Original paper

Exploring the potential of technology to promote “exercise snacking” for pre-frail older adults in the home setting: User-Centered Design Study

Abstract

Background: Older adults have an increased risk of falls, injury, and hospitalization. Maintaining or increasing participation in physical activity (PA) into older age can prevent some of the age-related declines in physical functioning that contribute to loss of independence and lower reported quality of life. ‘Exercise snacking’ may overcome some commonly cited barriers to exercise and encourage older adults to engage in muscle strength and balance activity, but the best way to deliver and support this novel format remains unknown.

Objective: Our aim was to explore how the novel ‘exercise snacking’ approach, i.e., incorporating short bouts of strength and balance activities into everyday routines, could be supported by technology within a home setting; and what types of technologies would be acceptable for pre-frail older adults.

Methods: Following a user-centered design process, two design workshops (Study 1) were conducted first to understand older adults' (n=11, aged 69-89 years old) attitudes towards technology aimed at supporting exercise snacking at home, and to inform the design of interactive prototypes. Next, based on the findings of Study 1, an exploratory pilot study (Study 2) was conducted over one day with two prototypes (n=5 participants, aged 69-80) at participants’ homes. Participants were interviewed over the telephone afterwards about their experience. Transcripts were analyzed using Framework analysis.

Results: Results showed that participants were positive towards using technology at home to support exercise snacking, but both the exercises and technology would need to be simple and match participants’ everyday routines. Workshop discussions (Study 1) led to the design of two prototypes using a pressure mat to support resistance and balance exercises. The exploratory pilot study (Study 2) participants reported potential in using smart devices to support exercise snacking, but the design of the initial prototypes influenced participants’ attitudes towards them. It also hampered the acceptability of these initial versions and highlighted challenges in fitting exercise snacking into everyday life.

Conclusions: Older adults were positive about using technology in their homes to support strength and balance exercise snacking. However, while promising, the initial prototypes require further refinement and optimization prior to feasibility, acceptability, and efficacy testing. Technologies to support exercise snacking need to be adaptable and personalized to individuals, to ensure that users are 'snacking' on balance and strengthening exercises that are appropriate for them.

Keywords: physical activity, older adults, Internet of Things, user-centered design, qualitative research

Introduction

Background

The benefits of physical activity (PA) across the lifespan are well documented [1]. Within the UK, older adults (aged 65 years and over) should accumulate 150 minutes per week of moderate intensity aerobic activity [2]. Furthermore, the guidelines highlight that any level of PA should be encouraged, and activities to improve or maintain muscle strength and flexibility should be incorporated at least 2 days per week [2]. However, many older adults are failing to meet these guidelines and report low levels of muscle and bone strengthening activities [3]. Older adults are at increased risk of falls and injury due to age-related declines in physiological functioning [4], which can impede their quality of life and independence, and place an enormous strain on health and social care costs at the societal level [5].

Recent research has also indicated that older adults spend a high proportion of their day engaged in sedentary behaviors [6], that is any waking activity in a sitting, lying or reclining posture where energy expenditure is <1.5 metabolic equivalents [7]. As the proportion of older adults in our society increases [8], strategies to promote PA and reduce sedentary behavior in this age group are important to maintain physical functioning [9] and improve health related quality of life [10].

In order to promote and sustain participation in strength and balance exercise as individuals age, there is a need to develop interventions for this population that are effective, inclusive, acceptable and safe [11]. Furthermore, interventions should enable older adults to overcome some of the commonly cited barriers to current participation in PA. Such barriers include a dislike for activities that are structured or sport-based, time commitments and limited access to facilities [12–14]. Integration of functional exercise into daily routines may provide

another alternative to PA promotion in this population, and overcome the recognized barriers in relation to structured exercise programs [15].

Incorporating short bouts of exercise across the day, or "exercise snacking" [16] represents an innovative approach to PA promotion amongst older adults. It is similar to Snacktivity™ [17,18], which is mostly used in the context of aerobic physical activity. Both promote opportunities to engage in exercises that are safe and compatible with individuals' surroundings and lifestyle [16]. To date, exercise snacking has been shown to be an accessible, acceptable and effective alternative to traditional exercise in older adults [16,19].

Technology has the potential to support PA at home. Recent work has focused on wearables and activity trackers such as Fitbit [20], which can be effective at encouraging PA and reducing sedentary behaviors [21]. However, these devices tend to focus on supervising or monitoring older adults and tend to support a limited number of activities, especially cardiovascular activities such as walking [20]. Given their reliance on measuring steps and location, they are unsuitable for supporting strength and balance exercises. Similarly, prior research on supporting older adults' exercise at home have focused on more complex solutions such as Kinect [22] or social robots to support (predominantly aerobic) PA [23]. These solutions are expensive and require prior planning to fit exercise sessions into one's day. Due to the situated nature of exercise snacking and its links with everyday routines, Internet of Things (IoT) devices are well suited to provide technological support. IoT devices can be easily embedded at home and provide both monitoring and guidance, such as reducing office workers' sedentary behavior [24], supporting good posture while sitting [25], or exercising [26]. As such, they could be used to support exercise snacking at home as part of routine everyday activities.

Objectives

This project explored how ubiquitous technology could be embedded in the home setting to support community dwelling pre-frail older adults with exercise snacking activities to improve strength and balance. It builds on prior work that has demonstrated exercise snacking to be as effective as resistance training at improving muscle functioning [16], but has the added benefit of overcoming barriers to engagement in PA for older adults.

The main objective was to develop and test a set of interactive prototypes that could be embedded in the home environment to support strength and balance exercises. To do so, we engaged pre-frail older adults in the design of the prototypes and conducted an exploratory

home evaluation. Health technologies tend to be designed without consideration of older adults' perspectives on PA [27], which can reduce their usability or adoption within this user group. Therefore, our goal was to work directly with older adults and use their input and ideas as a starting point to ensure the prototypes addressed their needs.

Methods

Approach

This project followed an iterative, user-centered design (UCD) process [28] to identify the requirements for initial prototypes and explore their potential, although we did keep in mind the principles of Person-Based Approach [29] as this work will be used as a starting point for the development of a future behavior change intervention. To this end Study 1 (design workshops) aimed to identify appropriate exercises older adults are willing to do at home as well as attitudes and preferences towards technologies that might support PA. Study 2 (home evaluation) then developed and piloted new prototype technology informed by the results of Study 1.

Participants and recruitment

We recruited 16 pre-frail community-dwelling older adults amongst participants of a randomized controlled trial (focused on encouraging PA amongst pre-frail older adults [30]) who consented to be approached for future research projects. Eleven participants attended Study 1, aged 69-89 years old (Mean=74, SD=5.5), seven (64%) were women and all were white British. A further five participants participated in Study 2, aged 69-80 years (SD=4.87) and three were women. Participants who responded to the study email adverts were sent a participant information sheet detailing the study.

Study 1: Design workshops

Materials

Study 1 involved two 2-hour design workshops in Bristol, UK. To facilitate discussions, participants were provided with handouts showing examples of specific muscle strengthening and balance exercises and simple Tai Chi movements they could do in the home, which were also demonstrated to participants by a trained exercise instructor (IJL). A set of electronic components (e.g., proximity sensors, pressure mats, vibrating components, lights), examples of wearable devices (e.g., a smart watch, an activity tracker), and an Alexa were used to facilitate the discussions on technology supporting exercise snacking at home.

