Kilcullen et al., Gerontechnology (2022) 21:1
https://doi.org/10.4017/gt.2022.21.1.591.12

A Theoretical Domains Framework (TDF) approach to the qualitative analysis of older adults' intentions to adopt assistive smart home technology

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Abstract

Background: There is a need for a broader understanding of the psychological influences impacting healthy older adults' intentions to use assistive smart home technologies if these technologies are to succeed in helping older adults to continue to live independently in their own homes.
Objective: This qualitative paper aimed to analyse healthy older adults' intentions to adopt and use assistive smart home technologies using the Theoretical Domains Framework (TDF), which synthesises a large number of theories of psychology and behaviour change.
Method: Using a focus group methodology, an in-person workshop presented fictitious personas representing end-user cases to participants, soliciting potential problems that may arise while living independently and solutions that might help. Online Zoom workshops facilitated discussions centred on participant opinions about how various forms of technology could support independent living for older adults. Comments were analysed using a TDF approach.
Results: Key domains identified as influencing intention to adopt and use assistive smart home technologies included Knowledge, Skills, Beliefs about Capabilities, Goals, Beliefs about Consequences, Social Influences, Emotions, and Environmental Context and Resources.
Conclusion: This paper has identified the eight most relevant TDF domains and mapped these to some of the theories and associated behaviour change strategies most suited to investigating and shaping intentions to use assistive smart home technology. The TDF-based analysis successfully elucidated a broad range of psychological influences driving intentions to adopt and use such technology. Knowledge of these influences can assist those involved in technology design, development, and marketing to ultimately increase the uptake of smart technology by older adults. Key advantages of the TDF include its comprehensive theoretical coverage contained within domains comprising mediators of behaviour change, and its capacity to elicit a wide range of influences with the potential to drive acceptance and adoption of smart technology among community-dwelling older adults.

Keywords: assistive smart home technology, technology acceptance, technology adoption, older adults, Theoretical Domains Framework

Introduction

The number of older adults worldwide will increase in the next 30 years, presenting both opportunities and challenges to society. For older populations, assistive smart home technologies can help to improve life quality, decrease healthcare costs, and offer more independent living (Colnar et al., 2020; Pal et al., 2018). Many older adults want to remain in their homes as long as possible (Normie, 2011) and they are open to using smart home technology if it can support health and independence without compromising their safety and quality of life (Fritz et al., 2016; Peek et al., 2016).

Assistive smart home technology systems integrate modern technologies into the homes and lives of older adults, offering intelligent, unobtrusive, and ubiquitous support to assist individuals with living independently and well (Dermody & Fritz, 2019; Zulas, 2014). Successful application of such assistive smart home technologies depends on how readily it is received or accepted. However, in light of the evidence of low

readiness for uptake of these technologies (Dermody et al., 2021; Pal et al., 2018), research is needed to understand from a behaviour change perspective, the expectations, motivations, and psychological factors related to the intentions to adopt these technologies before they are made available for widespread use, and before considerable costs in terms of time, labour, resources, and reputation are incurred. This is further underlined by studies suggesting that inadequate user involvement during the needs assessment, development, and implementation of technologies is a barrier to the adoption of technology (Wang et al., 2019; Nymberg et al., 2019). A better understanding of the influences at play at the pre-adoption stage will enable designers and developers to better tailor technology to older adults' needs and expectations, thereby optimising the potential adoption and sustained use of these technologies in this population.

Previous studies investigating older adults intentions to adopt new and emerging technologies have revealed a number of influences. For example, Berkowsky, Sharit, & Czaja (2017) concluded from their mixed-methods study that older adults' perceived value of the technologies, their confidence in their ability to learn the technology, and the perceived impact on quality of life were the most robust predictors of readiness to adopt the technology. A study that looked at user habits, perceived healthiness, and beliefs towards sensing technologies found that, amongst other factors, readiness to adopt and use sensing technology was influenced by perceived healthiness (Chen, Le Yumak & Pu, 2017). A systematic review by Pirzada et al (2022) showed that design features such as aesthetics, perceived ease of use and user control, personalisation of the technology, and user factors like lack of awareness, perceived benefit, concerns about privacy, stigma, and social/environmental factors like social pressure to adopt technology, training, and support from others to use the technology impacted older adults' intentions or readiness to adopt assistive smart technologies. Importantly, the perceived cost has also been cited as a barrier (Li, Yigitcanlar, Erol & Liu, 2021). There is also a perception that assistive smart technologies may increase dependence on technology (e.g. Yusif et al., 2016).

However, researchers agree that we need to know more about factors that influence initial decisions about adoption by older adults who may not be familiar with – or may not have direct experience with - the technology (Berkowsky et al., 2017), how acceptable they consider such technology and their motivations towards using such a system (Pal et al., 2018; Mulcahy et al., 2019). Moreover, the factors associated with intentions to adopt technology are likely dependent also on the type of technology under consideration (Berkowsky et al., 2017). Different degrees of acceptability across smart home technology devices were evident in one smart home feasibility study of healthy older adults (Choi et al., 2020). There remains, therefore, the need for more studies that examine imagined experiences with technology and the factors that influence initial intentions to adopt assistive smart home technology by older adults at the pre-adoption stage.

Many studies looking at either perception of or actual adoption of technology by older adults employ a technology acceptance model. Traditional technology acceptance models such as TAM (Davis, 1989) or the unified theory of acceptance and use of technology (UTAUT) (Venkatesh et al., 2003) emphasise the importance of perceived usefulness and perceived ease of use, but cited limitations of these models include inadequate recognition or treatment of the role played by users' goals, emotions, and the social aspects of decision-making (Bagozzi, 2007), and the personal importance of older adult privacy and autonomy. Although evidence is scattered, extant literature identifies a wide range of psychological and behavioural factors that might influence smart home technology acceptability, acceptance, and adoption. Almost all of these studies tend to identify specific factors or sets of factors, but they do so without a comprehensive conceptual framework to systematically investigate and identify those psychological influences that might be at play in assistive smart home technology acceptance and adoption decisions.

