S., Monteiro, L. A., Iunes, D. H., de Assis, B. B., & de Cássia Lopes Chaves, E. (2020). The effect of operative groups on diabetic foot self-care education: a randomized clinical trial. Revista Da Escola de Enfermagem, 54, 1–9. https://doi.org/10.1590/S1980-220X2019005403624

Najafi, B., Reeves, N. D., & Armstrong, D. G. (2020). Leveraging smart technologies to improve the management of diabetic foot ulcers and extend ulcer-free days in remission. Diabetes/Metabolism Research and Reviews, 36(S1), e3239. https://doi.org/10.1002/DMRR.3239

Noorbergen, T. J., Adam, M. T. P., Roxburgh, M., & Teubner, T. (2021). Co-design in mHealth Systems Development: Insights From a Systematic Literature Review. AIS Transactions on Human-Computer Interaction, 13(2), 175–205. https://doi.org/10.17705/1thci.00147

Orlando, G., Prior, Y., Reeves, N. D., & Vileikyte, L. (2021). Patient and Provider Perspective of Smart Wearable Technology in Diabetic Foot Ulcer Prevention: A Systematic Review. Medicina 2021, Vol. 57, Page 1359, 57(12), 1359. https://doi.org/10.3390/MEDICINA57121359

Pappachan, J. M., Cassidy, B., Fernandez, C. J., Chandrabalan, V., & Yap, M. H. (2022). The role of artificial intelligence technology in the care of diabetic foot ulcers: the past, the present, and the future. World Journal of Diabetes, 13(12), 1131–1139. https://doi.org/10.4239/WJD.V13.I12.1131

Ploderer, B., Clark, D., Brown, R., Harman, J., Lazzarini, P. A., & Van Netten, J. J. (2023). Self-Monitoring Diabetes-Related Foot Ulcers with the MyFootCare App: A Mixed Methods Study. Sensors (Basel), 23(5). https://doi.org/10.3390/s23052547

Rinaldi, G., Hijazi, A., & Haghparast-Bidgoli, H. (2020). Cost and cost-effectiveness of mHealth interventions for the prevention and control of type 2 diabetes mellitus: A systematic review. Diabetes Research and Clinical Practice, 162, 108084. https://doi.org/10.1016/J.DIABRES.2020.108084

Rondom Podotherapeuten. (2024). Diabetes Voetencheck App. Google Play Store. https://play.google.com/store/apps/details?id=nl.stofloos.zelfcheck&hl=nl&gl=US

Rubin, J., & Chisnell, D. (2008). Handbook of usability testing: How to plan, design, and conduct effective tests. John Wiley & Sons, Ltd.

Sanders, E., & Stappers, P. J. (2008). Co-creation and the new landscapes of design. CoDesign, 4(1), 5–18. https://doi.org/10.1080/15710880701875068

Sanders, E., & Stappers, P. J. (2014). Probes, toolkits and prototypes: three approaches to making in codesigning. CoDesign, 10(1), 5–14. https://doi.org/10.1080/15710882.2014.888183

Sanz, M. F., Acha, B. V., & García, M. F. (2021). Co-Design for People-Centred Care Digital Solutions: A Literature Review. International Journal of Integrated Care, 21(2). https://doi.org/10.5334/IJIC.5573

Scheibe, M., Reichelt, J., Bellmann, M., & Kirch, W. (2015). Acceptance Factors of Mobile Apps for Diabetes by Patients Aged 50 or Older: A Qualitative Study. Medicine 2.0, 4(1), e1. https://doi.org/10.2196/MED20.3912

Schiller, C., Winters, M., Hanson, H. M., & Ashe, M. C. (2013). A framework for stakeholder identification in concept mapping and health research: A novel process and its application to older adult mobility and the built environment. BMC Public Health, 13(1), 1–9. https://doi.org/10.1186/1471-2458-13-428

Swerdlow, M., Shin, L., D'Huyvetter, K., Mack, W. J., & Armstrong, D. G. (2021). Initial Clinical Experience With a Simple, Home System for Early Detection and Monitoring of Diabetic Foot Ulcers: The Foot Selfie. Journal of Diabetes Science and Technology. https://doi.org/10.1177/19322968211053348

Wang, Y., Min, J., Khuri, J., Xue, H., Xie, B., Kaminsky, L. A., & Cheskin, L. J. (2020). Effectiveness of mobile health interventions on diabetes and obesity treatment and management: Systematic review of systematic reviews. JMIR MHealth and UHealth, 8(4), e15400. https://doi.org/10.2196/15400

Whiting, D. R., Guariguata, L., Weil, C., & Shaw, J. (2011). IDF Diabetes Atlas: Global estimates of the prevalence of diabetes for 2011 and 2030. Diabetes Research and Clinical Practice, 94(3), 311–321. https://doi.org/10.1016/J.DIABRES.2011.10.029

Zhang, Y., Liu, C., Luo, S., Xie, Y., Liu, F., Li, X., & Zhou, Z. (2019). Factors Influencing Patients' Intentions to Use Diabetes Management Apps Based on an Extended Unified Theory of Acceptance and Use of Technology Model: Web-Based Survey. Journal of Medical Internet Research, 21(8), e15023. https://doi.org/10.2196/15023

About the Authors:

Deborah Pelders is a design researcher in the field of health and well-being at Fontys Allied Health Professions. She approaches challenges with a person-centered perspective. Understanding the socio-technical system, she strives to develop (technical) solutions addressing complex issues in healthcare.

Roy van den Heuvel is a design researcher in interactive health & well-being systems at Fontys Allied Health Professions and a PhD-candidate at Eindhoven University of Technology working on technology-enabled health promotion at the department of Industrial Design.

Mark L.J. Arts is a Human Movement Scientist currently working at Fontys Allied Health Professions in Eindhoven. He gained specific expertise around Diabetic foot related research during his PhD-project at the University of Amsterdam.

Rens Brankaert is a professor in Warm Technology in the group Health Innovations and Technology at Fontys Allied Health Professions and departmental fellow at Eindhoven University of Technology where he set up and runs the Expertise Center for Dementia and Technology.

Ittay Mannheim is a postdoctoral researcher at the Ben Gurion University of the Negev on ageing, ageism, and datafication in co-designing social-assistive robots for older persons. He received his PhD in 2023 from Tilburg University with the thesis "Ageism in the Use and Design of Digital Technology".