Procedures

Workshops were conducted on the same day in February 2020 within a SPHERE smart home [31]. The smart home belongs to University of Bristol and is a terraced house with several rooms equipped with various sensors such as movement sensors and Near-Field Communication (NFC) tags. The sensors were visible throughout the home, although they were not used as part of this study. Nevertheless, participants were able to see how smart technologies could be implemented in a home environment which facilitated discussions on how new devices could fit into their existing homes.

Each session started by discussing participants' current PA levels, including home based and group activities, and any barriers to exercise they had encountered. Exercise snacking and exercise handouts (preferred format and content) were then discussed. A researcher and trained exercise instructor demonstrated five exercise snacking and five Tai Chi snacking movements [19] with participants trying each. This session took place in a living room, and participants were able to use chairs and a sofa as part of the exercises. Participants then discussed their thoughts about the exercises, and how they could fit into their daily routines and home environment.

Participants then moved through the house (kitchen, bathroom, bedroom, dining room), discussing suitable exercises for each room, how rooms differed from their own environment, and how that difference could affect the exercise. Additionally, any technology that could support and prompt exercise was discussed. This was facilitated by a member of the research team. Subsequently, one researcher presented examples of various technologies and sensors, explaining how each item worked, and how it could be used in practice. Participants then discussed which components and devices could be useful to support exercise snacking in their home environment.

Study 2: Feasibility evaluation with semi-structured interviews

Materials

Based on the key findings from Study 1, two types of interactive prototypes were built: one to support one-legged balance exercises, and one to support sit-to-stand exercises (see Figure 1). These two activities were chosen as participants agreed that they were useful and were the easiest to integrate into their everyday routines, i.e., were easy to master and could be done anywhere in the home. Each prototype consisted of a pressure mat and a companion screen. As their design was influenced by Study 1 results, more details are provided in the Prototype development section after Study 1 results.

Figure 1. *Exercise snacking prototypes for supporting one-leg balance (top) and sit-to-stand (bottom) exercises. Images taken by the researchers to demonstrate potential locations for the prototypes.*

The prototypes were accompanied by a booklet explaining exercise snacking and the two selected exercises, with advice on how to do them correctly and suggestions of times and places at home where they could be done. The booklet also included a setup and troubleshooting guide.

Procedures

The evaluation study consisting of two parts (an exploratory home evaluation and an interview) and took place in Bath, UK between May and June 2021. Prototypes were delivered to participants' homes by a researcher; participants also received written setup instructions and the researcher was available via telephone to provide any further technical and exercise support. Due to COVID-19 restrictions the researcher followed a COVID secure process which involved contactless delivery and collection, with no entry into the participant's home. Each participant received both prototypes (balance mat and sit-to-stand mat) and was requested to use them for a single day. They were asked to think about their everyday routines and place the prototypes and the feedback screen in spaces where they would be the most likely to see and use them without having to go to a dedicated room. After the drop off, the researcher explained each exercise to the participant over the telephone.

At the end of the day, a researcher collected the protypes and later conducted the telephone interview. Interviews lasted approximately 30-45 minutes and covered participants' general experience of setting up and using the prototypes, views on the utility of the technology going

forward, and their general views on how to improve the prototypes or better integrate technology into their daily lives.

Ethical considerations

Both studies received favorable ethical opinion from University of Bristol (Project ID 99482) and Cardiff University (COMSC/Ethics/2020/071). Written informed consent was obtained from all participants. No personally identifying information was collected and the data was anonymized. Any mention of participant's names in the transcripts was replaced by participant numbers before the analysis. Study 1 participants received a £10 shopping voucher for taking part in the workshop. Study 2 participants received a £30 shopping voucher for testing the prototypes at home and participating in the phone interviews.

Data Analysis

Study 1 workshop discussions were audio recorded and transcribed verbatim for subsequent analysis. Transcripts were analyzed thematically [32] using both deductive and inductive approaches to explore insights relating to the specific topics we focused on, and any unexpected findings. Prior to analysis, transcripts were read to identify specific features for the prototypes so that they could be incorporated by the developer while data analysis continued. One author (IJL) coded all transcripts. Codes were then reviewed and discussed by two other authors (KS, MW), who identified the provisional themes and drafted the results. The themes and draft findings were then reviewed and discussed with all authors until the final themes were fully defined.

Study 2 ended with semi-structured telephone interviews, which were audio recorded and transcribed verbatim. Framework analysis [33] was applied to the data as the authors were interested in specific topics. Following familiarization and coding of the transcripts, one author (AW) created a framework table using interview questions as categories (columns) and each participant was allocated a row, with codes in corresponding cells. Two authors (AW, KS) then summarized findings in each cell to identify potential themes. Provisional themes were drafted by two authors (KS, MW) and then discussed with all authors leading to strengthening of some themes and discarding others.

Results

Study 1: Workshops

We were interested in understanding participants' views about and attitudes towards exercise, PA at home and technology – these discussion topics formed the initial structure for resulting themes. Within each topic, themes and sub-themes identified through the analysis are reported. They are summarized with representative quotes in Table 1 and described in more detail below.

Table 1: *Quotes to illustrate the sub-themes identified in the workshops for each discussion topic*

Topic	Theme	Sub-theme	Quotes
Attitudes towards exercise	Barriers to exercise	• Dislike of leisure settings • Lack of motivation to exercise or 'laziness' • Physical limitation, safety or injury risk	"I hate going to the gym and getting sweaty. I think it's just horrid, whereas you can do that and build up your strength gradually with that and I thought that was a nice set of exercises." "I found myself getting lazier and lazier and lazier in the morning because I like reading so it's quite easy for me to sit in bed, get out make a cup of tea, sit in bed with a cup of tea." "You thought well it's time to do my practice but that means I've got to go and get changed and get into a leotard and [sigh]." "I did fall off a bike a few years ago which put me off cycling completely and I haven't been on a bike since."
	Exercise considered important	• Health and wellbeing benefits • Build confidence • Social engagement	"...being active and doing things can help slow that decline and give you a better quality of life" "And when you see the results – I mean I already feel the effect of exercises that I've been doing. You know I'm aware my muscles are telling me that I'm making them work and when you see the effect of it on yourself, that's the incentive for me to carry on and just to be fit." "I like the groups as well because they can be quite sociable things as well because there's always the period after when you've had the exercises and things."
	Exercise snacking promise	• Need for tailoring to ability • Could overcome barriers to exercise	"[The exercise should be] age appropriate – somebody actually saying, do it to your own ability rather than you at home thinking, I can do that and then you know, you can't but if you can't find somebody age appropriate to actually do it, you can do that verbal." "Sometimes you're just relaxing but I think this concept of 'snacking' is very good because it's not like now I have to go and exercise. It's like I'm walking into the kitchen to make a cup of tea and while I'm there, I can do this for a moment or two."
Exercise in the home environment	Impact of location	• Amount of floor space • Room function	"We touched on the kitchen, it might be an option to do things but limited space in terms of houses and I think a big barrier to doing this perhaps could be that you've got to go and shift a coffee table to do an exercise because you got to then do that every time." "In my experience old people tend to have a load of furniture in their houses." "The dining room I mean it's not the sort of place, it's not really the sort of room you sort of have to go to do. It's basically where you'd have your meals."
	Safety	• Objects to hold on to • Soft furnishings	"That's the advantage of the kitchen or the bathroom isn't it, because generally you don't have – you have a bit of space in the kitchen or the bathroom to do the exercise standing up at the sink or the work surface or whatever and you don't have to move furniture to do that." "The nice thing about [the bedroom] for some of the balance work though is if you unbalance, if you get a little bit unbalanced, if you fall back, you're on a bed."
	Cues to exercise	• Prompt when sitting • Home activities as prompts	"It could be to make it more habitual and more part of the routine, it is the same place every time, so it is something on the kettle so when you're doing the tea you're doing your thing or it is brushing your teeth in the bathroom."
Using technology at home	User expectations	• Need to be discreet • Clear instruction and guidance	"I think people look at [an activity tracker] and think what's that old lady doing with wearing one of those! I'd like something much more unobtrusive." "I think it's that you run the risk of doing that and it's the KISS principle, isn't it, is the Keep it Simple and therefore the more straightforward and simple it is but if

