



Toward digital inclusion of older adults in e-health: a case study on support for physical activity

Åsa Revenäs^{1,2,3} · Lars Ström⁴ · Antonio Cicchetti⁵ · Maria Ehn⁵

Accepted: 20 September 2023
© The Author(s) 2023

Abstract

Older adults are a heterogeneous population for which many e-health innovations are inaccessible. Involving older adults in user-centered design (UCD) with a specific focus on inclusive design is important to make e-health more accessible to this user group. This case study aimed to explore the feasibility of a new UCD approach aiming to minimize bias in the design phase of a digital support for older adults' physical activity (PA). The study used mixed methods and applied UCD principles in a four-iteration design phase followed by an evaluation phase where 11 and 15 older adults participated, respectively. The users' gender, PA level and technology experience (TE) were considered in recruitment, data analysis and prioritization of improvement efforts. In the design phase, users with different gender, PA level and TE participated and contributed with feedback, which was prioritized in the development. The adaptation included improving readability, simplifying layout and features, clarifying structure, and making the digital content more inclusive and relevant. The evaluation showed that the users had a positive experience of the prototype and could use it with some help. The study demonstrated that adopting e-health to assure digital inclusion among older adults must address several aspects. The UCD approach was feasible for amending user bias and for confirming that users of both genders and with varied PA- and TE level shaped the design. However, evaluation of the method with larger samples is needed. Moreover, further research on methods to involve digitally excluded populations in UCD is needed.

Keywords Equity · Gender · Digital technology · Older adults · User representation

1 Introduction

Insufficient physical activity (PA) is a global health challenge that is particularly severe in specific groups such as older adults [1], a globally growing population [2] for which PA has additional health advantages including prevention of falls, fall-related injuries, functional decline, and

osteoporosis [3]. Since e-health interventions are effective for increasing older adults' PA, it has been recommended that e-health interventions should be included in guidelines to enhance PA [4]. However, digital exclusion is especially acute in older adults [5]. As e-health traditionally is a technology-driven domain [6], the need to pay specific attention to health-risk groups during design and development of health information technologies has been emphasized [7].

Digital inclusion, broadly defined as different strategies designed to ensure that all people have equal access, opportunities, and skills to benefit from digital technologies and systems [8], is essential in e-health [9]. To increase the accessibility of e-health innovations to digitally excluded populations, user-centered design (UCD) [10–12], with a specific focus on inclusive design [8] needs to be more influential in e-health [13]. Moreover, since older adults are a heterogeneous population, the problem of underestimating the diversity of target users [14] needs to be considered. Notably current digital solutions for older adults' PA, such as research-based apps

✉ Åsa Revenäs
asa.revenas@mdu.se

¹ School of Health, Care and Social Welfare, Mälardalen University, Box 223, 72123 Västerås, Sweden

² Centre for Clinical Research, Region Västmanland – Uppsala University, Västerås, Sweden

³ Orthopaedic clinic Västerås hospital, Region Västmanland, Västerås, Sweden

⁴ Livanda Internetkliniken AB, Ludvika, Sweden

⁵ School of Innovation, Design and Engineering, Mälardalen University, Västerås, Sweden

containing digital exercise programs and motivational instruments (ActiveLifeStyle [15], Safe Steps [16], and M-OTAGO [17]), as well as apps/web sites adopting behavioral change techniques (Delbaere et al. [18] found significant reduction in falls and severe fall accidents in older adult in a randomized control trial) are supposed to be used independently by the users.

Inclusive UCD has been used in development and improvement of web-based mental health interventions to increase uptake, adherence, and efficiency [19, 20]. However, a systematic review on UCD and participatory design with older people showed that research on new methods that are flexible and responsive to the limitations and specific characteristics of older adults are needed [21]. Newell et al. claim there are challenges in conventional UCD in including needs of older and disabled users in the design process [22]. They therefore proposed an adaptation called User-Sensitive Inclusive Design focusing on defining the user group, building empathic relationships between users and researchers, considering the whole person in design, designing for dynamic diversity, as well as using critical design- and professional theater techniques to address sensitive issues [23].

Finding and recruiting representative users is essential in UCD [14, 24] and a challenge in research on digital health for older adults where participants, as compared to non-participants, on average are slightly younger, more educated, and report better memory, higher social participation, as higher familiarity with and greater use of digital technologies [25]. Hence, methods on how to recruit and engage older adults representing the heterogeneous user group in UCD are needed. A second gap in current knowledge on how to involve older adults in UCD concerns how to consider the heterogeneity of the older population in UCD: Schlesinger et al. [26] stated that understanding users becomes increasingly complicated when considering various overlapping attributes of an individual's identity. Moreover, they identified that previous identity-focused Human-Computer Interaction research mainly analyzed one attribute at a time and introduced intersectionality as a framework for engaging with the complexity of users [26]. Related to this, Grates et al. identified representative clusters of older adults based on life-situations and involved cluster representatives in digital platform development [27]. However, as Grates et al. [27] describe their approach is time consuming and lighter methods for considering the complexity of users in UCD are needed. A third gap in knowledge on how to include older adults in UCD is related to methodologies available for prioritizing user needs of this heterogeneous user group in design of user interface. In fact, in the current UCD design literature methods for prioritizing user needs mainly focus on early design stages such as prioritization of requirements [28] and features to include in prototypes [29], or in UX road mapping [30].

This case study proposes a new, more inclusive, solution to support older adults' PA, which combines a digital PA-application used independently and a video application by which the older adult gets support from a coach. Video communication was included based on previous research [31]. Video coaching may improve adherence and effectiveness of digital health interventions for PA [32]. In addition, the proposed solution contained step count, which has been suggested to increase PA participation [33, 34]. The proposed system was based on user needs [35] and created by adaptation of an existing e-health service followed by its integration into a software system to which industrial partners contributed with specific sub-solutions. The objective of this case study was to explore the feasibility of a new proposed UCD approach aiming to consider the heterogeneity of and minimize bias among users of a digital support for older adults' PA. The study addressed three research questions:

- (1) What kind of improvements were requested by the users in adaptation of digital support for PA aiming to make it more inclusive for older adults?
- (2) How may the heterogeneity among older adults be considered in UCD to prevent bias in the design phase?
- (3) How effective was the new proposed UCD approach in producing a high-fidelity prototype that older adults could and wanted to use?

This article is structured as follows: Sect. 2 describes the method adopted to drive the research activities while Sect. 3 reports the results obtained in the various development phases, including requirements collection, implementation of the solutions, users' validation, feedback evaluation and planning for the next phase. Section 4 discusses both the qualities and the critical aspects of the proposed approach and Sect. 5 concludes the work.

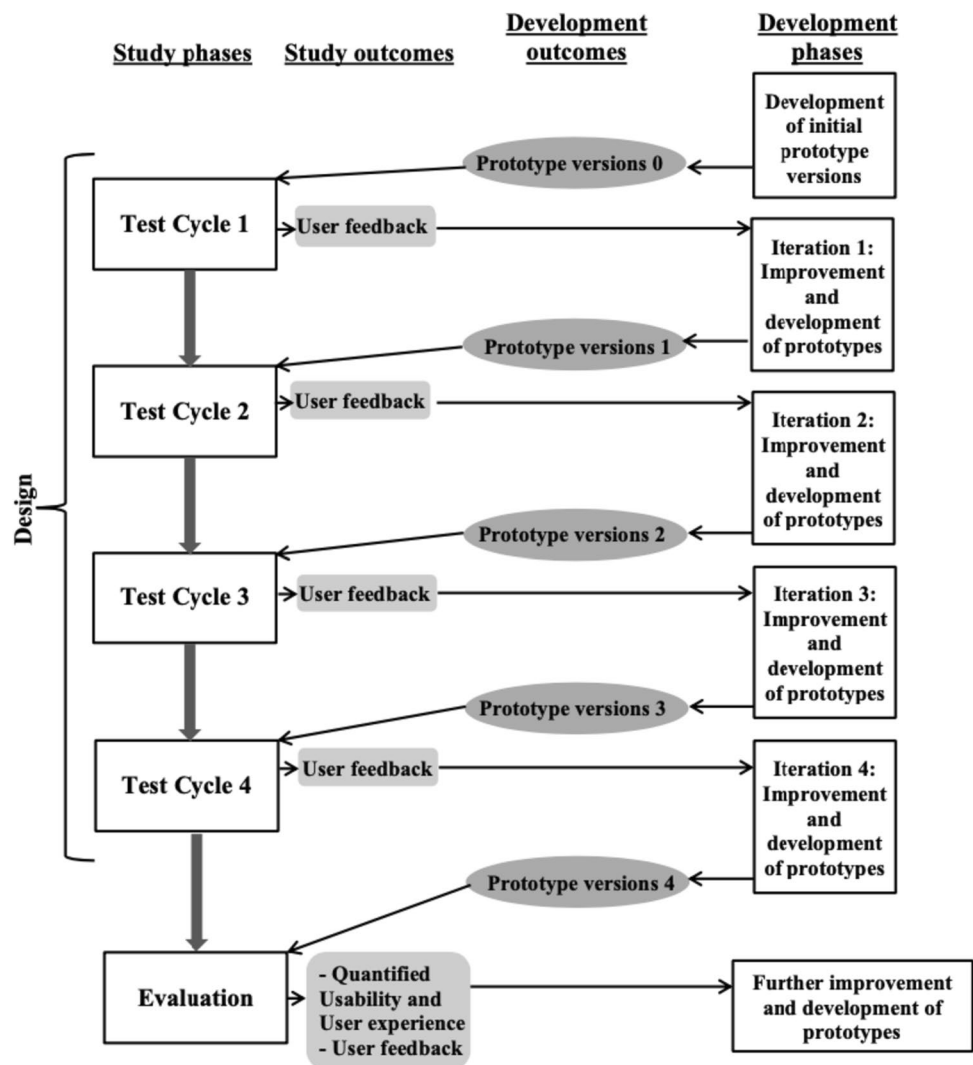
2 Methods

This study had an explorative, mixed method design to support an open innovation (OI) development. It was performed according to UCD principles [36] and included a four iterations design phase followed by an evaluation phase. The study was conducted during April to October 2018. An overview of the study design including study outcomes and their exploitation in the OI development is presented in Fig. 1.