The Theoretical Domains Framework (TDF; Cane et al., 2012) is a synthesis of 33 theories of behaviour and behaviour change clustered into 14 (originally 12) domains and associated constructs (*Table 1*). By applying the TDF to assess older adults' intentions to adopt assistive smart home technology, the TDF provides a theoretical lens through which to view the wide range of cognitive, affective, social, and environmental influences on behaviour. The TDF, when employed as an analytic framework, also provides a point of entry to a taxonomy of empirically supported behaviour change techniques (Michie et al., 2008; Cane et al., 2015). The behaviour change techniques map on to individual TDF domains. Technology researchers and developers may like to consider integrating these techniques or strategies as appropriate in design, training and marketing efforts to help increase the likelihood of future adoption of these technologies. This research aimed to elucidate the various psychological and behaviour change influences that drive community-dwelling older adult intentions to adopt an integrated suite of smart home tech-

Table 1. TDF (v2) domains and associated constructs (as outlined in Atkins et al., 2017)

Domain (definition)	Constructs
Knowledge (awareness of the existence of something)	Knowledge, procedural knowledge, knowledge of task environment
Skills (ability or proficiency acquired through practice)	Skills, skills development, competence, ability, interpersonal skills, practice, skills assessment
Social/Professional Role and Identity (a coherent set of behaviours and displayed personal qualities of an individual in a social/work setting)	Professional identity, professional role, social identity, identity, professional boundaries, professional confidence, group identity, leadership, organisational commitment
Beliefs about Capabilities (acceptance of the truth, reality, and validity about an ability, talent, or faculty that a person can put to constructive use)	Self-confidence, perceived competence, self-efficacy, perceived behavioural control, beliefs, self-esteem, empowerment, professional confidence
Optimism (confidence that things will happen for the best or that desired goals will be attained)	Optimism, pessimism, unrealistic optimism, Identity
Beliefs about consequences (acceptance of the truth, reality or validity of a behaviour in a given situation)	Beliefs, outcome expectancies, characteristics of outcome expectancies, anticipated regret, consequents
Reinforcement (increasing the probability of a response by arranging a dependent relationship, or contingency, between the response and a given stimulus)	Incentives, punishment, consequents, reinforcement, contingencies, sanctions
Intentions (a conscious decision to inform a behaviour or to resolve to act in a certain way)	Stability of intentions, Transtheoretical model and stages of change
Goals (mental representations of outcomes or end states that an individual wants to achieve)	Goal priority, goal/target setting, goals (autonomous/controlled), action planning, Implementation intentions
Memory, attention & decision processes (ability to retain information, focus selectively on aspects of the environment and choose between two or more alternatives)	Memory, attention, attention control, decision-making, cognitive overload/tiredness
Environmental context & Resources (any circumstances of a person's situation or environment that discourages or encourages the development of skills and abilities, independence, social competence and adaptive behaviour)	Resources/material resources, organisational culture/climate, salient events, critical incidents, person X environment interaction, barriers and facilitators
Social Influences (those interpersonal processes that can cause individuals to change their thoughts, feelings or behaviours)	Social norms, group conformity, social comparisons, group norms, social support, power, intergroup conflict, alienation, group identity, modelling
Emotion (a complex reactive pattern involving experiential, behavioural and physiological elements, by which the individual attempts to deal with a personally significant matter or event)	Fear, anxiety, affect, stress, depression, positive/negative affect, burn-out
Behaviour Regulation (anything aimed at managing or changing objectively measured actions)	Self-monitoring, breaking habit, action planning

All definitions are based on the American Psychological Association's Dictionary of Psychology (American Psychological Association (APA): APA Dictionary of Psychology. 2007, American Psychological Association, Washington DC)

nologies, using the TDF as a framework for the analysis and identification of these influences. Specifically, these technologies were a voice-activated assistant that could assist with day-to-day tasks, an ambient sensor system that detects activities and environmental information from a person's home over time, and a wrist-worn smart wearable with the functionality to collect information on an individual's sleep and step count and display this feedback to the wearer.

Method

Design

This was a cross-sectional qualitative interview study consisting of focus groups of community-dwelling older adults.

Sample

Eligibility criteria applied to older adults included: age 60 years and older, living at home in the community. Participants were recruited through advertising in print media, social media, libraries, primary care centres, community centres, family resource centres, parish newsletters, and churches in Dublin. Those who met the eligibility criteria and provided informed consent took part in the focus groups. The final sample consisted of 24 older adults who participated in face-to-face (n=15) or online workshops (n=9). These interview data were collected as part of a user-needs requirements study exploring healthy older adults' views on technology and in particular assistive smart home technology and how it might be helpful for them in their lives.

Procedure

Ethical approval of the study was granted by our institutional review committee. Informed consent was provided by each participant in advance of each workshop, and workshops were audio-recorded and transcribed verbatim. Demographic information was collected at the commencement of each workshop; in face-to-face workshops by means of paper-based questionnaire, and in online workshops via electronic questionnaires. Demographic information for older adult participants included their age, sex, digital literacy profile, falls risk, information on who supports them to live independently, and the type and amount of support they receive.

Face-to-face workshops presented fictitious personas representing authentic end user cases to participants, about which participants were asked to identify potential problems these characters might face while living independently and solutions that might help them; and online Zoom workshops facilitated discussions centred

on participant opinions about how various forms of technology could support independent living for older adults. All workshops were originally planned as face-to-face gatherings but were moved on-line for safety reasons after the outbreak of Covid-19. In these workshops, specific technology solutions (a voice-activated assistant, a smart watch wearable and an ambient sensing system, and an integrated technology system comprising the three applications as a coherent technological solution) were demonstrated to participants via separate video clips, and participants were asked for their views on these technologies. These assistive smart home technologies were chosen based on analysis of the user needs discussed in the in-person workshops and for the ability of these technologies to assist older adults with remaining independent and well as they age in place. Ambient sensors are unobtrusive and the activity recognition resulting from the machine learning algorithm employed for prediction purposes provides opportunities for interventions to assist older adults in the maintenance of their wellbeing. The smart wearable also assists the older adult in staying physically fit and healthy through monitoring and feedback on activity levels and sleep information. Voice-activated assistants assist with task completion through reminders and information provision and enhance the quality of life by facilitating social connection and providing entertainment.

