Measuring Older People's Attitudes Towards Personal Robots

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Abstract: Robotic technologies are increasingly an important form of technology to support older people. It is important to have easy ways of measuring their attitudes to the kinds of robots which might support them. A study was conducted with 249 older people in the UK who viewed videos of three different types of robots (abstract, pet and humanoid) and rated their attitudes to each using an adaptation of the Almere model questionnaire. Analysis of the Almere Questionnaire revealed three underlying components to attitudes to the personal robots: Positive User Experience; Anxiety and Negative Usability; and Social Presence. There were significant differences between the three personal robots in older people's attitudes to them, with the pet robot having the most positive attitudes. These results are a set towards creating simple methods for developing a clear understanding of older people's attitudes to personal robots which may be useful in helping them choose appropriate robots to support themselves. The results make a contribution to understanding the attitudes of older people in the UK to three types of personal robot that they may find useful and companionable.

1 INTRODUCTION

It is well known that the world's population is ageing, particularly in more developed parts of the world. The United Nations (UN, 2022) estimates that in 2020 there approximately 6% of the world population was aged 65 or over (a widely used, if rather coarse, criterion for "older people"). By 2050 it is estimated that number will increase to approximately 16.0% of the population, nearly a three-fold increase in percentage terms. However, what is perhaps more important than the raw numbers or percentages of older people, is the Potential Support Ratio (PSR). This is the ratio of the number of people of working age (i.e. those who produce most of the wealth and value in a society and who are also available as the main carers for older people who need support) to the number of older people. Europe currently has a PSR of approximately four younger people for each older person, although many European countries have a PSR of less than three younger people to each older person, and Japan has the lowest ratio in the world at just over two younger people to each older person (UN, 2019).

Digital technologies are often seen as a major part of the solution to this problem (Petrie & Darzentas, 2020), with the concept of ambient/active assisted living (AAL) emerging as early as the 1970s (Monekosso et al., 2015) to describe "the use of information and communication technologies in people's daily living and working environment to enable them to stay active longer, remain socially connected, and live independently into old age" (AAL Association, n.d.). This also aligns with the "aging in place" concept (Mynatt et al., 2000), as most older people wish to live independently in their own homes for as long as possible. Since the COVID-19 pandemic and the resulting social isolation measures, there is a particular relevance and motivation to understand the technological support that can be provided to older people and find solutions to combat lowering PSR ratios globally.

There has been extensive research and development of robotic technologies. An important part of this research is assistance provided by robotic technologies to provide care and support for older people. These can range from physical care such as encouraging activity (e.g., El Kamali et al., 2018) or

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intelligent mobility aids (e.g., López Recio et al., 2013) to more social care such as mediating communication and providing companionship (Feil-Siefer & Matarić, 2011).

Robots to support older people can come in many shapes and sizes ranging from abstract robots such as Afobot (Fig. 1A) to pet robots such as Miro (Fig. 1B). and humanoid robots such as Sanbot (see Fig. 1C). With the range of functionalities and types available, robots may be perceived as intimidating (Frennert, 2020), not useful for general day-to-day care (Samaddar & Petrie, 2020), or not designed with the needs of older people in mind (Eftring & Frennert, 2016). Care needs to be taken in the development of robot technologies for older people to ensure that they are acceptable to the varied target audience of older people. Therefore, it is important to have instruments to easily measure older people's attitudes to robot technologies.

Some research has been undertaken to measure older people's attitudes to robots. A widely used measure is the Almere model (Heerink et al., 2010) which provides a questionnaire which measures the attitudes to "assistive social agents" by older people. This was developed from the theoretical constructs of the Technology Acceptance Model (TAM) developed in the 1980s about technology in general (Davis, 1989) and was tested with Dutch older people mainly using one small pet robot, the iCat. Other measures have also been developed to measure attitudes to robots by users of any age (Bartneck et al; 2009; Nomura et al, 2008; Smarr et al, 2012). All these measures are now over a decade old, and the components of attitudes to robots may have changed in that time, as there has been much more exposure to robotic technology.