		• Simple to use	could start going into reams and reams and reams of why you should do this, you switch off a bit, don't you?" "For me if this is designed to help you exercise it's got to be a basic thing."
	Need to consider the context of use	• Realities of everyday life • Home technology ecosystem	"Often like a lounge area, which is often where people maybe do some exercises, there's a coffee table in the way. They have to shift it and I sometimes wonder is it feasible to ask people to have to shift furniture to do these types of exercises? I think that's a little bit of a…"
	Opportunities for exercise snacking technologies	• Importance of feedback • Need for visual prompts • Technology as part of everyday routines	"When we had the step counters, I found that quite an incentive to actually go out and do more walking" "I might want to see at the end of the week how I got on compared to the end of last week." "I'm not a technology person but something that will pop up with a smiley face and say, hmm, have you bent your knees today or… you know, something like… well, that would work for me, things that would make me smile and laugh." "[You could have] a bathmat in your bathroom that had that little square black center [the pressure mat] in it, so it was there, you forget it's there but it takes on board information and gives feedback to you about your balance without you having to think about it"

Topic 1: Attitudes towards exercise

Several themes were identified in relation to common *barriers to participation*. One common point of discussion centered around leisure settings being viewed as a non-welcoming space for older adults. Several participants pointed to leisure centers and gyms as being young and male dominant, while others recognized that much of the provision for older adults was group-based, with participants noting they felt a lack of confidence in exercising with others. There were also barriers relating to individuals' motivation to do regular exercise. This was linked to the fear of falling, injury, or a lack of baseline strength, which made exercise a perceived risky prospect. However, despite these participation barriers, there was a strong sense that *exercise was important to the participants,* with many championing the health and wellbeing benefits it brings. Participants also recognized exercise to be a way of building confidence to stay engaged in other forms of social and leisure activity. Likewise, the social aspect of exercise itself was regarded as a key driver for participation, particularly for walking and aerobic activities.

Participants generally agreed that exercise should match the profile and ability of the target user and saw *promise in exercise snacking* overcoming this issue. For example, there were exercises that were much more suited to people in their later life, particularly their physical capabilities, such as balance or sit-to-stand exercise. In this vein, the exercise snacking concept was viewed favorably as it was seen to enable people to build up from different baselines, progress on their own terms and appeared easy to master as a set of exercises. In addition, it could help to overcome other barriers participants had mentioned – including the ability to do PA in a low-risk environment that was not a leisure setting. Tai-chi movements,

as a proposed format of exercise snacking, had more of a mixed reception, with preconceptions both acknowledging it as a useful, relaxing exercise, but potentially tricky to learn.

Topic 2: Exercising in the home environment

The second topic explored how the home environment might support or hinder regular engagement in exercise snacking. While walking round the smart home environment, some participants commented on the *impact of location* and how different spaces lend themselves to exercise more than others. For example, it was apparent that the amount of floor space in a room was important for it to be seen as a space to exercise in. Another consideration was the need to work around other people in the home, including partners, spouses, grandchildren, or pets. There was also a sense that certain rooms had a particular function that would preclude them from being a place for exercise, such as the dining room.

Much of the conversation on the suitability of spaces to exercise centered on *safety in the home environment*. Having solid objects to hold on and to support balance and stability where necessary was seen as an important consideration, with key examples in the more spacious rooms being kitchen worktops and chairs. Additionally, for some formats of exercise, such as balancing, having soft furnishings and carpeted floors would make the environment feel safer than hard spaces.

A final theme relating to the home environment was how certain spaces or everyday tasks could be used as opportunistic *contextual cues to prompt exercise snacking*. For example, the lounge was suggested as a good place to be prompted and do exercise as it is typically the space in which older adults would otherwise sit for long periods of time – as such, it would be suitable for exercises that can be done while sitting. Some people identified everyday actions that could prompt their exercise snacking, like brushing teeth, boiling the kettle, or washing dishes. As they were part of the routine and usually took place in the same spot, they could be linked with exercises suitable for that space, e.g., balance exercises.

Topic 3: Opportunities and challenges of using technology in the home

Finally, when discussing the use of technology, it was apparent that participants were already familiar with a range of technologies (e.g., apps, Amazon Alexa, Fitbit for tracking steps, YouTube videos to support exercise), and referred to existing solutions to highlight their strengths and weaknesses. Based on this prior experience they had clear *expectations* of what technologies would and would not work for them. For example, they all agreed that any system that aims to support PA at home should be discreet or even hidden, as not everyone

felt comfortable “advertising” with technology that they were trying to be more active. In addition, such systems should also work for people with low technology literacy and be as simple and easy to use and set up as possible. As such, some participants also thought that limiting functionality would help to make the technology easier to use.

This need for simplicity was also linked with a *need to consider the context of use*. This included accounting for the realities of everyday life and characteristics of the users. One participant mentioned that ideal technology would be something they could use without having to wear glasses. Another participant pointed out that the technology would be a part of a wider ecosystem and therefore would need to easily connect to the local wireless network and work with other devices at home. Furthermore, it should be inexpensive as even smartphones or smart watches were seen as beyond the reach of a regular person.

Participants also identified several *opportunities for exercise snacking technologies*. They agreed that technology should provide instructions, feedback, and reminders. Instructions were seen as an important feature that could help to introduce the correct movements, help users understand how to exercise (e.g., frequency, when to stop) and later help check whether they were exercising correctly, especially if no additional support was provided. With the latter point, participants expressed a desire to have access to either support groups or someone they could discuss their progress with. Furthermore, visual prompts could also be used to provide ongoing feedback and situated instructions, e.g., by showing the movements one is supposed to execute or simply providing encouragement to motivate the user. In addition, some participants thought that this type of interaction could be more playful and “witty”. Overall, participants were open to trying out new technologies. Having identified the best locations and types of exercises, they also suggested building devices that could be incorporated into everyday objects to encourage exercise snacking in a specific location.