Materials

Voice-activated assistant (VAA)

The first video clip depicted a voice-activated assistant that can assist with various day-to-day tasks when prompted by a command. It does this via an inbuilt microphone and internet connection, and it provides an update of results to any given request through its in-built speaker. Some VAAs have a built-in touch-screen. Some tasks VAAs may be used for include: reminders, alarms, shopping lists, communication (calling family, and friends), news and music access, internet searches, and local information such as weather and shop closing times.

Ambient sensors

The second video clip described ambient sensors; those that can detect various activities and environmental information in an individual's home over time. Data from these sensors can be combined to provide a picture of the home and activities within the home over time. For example, they can detect movement, humidity, light, vibration, and temperature. They can determine if a door is open or closed, or if a device has been left on. These devices send information to a central location to be analysed. Over time, the system learns to recognise the normal pattern of daily activities. If the system identifies a potentially significant change in the older adult's usual pattern of behaviour that is judged to be potentially indicative of an underlying ailment, it can alert the older adult and their friends, family, and caregivers as appropriate so that they may check in with the older adult or take further steps to investigate and ensure their wellbeing. For example, the video describes a case vignette of "Jenny", an older user, who does not return from the bathroom one night, and so an alert is issued to her son. These sensors are fitted in non-obtrusive locations around the home, for example, the top corners of doors, or attached to plugs.

Wearables

The third video clip described wearable health and wellbeing monitors such as wrist-worn, pendant-style, and finger-ring wearable technology. These devices can collect information on an individual's health and movement and provide feedback. In addition, some devices can detect falls, track location and have emergency response features. In most cases, these devices are worn on the wrist, and they can track individual activity inside and outside of the home. They are powered by battery and require re-charging. The wearable devices can be connected to an iPhone, smartphone, or tablet so that activity can be viewed. Common features of wearable technology include activity monitoring, sleep tracking, heart rate monitoring, fall detection, emergency response, and location tracking.

Integrated system

The fourth video clip described how the previous three types of assistive smart technologies can be brought together into an Integrated System, providing concrete examples to participants of how this type of system can provide support to individuals and caregivers.

Prior to viewing the videos participants in each focus group were asked to discuss two questions: the first question related to what they thought of using different types of technology to support independent living at home. The second question related to what behaviour would they like to change, or what aspect of daily living at home would they like to change or work on. Following this, participants were shown each of the demonstrator technology videos, and discussions about the technologies shown in the videos were facilitated by a topic guide that centred on usefulness and barriers and challenges to using each of these technologies. Specifically, after each of the videos, participants were asked about their initial thoughts about the technology, the opportunity for, and the likelihood that they would use it if they could see benefits and challenges to using the technology, whether they felt the technology might change their behaviour and how confident

were they that they could use the technology.

Analytic approach
Interviews were recorded, transcribed, and imported into the qualitative analysis software Nvivo v1.4. The first stage of analysis followed a deductive approach. Applying the TDF as the analytic framework, participant opinions and experiences were mapped to the relevant domains of the TDF. Specifically, coding began by reading the participant's response in the transcript, considering their relevance to the definitions of the domains and/or the constructs within the domains, and then attributing them to the domain. In cases where information could relate equally to more than one domain, the information was coded to both or all relevant domains, however, efforts were always made to attribute the information to the most relevant domain based on its likelihood to influence the adoption and use of assistive smart home technology.

After coding interview data into theoretical domains, data were further analysed within domains for subthemes. This second stage of analysis followed a more inductive approach. Key belief statements were generated to reflect the subthemes or key messages that emerged within each of the domains. Belief statements captured both cognitive and emotional attitudinal factors since both cognitions and emotions influence technology use (Bagozzi, 2007). They also captured contextual factors at play in participants' attitudes toward technology.

The most relevant or salient theoretical domains arising from the analysis were: those in which key beliefs or subthemes were mentioned by a greater number of participants; where a relatively larger number of subthemes were identified; where beliefs or subthemes were discussed at the greatest length, and/or were judged from audiotape to be discussed passionately by participants.

Results

Of the 14 TDF domains, 8 were identified as influencing intention to adopt and use smart home assistive technologies: Knowledge, Skills, Beliefs about Capabilities, Goals, Beliefs about Consequences, Social Influences, Emotions, and Environmental Context and Resources.

There was wide variation among participants with regard to prior experience (Skills) and knowledge about smart home technologies (Knowledge) (*Table 2*). A small number of older adults were already owners of a voice-activated assistant at home or a Fitbit wearable and talked about how these pieces of technology benefited their lives. Some participants also had some knowledge about the existence and role of sensors in the home. However, many others highlighted their lack of knowledge about the technologies by asking the researcher(s) and other participants about specific details regarding the technologies. There was an expressed desire for information about the cost of technologies, in particular the integrated smart home system. Participants also voiced queries about whether and to what extent: (i) Amazon Alexa could listen in on conversations, and (ii) what happened to the data collected from remote monitoring of peoples' movements and activities in the home by the ambient sensors.

Participants varied in self-efficacy in relation to using smart home technologies (Beliefs about Capabilities), most likely a reflection of the wide variation in previous experience with these types of technologies. However, it was evident from discussions that older adults would welcome training to help familiarise them with the technology and build their confidence. Recounts of past attempts to use everyday technology like mobile phones highlighted that some participants had experienced frustration at (i) user interfaces that they thought were overly complex, and (ii) choice menus that they found difficult to remember how to navigate. A number also expressed the wish for some form of ongoing support from technology providers to help troubleshoot issues with the technology when they arise (*Table 2*).