2.1 Proposed UCD approach

In this case study, we wanted to illustrate how a new UCD approach, aiming to finding views and perceptions which were common for users with different personal characteristics, may be applied in the design and

Fig. 1 Overview of the study design including the design and evaluation phases of an UCD process



development of a digital support system for older adults' PA. Hence, the approach characterized the users by a limited number of main characteristics potentially relevant for the users' experiences of the developed applications. In this case, the UCD approach was founded on three main characteristics: gender, technology experience (TE) and PA level. Previous research describes that sampling in UCD can be based on user groups identified by the main user characteristics, i.e., the most relevant characteristics for the specific product- or system type [14], and personal characteristics [37]. The characteristics were selected from scientific literature on fall prevention, PA, and technology adoption among older adults, as detailed in the following.

Gender was chosen since gender-based differences have been demonstrated as related to fall risk [38, 39], fall injury [40], fear of falling [41, 42] and have been indicated in exercise- and PA habits [43, 44], as well as in preferences for PA [45]. The need to integrate a gender perspective in the

strategies to support older adults' exercise for fall prevention has also been highlighted in a review by Sandlund et al. [46] and gender-bias in software is a well-documented problem [47].

Technology Experience (TE) was selected since integration of values from older adults not engaged in digital technologies, i.e., non-users [48], has proven to yield beneficial outcomes in technology adoption but also in terms of learning and increased sense of participation [49]. In addition, a case study has identified that most of the innovation initiatives in a participatory design process of software artifacts came from future users (i.e., users with no or limited previous experience of similar software) [50].

PA level was selected since the purpose of the digital application was to increase older adults' PA level and thereafter maintain healthy activity habits in a behavior change process

[51]. Consequently, users' activities and goals could differ between users with different PA levels.

All three main characteristics had two possible values (gender: male/female, PA level: high/low, TE: high/low). Eight ($= 2^3$) different combinations of values, i.e., user profiles, could be defined (Fig. 2).

The case study aimed to recruit a group of users that represented all six values and with a distribution of user profiles (Males, Females, High PA level, Low PA level, High TE, Low TE) which was as equal as possible. Moreover, it was estimated that at least eight users would be plausible to involve in each test cycle (TC) of the UCD, a group size in line with recommendations from previous research [52].

In the design phase, the users contributed with individual feedback and usability data on high-fidelity prototype versions in four iterations. A user's feedback was coded with his/her user profile (for example, "Males, Low PA, Low TE" indicated by a blue asterisk in Fig. 2). In the thematic analysis, feedback from all users was clustered according to similarity. When a cluster was identified, the codes of all included feedback (i.e., views) were summarized. The summarized code of a cluster was intended to describe the link between users' characteristics and corresponding feedback. Our underlying idea was that summarized codes including higher numbers of values reflected that diverse groups from at least two user profiles had provided the same feedback. More specifically, a summarized code with three values (of the six possible) corresponded to users from a single user profile (e.g., "Females, High PA, High TE" indicated by a black asterisk in Fig. 2), while a summarized code including four values corresponded to users from two user profiles which only differed in values of one main characteristic (e.g., "Females, High PA, High TE" and "Females, Low PA, High TE," indicated by black and red asterisks, respectively, in Fig. 2). Accordingly, summarized codes with five and six values corresponded to users from combinations of user profiles that differed in values on two and three main characteristics, respectively. For example, a combination of the two user profiles "Males, Low PA, High TE" and "Females, High PA, High TE" (both indicated by green asterisks in

Fig. 2) resulted in a summarized code representing five possible values.

2.2 Co-production team and team member roles

The researchers (ME, ÅR, AC) represented academia and were responsible for the research study's planning and execution. One of them (ME) was also the leader of a larger project which included the current case study. The project was a collaboration between the university, one municipality and one regional health care provider, as well as four companies. Developers engaged in this case study were representatives of two companies. The companies had been identified by the researchers based on their existing products and recruited to the project based on their interest to contribute to the development. After each test cycle, the researchers presented results from the user tests to the company representatives and joint discussions concluded how prioritized suggested improvements could be implemented. Thereafter, the developers were responsible for developing their prototype based on the users' feedback and the prioritization. The municipality and region representatives contributed with knowledge on the system's potential context of use.

2.3 Participants

Users were selected according to the rationale presented above and the published protocol in Revenäs et al. [53]. In total, 11 older adults participated in the design phase, which included four iterations where 8–10 participants used the applications during observation. Fifteen older adults participated in the usability evaluation phase, where eight of these also had participated in the design phase (Table 1).

Inclusion criteria were age 65 years or older and living independently. Exclusion criteria were sight or hearing impairment that could not be compensated by aids and cognitive impairments considered to affect the ability to provide feedback. The older adults were recruited through contact persons in primary care, municipality, a fitness organization and by direct contact with the researchers after having heard about the project. The contact persons informed about the

Fig. 2 Definition of eight possible user profiles by three main dichotomized characteristics (Physical Activity (PA) Level, Technology Experience (TE), and gender). The asterisks indicate different user profiles referred to in the text

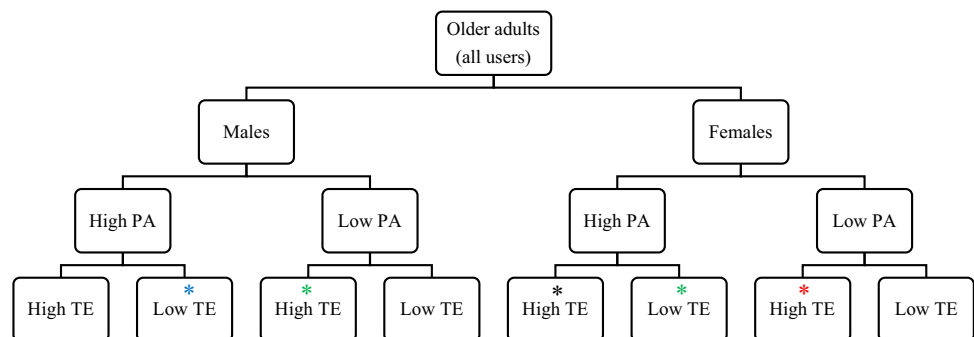


Table 1 Users in the case study's design- and evaluation phases presented in numbers (n) of users per gender, physical activity (PA) level and technology experience (TE)

Study phase	Design				Evaluation
	Test cycle 1	Test cycle 2	Test cycle 3	Test cycle 4	
Total, n	8	10	8	9	15
Men/women, n	5/3	6/4	5/3	5/4	7/8
Users with high PA level/users with low PA level, n	6/2	7/3	4/4	5/4	8/7
Users with high TE /users with low TE, n	7/1	8/2	6/2	8/1	15/0

Fig. 3 Screen shot of the homepage's prototype version of the motivation support used in the evaluation (the language used in the application is Swedish)

SALUTOGEN
Logga ut

Hitta balansen

Välkommen Testare!

"Hitta balansen" är ett program för att hjälpa dig att bli mer fysiskt aktiv så att du blir starkare och får bättre balans. Dina inplanerade aktiviteter de närmaste dagarna:

Du har inga inplanerade aktiviteter de närmaste dagarna.

Klicka på datum för att komma till **Aktivitetsdagboken.**

15 mån	16 tis	17 ons	18 tor	19 fre	20 lör	21 sön
<< v. 41			v. 43 >>			

Dina resultat

Dina stegresultat för de senaste 7 veckorna.

Vecka	Genomsnitt antal steg
31	5465
32	5225
33	6500

[Se alla dina resultat](#)

Träningsprogram

- Så här fungerar det
- Om fysisk aktivitet
- Dina rörelsemål
- Träna balans och styrka

Extrainfo och övningar

- Mål och motivation
- Mirakelkuren
- Hälsosam andning
- Närvarande i nuet

Producerad av Livanda Internetkliniken AB 35081

self-rated low TE was low in all TCs. In the evaluation, it was desired that users had experience of using a smart phone. Here, 7 of the 15 users had not participated in the design phase (i.e., inexperienced users) and 8 had participated (i.e., experienced users) in 2–4 of the previous TCs.

2.4 The high-fidelity prototypes

Prototypes of two digital applications (“motivation support” and “social support”) were used on a tablet. The former aimed to support older adults to increase PA in daily life and to perform regular PA (a screenshot is shown in Fig. 3). It was based on a web-based self-help program for cognitive behavioral therapy developed for other target groups [54]. The social support aimed to enhance coaches’ work in supporting older adults changing PA behavior. The application included a calendar (commercialized product [55]) and a video-communication feature, integrated and developed in the OI process. Both prototypes represented the appearance and interaction of the final products, i.e., they were high-fidelity prototypes [56], which were gradually improved and developed based on feedback and identified in the four iterations.

2.5 Procedures

All user tests were performed in a meeting room in a municipal social meeting point for older adults. They were performed individually under supervision of a researcher who was also a physiotherapist.

2.5.1 Design phase

The users completed a questionnaire [53] on background information in the beginning of their first test session. Thereafter, the test was performed during 30–45 min following the same procedure:

- 1) Users were informed about improvements made in the prototypes after the previous TC;
- 2) Program features to be used were briefly demonstrated and the pre-defined tasks introduced;
- 3) Users performed tasks according to a think-aloud methodology [57]. The researcher asked questions to facilitate for the users to verbalize thoughts and experiences;
- 4) Users were interviewed about their experiences.

Each TC included 2–5 tasks, in particular: TC 1—registering as a user and reading about PA in the motivation support; TC 2—setting activity goals in the motivation support; scheduling activities in calendar and setting activity reminders in the social support; TC 3—reading improved texts and using improved features (goal setting, PA planning

and self-evaluation) in the motivation support; TC 4—reviewing the welcome page and using improved features (goal setting, PA planning, support texts) in the motivation support; making video calls in the social support.