Prototype development

Study 1 results informed the design of the prototypes. Given that participants expressed interest in exercise snacking and engaging with simple exercises at home, we decided to develop prototypes based around a pressure mat that could be placed anywhere at home where it would fit best into participants’ daily routine. This form factor would also allow participants to just use it (stand or sit on it) without having to set things up in preparation, which was another aspect identified by participants. Finally, as participants expressed an interest in systems that are discreet or hidden, an LED companion screen was included to provide additional visual feedback that did not explicitly mention exercise.

We developed two prototypes. Each consisted of a pressure mat and a battery pack. We used SensingTex Switch mat that enabled a single pressure point recognition (see Figure 2). We selected a pressure mat as the basis of each prototype as it would not require any complex interactions and participants would only need to stand on it if they were ready to exercise. Each mat was connected via Bluetooth to a Raspberry Pi 4 and a Unicorn HAT LED Matrix. The LED screen provided feedback to the user as without it, due to the mat's minimal interface, it was not clear if the prototype was active or whether participants were reaching their goals. The screen also provided encouragement and motivation.

Figure 2. *A pressure mat and a battery pack that were used as a basis of the prototypes.*

While each prototype appeared similar, they had different underlying algorithms to account for differences in the exercises. The balance mat was set up for two daily repetitions, 60 seconds each, as a default, and the sit-to-stand mat was set up to measure movement repetitions for 60 seconds during each exercise session with the target of 30 repetitions per day. When stepped on, the prototype would trigger a timer, which was shown on the LED screen. The devices recorded the number of repetitions and time spent on each exercise. Figure 3 shows examples of the visual feedback: a smiling face if the daily target has been reached, a frowning face if it has not been reached yet, and a progress bar to help count time during an exercise session.

A flow diagram showing how the prototypes worked is available in Multimedia Appendix 1.

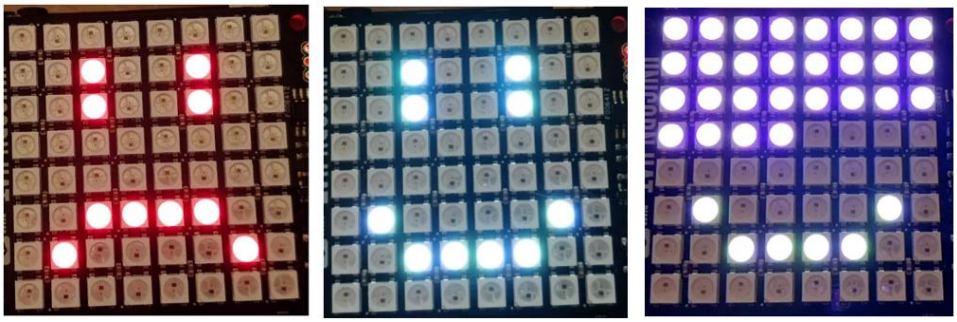

Figure 3. *Companion LED displays available to the user, showing a) that the total number of activities for the day has not been reached yet, b) the activities for the day have been completed, and c) a progress bar that fills in the screen showing the user how long they should engage with the exercise.*

Study 2: Home Evaluation

The second study focused on evaluating the prototypes at home. Unlike Study 1, it was more exploratory in nature: we did not have predefined topics in mind beyond understanding how the participants used the prototypes and what they thought about them.

Participants' use of technology

All five participants reported using the Internet and having previous experience using mobile phones, laptops, personal computers, and tablets. Consumer electronics they used were often Apple products whose sleek design was referenced by participants when discussing the study prototypes. Most participants reported that they used some sort of an activity tracker (often step counters on their phone) and were generally positive towards these types of technologies. One participant mentioned using a heart rate monitor and two reported watching exercise videos on YouTube (fitness, yoga) during COVID lockdowns to help them stay active.

These technologies and participants' experiences influenced how they interacted with our prototypes and their expectations towards the devices. Below we describe four themes identified in the interviews conducted after the home evaluation.

Importance of design aesthetics and reliability

The study findings highlighted the importance of selecting the right level of complexity and polish of the initial prototypes used for testing. As the study goal was to explore how the technology fits into people's homes and could support exercise snacking, we focused primarily on the functionality and did not prioritize the design at this stage. As a result, our participants thought the prototypes were crude ("The graphics I thought were very crude. I think they could have been more pixels in the display to make the pictures easier to understand", P5) and unfinished ("That equipment was quite awkward, you know, the cables and the fittings and the plugs didn't seem to fit very securely. It was all kind of it all looked a

bit fragile", P3), which affected how they used them. Some participants were not sure whether they could fold the mats for storage or whether that would damage them.

Participants also found it cumbersome to assemble the prototypes and to remember to switch them on and off to preserve the battery. This led to technical issues when they connected things incorrectly or the prototypes were not working properly, which discouraged participants from using the devices. As a result, while participants agreed the devices had potential and "tools like this" could be useful, they did not see a clear benefit to using the prototypes in their current form ("the technology is too crude and intrusive at this early stage, compared with either a) doing without or b) doing something clever with it", P1).

Challenges with fitting the device into everyday life

The prototypes were designed so they could be used in different places at home to enable participants to fit exercise snacking into their routines. While it mostly worked, participants highlighted a few practical considerations. One participant reported they had to rearrange their house and move a chair to the kitchen so that they could do the sit-to-stand exercise ("I've got lots of things all over the place. For this trial, I put them in the kitchen. But it would be in the way if I left there every day. I'd have to find somewhere else.", P1). In addition, the balance mat was perceived as a potential trip hazard and participants were not keen to leave it on the floor when not in use ("If I kept it there during the day, I could easily trip on it. Anybody could trip or slip as well because I have a wooden floor so it could slip quite easily", P2). Additionally, some did not want the prototypes to always be visible due to their looks and found packing and unpacking the devices cumbersome. Similarly, the limited battery life required the device to be switched off when not in use, which added an extra burden.

Overall, while exercise snacking was supposed to be easy and effortless, having to set things up defeated the purpose of the prototypes. Participants acknowledged that while having a dedicated tool could in principle make exercising easier, using pre-existing methods or devices was perceived as easier and more useful. Improved reliability, more polished look, and easier set up would make exercise snacking systems more motivating and appealing ("I think [the prototypes] just feel, um, they don't feel user friendly and they don't feel... they feel like old technology. I think it would need to have a screen; it would need to look like a phone; it would need to have a digital reader, you know, all of that, like the apps we have on our phone.", P3).

Need for personalization

The initial design of the prototypes allowed changes to the difficulty levels and the number of repetitions. However, in scaling down the project due to the COVID-19 pandemic, the researcher gave all participants the same device default settings. This proved problematic and participants consistently commented that the exercises were either too easy or too difficult ("The balance exercise is quite easy, and the sit-to-stand is more strenuous. It's hard work. It takes more energy and makes me tired.", P5). A positive side effect observed was increased motivation of one participant who started using weights to make the exercises more challenging ("I put a rucksack on my back and weights in it and I did it like that to get myself... to make [sit-to-stand exercises] harder", P3), which suggested that the device could be useful for initiating exercise behavior or as a gateway to people forming a new routine ("If it's there, you'll use it. And that's just getting into the regime, it's like, in the morning, you'll sort of do 10 minutes of different exercises... And it just becomes a habit", P4).