Participant discussions revealed a number of goals and end-states older adults are striving to achieve, when they use, or think about using, smart home technology (*Table 2*). Analysis of discussions indicated goals such as remaining independent, aging "in place" in one's home, staying physically safe and secure, and keeping active (physically and cognitively). A number of participants used Fitbits or activity monitors on their mobile phones to track their daily steps. There was a belief that doing puzzles and crosswords for example could help one stay cognitively healthy and these mental and physical activities were enjoyed to a large extent. A significant goal of most older adults was maintaining and/or increasing social ties and connections with family, friends, and their community. This goal also appeared to be partly driven by the wish to reduce or prevent loneliness and associated feelings of depression, especially when an older adult lived alone or did not have a family. Another important goal of technology use was to make life easier for themselves. Ideas about how technology could render life more convenient ranged from alerts and prompts for remembering to take medications and appointments, using Alexa to access a phone number quickly, to sensors that would automatically turn off kitchen appliances, and light sensors that would illuminate their path

Table 2. Overview of key quotes mapped on to TDF domains

TDF domains	Quotes
Knowledge	*"The question I would ask on the voice activation piece, and again it goes maybe to a person's cognitive function, does it have to be your own voice? Can somebody else put the reminders in for you? Is that possible with this or it has to be your own voice? Say you weren't able."* [participant from Workshop 2 Group 2]
	"So what happens is that somebody else has access to what this sensor is doing, does a particular person have to be tuned in or have the same system in their house, is that what happens?" [participant from Workshop 2 Group 2]
	"Where does the information go to?" [participant from Workshop 2 Group 1]
	"Some people are very resistant to it and some people weren't brought up like that and they don't know anybody who was using them so it is not so much resistance but they don't understand it." [participant from Workshop 2 Group 4]
Skills	*"But you see, we haven't been reared with the technology."* [participant from Workshop 1 Group 1]
	"If there was somebody who could come to your home and explain how everything is working when you actually have it in situ, that you wouldn't be fumbling with stuff, that would be like a monitor or a teacher who could explain all these things who would come in and you could pay by the hour or whatever to show you everything." [participant from Workshop 2 Group 2]
	"So it is not getting dependent on them before we should be but actually being comfortable with them and capable of using them before we are in need if that makes sense." [participant from Workshop 2 Group 3]
Beliefs about capabilities	*"…and I'm not bad with computers."* [participant from Workshop 2 Group 4]
	"I think a lot of people our age, they are afraid of it." [participant from Workshop 1 Group 1]
	"…when you are talking about it just keep it very simple and basic because people are put off, especially older people if you get too technical explaining things, just keep it very simple…" [participant from Workshop 2 Group 3]
	"I got a new phone last week and when they were explaining to me all the different things you could do on the phone…It was mind-boggling. I didn't understand half of what she was saying and I am not too bad with computers." [participant from Workshop 2 Group 4]
Goals	*"…people want to stay at home, they want to live at home and be in their own environment."* [participant from Workshop 2 Group 2]
	"puzzles would be very good for anybody's mind." [participant from Workshop 1 Group 2]
	"Because if you don't interact you deteriorate." [participant from Workshop 1 Group 1]
	"I started using Google Home to play Spotify and I recommend it to everyone I know because you can play any music you want, I have expanded into pod casts, foreign radio stations. And I am finding it very entertaining….So I think there is huge potential on using something like Spotify to create your own entertainment and enjoy your own type of music without having to be tied to ads or television programmes." [participant from Workshop 2 Group 1]
	"I love that, the sensor, getting out of the bed and the light coming on." [participant from Workshop 1 Group 2]
Beliefs about consequences	**Positive beliefs**
	"I have nothing against nursing homes but I think we all agree we don't want to end up there if we can avoid it and one way to have independent living is to have these things as [name] says for emergencies." [participant from Workshop 2 Group 3]
	"Supposing you fell, you could be lying on the floor and you could say Alexa call 999." [participant from Workshop 2 Group 2]
	"Yes, they would because I think again it takes some responsibility from them and I am assuming it can be alerted to their phone so that they would sleep at night and say well if something goes wrong the phone will ring, I don't have to worry about that" [participant from Workshop 2 Group 4]
	"Just recently we have been having a lot of renovations done in the house and I am checking my list every morning to see who is coming and what time they are coming at and it would have been so much handier to just speak it instead of having to either type it or write it. And then come down in the morning and say, 'what is happening today,' or whatever and get my list for the day. So I would find that very useful." [participant from Workshop 2 Group 1]
	"Something that would remind me in one way or another to get on, get out, get active, yeah that could be a very good thing." [participant from Workshop 2 Group 3]
	"And the same thing with the Fitbit, if I haven't done a lot of steps I am kind of looking at it and thinking maybe I will use that little peddle device for a half an hour while I am watching telly. So they definitely do impact your behaviour, of course they do." [participant from Workshop 2 Group 3]
	"If she has no contact with people and she has Alexa at least she is there for her"…"She (Alex) would be a great help if you were housebound." [participant from Workshop 2 Group 3]
	"Yes absolutely because they can't be around you all the time and they don't want to be around you all the time, you don't want them around all the time. So I think they would be keen to see you keeping your independence but being able to know that you are okay." [participant from Workshop 2 Group 3]
	"Yes they would because I think again it takes some responsibility from them and I am assuming it can be alerted to their phone so that they could sleep at night and say well if something goes wrong the phone will ring, I don't have to worry about that." [participant from Workshop 2 Group 4]

from bed to bathroom at night. Physical comfort was conveyed as a goal, for example, one participant mentioned that she was not able to wear a wrist wearable because of arthritis in her hands. Enjoying oneself emerged as another important goal. Comments illustrated that traditionally non-technological solutions such as crosswords and puzzles are now engaged with on technical platforms like tablets and mobile phones by older adults. In particular, voice-activated assistants were valued for their ability to entertain by providing personalised music choices on demand, without the interruption of advertisements.