The aim of this research is to extend the work of Heerink and colleagues in order to develop a more up-to-date questionnaire to easily measure the attitudes of older people to robots. We developed this questionnaire by asking older people to react to a range of different types that might support them: abstract, pet and humanoid robots. We worked with a large sample of UK older people, to complement the Dutch participants who participated in the development of the Almere questionnaire. We investigated whether the theoretical constructs of the TAM model were appropriate in this situation. This is a first step towards a more robust questionnaire for measuring older people's attitudes to the robotic technologies which might be developed to support them.

2 RELATED WORK

2.1 Terminology for Robots for Older People

Thus far we have used the term "robot" to refer to any robotic technology to support older people. There is no universally accepted or preferred term for the wide range of robotic technologies being developed in this area. The term "robot" has been used as an umbrella term, with a description of the functionality preceding the basic word, often "social robot" or "assistive robot". Petrie et al. (2018) found there were nearly 30 terms used in relation to robot technologies for older people. While they suggested a classification of robots, both physical and virtual, we propose a more general term to refer to the technologies discussed in this paper: "personal robot". This term allows us to refer to all the different types of robots and robot-like devices now available, while not focusing particularly on their type or use. In addition, we feel this term provides a less stigmatizing term than "assistive robot" and a more accessible term for a general audience not familiar with the nuances and differences between terms such as robot, agent, social agent etc.

2.2 Personal Robots for Older People

Research on personal robots for older people has mostly focused on three areas of care: physical healthcare, supporting declining cognitive capabilities, and social interaction and companionship. Healthcare is by far the most researched and developed area with robots used in a variety of ways: to help with physical tasks (Hebesberger et al., 2016), health monitoring (Rosales et al., 2017), smart walkers (Sinn & Poupart, 2011), and fall detection (Mundher & Zhong, 2014).

To support and aid with cognitive decline and provide coaching in this area there are robots that have been designed to act as coaches for both physical and cognitive tasks. One example is a robot that provides mental games and tasks for a user to do and tailors the games to suit the user's level of cognitive ability (Agrigoroaie & Tapus, 2016). Other robots combine both entertainment and cognitive stimulation by providing games such as bingo (Li et al., 2016) or a card matching memory game (Khosla & Chu, 2013). Lastly, there is an abundance of research into pet robots and other robots that provide a means of social interaction and which aim to combat loneliness for older people. Pet robots provide companionship like a real pet but are sometimes more suited for older people who may not be capable of taking care of a real pet's needs. The most well-known is probably Paro (Wada & Shibata, 2007), a small, furry baby seal robot that reacts to touch. Paro has had a significant positive influence on older people's lives at care homes. Following this innovation, there has been much research into pet robots including other animals as diverse as koalas, penguins, and dogs (Lazar et al., 2016).

2.3 Measuring Older People's Attitudes to Personal Robots

Heerink et al. (2008, 2009, 2010) investigated the attitudes to "assistive social agents" by older people, and developed the Almere model and questionnaire. The Almere questionnaire includes 41 items divided into 12 different constructs derived from TAM (see Table 1). Different parts of the model were validated in four experiments with older people and several social robots. We argue that while the model and results are strong, the model was created on the theoretical model of the TAM rather than empirical work with older people and therefore would benefit from further validation with data from a large sample of older people, as it is not clear that these constructs are both sufficient and necessary. In addition, there have been many studies that have adapted the Almere model, selecting only specific constructs that apply, to measure or predict acceptance. For example, removing the social constructs if the robot's core functionality is not social in nature (e.g., Karunarathne et al., 2019). But taking always small parts of a questionnaire can be a threat to the validity of the instrument. These points all provide motivation to extend Heerink et al's work to see if a more general model can be developed for understanding older people's attitudes towards personal robots.