Issues with difficulty levels and progression led to discussions about exercise personalization and suggestions for future improvements. Participants believed that exercises needed to adapt to the user and therefore suggested building in some progression to keep users engaged, e.g., through increasing complexity or difficulty of movements ("trick is to make it sufficiently interesting and challenging to those who find it fairly easy, but also not to put off people who find it harder and struggle to get out of the chair, so maybe if you had a series of levels so you could come in at level one or you could jump to level three", P3). They also highlighted the need for feedback on the movements and progress, which would help with motivation and could support the increasing difficulty levels (one participant suggested a potential app similar to the Couch to 5K running program but for strength and balance).

Future Opportunities

When asked for views on the potential for technology to support home-based exercise after using the prototypes, participants identified several desirable features to improve utility. Features included linking of the devices to a more sophisticated application or sensors to provide more detailed feedback ("if the mat sensed the growing extent of my imbalance and reduced the time, or increased it if my balance was perfect, that would be a bit more useful, and if it sensed where my toes or heel or whatever was going wrong, and issued warnings about posture then that would make it more useful", P1); adding in voice or sound as a way of providing feedback on performance of exercises and encouragement; and prompts and reminders to do the exercise.

Participants also discussed how the prototypes could be improved. Some suggestions focused more on how the mat could support a more diverse array of exercises ("It would be nice to have a wider range of exercises. I mean, as you get old your backs get stiff. You get stiffness in lots of joints. I think that it could be done to use more joints as a body, try and create more flexibility", P5). Participants also provided positive perspectives on the role of technology in supporting home-based exercise, e.g., providing visual prompts ("the little pad would be sitting on the floor, would be a reminder", P5). Others discussed how functioning technology could provide structure to support current activity and could be useful for engaging people in new activities in the short term, even if not used continuously ("At the moment I do it when I can see I've got two or three minutes to do sit to stand. So I do", P1).

Discussion

Principal findings

The aim of this project was to develop and test interactive prototypes to be used in the home to support strength and balance exercise snacking in pre-frail older adults. Our workshops identified that participants were open to using technology in the home setting, but personalization of exercise snacking regime and simplicity in technology use are important. Participants who subsequently tested two prototypes (balance mat and sit-to-stand mat) in a home evaluation demonstrated that this technology had potential to support exercise snacking in the home setting with further development and testing. In the following sections, we discuss the main results and implications for designing systems that support exercise snacking at home for pre-frail older adults.

Home environment as a space to exercise

Exercise was identified as an important activity for participants and using the home setting as a location for exercise snacking elicited both positive and constructive views, which will inform the next iterative step in the design process. The home setting has been frequently used for rehabilitative exercise for multiple conditions such as musculoskeletal joint replacement, neurological conditions and cardio-respiratory conditions and has been shown to be as effective as supervised or group exercise at 12 weeks on health outcomes for women with type 2 diabetes [34]. A recent pilot randomized controlled trial has demonstrated that resistance exercise snacking is safe and acceptable for community dwelling older adults over a four-week period. While the current project focused on only one resistance/strength

exercise and one balance exercise, the results align with Fyfe et al. [35] and Liang et al. [19] who found the exercises to be feasible and safe.

Role of technology for overcoming barriers

A key challenge for any exercise program, in particular those targeting individuals in the home setting, is prolonged adherence [36]. Participants in this study were largely positive about the potential for technology to support the implementation of home-based exercise snacking providing that the technology was simple, reliable, and unobtrusive to use. This key guiding principle on the simplicity and reliability for the adoption and sustained use of technology has been found in other studies into older adults' perception of technology [37]. Technology, if designed appropriately, also enables the integration of some key behavioral science principles that can help with exercise motivation, such as self-regulatory behavior change techniques (e.g., feedback and goal setting) and gamification to make exercise fun and engaging [37–39], and nudges or cues to help turn exercise into a more automatic behavior [40]. Our preliminary evaluation suggested that more work could be done to both improve the reliability of the technology, better integrate feedback, and make the device more personalized to the user's needs and preferences for exercise.

Recommendations for future practice and research

Accordingly, we provide design recommendations for developing home-based systems that support exercise snacking and other types of PA aimed at older adults. Researchers and developers working in this area should:

- **Support personalization.** As older adults can have varying levels of activity, any home-based system that facilitates and supports exercise needs to be able to accommodate different baseline circumstances, from fully sedentary routines to physically active users who may want to move more at home. As such, systems should allow users to change difficulty levels, which should then progressively adapt based on user's progress.
- **Provide clear and meaningful feedback.** As exercise snacking is a situated activity, any system that supports it needs to recognize and clearly communicate that it has started and to notify the user when they can finish, regardless of whether they are doing timed exercises or a specific number of repetitions. It should also notify the users when they reach their goals and show their progress. Furthermore, different feedback modalities need to be considered to improve accessibility and usability through combinations of visual and auditory feedback to support older adults with hearing and visual impairments.

- **Take the environment into account.** Any system supporting exercise at home needs to be flexible enough so that people can use it in the most suitable location. Different people have different routines, and the living situation of older adults varies, which makes it impractical to design a one-size-fits-all solutions. For example, some people may prefer to exercise snack in the living room, while others would prefer to do so in the kitchen; ideally, the system should work in both.
- **Remember the aesthetics.** The design of technologies aimed at older adults is often based on a wrong assumption that aesthetics does not matter for this user group. However, increasing access to consumer electronics influences the perceptions of technology, and people's expectations and values; older adults are no different [41]. Furthermore, any device that is meant to become part of an environment should fit into that environment and ideally provide subtle and discreet feedback as not all users may want to advertise to visitors that they are trying to be more active.
- **Ensure the system is accessible and easy to use.** As older adults' experiences with technology or digital literacy may be limited, any system aimed at them should have an intuitive design and require minimal setup. Switching technology on and off and selecting user goals and preferences should be implemented in a user-friendly way that is suitable for the target population. Furthermore, systems should be compatible with the technologies people already have at home, e.g., wireless networks. As most IoT systems rely on the Internet connection, the ease of setup and seamless connectivity are key.
- **Provide guidance to reduce risks.** Finally, any system that supports PA needs to be able to guide the users as the movements may not be familiar to them or they may require a reminder. This can be directly embedded into the physical system or be provided through a companion app. Regardless of the format, guidance could help to reduce risks of falls, support older users, and educate users about PA.

Limitations and Future Work

This was an exploratory project focusing on the early stages of the iterative UCD process and as such had some limitations. Study 1 participant numbers were limited by space and maximum capacity for people in the smart home at the time, although the numbers were in line with previous design research using workshops to design digital interventions, e.g. [42]. Study 2 involved five participants who used the prototypes for one day. As our goal was to assess usability of the prototypes and gather early feedback, this was sufficient as usually 4-6

participants are required to identify key usability issues [43]. Indeed, participants were vocal about issues and constructive suggestions for improvements. Overall, our participant numbers are consistent with user-centered design studies, and evidence has shown that these methods can provide generalizable design guidelines [44–47].