In regards to Beliefs about Consequences, participants talked about a range of positive and negative outcome expectancies regarding the proposed smart home system and its components (*Table 2*). Perceived advantages included remembering, encouragement to stay active through reminders from Alexa and the Smart Watch, and also feedback in relation to a number of steps taken in a day. Participants believed it would facilitate social connection and help reduce loneliness; people envisaged asking Alexa to call family members and friends. Negative beliefs about the consequences of adopting the smart home system were that users could end up feeling controlled by the system, and that au-

Table 2. Overview of key quotes mapped on to TDF domains (cont')

TDF domains	Quotes
	Negative beliefs
Beliefs about consequences	*"I think it stops you doing these things for yourself. I am older, I am nearly 80 and I think you can get too dependent on these things and stop doing these things for yourself."* [participant from Workshop 2 Group 3]
	"I am delighted to fit in so much stuff, I like technology and I am very open to it, I like to see it there. But I don't want the system to be in charge of me, I would like me to be in charge of the system." [participant from Workshop 2 Group 4]
	"I just think Alexa is too intrusive and I have sort of security concerns." [participant from Workshop 2 Group 1]
	"They can listen to you on Alexa…Alexa is listening to you talking." [participant from Workshop 1 Group 2]
	"If I may say, at the moment I have dishwashers, cookers, kettles, you name it, microwaves, and they are all beeping. Everything is beeping when they are finished and they drive me mad. If it is not the dishwasher it is the bloody washing machine and that goes on, beep, beep, beep every few minutes. So our lives are completely dominated at the moment by beeps. Things like that, if it was all connected to sensors, if they were going off every five minutes that would drive me mad." [participant from Workshop 2 Group 2]
	"I personally find if it was telling me in the morning, oh your heart rate got to such and such a thing every day that would definitely make me stressed [unclear 01:07:34]. It would make my heart rate go." [participant from Workshop 2 Group 4]
	"Is all this replacing friendship with other people, is it isolating yourself, oh let the computer deal with it or Alexa?" [participant from Workshop 1 Group 2]
Social influence	*"I would just like something that would look nice like a nice piece of jewellery or a bit smaller."* [participant from Workshop 2 Group 3]
	"I hadn't thought about it in terms of an alarm system but something discrete as [name] said, no something like oh look at me with the alarm around my neck. If it was attractive or... I think I would prefer it as a watch, like a smart watch type of stuff." [participant: Workshop 2 Group 1]
	"…and another one is making the devices so they don't stand out in the house, so they are pushed into a corner so that they are not going to be part of the furniture basically, or make them part of the furniture." [participant from Workshop 2 Group 3]
Emotions	*"And it would reduce whatever guilt, because I still think back did I do enough, that kind of thing….So I wouldn't like them to be over burdened with oh we have to be here to look after mum or dad or whatever."* [participant from Workshop 2 Group 4]
	"If anything it would make me a bit more relaxed I think because I would feel that there was a second pair of eyes on me behind myself." [participant from Workshop 2 Group 4]
	"The biggest thing I think when you get older is loneliness and being on your own, and having nobody to talk to." [participant from Workshop 1 Group 1]
	"So for me any dependency, and hopefully not much will come, but if some dependency comes later on I would like that to be as much robotics as possible or technology, and the personal contact still to remain a personal relationship rather than dependency." [participant from Workshop 2 Group 3]
	"I like technology and I am very open to it, I like to see it there. But I don't want the system to be in charge of me. I would like to be in charge of the system." [participant from Workshop 2 Group 4]
	"It gets you up off the chair..it is good for that but I find it a bit, what would I say, not addictive, but it is oppressive at times, you are a kind of slave to it a little bit, have I got the steps done today…But I have to say yes it certainly keeps you motivated." [participant from Workshop 2 Group 2]
	"It may keep you very secure but again back to my point, I think the setting up of it would have to be done in a way that would leave you feeling secure. And I suppose the very opposite of that is it might make you feel very vulnerable if you are not comfortable with it." [participant from Workshop 2 Group 2]
Environmental context and resources	*"I suppose my questions would be is there a cost to it and that would be in terms of people maybe on low income and I suppose the bigger question would be if you are looking to the provision of healthcare to an older person and the whole issue of keeping people independent at home is there any talk in terms of policy making around this technology? Who provides it? Can you get it even through a grant system or whatever?... I am sure there is a cost to it and there is a maintenance fee. Or not, I don't know."* [participant from Workshop 2 Group 2]
	"Well I think cost is going to be a huge one for people who don't have private health care. As it is private health care is very expensive so if they add all this onto it how much will it be if they don't change the way they are doing it. I think cost will be one of the main things for people. I know my mother wouldn't have possibly ever been able to afford anything like that unless they do it like they do with a medical card, that they give it free to some people." [participant from Workshop 2 Group 4]
	"…is there any talk in terms of policy making around this technology? Who provides it? Can you get it even through a grant system or whatever?" [participant from Workshop 2 Group 2]
	"And then sometimes where I live we don't have great WiFi at times and you have to move it around a bit." [participant from Workshop 2 Group 4]
	"We all talk about, at least I talk about changing my bathroom and putting a wet room, a level deck shower in and all that. But I mean this sort of thing is probably part of that conversation." [participant from Workshop 2 Group 2]

tonomy would be undermined by, for instance, Alexa "telling you what to do". Some participants were afraid that Alexa would listen in on conversations, or felt uncomfortable with being monitored constantly by ambient sensors. A few reported that constant reminders or alerts would cause them to feel agitated. Many older adults saw potential health benefits to adopting the system, for example by alerting someone if the individual was unwell, but a small number of older adults expressed a fear that adopting technology with monitoring capabilities would lead them to become overly-focused and anxious about their health. In contrast to older adults who perceived a role for technology in preventing social isolation and loneliness, others anticipated a reduction in person-to-person interaction in daily life if they adopted the smart home system.