2.5.2 Evaluation phase

The evaluation was performed according to the following procedure:

- 1) Users were asked to perform pre-defined tasks in a list, as many as possible in 30 min. The evaluation included seven tasks which had been conceived by considering their relevance for the purpose of the applications and were ordered according to their estimated level of difficulty. The tasks following were included: level 1—logging in and retrieving specific information in the motivation support (2 tasks); level 2—setting goals, planning PA, and evaluating PA in the motivation support (3 tasks); and level 3—retrieving PA results in the motivation support and making video calls in the social support (2 tasks);
- 2) The researcher observed and noted down which tasks the user completed, if support was requested, and the kind of support provided;
- 3) Users completed the User Experience Questionnaire (UEQ) [58] and an interview.

2.6 Data collection

2.6.1 Questionnaire on users’ background characteristics

A study-specific questionnaire [53] collected data on users’ demographics, PA, and TE levels.

2.6.2 Observation protocols

The researchers documented observations in study-specific protocols. In the design phase, observations focused on what the users did and said when using the prototypes; notably, the experienced difficulties, errors, or lacking features. In the evaluation, the observations focused on the number of tasks completed within the test time (30 min) as well as the number and type of support requested per task.

2.6.3 Interviews including rating questions

In the design phase, the users were interviewed about their experience of performing the tasks and answered 1–3 rating questions on a 100 mm visual analog scale. In the evaluation, the researcher asked open questions related to the user’s experience with the program; the overall impression, if it

was perceived as motivating, supportive, valuable, useful and if anything was missing in the program. The answers were noted down by the researcher. The test sessions in the design- and evaluation phases were audio recorded to allow for validation of written documentation.

2.6.4 User experience questionnaire (UEQ)

In the evaluation, user experience was measured using the validated questionnaire UEQ [58]. UEQ contains six scales, all including four or six items formed as semantic differentials (i.e., each item is represented by two terms with opposite meanings) on a scale from -3 to 3. UEQ enables comparing products, identifying deficiencies, evaluating users' overall experience of products and benchmarking products against a data set from more than 450 evaluations [59]. The questionnaire is available in 30 languages [60], including Swedish, which is the native language of the users in this study.

2.7 Data analysis

Data analysis was performed by the researchers in both study phases. In the design phase, clinically active PTs also participated in the thematic analysis [61] of observations and interviews in most of the TCs and representatives from the companies that owned the digital applications participated in discussions on how to realize prioritized improvements after each TC.

2.7.1 Questionnaire on users' background characteristics

Background data collected in questionnaires on the users' demographics, PA, and TE levels, were analyzed using descriptive statistics. In the UCD, a user's feedback was coded with his/her user profile based on gender (man, M/ woman, W), PA level (High PA level, HA/ Low PA level, LA) and TE (High TE, HT/ Low TE, LT). These codes were used in the thematic analysis of user feedback according to Revenäs et al. [53]. In the evaluation, a user's quantitative results and qualitative feedback was coded with his/her gender (M/W), PA level (HA/LA) and number of test iterations that he/she had participated in (0–4) in the design phase.

2.7.2 Observation protocols and interviews

In the design phase, the researcher's notes on user feedback from observation protocols and interviews were processed and analyzed according to Revenäs et al. [53]. The analysis followed a thematic approach [61] and identified both the users' overall experiences as well as deficiencies in the applications. Here, the codes of all users in a cluster of feedback were summarized and the summarized code was

analyzed based on which values of the main characteristics represented (for detailed description see Sect. 2.1).

In the evaluation, quantitative data from observation protocols on user performance was analyzed per task and by descriptive statistics. The types of support that the users requested for each task were analyzed qualitatively to identify deficiencies in the applications: support types were categorized according to similarities in underlying reasons. Also in this analysis, the codes of all users in a cluster of feedback were summarized and the summarized code was analyzed based on which values of the main characteristics that were represented. The notes on users' answers to the interviews were analyzed by following principles of a qualitative thematic analysis [61]. The answers were categorized according to similarities in experiences or deficiencies related to the involved applications. Identified themes were labeled to reflect users' views and coded as described above. The themes were further categorized according to the UEQ-scales [58] and two additional categories (namely, Suggestions of new/modified functionality and Potential). The qualitative data provided an additional description of the users' experiences related to the ratings on the UEQ-scales.

2.7.3 User experience questionnaire (UEQ)

In the evaluation, UEQ data were analyzed in the corresponding analysis Excel-tool [62]. As the sample in this study was limited, the tool was used to estimate the user experience of the prototype. Therefore, the Excel-tool was used to calculate means for each UEQ-scale, as well as compare means of all items within a scale with each other to enable comparison of the results with a benchmark dataset from 452 UEQ studies with 20,190 users [62]. The UEQ analysis included data from 13 of the 15 users since data from two users was omitted due to identified score inconsistencies.

2.8 Prioritization of user feedback in OI development

In the design phase, improvements to amend the elicited deficiencies were prioritized based on criteria. The following three criteria had been defined: (1) The number (3–6) of values of the user characteristics in the summarized code; (2) Whether the users had rated the deficiency as important; and (3) Whether the researchers and developer considered that the deficiency had a high impact on the prototypes' overall aim and usability [53]. The second criterion was based on the users' scores on a 100 mm rating scale which were measured and dichotomized as "important" (scores > 50 mm) or "not important" (scores < 50 mm). The researchers decided the cut-off score.

2.9 Quantification of user feedback in the design phase

Contributions (i.e., feedback clusters) from each TC were categorized as “overall experiences” or “improvements.” “Improvements” were priority-categorized as “immediate,” “later” or “not prioritized.” Numbers of contributions per category and per TC were summarized. In particular, the numbers of contributions that came from both men and women, from only women and from only men, respectively, were counted. The same calculations were performed in relation to the users’ PA level (low PA level (LA) + high PA level (HL), LA only, HA only) and TE (high TE (HT) + low TE (LE), HT only, LT only). The method had a similar aim as the analysis of user group contributions performed in a case study by Rocchetti et al. [50] but was less sophisticated since no statistical methods was included.

3 Results

3.1 Qualitative user feedback in design phase

This section presents results to address the first research question “What kind of improvements were requested by older adults in adaptation of a digital support for PA aiming to make it more inclusive for older adults?”.

Overall, the design phase focused on making the digital support easier to understand and use. For example, navigation was facilitated, readability and layout were clarified and features for complex tasks (goal setting, planning and evaluation) were simplified. Moreover, the text content was expanded and processed according to the users’ needs to make the examples of activities more relevant as well as the texts more precise and meaningful. A more detailed presentation of the results from the user tests per TC and their exploitation in the innovation development is provided next.

In TC1, the users registered themselves as users of the motivation support, logged in and retrieved information on PA. A group of users whose summarized profiles containing all six possible values, i.e., Low PA, High PA, Low TE, High TE, Men, Women) expressed that the motivation support was thought-provoking, seemed useful for motivating PA, but also seemed to require a support from another person during an initial learning period (Table 2). The user tests identified several needed improvements (Table 2). The prioritization focused on improving the application’s feasibility for the users, for example, by improving the layout and increasing the font size. Also, minor alterations and additions of texts and pictures that could positively influence the user experience were prioritized. The prioritization included feedback that came from a narrower range of users. For example, touch pens were purchased since men found it

difficult to click on targets on the touch screen that were too small for their fingers. Things had been identified in TC1 but not prioritized for immediate action included both functions that were planned to be developed in later iterations (reminders, diary) or that were considered non-essential for the application’s feasibility (sound files of text content, option to hide to login letters). All had been expressed by users representing only single user profiles (summarized profiles containing three values).

In TC2, the users logged into the motivation support where they set activity goals. Thereafter, they jumped to the social support to schedule specific activities and set up reminders in calendar. A group of users whose summarized profile contained all six possible values expressed positive views on the motivation support and the video application and described the motivation support as thought-provoking (Table 3). The users expressed different views on whether the motivation support was easy or difficult to navigate in and use. They also had different opinions about whether the concept of self-rewards after performed PA (described in the motivation support) seemed relevant or not. It was also stated that the test situation was stressful and that learning how to use the tablet and the applications took some time. Making the goal setting and PA planning smoother for the users gained the highest priority after TC2. The overall result indicated that jumping between the two applications for goal setting and planning procedures caused confusion and problems. Consequently, researchers and developers agreed that the two applications needed to be better integrated. Therefore, a calendar feature was included in the motivation support thus enabling all necessary steps in goal setting and planning to be performed in the same application. Moreover, textual descriptions in the motivation support were revised and the goal setting feature was refined. Some issues identified in TC2 were not prioritized for action, for example problems impossible to address in the OI development (e.g., dazzling screen) and functions in the abandoned calendar. Some suggested functions were also scheduled for later: for example, a group of users whose summarized profile contained all six possible values had asked for rewards after performed PA as well as confirmations on goal-achievement. Also, users representing single user profiles had asked for statistics on performed training, overviews of planned activities, and exercise videos.