Participant recruitment was from a cohort that had previously participated in a PA trial [48], albeit a mixture of intervention and control participants. Selection bias may have impacted on the results obtained as the participants may have had more positive attitudes towards PA. However, as this was the initial phase in the design process, both benefits and challenges to developing technology were identified and future stages in this process (acceptability, feasibility and efficacy testing) will ensure a wider, representative and larger recruitment of pre-frail older adults to avoid potential bias [49]. Additionally, recruitment from this population enabled participants to reflect on their previous experiences with exercise snacking and provide feedback and suggestions for improvements, which was crucial for the current study.

Study 2 was a home study conducted during the COVID-19 pandemic and consequently was subject to several deviations from the initial protocol. These limitations influenced participants' experiences, which is reflected in the themes. Nevertheless, key lessons were learned for the design and delivery of technology home testing during COVID-19 which can be embedded into future stages of this project to ensure successful delivery and completion, regardless of whether there is face-to-face or remote delivery. Furthermore, as home testing occurred over a single day, we were unable to evaluate the adherence to exercise snacking. As adherence is crucial to the acceptability and feasibility of the exercise snacking technology design, factors predicting adherence to home-based rehabilitation (intention to engage, self-motivation, self-efficacy, previous adherence and social support [50]) will be incorporated into subsequent iterations of the design process.

Finally, the design of our prototypes may have influenced the results. Our primary focus was the functionality of the prototypes; we did not fully consider aesthetics or visual design at this stage. This resulted in negative comments and to some degree affected participants' interactions with the prototypes. While we were still able to gather relevant feedback, more polished prototypes and user interfaces would have helped to concentrate the feedback on functionality. As we are following the UCD process, this will be incorporated into the next iterative phase of development for the prototypes.

Conclusions

Exercise snacking offers a promising approach to incorporating balance and strength-building PA in older adults' routines. Our results demonstrated that technology has the potential to support exercise snacking in the home environment for pre-frail older adults. However, the design of devices not only needs to be easy to use and set up but must also fit into users' routines and physical spaces. Exercise snacking technology devices also need to be adaptable and personalized to individuals, to ensure that users are 'snacking' on balance and strengthening exercises that are appropriate for them.

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Data Availability

The data sets generated and/or analyzed during the current study are available from the corresponding author on reasonable request.

Conflicts of Interest

None declared.

Abbreviations

IoT: Internet of Things
LED: Light-emitting diode
NFC: Near-Field Communication
PA: Physical activity
UCD: User-Centered Design

Multimedia Appendix

Multimedia Appendix 1. A flow diagram showing how the prototypes work.

References

1. Warburton DER, Nicol CW, Bredin SSD. Health benefits of physical activity: the evidence. CMAJ [Internet] CMAJ; 2006 Mar 14 [cited 2022 Mar 9];174(6):801–809. PMID:16534088
2. Department of Health and Social Care. Physical activity guidelines: UK Chief Medical Officers' report [Internet]. Gov.uk. London, UK; 2019. Available from: https://www.gov.uk/government/publications/physical-activity-guidelines-uk-chief-medical-officers-report
3. Keadle SK, McKinnon R, Graubard BI, Troiano RP. Prevalence and trends in physical activity among older adults in the United States: A comparison across three national surveys. Prev Med (Baltim) Academic Press; 2016 Aug 1;89:37–43. PMID:27196146

4. Rubenstein LZ, Josephson KR. The epidemiology of falls and syncope [Internet]. Clin Geriatr Med. Elsevier; 2002 [cited 2022 Feb 3]. p. 141–158. PMID:12180240
5. Zijlstra GAR, Van Haastregt JCM, Van Rossum E, Van Eijk JTM, Yardley L, Kempen GIJM. Interventions to Reduce Fear of Falling in Community-Living Older People: A Systematic Review. J Am Geriatr Soc [Internet] John Wiley & Sons, Ltd; 2007 Apr 1 [cited 2022 Feb 3];55(4):603–615. PMID:17397441
6. Giné-Garriga M, Sansano-Nadal O, Tully MA, Caserotti P, Coll-Planas L, Rothenbacher D, Dallmeier D, Denkinger M, Wilson JJ, Martin-Borràs C, Skjødt M, Ferri K, Farche AC, McIntosh E, Blackburn NE, Salvà A, Roqué-I-Figuls M, Newman A. Accelerometer-Measured Sedentary and Physical Activity Time and Their Correlates in European Older Adults: The SITLESS Study. Journals Gerontol - Ser A Biol Sci Med Sci [Internet] Oxford Academic; 2020 Sep 16 [cited 2022 Feb 3];75(9):1754–1762. PMID:31943000
7. Tremblay MS, Aubert S, Barnes JD, Saunders TJ, Carson V, Latimer-Cheung AE, Chastin SFM, Altenburg TM, Chinapaw MJM, Aminian S, Arundell L, Hinkley T, Hnatiuk J, Atkin AJ, Belanger K, Chaput JP, Gunnell K, Larouche R, Manyanga T, Gibbs BB, Bassett-Gunter R, Biddle S, Biswas A, Chau J, Colley R, Coppinger T, Craven C, Cristi-Montero C, de Assis Teles Santos D, del Pozo Cruz B, del Pozo-Cruz J, Dempsey P, do Carmo Santos Gonçalves RF, Ekelund U, Ellingson L, Ezeugwu V, Fitzsimons C, Florez-Pregonero A, Friel CP, Fröberg A, Giangregorio L, Godin L, Halloway S, Husu P, Kadir M, Karagounis LG, Koster A, Lakerveld J, Lamb M, LeBlanc AG, Lee EY, Lee P, Lopes L, Manns T, Ginis KM, McVeigh J, Meneguci J, Moreira C, Murtagh E, Patterson F, da Silva DRP, Pesola AJ, Peterson N, Pettitt C, Pilutti L, Pereira SP, Poitras V, Prince S, Rathod A, Rivière F, Rosenkranz S, Routhier F, Santos R, Smith B, Theou O, Tomasone J, Tucker P, Meyer RU, van der Ploeg H, Villalobos T, Viren T, Wallmann-Sperlich B, Wijndaele K, Wondergem R. Sedentary Behavior Research Network (SBRN) - Terminology Consensus Project process and outcome. Int J Behav Nutr Phys Act [Internet] BioMed Central; 2017 Jun 10 [cited 2022 Feb 3];14(1). PMID:28599680
8. World Health Organization. Ageing and health [Internet]. Ageing Heal. 2021 [cited 2022 Aug 9]. Available from: https://www-who-int.abc.cardiff.ac.uk/news-room/fact-sheets/detail/ageing-and-health
9. Vogel T, Brechat PH, Leprêtre PM, Kaltenbach G, Berthel M, Lonsdorfer J. Health benefits of physical activity in older patients: a review. Int J Clin Pract [Internet] John Wiley & Sons, Ltd; 2009 Feb 1 [cited 2022 Mar 15];63(2):303–320. PMID:19196369
10. Kim J, Im JS, Choi YH. Objectively measured sedentary behavior and moderate-to-vigorous physical activity on the health-related quality of life in US adults: The National Health and Nutrition Examination Survey 2003–2006. Qual Life Res [Internet] Springer; 2017 Nov 11 [cited 2022 Feb 3];26(5):1315–1326. PMID:27837382
11. Zubala A, MacGillivray S, Frost H, Kroll T, Skelton DA, Gavine A, Gray NM, Toma M, Morris J. Promotion of physical activity interventions for community dwelling older adults: A systematic review of reviews. PLoS One [Internet] Public Library of Science; 2017 Jul 1 [cited 2022 Feb 3];12(7):e0180902. PMID:28700754
12. Chao D, Foy CG, Farmer D. Exercise adherence among older adults: Challenges and strategies. Control Clin Trials Elsevier; 2000 Oct 1;21(5 SUPPL. 1):S212–S217. PMID:11018578
13. Cohen-Mansfield J, Marx MS, Guralnik JM. Motivators and barriers to exercise in an older community-dwelling population. J Aging Phys Act [Internet] Human Kinetics, Inc.; 2003 Apr 1 [cited 2022 Feb 3];11(2):242–253. DOI: 10.1123/japa.11.2.242