Findings relevant to the domain of Social Influences highlighted those interpersonal processes at play that could influence thoughts, feelings, or behaviours about the technology. Participants reported receiving gifts of voice-activated assistants from family members which encouraged people to use the technology. Participants anticipated that the ambient sensor system would be well accepted by their family carers, who would

derive peace of mind from being able to monitor their wellbeing from a distance, and this type of social influence was conveyed as an incentive for considering the adoption of the system. This sentiment was juxtaposed with a strong assertion from some participants that maintaining autonomy and privacy around the home was important and they wouldn't like technology or those monitoring their data to intrude on their autonomy and privacy. Some participants were concerned that families receiving alerts from a smart monitoring system would cause additional worry to them. A notable preference expressed was that wearable or ambient sensor technology would not be immediately obvious to others, suggesting concern for what others would think about them if they knew about them owning the technology. Some participants preferred wearable technology to look like fashionable jewelry. This speaks to another aspect of the construct of self-identity that is more closely related to the concern for looking nice and maintaining a fashionable image in front of others. Finally, smart technology was seen to have an ambiguous impact on older adults' social relationships with others; some participants saw the value in voice-activated assistance for connecting with loved ones and preventing loneliness, while others hoped that ambient sensor technology in particular would not replace traditional care or human contact.

Emotions was another relevant domain as illustrated by the range of feelings and sentiments expressed by the participants. So-called "social" or "self-conscious" emotions like pride in one's appearance (Bagozzi & Dholakia, 2006) emerged as an influence on whether one would use smart wearable technologies. Unattractive aesthetics was inferred as a disincentive to use the technology. Another important disincentive was the possibility that older adults might experience increased health-related anxiety if using the smart wearable for health monitoring. Anxiety also pervaded interviews about potential intrusions on one's privacy in the home, for example, whether a VAA could "listen in" on conversations in the home. Some participants perceived the potential for constant alerts and reminders from technology to agitate them. They expressed clearly that they would be disinclined to use any technology that undermined personal control of their home environment and routine through prompts. By contrast, other participants were excited by perceived emotional benefits such as reassurance and security they anticipated feeling should they adopt an ambient monitoring system. They expressed relief about a prospective alternative to placement in residential care or to becoming a self-perceived burden to loved ones in older age. Acknowledgement that loneliness is often a feature of old age and that technology like a voice-activated assistant can help overcome loneliness by connecting older adults with friends and loved ones were conveyed as a salient incentive to adopt this type of technology. Interest and enthusiasm for the technology was positive emotion commonly expressed by interviewees; for example, interest in the way that voice-activated assistants could provide information, and enthusiasm for the step count feedback provided by the smart wearable.

Subthemes that mapped on to the domain Environmental Context and Resources centred around older adults' beliefs that smart home systems should be affordable to be accessible to all older adults. Some participants had ideas regarding accessibility, including the provision of grants, and the opportunity to try out new technology when given presents by family. However, connectivity issues emerged as an environmental barrier to the use of technology such as Alexa for some participants. Planning other structural changes to the home (e.g. chair in bath, handrails in the bathroom) was indicated by some participants as a good opportunity to adopt the NEX system as a complement to more traditional home modifications and additional support to aging in-place.

Finally, when asked if they could see themselves adopting the assistive smart home technology system, participants reported that they did not intend to adopt the system at present, but they would consider adopting it when older.

Discussion

This paper highlights the usefulness of the TDF for illuminating the wide range of influences on older adults' intentions to use smart home technologies from a psychological and behavioural change perspective. Key domains identified as influencing intention to adopt and use smart home assistive technologies were Knowledge, Skills, Beliefs about Capabilities, Goals, Beliefs about Consequences, Social Influences, Emotions, and Environmental Context and Resources. Smart home technology designers, developers, and promoters should address each of these domains to increase the potential for adoption and use of smart home assistive technology by older adults.

Importantly, to our knowledge, this is the first paper to analyse older adults intentions to adopt and use assistive smart home technology (or indeed any technology) using the TDF. While prior studies identified specific factors or sets of factors that influence technology adoption and acceptance, they did so without a comprehensive, theory-based, conceptual framework (Hubert et al., 2018) to systematically investigate and identify those influences that might play a key role in smart home technology acceptance and adop-

tion decisions. Key advantages of the TDF for analysing older adults' intentions to adopt and use assistive smart home technologies include its comprehensive theoretical coverage and its capacity to elicit a comprehensive set of beliefs (including emotional ones) and other influences according to domains that comprise potential mediators of behaviour change to which behaviour change strategies can be applied. Simplifying and integrating a vast range of behaviour change theories, the framework makes theory more accessible to various disciplines (Francis et al., 2012), thus facilitating more effective interdisciplinary work regarding the design, production, acceptance, and adoption of assistive smart technology by older adults.

Regarding the influence of knowledge, the first TDF domain identified in our study, some participants knew of assistive smart home technologies, particularly of smart wearables (mostly Fitbits) and voice-activated assistants like Alexa. Those participants who already owned and used voice-activated assistants and smart wearables, such as Fitbits, had gained the skills required to operate them, whether through observation of others, instruction, trial, and error, or practice. Skills were closely linked also with beliefs about one's capability to successfully carry out a behaviour (such as the use of technology), a concept that is also referred to as self-efficacy (Bandura, 1977). Interviewee responses aligned to the domain Beliefs about Capabilities highlighted the range of individual beliefs about the capability to use technology. Previous research has shown that self-efficacy, or belief in one's capability to use technology is a crucial factor influencing the adoption and acceptance of technology (Golant, 2017).

The importance of the TDF domain of Goals lies in the fact that technology is used as a means to an end. Indeed, Bagozzi and Dhalokia (1999) suggested conceiving technology use as a process constituted by goal striving. Nonetheless, it is notable that most technology acceptance models neglect to include users' goals or desired end-states as a factor in predicting acceptance or use of technology. If technology does not address the things that are important to older adults, then they are less likely to adopt it or engage with it over time. For example, research has shown that failure to help users reach their goals led to the abandonment of health-tracking devices (Clawson et al., 2015).