In TC3, the users logged into the motivation support, read the improved textual descriptions, and used the improved features for goal setting, PA planning and self-evaluation. A group of users whose summarized profile contained all six possible values described the applications as easy to use, motivating for PA and having good help texts (Table 4). Most of the identified deficiencies were prioritized for immediate action (Table 4), for example, making the features for goal setting, PA planning and self-evaluation clearer and

Table 2 User feedback on prototype version 0 (motivation support) in test cycle (TC)1

Area	User feedback (deficiencies or overall experience)	User profiles					
		M	W	LA	H A	H T	L T
Maneuvering	Font too small	X	X	X	X	X	X
	Navigation between pages too difficult (suggestions: rename headings, reduce content, enlarge buttons for links, simplify structure and names on links)	X	X	X	X	X	X
	Difficult to understand where to click to get back to start page	X	X	X	X	X	X
	Spelling errors in text	X	X		X	X	
	Difficult to interact with touch screen	X		X	X	X	X
	Too much text on start page	X			X	X	
	Cleaner layout needed		X	X		X	
	Make optional to see letters in login		X		X	X	
Content	Evokes thoughts on physical activity (PA)	X	X	X	X	X	X
	Confirmation of knowledge	X	X	X	X	X	
	A general positive experience	X	X	X	X	X	
	Diary to tick off performed PA needed	X	X	X	X	X	
	Small news value	X	X		X	X	
	Info/tips on how to get PA done in challenging times (winter, injuries) needed	X	X		X	X	
	Sound to complement text info needed	X			X	X	
	Pictures/films complementary to text needed to convey joy, psychosocial effects of PA	X			X	X	
	Reminders on exercise needed	X		X		X	
	Sound complementary to text	X			X	X	
Human support	In learning period, informing on fall prevention training/introducing exercises	X	X	X	X	X	X
Aim of application	Facilitate/motivate/push/support/inform/follow up/ push oneself/ to be active/see importance of PA/support rehabilitation	X	X	X	X	X	X
Requirement	Intuitive and motivating without giving cues	X		X		X	

User profiles: Men (M), Women (W), Low physical activity level (LA), High physical activity level (HA), high technology experience (HT), Low technology experience (LT)

X = feedback from users with that characteristic

Green cells = feedback on needed improvements that were implemented before the next TC

Yellow cells = feedback implemented in later TCs

Red cells = feedback not implemented

Blue cells = feedback that describe general experiences which could not be translated to specific needed improvements

Table 3 User feedback on prototype versions 1 (motivation- and social support) in test cycle (TC) 2

		User profile					
<i>Motivation support application</i>							
Area	User feedback (deficiencies or overall experience)	M	W	L	H	H	L
		A	A	A	A	T	T
Positive experiences	Easy to use, easy to find routes in, concrete/good examples	X	X	X	X	X	X
Evokes feelings and thought	Makes me think about physical activity (PA), exercise goal, benefits of PA	X	X	X	X	X	X
	Confused by terms in texts (reminder-goal, exercise-PA)	X	X	X	X	X	X
	Test situation stressful, makes it difficult to absorb text content		X	X			X
	Interest-raising		X	X			X
Goal setting feature	Words/terms (goal, reward) not clear	X	X	X	X	X	X
	Difficult to understand what is reasonable	X	X	X	X	X	
	Hard to estimate time for PA in minutes	X		X	X	X	
	Should be possible to monitor more types of goals	X			X	X	
	Feels natural, I have one	X			X	X	
Feature to plan PA	Difficult to delete existing help text	X	X	X	X	X	X
	Want to be able to add same activity on several occasions	X	X	X	X	X	
	Difficult to put in letters	X	X		X	X	
Help texts	Useful	X	X	X	X	X	X
	Not useful	X	X	X	X	X	
Text about self-rewards	Unnecessary/never thought of/do not understand	X	X	X	X	X	X
	Interpreted as obtained health effects or increased PA	X	X	X	X	X	
	Interpreted as praise (from others/the system)	X	X		X	X	
	Must not cause financial costs	X		X		X	
	Want to reward myself long term (materially)		X		X	X	
	Want rewards often		X		X	X	
	Interpreted as long-term goal		X	X			X
Feedback wanted	Statistics on performed PAs	X			X	X	
	Overview of planned PAs	X		X		X	
Navigation	Difficult to find routs and text on pages	X	X	X	X	X	X
	Difficult to understand when to save and where to find save-button	X	X	X	X	X	
Login and logout	Cannot find the login button (use commoner or uppercase?)	X	X	X	X	X	X
	Difficult to understand how, too small font	X	X	X	X	X	X
Touch pen	Liked to use it	X			X	X	
<i>Social support application</i>							
Area	User feedback (deficiencies or overall experience)	M	W	L	H	H	L
		A	A	A	A	T	T
Positive experiences	“Dead on target”, did not seem difficult, no problems when I have done once, good with reminders, clear (icons and text)	X	X	X	X	X	X
Difficulties	General: A bit hard to understand/cumbersome, illogical menu, hard to understand how to reach weekly/monthly overview	X	X		X	X	
	Dazzling screen		X	X			X
Usage	Need time to get used to the tablet and learn the application	X	X	X		X	X
	Want information on hardware platforms for app use	X			X	X	
Feature to plan PA	Need help to add new activities in calendar (confused)	X	X	X	X	X	X
	Need guidance in what to add information and where	X	X	X	X	X	X
	Want a confirmation /overview of my planned activities	X	X	X	X	X	X
	Difficult to jump between the two apps, apps need to be better integrated	X			X	X	
	Want to be able to plan activities directly in calendar		X		X	X	
Reminders	Do not want/do not needed	X	X	X	X	X	X
	Want another sound (than “bling”) when reminded	X	X	X	X	X	X
	Need guidance in adding reminder on specific activity	X	X	X	X	X	
Feedback wanted	Praise (bling, thumb up, message, or star) after performed PA	X	X	X	X	X	X
	Confirmation of goal-achievement (summary of performed PA, graph over time, energy consumption)	X	X	X	X	X	X
Exercises wanted	Videos with exercises and access to exercises from physiotherapist should be accessible in the application	X			X	X	

Table 3 (continued)

User profiles: Men (M), Women (W), Low physical activity level (LA), High physical activity level (HA), high technology experience (HT), Low technology experience (LT)
X = feedback from users with that characteristic
Green cells = feedback on needed improvements that were implemented before the next TC
Yellow cells = feedback implemented in later TCs
Red cells = feedback not implemented
Blue cells = feedback that describe general experiences which could not be translated to specific needed improvements

less complex. Also, textual descriptions were improved by revising unclear concepts and adding more relevant examples on PAs. Further, a set of technical errors (bugs) discovered during the tests were fixed. Things not implemented after TC3 included a suggested feature to evaluate effects of PA as well as functions to make help texts optional, adding exact time for planned activities and spell check of text insertions. These features were not considered to be essential for the application's feasibility and were expressed by users representing single user profiles.

In TC4, the users logged into the motivation support application, reviewed the welcome page and the support texts as well as used the improved features for goal setting and PA planning. Thereafter, they were asked to enter the social support application and make a video call with a researcher in another room. A group of users whose summarized profile contained all six possible values described that the digital support was overall easy to manage and understand (Table 5). It was also stated that the step count was not wanted by some users and excluded users that cannot walk. Except for two functions (exercise training videos and chat functions) that were suggested by users representing single user profiles, all identified improvements were implemented immediately. Those aimed to make the motivation support application easier to understand and use. Notably, unclear words still needed to be changed or explained by concrete examples. Moreover, the goal setting feature was further refined based on user feedback.

3.2 Quantification of user feedback in the design phase

This section presents results to address the second research question, i.e., "How may the heterogeneity among older adults be considered in UCD to prevent bias in the design phase?" In this case study, the user groups were small, and this analysis was performed to illustrate how the UCD approach may be evaluated in larger samples.

Each TC in the design phase yielded 20–40 feedback clusters, hereafter called contributions (Fig. 4).

Numbers of contributions per TC were analyzed based on which users had expressed them. The analysis considered one main characteristic at a time to count the number of contributions that had been expressed by both variants of a

characteristics (e.g., both men and women), as well as only by the two variants (e.g., only by men, and only by women, respectively) (Fig. 5).

Gender (Fig. 5a): Contributions expressed by both men and women outnumbered contributions expressed only by men and only by women, respectively (Fig. 5a). However, in TC 3 and 4, the number of contributions expressed by both men and women was only slightly higher than the amount expressed by men only. The number of contributions expressed by only women was lower than the amount expressed by only men. In the user groups of all TCs, numbers of females and men had been almost equal.

PA level (Fig. 5b): In TC1 and TC2, contributions expressed by both users with high and low PA level outnumbered contributions expressed by only users with high PA level, as well as by only users with low PA level (Fig. 5b). Here, the number of users with a low PA level was slightly lower compared to the number of users with a high PA level. However, in TC3 and TC4, where numbers of the users with high and low PA level were almost equal, contributions expressed only users by with high PA level outnumbered contributions expressed both high and low PA level users, as well as by only users with low PA level.

TE (Fig. 5c): Considering TE, which is difficult since only one or two users in each TC had low TE, the analysis indicated that contributions expressed only by users with high TE outnumbered contributions expressed by users with both high and low TE in all TCs. The number of contributions expressed only by users with low TE was low in all TCs.

Although some of these received contributions described the users' overall experience, most contributions identified needed or suggested improvements. Most of the improvements were prioritized immediately (Fig. 4). Three prioritization criteria were set up before TC1 (Methods section). However, the criteria were only used as support in the prioritization for downgrading suggested improvements. Suggested improvements were downgraded if they suggested additional features rather than improving existing once (e.g., features for evaluating effects of performed PA and for chatting with the coach) or required larger efforts perceived not feasible in the project time (e.g., sound files and films presenting information and training exercises). Downgrading was decided in joint discussions between the researchers and the company representatives. Also, a few suggested

Table 4 User feedback on prototype version 2 (motivation support) in test cycle (TC) 3

Area	User feedback (deficiencies or overall experience)	User profile					
		M	W	L A	H A	H T	L T
Positive experiences	Easy to use, useful help texts and examples, believe it motivates physical activity (PA)	X	X	X	X	X	X
Overall experience	Fit inactive more than active people	X			X	X	
Goal setting feature	Unclear what every day PA is compared to exercise	X	X	X	X	X	X
	Difficult to set and formulate a long-term goal (vision)	X	X	X	X	X	X
	Concepts unclear in help texts (e.g., everyday PA, exercise)	X	X	X	X	X	X
	Difficult to estimate time for everyday PA	X	X	X	X	X	
	Additional relevant example activities (also low intensity) wanted	X	X	X	X	X	
Help texts	Want to be able to choose to see the help texts or not	X			X	X	
	Help texts not encouraging (now more targeted to inactive persons), should give a vision of feeling proud, strong and in balance.	X			X	X	
Confirmation	Want a confirmation from the system after completing actions	X	X	X	X	X	X
	Unclear how to get back to the goal overview page	X			X	X	
Evaluation and self-reflection	Difficult to understand the instruction "reflect on performed PA"	X	X	X	X	X	X
	Want to be able to evaluate effects of PA		X		X	X	
	Want guiding/someone showing me how to do the reflection task		X	X			X
Feature to plan PA	Difficult to set time for PA	X	X	X	X	X	X
	Too complicated	X	X		X	X	
	Want to register exact time for PA		X	X			X
	Want a better overview when registering PAs	X			X	X	
	Today's activities should be displayed clearly	X			X	X	
	Want to be able to choose from the PA examples that comes up instead of registering manually, i.se. a scroll down list	X			X	X	
	Difficult to read text on screen due (poor contrast, too small font)	X			X	X	
	Difficult to change/delete text	X			X	X	
	Unclear what to put in/register	X	X		X	X	
	Want a spelling error check function	X			X	X	
Rewards	Feeling healthy is the reward wanted	X	X	X	X	X	X
	Want the system to provide me with rewards		X		X	X	
	The examples on what a reward can be are irrelevant	X		X		X	
Examples of exercises	Want examples on simple exercises	X			X	X	
Technical bugs/errors	Login function did not work properly	X	X	X	X	X	X
	Time for everyday PA can be registered on two separate pages	X	X	X	X	X	X
	Application not optimized for fitting tablet screen	X			X	X	