14. Schutzer KA, Graves BS. Barriers and motivations to exercise in older adults. Prev Med (Baltim). Academic Press; 2004. p. 1056–1061. PMID:15475041
15. Weber M, Belala N, Clemson L, Boulton E, Hawley-Hague H, Becker C, Schwenk M. Feasibility and Effectiveness of Intervention Programmes Integrating Functional Exercise into Daily Life of Older Adults: A Systematic Review. Gerontology [Internet] Karger Publishers; 2018 Feb 1 [cited 2022 Feb 3];64(2):172–187. PMID:28910814
16. Perkin OJ, McGuigan PM, Stokes KA. Exercise Snacking to Improve Muscle Function in Healthy Older Adults: A Pilot Study. J Aging Res Hindawi Limited; 2019;2019. PMID:31687210
17. Gokal K, Amos-Hirst R, Moakes CA, Sanders JP, Esliger DW, Sherar LB, Ives N, Biddle SJH, Edwardson C, Yates T, Frew E, Greaves C, Greenfield SM, Jolly K, Skrybant M, Maddison R, Mutrie N, Parretti HM, Daley AJ. Views of the public about Snacktivity™: a small changes approach to promoting physical activity and reducing sedentary behaviour. BMC Public Health [Internet] BioMed Central Ltd; 2022 Dec 1 [cited 2023 Jan 27];22(1):1–12. PMID:35351075
18. Tyldesley-Marshall N, Greenfield SM, Parretti HM, Gokal K, Greaves C, Jolly K, Maddison R, Daley AJ, Biddle S, Edwardson C, Esliger D, Frew E, Ives N, Mutrie N, Sanders J, Sherar L, Skrybrant M, Yates T. Snacktivity™ to Promote Physical Activity: a Qualitative Study. Int J Behav Med [Internet] Springer; 2022 Oct 1 [cited 2023 Jan 27];29(5):553–564. DOI: 10.1007/S12529-021-10040-Y/TABLES/2
19. Liang IJ, Perkin OJ, McGuigan PM, Thompson D, Western MJ. Feasibility and Acceptability of Home-Based Exercise Snacking and Tai Chi Snacking Delivered Remotely to Self-Isolating Older Adults During COVID-19. J Aging Phys Act [Internet] J Aging Phys Act; 2021 Jun 22 [cited 2022 Feb 3];30(1):33–43. PMID:34157675
20. Vargemidis D, Gerling K, Spiel K, Abeele V Vanden, Geurts L. Wearable Physical Activity Tracking Systems for Older Adults—A Systematic Review. ACM Trans Comput Healthc [Internet] ACM PUB27 New York, NY, USA ; 2020 Sep 30 [cited 2022 Feb 3];1(4):1–37. DOI: 10.1145/3402523
21. Brickwood KJ, Watson G, O'brien J, Williams AD. Consumer-Based Wearable Activity Trackers Increase Physical Activity Participation: Systematic Review and Meta-Analysis. JMIR Mhealth Uhealth 2019;7(4)e11819 https//mhealth.jmir.org/2019/4/e11819 [Internet] JMIR mHealth and uHealth; 2019 Apr 12 [cited 2022 Mar 15];7(4):e11819. PMID:30977740
22. Ganesan S, Anthony L. Using the Kinect to Encourage Older Adults to Exercise: A Prototype Work-in-Progress. CHI '12 Ext Abstr Hum Factors Comput Syst [Internet] New York, NY, USA: ACM; [cited 2022 Mar 9]; DOI: 10.1145/2212776
23. Lotfi A, Id C, Langensiepen ID, Wada S, Id Y. Socially Assistive Robotics: Robot Exercise Trainer for Older Adults. Technol 2018, Vol 6, Page 32 [Internet] Multidisciplinary Digital Publishing Institute; 2018 Mar 10 [cited 2022 Mar 9];6(1):32. DOI: 10.3390/TECHNOLOGIES6010032
24. Huang Y, Benford S, Price D, Patel R, Li B, Ivanov A, Blake H. Using internet of things to reduce office workers' sedentary behavior: Intervention development applying the behavior change wheel and human-centered design approach. JMIR mHealth uHealth [Internet] JMIR Publications Inc.; 2020 [cited 2021 Oct 14];8(7). PMID:32723716
25. Kim Y, Lee T, Cho J. Smart-Rug: Haptic feedback for restraining crossed leg. UbiComp 2016 Adjun - Proc 2016 ACM Int Jt Conf Pervasive Ubiquitous Comput [Internet] New York, New York, USA: ACM Press; 2016 [cited 2019 Oct 15]. p. 125–128. DOI: 10.1145/2968219.2971438