The TDF also enabled the delineation of numerous beliefs about the consequences of adopting the technology system beyond perceived usefulness alone (a popular TAM construct). Similar to other studies (Peek et al., 2014) many participants commented about the ways in which they could see how the smart home technology could help them to remain independent as they age in place, for example, by enabling loved ones to monitor their wellbeing from a distance and intervene when necessary. Also similar to other studies (e.g. Yusif et al., 2016), a number of participants also remarked on the risk that they could become reliant and dependent on the system, and stated that they wished to be in control of the system rather than the system being in control of them. Fears that the use of the smart wearable might encourage an obsession with one's health are not a common finding in the literature to date and is an interesting barrier to investigate further. Many also feared that the technology might intrude on their sense of privacy, whether through the experience of being constantly monitored by the ambient sensors or Alexa listening in on their private conversations. Concerns about privacy is a recurrent finding of acceptability studies (Pirzada et al., 2022) and a systematic review of assistive smart technologies cited privacy as the top concern of older adults (34% of the articles examined) (Yusif et al., 2016). Thereby, the assistive smart home technology that promises to enhance the freedom and independence of older adults can be seen by some older adults as paradoxically compromising these same desired end-states. In a similar vein, the technology – primarily through the voice-activated assistant – was perceived as beneficial by some participants for facilitating connection with others, while other participants feared the reduced need for direct caregiving might result in loss of emotionally fulfilling face-to-face interactions with caregivers, similar to findings in Fritz (2015). These apparent paradoxes, which are common to many technologies (Mick &Fournier, 1998; Chae & Yeum, 2010; Wislon-Nash & Tinson, 2021), may lead to a perceived need to engage in trade-offs in important values such as, but not limited to, freedom, independence, and connection in order to avail of increased safety, security or convenience. Potentially, the perception of a required trade-off may cause emotional conflict for consumers, causing them to delay the final decision to purchase or adopt a smart home technology system (e.g. Luce, 1998; Luce, Bettman & Payne, 1997; Luce, Payne & Bettman, 1999; Melenhorst & Bouwhuis, 2004).

Participants believed that family caregivers could benefit from the technology system as it would reduce the burden on them and enable them to coordinate care from a distance while respecting the older adult's autonomy. Importantly, however, there was a desire amongst participants to maintain current ties with caregivers and to reduce caregiving responsibility rather than replace or weaken the social relationship with their family member/caregiver. These findings echo those of other work (Fritz, 2015).

Subthemes pertaining to the domain of Social Influences point to the social aspects of older adults decision-making about technology. Older adults in the study were very aware that the technology system would reduce the potential burden for future family caregivers, and that for this reason, it would appeal to their families, highlighting the strong social influence family is likely to have on older adults' decisions to adopt. Family caregivers are often purchasers of technology for their older relatives, as evidenced by the reports from some of our participants that they were gifted a voice-activated assistant or Fitbit smart watch by a family member.

Another subtheme of Social Influences spoke specifically to the stigmatising effects of assistive types of technology that may lead to the activation of ageist stereotypes such as a perception of being "other", or of poor health or having a disability. Such stereotypes make older adults feel self-conscious about using assistive technology. Identity Theory (Burke & Stets, 2009) would suggest that these ageist stereotypes are often resisted by older adults, who aim to preserve an identity congruent with concepts of independence, competence, and self-reliance (Dionigi, 2015; Nemmers, 2005; Spafford et al., 2010). It is not surprising, then, that participants preferred the technology to be invisible or blend easily into the home environment. Social acceptability and aesthetics have elsewhere been recognised as elements linked to possible stigmatisation with smart technology (Dehghani & Kim, 2019; Li, Lee & Xu, 2020). The literature also reveals the importance to many older adults of looking fashionable, as a means of expressing their personal identity. This means of identity expressiveness has elsewhere been shown to be an important determinant of technology adoption (Thorbjornsen et al., 2007).

Indeed, aesthetic appraisal as a determinant of older adult adoption of smart technology can be considered a type of emotional experience. Emotions influence the manner in which individuals process information and make decisions in a wide range of situations, including technology adoption contexts (Beaudry & Pinsonneault, 2010; Chang et al., 2014). The use of technology can trigger users' emotional responses (Chang et al., 2014; Partala & Saari, 2015) and impact technology adoption decisions (Partala & Saari, 2015). Subthemes relating to the TDF domain of Emotions highlighted the wide range of feelings relating to technology, including those inspired by aesthetic appeal. Besides having the potential to trigger negative feelings like shame or alienation via stigma processes, the aesthetics of a technology product can impact an individual's mood more generally, in turn influencing their cognition and judgements about the technology (Hoegg et al., 2018). Specifically, research has shown that an unattractive design can lower an individual's mood, causing them to be more analytical and heightening their tendency to expect and address problems with technology. By contrast, an aesthetically attractive product design can increase a positive feeling state and may alter the way people process other product attributes, making it more likely that they will overlook weaknesses in the product's functionality (Norman, 2004). Hoegg et al (2018) propose this phenomenon can be partly accounted for by the affect-as-information model which proposes that people, rightly or wrongly, believe their feelings to be relevant to the judgement task (Schwarz & Clore, 1996). Participants anticipated their sense of interest or curiosity could be inspired and satisfied via the use of a voice-activated assistant. This finding supports recent qualitative research by Yang et al., (2019) on affective responses toward conversational agents which found that interest was the most salient emotion experienced by users. The authors linked this emotion to participants' likely appraisal of what they term the conversational agent as a source of novelty-complexity.

Participant anxieties around knowing how to use technology and fears amongst some participants that the technology could make them dependent have been reported elsewhere in the literature (Yusif et al., 2016), and indicate older adults' underlying emotional need for competence. Likewise, fears amongst participants that the technology could threaten their privacy, or interfere with their preferred way of completing activities, echo other studies (e.g. Pirzada et al., 2022) support arguments that technology design should support their emotional need for autonomy. The strong desire to avoid feeling lonely, yet worry that technology could replace human contact, reflects concerns expressed by older adults in previous studies (e.g. Fritz, 2015). These concerns, alongside the excitement participants, conveyed in our study about expanded opportunities for social connection underline how important it is for technology to support older adults' emotional needs for relatedness. It is interesting to note to this end that some authors call for work on enhancing the human-like qualities of voice-activated assistants (e.g. Yang et al, 2019). Such enhancement could increase the perception amongst older adult users that the voice-activated assistant is a companion (Corbett et al., 2021; Kim & Choudhury, 2021; Pradhan et al., 2020), thereby helping to fulfill a sense of relatedness and to reduce social isolation. These three needs of competence, autonomy, and relatedness have been identified as central to the motivation, personal development, and psychological wellbeing of humans according to Self-Determination Theory (SDT; e.g. Deci & Ryan, 2008)

and are directly linked to technology acceptance and adoption by older adults (e.g. Dupuy et al., 2016). Highly compatible with these arguments, Socioemotional Selectivity Theory (Carstensen et al., 2003), which accounts for why most older adults would prioritise goals relating to deriving emotional meaningfulness over other goals, would arguably predict that older adults would adopt and use technology that enhances present experiences, social relationships and facilitates positive mood states (van der Groot et al., 2019).