User profiles: Men (M), Women (W), Low physical activity level (LA), High physical activity level (HA), High technology experience (HT), Low technology experience (LT)

Table 4 (continued)

X=feedback from users with that characteristic

Green cells=feedback on needed improvements that were implemented before the next TC

Yellow cells=feedback implemented in later TCs

Red cells=feedback not implemented

Blue cells=feedback that describe general experiences which could not be translated to specific needed improvements

improvements related to a calendar feature removed after TC2 were consequently not prioritized. Suggested improvements that were identified in TCs 1–3 but prioritized for later related to the features for planning and evaluating PA, which indeed were planned to be developed in future iterations. Moreover, improvements which were a bit out of scope yet potentially valuable for the users were prioritized for future developments. In fact, as their summarized codes contained only 3 values, they were only suggested by users from single user profiles. Thus, the codes indicated that the suggestions were not expressed by a broad group of users based on the three main characteristics.

3.3 Evaluation of prototypes developed in the design phase

This section presents results to address the third research question, i.e., “How effective was the used UCD approach in producing a high-fidelity prototype that older adults could and wanted to use?”.

3.3.1 Task performance

All users, both inexperienced (had not participated in the design phase) and experienced (had participated in the design phase), were able to log in to the motivation support and retrieve information (Supplementary file 1, Table 1: Tasks 1a–b). Many users asked for support from the researcher. All users initiated the block of tasks that included setting PA goals, planning PA, and evaluating performed PA (Supplementary file 1, Table 1: Tasks 2a–c) but only a subset of them completed all three tasks. Both inexperienced and experienced users were able to accomplish the tasks mentioned, help was needed in all cases. Fewer inexperienced users than experienced ones were able to initiate the tasks focusing on reviewing PA results as well as entering to the social support application and making a video call (Supplementary file 1, Table 1: Tasks 3a–b). All participants that used the video application were able to use it, though help was needed in all cases. No conclusions on gender-related differences in task performance should be drawn from the test results. Moreover, no clear differences between genders or users with previous experience of the applications could be identified in the type of help that the users needed (Supplementary file 1, Table 2). On the

contrary, both inexperienced and experienced users of both genders needed help to understand how to navigate between specific pages and how to use specific features (Supplementary file 1, Table 2).

3.3.2 User experience

The users’ experience of the prototypes was measured by the UEQ and explored by interviews.

Based on the users’ ($n = 13$) mean scores on UEQ-scales (Fig. 6) and a comparison with the benchmark data set (Fig. 6), the digital support prototype delivered a positive user experience.

The categorization of users’ experiences with the digital applications based on the interviews is presented in detail in Supplementary file 1, Table 3. A group of users representing men, women, inexperienced, and experienced users stated that the applications were too cumbersome to use: “Cost more energy than they give” and “Some technology experience and a certain educational level is needed to use the applications.” It was also described that the applications were not accessible and available for all older adults: for example, persons with dyslexia and walking impairments. A group of users representing men, women, inexperienced, and experienced users also described the applications as fun, interest-raising, helpful for establishing PA routines, as well as motivating inactive persons to PA. Features for making one’s own planning and video coaching were described as motivating. The analysis suggested that the motivation support application needed enhanced intuitiveness and clarity, simplified navigation, and structure, strengthened motivational feedback and praise, as well as features to provide clearer feedback on the users’ personal development.

4 Discussion

This article reports results of a case study on how the heterogeneity of the older population can be considered in prototype development of digital support for PA in UCD. In this study, the users’ gender, PA level and TE were considered in the recruitment, data analysis and prioritization of improvement effort to minimize bias in the design and evaluation phase by coding feedback from users according to their user profile (i.e., gender, PA level and TE). This

Table 5 User feedback on prototype versions 3 (motivation- and social support) in test cycle (TC) 4

Area	User feedback (deficiencies or overall experience)	Characteristics represented among users giving the feedback					
		M	W	L A	H A	H T	L T
Positive experiences	Overall easy to manage and understand, clear and nice start page, easy to log in and out	X	X	X	X	X	X
<i>Motivation support application</i>							
Layout of start page	Poor contrast in calendar and headings (green no good heading color)	X	X	X	X	X	X
	Difficult to understand some concepts and words	X		X	X	X	
	Too much information	X			X	X	
General layout	Too small boxes to write in	X			X	X	
Login and logout	Difficult to find the log out button	X	X		X	X	X
	Log out button can be found on two separate pages		X		X	X	
	Bigger font needed when register username and password	X			X		X
Goal setting feature	Additional examples of everyday physical activity (PA)s (i.e., gardening) wanted	X	X	X	X	X	X
	Want confirmation from the system when an action is completed	X	X	X	X	X	
	Want an easier way of registering activities, e.g., a scroll-down-list	X	X	X	X	X	
	Bigger font on numbers when registering step goal	X			X	X	
Step-counter	Step-counter not useful for persons that cannot walk	X			X	X	X
	Encouraging	X	X	X	X	X	
	Do not want it		X	X		X	
Feedback wanted	An overview of performed PAs per week	X			X	X	
Exercise instructions	Want an exercise video on breathing instructions		X		X		X
<i>Social support application</i>							
Area	User feedback (deficiencies or overall experience)	M	W	L A	H A	H T	L T
Positive experiences	Overall easy to manage and use, "clear-as-a-bell"	X	X	X	X	X	X
Video call feature	Difficult to hold the tablet still and at appropriate distance during call	X	X	X	X	X	X
	Difficult to hear coach for people with hearing deficiencies	X			X		X
	Want to be able to chat with coach as a complement to video calls		X		X	X	

User profiles: Men (M), Women (W), Low physical activity level (LA), High physical activity level (HA), High technology experience (HT), Low technology experience (LT)

X = feedback from users with that characteristic

Green cells = feedback on needed improvements that were implemented before the next TC

Red cells = feedback not implemented

Blue cells = feedback that describe general experiences which could not be translated to specific needed improvements

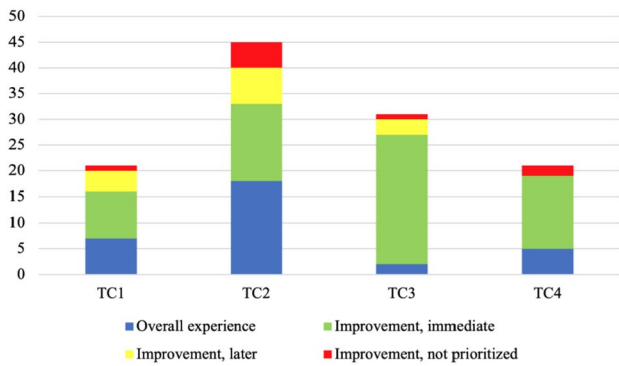


Fig. 4 Number of contributions received per test cycle (TC) categorized as “overall experiences” and “improvements,” further categorized as “immediate,” “later” or “not prioritized”

section discusses the main study results in relation to research literature and is structured according to the case study’s three research questions.

In this case study, the suggested adaptations of the motivation support included improving the readability (e.g., text fonts, contrasts), simplifying the layout,

clarifying structure and page content, as well as making the features easier to use. These suggestions are well in line with results from other research on barriers and facilitators to the use of e-health by older adults [63] and on research on usability as experienced by older adults [64]. Moreover, the users in this case study needed help in using the features for planning, goal setting, and evaluation of PA, both in the design and evaluation phases. These features required by the users to accomplish several successive steps and users asked for confirmation about the completion of each step. This might both reflect that the tasks were complex and that the users needed more flexible interfaces, a need also identified by [64]. Moreover, the users suggested modification of the content in the motivation support (e.g., texts, pictures, examples in features) to make it more inclusive and relevant for the older adults which are in line with the above-mentioned studies [63, 64]. The results confirm that there is a need to pay attention to older adults’ specific needs [7] to ensure e-health interventions to enhance PA are accessible and effective for older adults.