26. Matassa A, Manuguerra V. Designing a smart plantar to support people in sport activities. UbiComp ISWC 2015 - Proc 2015 ACM Int Jt Conf Pervasive Ubiquitous Comput Proc 2015 ACM Int Symp Wearable Comput [Internet] New York, New York, USA: ACM Press; 2015 [cited 2019 Oct 15]. p. 663–668. DOI: 10.1145/2800835.2809441
27. Gerling K, Leuven K, Ray BM, Vanden Abeele V, Adam Evans BB, Ray M, Evans AB. Critical Reflections on Technology to Support Physical Activity among Older Adults. ACM Trans Access Comput [Internet] ACM PUB27 New York, NY, USA ; 2020 Apr 21 [cited 2022 Feb 3];13(1). DOI: 10.1145/3374660
28. Gulliksen J, Göransson B, Boivie I, Blomkvist S, Persson J, Cajander Å. Key principles for user-centred systems design. Behav Inf Technol [Internet] Taylor & Francis Group; 2003 [cited 2019 Jun 25]. p. 397–409. DOI: 10.1080/0144929031000162432 9
29. Yardley L, Morrison L, Bradbury K, Muller I, Yardley L. The Person-Based Approach to Intervention Development: Application to Digital Health-Related Behavior Change Interventions. J Med Internet Res 2015;17(1). PMID: 25639757
30. Stathi A, Withall J, Greaves CJ, Thompson JL, Taylor G, Medina-Lara A, Green C, Bilzon J, Gray S, Johansen-Berg H, Sexton CE, Western MJ, de Koning JL, Bollen JC, Moorlock SJ, Demnitz N, Seager P, Guralnik JM, Jack Rejeski W, Fox KR. A community-based physical activity intervention to prevent mobility-related disability for retired older people (REtirement in ACTion (REACT)): Study protocol for a randomised controlled trial. Trials [Internet] BioMed Central Ltd.; 2018 Apr 17 [cited 2022 Feb 3];19(1):1–12. PMID:29665854
31. Elsts A, Fafoutis X, Woznowski P, Tonkin E, Oikonomou G, Piechocki R, Craddock I. Enabling Healthcare in Smart Homes: The SPHERE IoT Network Infrastructure. IEEE Commun Mag [Internet] 2018 Dec [cited 2019 Oct 14];56(12):164–170. DOI: 10.1109/MCOM.2017.1700791
32. Braun V, Clarke V. Using thematic analysis in psychology. Qual Res Psychol Braun, Virginia: Department of Psychology, University of Auckland, Private Bag 92019, Auckland, New Zealand, Hodder Arnold; 2006;3(2):77–101. DOI: 10.1191/1478088706qp063oa
33. Ritchie J, Lewis J, Nicholls CM, Ormston R, editors. Qualitative research practice: A guide for social science students and researchers. SAGE; ISBN: 9781446209127
34. Dadgostar H, Firouzinezhad S, Ansari M, Younespour S, Mahmoudpour A, Khamseh ME. Supervised group-exercise therapy versus home-based exercise therapy: Their effects on Quality of Life and cardiovascular risk factors in women with type 2 diabetes. Diabetes Metab Syndr Clin Res Rev Elsevier; 2016 Apr 1;10(2):S30–S36. PMID:26822461
35. Fyfe JJ, Dalla Via J, Jansons P, Scott D, Daly RM. Feasibility and acceptability of a remotely delivered, home-based, pragmatic resistance ‘exercise snacking’ intervention in community-dwelling older adults: a pilot randomised controlled trial. BMC Geriatr 2022 221 [Internet] BioMed Central; 2022 Jun 25 [cited 2022 Jul 19];22(1):1–12. doi: 10.1186/S12877-022-03207-Z
36. Hancox JE, Van Der Wardt V, Pollock K, Booth V, Vedhara K, Harwood RH. Factors influencing adherence to home-based strength and balance exercises among older adults with mild cognitive impairment and early dementia: Promoting Activity, Independence and Stability in Early Dementia (PrAISED). PLoS One [Internet] Public Library of Science; 2019 May 1 [cited 2022 Jul 19];14(5):e0217387. PMID:31120953
37. Hawley-Hague H, Boulton E, Hall A, Pfeiffer K, Todd C. Older adults’ perceptions of technologies aimed at falls prevention, detection or monitoring: A systematic review.

Int J Med Inform Elsevier; 2014 Jun 1;83(6):416–426. PMID:24798946
38. Kappen DL, Mirza-Babaei P, Nacke LE. Technology Facilitates Physical Activity Through Gamification: A Thematic Analysis of an 8-Week Study. Front Comput Sci Frontiers Media S.A.; 2020 Oct 22;2:44. doi: 10.3389/fcomp.2020.530309
39. Pettersson B, Janols R, Wiklund M, Lundin-Olsson L, Sandlund M. Older Adults' Experiences of Behavior Change Support in a Digital Fall Prevention Exercise Program: Qualitative Study Framed by the Self-determination Theory. J Med Internet Res 2021;23(7)e26235 https//www.jmir.org/2021/7/e26235 [Internet] Journal of Medical Internet Research; 2021 Jul 30 [cited 2022 Jul 19];23(7):e26235. PMID:34328438
40. Forberger S, Reisch L, Kampfmann T, Zeeb H. Nudging to move: a scoping review of the use of choice architecture interventions to promote physical activity in the general population. Int J Behav Nutr Phys Act [Internet] BioMed Central; 2019 Dec 3 [cited 2019 Oct 6];16(1):77. doi: 10.1186/s12966-019-0844-z
41. Desai S, McGrath C, McNeil H, Sveistrup H, McMurray J, Astell A. Experiential Value of Technologies: A Qualitative Study with Older Adults. Int J Environ Res Public Health [Internet] Multidisciplinary Digital Publishing Institute; 2022 Feb 16 [cited 2022 Jul 19];19(4):2235. PMID:35206435
42. Stawarz K, Preist C, Tallon D, Wiles N, Kessler D, Turner K, Shafran R, Coyle D. Design Considerations for the Integrated Delivery of Cognitive Behavioral Therapy for Depression: User-Centered Design Study. JMIR Ment Heal [Internet] 2020 Sep 3;7(9):e15972. doi: 10.2196/15972. PMID: 32880580
43. Nielsen J, Landauer TK. Mathematical model of the finding of usability problems. Conf Hum Factors Comput Syst - Proc [Internet] New York, New York, USA: Publ by ACM; 1993 [cited 2020 May 28]. p. 206–213. doi: 10.1145/169059.169166
44. Anderson NS, Norman DA, Draper SW. User Centered System Design: New Perspectives on Human-Computer Interaction. Am J Psychol 1988;101(1):148. doi: 10.2307/1422802
45. Dix A, Dix AJ, Finlay J, Abowd GD, Beale R. Human-computer interaction. Pearson Education; 2003. ISBN: 9780130461094
46. Preece J, Sharp H, Rogers Y. Interaction design: beyond human-computer interaction. John Wiley & Sons; 2015. ISBN: 978-1-119-54725-9
47. Shneiderman B, Plaisant C. Designing the user interface: strategies for effective human-computer interaction. Pearson Education; 2010.
48. Stathi A, Greaves CJ, Thompson JL, Withall J, Ladlow P, Taylor G, Medina-Lara A, Snowsill T, Gray S, Green C, Johansen-Berg H, Sexton CE, Bilzon JLJ, deKoning J, Bollen JC, Moorlock SJ, Western MJ, Demnitz N, Seager P, Guralnik JM, Rejeski WJ, Hillsdon M, Fox KR. Effect of a physical activity and behaviour maintenance programme on functional mobility decline in older adults: the REACT (Retirement in Action) randomised controlled trial. Lancet Public Heal [Internet] Elsevier Ltd; 2022 Apr 1 [cited 2022 Jul 20];7(4):e316–e326. PMID:35325627
49. Skivington K, Matthews L, Simpson SA, Craig P, Baird J, Blazeby JM, Boyd KA, Craig N, French DP, McIntosh E, Petticrew M, Rycroft-Malone J, White M, Moore L. A new framework for developing and evaluating complex interventions: update of Medical Research Council guidance. BMJ [Internet] British Medical Journal Publishing Group; 2021 Sep 30 [cited 2022 Aug 9];374. PMID:34593508
50. Essery R, Geraghty AWA, Kirby S, Yardley L. Predictors of adherence to home-based physical therapies: a systematic review. https://doi-org.abc.cardiff.ac.uk/103109/0963828820161153160 [Internet] Taylor & Francis; 2016 Mar 13 [cited 2022 Jul 19];39(6):519–534. PMID:27097761