The domain of environmental context and resources on the adoption and use of smart home technologies highlighted participant concerns about cost and access, as well as the need for Wi-Fi or Broadband connectivity. Technology must be affordable to be accessible, not only for older adults but also for family carers, since family carers may be the first to perceive the older adult's need for this technology in the home. The anticipated cost of smart technology and the way in which financial resources differ amongst older adults can influence the real-life opportunities for older adults to adopt the system. Older adults who are less wealthy are less likely to purchase new technology devices and may be more inclined to discount the value of new technology because of its costs (Czaja et al., 2006).

Recommended strategies

As part of a concerted awareness campaign, strategies for increasing knowledge and understanding of these technologies should include providing information about the positive preventive health consequences of adopting assistive smart home technology. This should involve details regarding the detection of meaningful change in the older adult's behaviour patterns, information on who will be alerted to, and interpret this change, and what potential actions can or will be taken to facilitate the older adult's wellbeing and independence. Accessible, jargon-free language should be an essential part of any such campaign as well as opportunities for real-life observation, perhaps via pop-up or mobile "home labs" held in locations like shopping centres and social clubs frequented by older adults. Creating opportunities for observing and learning about the technology is important for the uptake and eventual diffusion of the technology (Rogers, 2003).

Instruction and guidance are well-established drivers of technology adoption in older adults (Kononova et al., 2019). Thus, the release of smart technology applications to older adult consumers should always be accompanied by a programme of training in its use. Evidence-based change strategies such as providing instructions on how to use the technology, demonstrating how to use the technology (providing vicarious experience), facilitating guided practice with feedback, and organising any technology use training so that tasks are graded from least difficult to more difficult (enabling the acquisition of mastery experiences), should facilitate older adults' beliefs in their capabilities to use technology (Bandura, 1977). Where the situation allows, in-person training should ensure that older adult users receive positive feedback in the form of verbal persuasion about their capability (telling the individual that they can successfully perform the wanted behaviour, arguing against self-doubts, and asserting that they can and will succeed).

From a design perspective, reducing the complexity of technology user interfaces is another crucial strategy for protecting users' beliefs about their capabilities to engage with technology.

The promotion of assistive smart home technology should emphasise that the technology does not have to replace human care, but can certainly enhance and complement care, for example by providing timely, contextually-appropriate information to caregivers about changes to the older adult's daily activities or established routines.

Perceived threats to privacy and concerns about autonomy and security should be addressed in design protocols, and informational materials for older adults and caregivers. Older adults and caregivers should be included in decisions about privacy controls, data sharing protocols, and options for personalisation of technology features.

Autonomy can be supported if scheduled reminders and alerts from the technology are programmed in a flexible way that accommodates, rather than interferes with the user's and individualised routines, and if privacy protocols are transparent and agreed upon in advance with the user. Autonomy will also be supported if, for example, a prompting approach similar to that espoused by Dupuy et al., (2016) that does not pre-empt users' actions, is configured into the technology.

Smart technology for older adults should address and reflect the way older adults view themselves and should verify their desired identity. One way that technology developers could achieve this type of identity verification, in tandem with mitigating stigma processes, is by offering customisation of the technology (e.g. Jacobson, 2014). Since group norms are powerful influences on individual perceptions and behaviour, the diffusion of assistive smart home technology in older adult households is also essential for its normalisation (e.g. Diaz-Orueta et al., 2020) and for assuaging stigma. Important strategies for enhancing the appeal of assistive smart home technology to the general public involve follow-

ing the principles of inclusive design and "design for social acceptance" (Shinahora & Wobbrock, 2011) that prioritise the social contexts in which the technology is used, and making smart technology "fashionable" and aesthetically pleasing.

Facilitation (Kok et al., 2016) is an effective environmental-level strategy that can increase access to technology. Accessibility can be facilitated by others; some participants spoke about the opportunity to try out new technology when given presents by family and others. Participants also had ideas about how technology could be more accessible, including the provision of financial grants. Facilitated access can still be hindered by a lack of reliable access to Wi-Fi and Broadband. Events, such as structural home modifications to prepare for aging-in-place, present an opportunity to introduce assistive smart home technology.

Personalisation of the technology, based on an adequate needs assessment of the user is a design strategy crucial for ensuring the technology meets their expectations and helps, rather than hinders, their day-to-day goal attainment.

Conclusion

Understanding the range of influences on older adults' intentions to adopt assistive smart home technology is important to assist with its successful introduction so that independent living can be facilitated and optimised (e.g. Vaportzis, Clausen & Gow, 2017). In this study, the TDF helped to highlight a range of psychological influences that appear to drive intentions to use an assistive smart home technology solution by older adults. Participant comments were mapped onto the relevant TDF domains, highlighting features in the technologies under examination that lend themselves to a number of recommended strategies for the design and marketing of these technologies with the aim of increasing their perceived benefit and eventual adoption by older adults. While the TDF framework aims to be comprehensive, it may not be exhaustive, since many influences have been identified (or are yet to be identified) in the literature that could be at play in different contexts. This provides useful grounds for future research aimed at refining or further developing the framework to improve its coverage and applicability.

Funding

This research was funded through the Government of Ireland Disruptive Technologies Innovation Fund (Nex DT2018-0258).

Acknowledgements

We would like to acknowledge the generous payment of the APC by the School of Psychology, Dublin City University, Ireland. We also thank the editor and two anonymous reviewers for their helpful feedback and suggestions regarding the improvement of the paper.

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