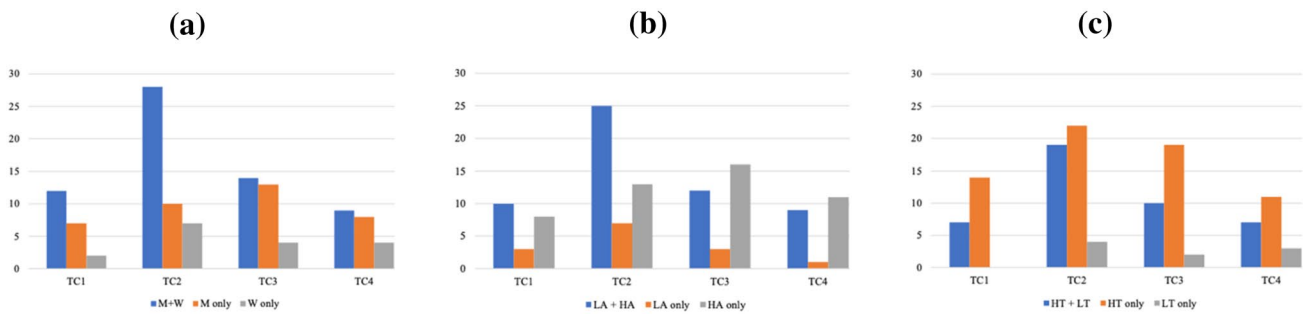


Fig. 5 Number of contributions per test cycle (TC) received: **a** Both Men (M) and Women (W), only Men, and only Women, respectively; **b** Users with both Low and High physical activity (PA) level, only users with Low PA (LA) level, and only users with High PA (HA)

level, respectively; **c** Users with both Low and High technology experience (TE), only users with Low TE (LT), and only users with High TE (HT), respectively

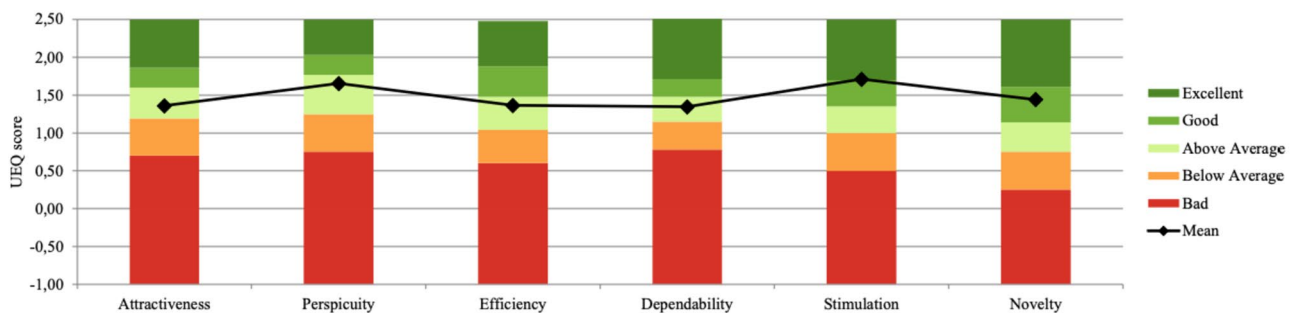


Fig. 6 Benchmarking of the study’s user experience questionnaire (UEQ) data against the UEQ benchmark dataset. For each of the six UEQ-scales, the colored bar indicates UEQ score intervals corre-

sponding to excellent, good, above average, below average and bad user experience. The mean UEQ score from the study is plotted in each bar

This study recruited a group of users with almost equal distributions of gender and PA level, both for the design- and evaluation phases. However, it was difficult to recruit users with low TE in the UCD, a challenge also described previously [25]. Nevertheless, the approach used to code each user by gender, PA level and TE, made the researchers aware of this bias and resulted in efforts to recruit users with low TE after TC1. The number of users involved in the design iterations was in line with previous recommendations [52, 65]. Finding and recruiting less experienced users of e-health in the design and development of e-health interventions is a challenge, though essential to understand these users' needs and enable digital inclusion of these groups.

The difficulty in engaging users with low TE in the design phase was also reflected in the results: While large amount of user feedback was obtained in the test sessions, a relatively small amount of feedback was conveyed only by users with low TE. The tests were performed in a familiar place (a meeting room at the municipality social meeting point for older adults) with an individual test approach which made it possible for the user to perform the tests at own pace where the researchers could guide and answer questions when needed. However, users with low TE described that the test situation could be rather stressful. This clearly indicates that there is a need to further adopt UCD to user groups with specific needs, for example user with low TE, something addressed by the User-Sensitive Inclusive Design approach [23]. Although concurrent think-aloud has been shown to outperform both the retrospective and the hybrid methods in facilitating successful usability testing [66], co-discovery has proven to be the more effective among frail older adults [67]. The low abundance of user feedback unique for users with low TE can also reflect that few users with low TE participated in the UCD.

In this case study we propose a novel strategy to prioritize design ideas and modifications of already existing e-health applications. The prioritization was guided by relevance for the systems' aim, size of needed effort, and impact for users representing as many of the user profiles as possible. This is all in line with previous research [14, 28, 30]. Most of the improvements identified in the design phase were implemented immediately (prior to the next TC). The defined criteria for prioritizing needed improvements, were used as guidance in the OI development which focused on increasing usability and inclusiveness for users representing as many of the user profiles as possible. Thereby, new functions considered a bit out of the system's scope were not prioritized for action in the project but were documented for future development. The same thing applied to suggested improvements that required larger efforts from the development team and that were not crucial for usability or inclusiveness. The approach used by Rothgangel et al.,

(2017) [28] to select features for a digital application, to include available evidence from research literature in the prioritization, was not used as a direct criterion in the design phase of this case study. Instead, all the features of the motivation support prototype were evidence-based and the TCs focused on adapting them to the needs of the users.

The qualitative and quantitative results from the evaluation indicated that the design iterations had been fruitful but not entirely sufficient for developing a prototype that met the needs of older adults. The four iterations identified and implemented improvements to increase the prototype's usability and user experience. Nevertheless, the evaluation showed that the participants could use the support but needed help. The UEQ indicated that the digital support was overall positively experienced by the participants. Although this result should be interpreted with caution due to the small sample. The users expressed that they would like to get more positive feedback and praise from the applications. These suggestions are relevant since digital behavioral change interventions to promote PA in older adults often include feedback on behavior as a supporting technique [68]. The interviews also identified that further development was needed to make the support more intuitive, motivating, and easy to use. These needed improvements are in accordance with identified facilitators to older adults' use of e-health [63]. The users also pointed out that the support was inaccessible for users with visual impairment, dyslexia, and gait problems. This result is in line with previous research stating the complexity of understanding the various attributes of an individual that should be considered in UCD [26].

One main strength of this study is the group of recruited participants that, both in the design- and evaluation phases, had a representation of users of both genders and of users with self-rated high and low PA level. Moreover, all TCs of the design phase involved both users with high and low self-rated TE and had group sizes well in line with previous recommendations [52, 65]. Another strength is the combination of complementary methods used in the design- and the evaluation phases, which increased the comprehensibility of the users' views. Also, the four iterations in the design phase which enabled repeated testing of stepwise developed features proved to be valuable both for the development and for the understanding of users' needs [24]. The combination of usability testing and UX in the evaluation is another study strength: although both aspects are relevant [69] and the focus on UX has increased in product design, it is common that user evaluations still focus only on usability testing. On the contrary, this study used a validated tool to measure UX, which has been recognized to methodologically improve the UX field [70]. Finally, the multidisciplinary team involved created the preconditions for cross-fertilization thanks to

complementary roles, competences, and responsibilities throughout the study.

A weakness of this study is the small user group size in the evaluation, which limited the possibilities to draw any firm conclusions from the results, particularly regarding UEQ. With a bigger sample size statistical analysis of the impact of the users' personal characteristic, as for example performed in Ayalon and Toch [37] could have provided more solid evidence of the relevance of the three selected user characteristics. However, the approach is reported in this article with the aim of illustrating how it can be applied in a specific user group. Moreover, although evaluation participants had varied amount of previous experience with the applications, they all had high self-rated TE; this could constitute a bias in the sample and hence in the corresponding results. Furthermore, there were more contributions from men and from participants with high PA level and high TE, which may indicate a risk that the result reflects this group more specifically. Another potential discussion point is whether the single-occasion evaluation procedure in lab environment could represent a study weakness. In fact, tests in real environments can enable more authentic user experience [71] and may be particularly important when it comes to mobile devices [72]. Nonetheless, laboratory tests were considered appropriate in this case to quickly iterate on designs and address usability issues before real-life testing, thus avoiding releasing a poorly designed product [71].

This case study on digital support for PA has provided further insights into the design of e-health for the heterogeneous group of older adults, both related to practice and to research:

- Recruiting users with low TE is important yet challenging. Therefore, efforts should be made to recruit users with low TE both in UCD practice as well as in research on digital technology. Further research on best practice for performing tests with users with low TE is also recommended to strengthen their impact in UCD and thereby increase their digital inclusiveness. This recommendation is also relevant for other user groups with functional impairments, visual impairments or dyslexia;
- To gain a deepened understanding of the users' needs in UCD, repeated iterations are needed. This case study illustrated that it is not advisable to decide in advance how many iterations to perform since that may result in prototypes insufficiently inclusive for the users. Instead, deciding the number of iterations during the process is recommended;
- Combining data collection methods in prototyping and evaluation is valuable for collecting diverse types of user feedback and therefore recommended. In this case study, the users' immediate reactions and thoughts were

collected by think-aloud methodology while interview questions after the tests gave them time to reflect;

- Monitoring specific user characteristics in UCD is helpful for identifying potential biases in group composition and to ensure all user profiles are shaping the design. However, the method used in this case study for monitoring, coding and prioritizing user feedback was experienced as time consuming. Development of lighter methods with the same aim is recommended;
- Several aspects should be considered when prioritizing improvement efforts in UCD processes. The few suggestions that were not prioritized for actions in this case study were suggestions considered to be out of the system's scope.

5 Conclusions

The results from this case study confirmed the need of adapting e-health applications to promote digital inclusion among older adults. The study reports aspects that may be important to address in the adaptation: for example, applications must be easy to navigate, have clean pages, be experienced as helpful and efficient, and have a content that is relevant and inclusive. The approach to code the users' feedback according to user profiles made it possible for making strategic recruitment efforts to amend bias. Moreover, the approach confirmed that all user groups contributed to the design of the digital applications and facilitated decisions on prioritization. Further, the results confirm the heterogeneity of older adults and indicated that user characteristics, such as low TE, visual impairment, and dyslexia, should be considered in the testing and design of digital solutions.

This case study contributes with knowledge on how to better support diversity and promote digital inclusion for heterogeneous user groups with limited uptake of digital support systems. As such, this proposed UCD approach can be used both in the design of solutions and in future research on how interaction-design can support accessibility and inclusion of information technologies. Further research on lighter, less time-consuming methods to involve digitally excluded populations in UCD is needed. Moreover, older adults' adoption of the case study's digital applications needs to be evaluated in real-life setting with larger groups of users.

Supplementary Information The online version contains supplementary material available at <https://doi.org/10.1007/s10209-023-01049-z>.

Acknowledgments The authors would like to thank all older adults participating in the study. Moreover, the authors are grateful to Ann-Christin Johansson for contributing to the planning and execution of the study and to Titti Johansson, Birgitta Knutsson and Jakob Vosjö for contributing in recruitment of participants and in the analysis of the

user feedback. The authors also want to thank the companies Abilia and Real-Test for their contributions in the technical development of the system.

Funding Open access funding provided by Mälardalen University. This work was supported by the Swedish innovation agency (Vinnova) under Grant Dnr: 2017-0317 and the project partners (Abilia, Livanda Internetkliniken AB, Mälardalen University, Real-Test, Region Västmanland, Vital Integration of Scandinavia, Västerås Municipality).

Declarations

Conflict of interest Lars Ström is the CEO and founder of Livanda Internetkliniken AB that owns and developed the motivation support application within the article. The other authors have no conflict of interest to declare relevant to this article's content.

Open Access This article is licensed under a Creative Commons Attribution 4.0 International License, which permits use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons licence, and indicate if changes were made. The images or other third party material in this article are included in the article's Creative Commons licence, unless indicated otherwise in a credit line to the material. If material is not included in the article's Creative Commons licence and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder. To view a copy of this licence, visit <http://creativecommons.org/licenses/by/4.0/>.

References

- Ozemek, C., Lavie, C.J., Rognmo, Ø.: Global physical activity levels—need for intervention. *Prog. Cardiovasc. Dis. Cardiovasc. Dis.* **62**, 102–107 (2019). <https://doi.org/10.1016/j.pcad.2019.02.004>
- United Nations, D.o.E.a.S.A., Population division. Population Division, United Nations: New York, (2019)
- Bull, F.C., Al-Ansari, S.S., Biddle, S., Borodulin, K., Buman, M.P., Cardon, G., Carty, C., Chaput, J.-P., Chastin, S., Chou, R., et al.: World health organization 2020 guidelines on physical activity and sedentary behaviour. *Brit. J. Sport. Med.* **54**, 1451–1462 (2020). <https://doi.org/10.1136/bjsports-2020-102955>
- Kwan, R.Y.C., Salihu, D., Lee, P.H., Tse, M., Cheung, D.S.K., Roopsawang, I., Choi, K.S.: The effect of e-health interventions promoting physical activity in older people: a systematic review and meta-analysis. *Eur. Rev. Aging Phys. Act.* **17**, 7 (2020). <https://doi.org/10.1186/s11556-020-00239-5>
- Pérez-Escobar, M., Canet, F.: Research on vulnerable people and digital inclusion: toward a consolidated taxonomical framework. *Univ. Access Inf. Soc.* (2022). <https://doi.org/10.1007/s10209-022-00867-x>
- van Gemert-Pijnen, J.E., Wynchank, S., Covvey, H.D., Ossebaard, H.C.: Improving the credibility of electronic health technologies. *Bull. World Health Organ.* **90**, 323–323A (2012). <https://doi.org/10.2471/BLT.11.099804>
- Petersen, L.S., Bertelsen, P.: Equality challenges in the use of eHealth: selected results from a Danish citizens survey. *Stud. Health Technol. Inform.* **245**, 793–797 (2017)
- Carmi, E., Yates, S.J.: What do digital inclusion and data literacy mean today? *Internet Policy Rev.* (2020). <https://doi.org/10.14763/2020.2.1474>
- Sieck, C.J., Sheon, A., Ancker, J.S., Castek, J., Callahan, B., Siefer, A.: Digital inclusion as a social determinant of health. *npj Digit. Med.* **4**, 52 (2021). <https://doi.org/10.1038/s41746-021-00413-8>
- Abras C, M.-K.D., Preece, J.: User-centered design. in *Encyclopedia of Human-Computer Interaction*, Bainbridge, W., (Ed.) Sage Publications: Thousand Oaks, CA, US, (2004)
- Iso B., Standard, B.: *Ergonomics of Human-System Interaction*. (2010)
- Sharp, H., J.P.a.Y.R. *Interaction design: beyond human-computer interaction*, 5th (Ed.), Wiley, Indianapolis, (2019)
- Gibson, L., Sloan, D., Moncur, W.: E-health and digital inclusion. in *User-Driven Healthcare: Concepts, Methodologies, Tools, and Applications*, Management Association, I.R., Ed.; IGI Global: Hershey, PA, USA, pp. 197–210, (2013)
- Kujala, S.; Kauppinen, M.: Identifying and selecting users for user-centered design. in *Proceedings of the Proceedings of the third Nordic Conference on Human-Computer Interaction*, Tampere, Finland, pp. 297–303, (2004)
- van Het Reve, E., Silveira, P., Daniel, F., Casati, F., de Bruin, E.D.: Tablet-based strength-balance training to motivate and improve adherence to exercise in independently living older people: part 2 of a phase II preclinical exploratory trial. *J. Med. Internet Res.* **16**, e159 (2014). <https://doi.org/10.2196/jmir.3055>
- Mansson, L., Lundin-Olsson, L., Skelton, D.A., Janols, R., Lindgren, H., Rosendahl, E., Sandlund, M.: Older adults' preferences for, adherence to and experiences of two self-management falls prevention home exercise programmes: a comparison between a digital programme and a paper booklet. *BMC Geriatr. Geriatr.* **20**, 209 (2020). <https://doi.org/10.1186/s12877-020-01592-x>
- Arkkukangas, M., Cederbom, S., Tonkonogi, M., Carlsson, O.: Older adults' experiences with mHealth for fall prevention exercise: usability and promotion of behavior change strategies. *Physiother. Theory Pract.* (2020). <https://doi.org/10.1080/09593985.2020.1712753>
- Delbaere, K., Valenzuela, T., Lord, S.R., Clemson, L., Zijlstra, G.A.R., Close, J.C.T., Lung, T., Woodbury, A., Chow, J., McInerney, G., et al.: E-health standingtall balance exercise for fall prevention in older people: results of a two year randomised controlled trial. *BMJ* **373**, n740 (2021). <https://doi.org/10.1136/bmj.n740>
- de Beurs, D., van Bruinessen, I., Noordman, J., Friele, R., van Dulmen, S.: Active involvement of end users when developing web-based mental health interventions. *Front. Psychiatr.* **8**, 72 (2017). <https://doi.org/10.3389/fpsy.2017.00072>
- Hardy, A., Wojdecka, A., West, J., Matthews, E., Golby, C., Ward, T., Lopez, N.D., Freeman, D., Waller, H., Kuipers, E., et al.: How inclusive, user-centered design research can improve psychological therapies for psychosis: development of slowmo. *JMIR Ment Health* **5**, e11222 (2018). <https://doi.org/10.2196/11222>
- Duque, E., Fonseca, G., Vieira, H., Gontijo, G., Ishitani, L.: A systematic literature review on user centered design and participatory design with older people. in *Proceedings of the Proceedings of the 18th Brazilian Symposium on Human Factors in Computing Systems*, Vitória, Espírito Santo, Brazil, p. 9, (2019)
- Newell, A.F., Gregor, P., Morgan, M., Pullin, G., Macaulay, C.: User-sensitive inclusive design. *Univ. Access Inf. Soc.* **10**, 235–243 (2011). <https://doi.org/10.1007/s10209-010-0203-y>
- Lim, C.S.C., Newell, A.F.: *User-sensitive inclusive design for technology in everyday life*. Kwon, S., (Ed.) Springer Publishing Company: New York, pp. 157–180, (2016)
- Cornet, V.P., Toscos, T., Bolchini, D., Rohani Ghahari, R., Ahmed, R., Daley, C., Mirro, M.J., Holden, R.J.: Untold stories in user-centered design of mobile health: practical challenges and strategies learned from the design and evaluation of an app for older adults with heart failure. *JMIR Mhealth Uhealth* **8**, e17703–e17703 (2020). <https://doi.org/10.2196/17703>

25. Poli, A., Kelfve, S., Motel-Klingebiel, A.: A research tool for measuring non-participation of older people in research on digital health. *BMC Public Health* **19**, 1487 (2019). <https://doi.org/10.1186/s12889-019-7830-x>
26. Schlesinger, A., Edwards, W.K., Grinter, R.E.: Intersectional HCI: engaging identity through gender, race, and class. in *Proceedings of the Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems*, Denver, Colorado, USA, pp. 5412–5427, (2017)
27. Grates, M.G., Heming, A.-C., Vukoman, M., Schabsky, P., Sorgalla, J.: New perspectives on user participation in technology design processes: an interdisciplinary approach. *Gerontologist* **59**, 45–57 (2018). <https://doi.org/10.1093/geront/gny112>
28. Rothgangel, A., Braun, S., Smeets, R., Beurskens, A.: Design and development of a telerehabilitation platform for patients with phantom limb pain: a user-centered approach. *JMIR Rehabil. Assist. Technol.* **4**, e2 (2017). <https://doi.org/10.2196/rehab.6761>
29. Weber, S.J., Shearer, E., Mulvaney, S.A., Schmidt, D., Thompson, C., Jones, J., Ahmad, H., Coe, M., Hull, P.C.: Prioritization of features for mobile apps for families in a federal nutrition program for low-income women, infants, and children: user-centered design approach. *JMIR Form Res* **5**, e30450 (2021). <https://doi.org/10.2196/30450>
30. Gibbons, S.: 5 Prioritization Methods in UX Roadmapping. Available online: <https://www.nngroup.com/articles/prioritization-methods/> (Accessed on August 18th 2023)
31. Ehn, M., Johansson, A.C., Revenas, A.: Technology-based motivation support for seniors' physical activity—a qualitative study on seniors' and health care professionals' views. *Int. J. Environ. Res. Publ. Health* (2019). <https://doi.org/10.3390/ijerph16132418>
32. Alley, S., Jennings, C., Plotnikoff, R.C., Vandelandotte, C.: Web-based video-coaching to assist an automated computer-tailored physical activity intervention for inactive adults: a randomized controlled trial. *J. Med. Internet Res.* **18**, e223 (2016). <https://doi.org/10.2196/jmir.5664>
33. Brickwood, K.J., Watson, G., O'Brien, J., Williams, A.D.: Consumer-based wearable activity trackers increase physical activity participation: systematic review and meta-analysis. *JMIR Mhealth Uhealth* **7**, e11819 (2019). <https://doi.org/10.2196/11819>
34. Ehn, M., Eriksson, L.C., Akerberg, N., Johansson, A.C.: Activity monitors as support for older persons' physical activity in daily life: qualitative study of the users' experiences. *JMIR Mhealth Uhealth* **6**, e34 (2018). <https://doi.org/10.2196/mhealth.8345>
35. Ehn, M., Derneborg, M., Revenäs, Å., Cicchetti, A.: User-centered requirements engineering to manage the fuzzy front-end of open innovation in e-health: a study on support systems for seniors' physical activity. *Int. J. Med. Inform.* (2021). <https://doi.org/10.1016/j.ijmedinf.2021.104547>
36. Norman, D.A.: *User-centered system design: new perspectives on human-computer interaction*, Hillsdale, (1986)
37. Ayalon, O., Toch, E.: User-centered privacy-by-design: evaluating the appropriateness of design prototypes. *Int. J. Hum. Comput. Stud. Comput. Stud.* **154**, 102641 (2021). <https://doi.org/10.1016/j.ijhcs.2021.102641>
38. Ek, S., Rizzuto, D., Fratiglioni, L., Calderon-Larranaga, A., Johnell, K., Sjöberg, L., Xu, W., Welmer, A.K.: Risk factors for injurious falls in older adults: the role of sex and length of follow-up. *J. Am. Geriatr. Soc. Geriatr. Soc.* **67**, 246–253 (2019). <https://doi.org/10.1111/jgs.15657>
39. Tinetti, M.E., Doucette, J., Claus, E., Marottoli, R.: Risk factors for serious injury during falls by older persons in the community. *J. Am. Geriatr. Soc. Geriatr. Soc.* **43**, 1214–1221 (1995). <https://doi.org/10.1111/j.1532-5415.1995.tb07396.x>
40. Welmer, A.K., Rizzuto, D., Calderon-Larranaga, A., Johnell, K.: Sex Differences in the Association between pain and injurious falls in older adults: a population-based longitudinal study. *Am. J. Epidemiol. Epidemiol.* **186**, 1049–1056 (2017). <https://doi.org/10.1093/aje/kwx170>
41. Fletcher, P.C., Guthrie, D.M., Berg, K., Hirdes, J.P.: Risk factors for restriction in activity associated with fear of falling among seniors within the community. *J. Patient Saf. Saf.* **6**, 187–191 (2010)
42. Greenberg, M.R., Moore, E.C., Nguyen, M.C., Stello, B., Goldberg, A., Barraco, R.D., Porter, B.G., Kurt, A., Dusza, S.W., Kane, B.G.: Perceived fall risk and functional decline: gender differences in patient's willingness to discuss fall risk, fall history, or to have a home safety evaluation. *Yale J. Biol. Med.* **89**, 261–267 (2016)
43. Craft, B.B., Carroll, H.A., Lustyk, M.K.: Gender differences in exercise habits and quality of life reports: assessing the moderating effects of reasons for exercise. *Int. J. Lib. Arts Soc. Sci.* **2**, 65–76 (2014)
44. Sun, F., Norman, I.J., While, A.E.: Physical activity in older people: a systematic review. *BMC Public Health* **13**, 449 (2013). <https://doi.org/10.1186/1471-2458-13-449>
45. Ransdell, L.B., Vener, J.M., Sell, K.: International perspectives: the influence of gender on lifetime physical activity participation. *J. R. Soc. Promot. HealthPromot. Health* **124**, 12–14 (2004). <https://doi.org/10.1177/146642400312400105>
46. Sandlund, M., Skelton, D.A., Pohl, P., Ahlgren, C., Melander-Wikman, A., Lundin-Olsson, L.: Gender perspectives on views and preferences of older people on exercise to prevent falls: a systematic mixed studies review. *BMC Geriatr. Geriatr.* **17**, 58 (2017). <https://doi.org/10.1186/s12877-017-0451-2>
47. Burnett, M., Stumpf, S., Macbeth, J., Makri, S., Beckwith, L., Kwan, I., Peters, A., Jernigan, W.: GenderMag: a method for evaluating software's gender inclusiveness. *Interact. Comput. Comput.* **28**, 760–787 (2016). <https://doi.org/10.1093/iwc/iwv046>
48. Knowles, B., Hanson, V.L.: The wisdom of older technology (non) users. *Commun. ACM. ACM* **61**, 72–77 (2018). <https://doi.org/10.1145/3179995>
49. Fischer, B., Peine, A., Östlund, B.: The importance of user involvement: a systematic review of involving older users in technology design. *Gerontologist* **60**, e513–e523 (2019). <https://doi.org/10.1093/geront/gnz163>
50. Roccetti, M., Prandi, C., Mirri, S., Salomoni, P.: Designing human-centric software artifacts with future users: a case study. *HCIS* **10**, 8 (2020). <https://doi.org/10.1186/s13673-020-0213-6>
51. Kearney, J.M., de Graaf, C., Damkjaer, S., Engstrom, L.M.: Stages of change towards physical activity in a nationally representative sample in the European union. *Public Health Nutr. Nutr.* **2**, 115–124 (1999). <https://doi.org/10.1017/S1368980099000166>
52. Kujala, S., Mäntylä, M.: How effective are user studies?. in *People and Computers XIV—Usability or Else! Proceedings of HCI 2000* (pp. 61–71). Springer, London, (2000)
53. Revenas, A., Johansson, A.C., Ehn, M.: Integrating key user characteristics in user-centered design of digital support systems for seniors' physical activity interventions to prevent falls: protocol for a usability study. *Jmir. Res. Protoc.* **9**, e20061 (2020). <https://doi.org/10.2196/20061>
54. Livanda-Internetkliniken. Available online: <https://www.livanda.se> (Accessed on June 29th 2022)
55. Abilia. Memoplanner, <https://www.abilia.com/sv/our-products/kognition-tid-och-planering/minne-och-kalendrar/memoplanner-medium> (Accessed on August 18th 2023)
56. Jim Rudd, K.S., Isensee, S.: Low vs high-fidelity prototyping debate. *Interactions* **3**, 76–85 (1996). <https://doi.org/10.1145/223500.223514>
57. Van Someren, M., Barnard, Y.F., Sandberg, J.: The think aloud method: a practical approach to modelling cognitive. *Knowl. Based Syst.* **11**, 29–41 (1994)

58. Laugwitz B.H.T., Schrepp M.: Construction and evaluation of a user experience questionnaire. in *HCI and Usability for Education and Work. USAB 2008. Lecture Notes in Computer Science*, A, H., Ed.; Springer: Berlin, Heidelberg, vol. 5298, (2008)
59. Schrepp, M.: User experience questionnaire handbook. in *All You Need to Know to Apply the UEQ Successfully in Your Project* (2015)
60. Rauschenberger, M., Schrepp, M., Pérez Cota, M., Olschner, S., Thomaschewski, J.: Efficient measurement of the user experience of interactive products. How to use the user experience questionnaire (UEQ). Example: Spanish language version. (2013)
61. Braun, V., Clarke, V.: Using thematic analysis in psychology. *Qual. Res. Psychol.* **3**, 77–101 (2006). <https://doi.org/10.1191/1478088706qp063oa>
62. Team UEQ, M.S.: UEQ User experience questionnaire. Available online: <https://www.ueq-online.org> (Accessed on 10 Feb 2021)
63. Wilson, J., Heinsch, M., Betts, D., Booth, D., Kay-Lambkin, F.: Barriers and facilitators to the use of e-health by older adults: a scoping review. *BMC Public Health* **21**, 1556 (2021). <https://doi.org/10.1186/s12889-021-11623-w>
64. Kane, L.: Usability for seniors: challenges and changes. NN/g Nielsen Norman Group (2019)
65. Nielsen, J., Landauer, T.K.: A mathematical model of the finding of usability problems. in *Proceedings of the INTERACT '93 and CHI '93 Conference on Human Factors in Computing Systems* (1993)
66. Alhadreti, O., Mayhew, P.: Rethinking thinking aloud: a Comparison of three think-aloud protocols. in *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems*, Association for Computing Machinery, p. 44, (2018)
67. Franz, R. L., Neves, B. B., Epp, C. D., Baecker, R., & Wobbrock, J. O.: Why and how think-alouds with older adults fail: recommendations from a study and expert interviews. in *Perspectives on Human-Computer Interaction Research with Older People*, 217–235. (2019)
68. Stockwell, S., Schofield, P., Fisher, A., Firth, J., Jackson, S.E., Stubbs, B., Smith, L.: Digital behavior change interventions to promote physical activity and/or reduce sedentary behavior in older adults: a systematic review and meta-analysis. *Exp. Gerontol. Gerontol.* **120**, 68–87 (2019). <https://doi.org/10.1016/j.exger.2019.02.020>
69. Vermeeren, A.P.O.S., Law, E.L.-C., Roto, V., Obrist, M., Hoonhout, J., Väänänen-Vainio-Mattila, K.: User experience evaluation methods: current state and development needs. in *Proceedings of the Proceedings of the 6th Nordic Conference on Human-Computer Interaction: Extending Boundaries*, Reykjavik, Iceland, pp. 521–530, (2010)
70. Jia, Y., Wang, W., Dong, W., Liang, L., Gao, L., Lei, J.: Perceived user preferences and usability evaluation of mainstream wearable devices for health monitoring. *PeerJ* (2018). <https://doi.org/10.7717/peerj.5350>
71. Cornet, V.P., Toscos, T., Bolchini, D., Rohani Ghahari, R., Ahmed, R., Daley, C., Mirro, M.J., Holden, R.J.: Untold stories in user-centered design of mobile health: practical challenges and strategies learned from the design and evaluation of an app for older adults with heart failure. *JMIR mHealth uHealth* **8**, e17703 (2020). <https://doi.org/10.2196/17703>
72. Eshet, E., Bouwman, H.: Context of use: the final frontier in the practice of user-centered design? *Interact. Comput.* **29**, 368–390 (2017). <https://doi.org/10.1093/iwc/iww030>

Publisher's Note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.