In this paper we will build on the work by Heerink and colleagues on their Almere model by investigating the reactions of a large sample of older people in the UK with three types of personal robots. This will allow us to investigate the underlying structure of their attitudes to personal robots based directly on their data. It should also allow us to conduct a preliminary investigation of similarities and differences between their attitudes to the three different types of personal robots used in the study: abstract, pet and humanoid. We will investigate two research questions:

RQ1: Are the Almere model constructs appropriate to describe UK older people's attitudes to three types of personal robots?

RQ2: How do attitudes to the three robots differ on the most appropriate set of constructs?

Table 1: Almere model constructs (source: Heerink et al., 2010).

Construct	Definition
Anxiety	Evoking anxious or emotional reactions when using the system
Attitude	Positive or negative feelings about the appliance of the technology
Facilitating Conditions	Objective factors in the environment that facilitate using the system
Intention to Use	The outspoken intention to use the system over a longer period of time
Perceived Adaptability	The perceived ability of the system to be adaptive to the changing needs of the user
Perceived Enjoyment	Feelings of joy or pleasure associated by the user with the use of the system
Perceived Ease of Use	The degree to which the user believes that using the system would be free of effort
Perceived Sociability	The perceived ability of the system to perform sociable behaviour
Perceived Usefulness	The degree to which a person believes that using the system would enhance his or her daily activities
Social Influence	The user's perception of how people who are important to him/her think about him/her using the system
Social Presence	The experience of sensing a social entity when interacting with the system
Trust	The belief that the system performs with personal integrity and reliability

3 METHOD

3.1 Design

A within-participants online study was conducted. To investigate older adults' initial understanding of the idea of a "personal robot", participants were initially asked to describe what the term meant to them in an open-ended question. To assess older people's attitudes to personal robots, participants watched one-minute videos of three robot types (abstract: Afobot; pet: MiRo; humanoid: Sanbot; see Figure 1), each video contained several examples of the robot type

A B C

Figure 1: The three personal robots (A: Afobot; B: MiRo; C: Sanbot).

and a range of functions they could perform to assist older people to live independently at home. A large sample of participants was required for the validation planned, so it was not possible to have each participant actually interact with each robot. In addition, this research was conducted at the end of the coronavirus pandemic, when there was a possibility that social isolation regulations might be re-imposed which would prohibit in-person research, particularly with older participants.

After each video participants were asked two attention check questions to make sure they had watched the video (these asked for factual information about the video) and then completed a set of questions based on the Almere questionnaire. The order of presentation of the three videos and the order of the items within the questionnaire were counterbalanced to avoid practice and fatigue effects.

Ethical approval for the study was given by the Physical Sciences Ethics Committee of the University of York.

3.2 Participants

Inclusion criteria were to be 60 years or older, to be living in the United Kingdom and living independently (rather than in sheltered accommodation or a care facility). Participants were recruited via announcements of a variety of channels: a local community website, the University of York news bulletin and Slack channel, and the Prolific research participant website (prolific.co). Participants recruited via Prolific were offered GBP 2.00 (approximately USD 2.47, 2.28 euros) for their time, for the other participants, the researchers paid GBP 2.00 to the Disasters Emergency Committee (dec.co.uk) to support work with people in Afghanistan and the Ukraine.

261 people were recruited and completed the online study. However, 12 (4.6%) participants answered more than half the attention check questions incorrectly, so their data was removed, leaving 249 participants.

Demographic information about the participants is summarized in Table 2. 153 (61.4%) participants were in their 60s, 89 (35.7%) were in their 70s and 7 (2.8%) were in their 80s. There was a good gender balance and a good range of educational backgrounds. Participants were asked their current or last occupation and there was a wide range from builder and bus driver to IT project manager and biomedical scientist.

Table 2: Demographic information for the participants.

Age	Range: 60 - 87 years
	Median: 68 years
Gender	Women: 134 (53.8%)
	Men: 115 (46.2%)
	Other 0 (0.0%)
Education	High School: 107 (43.0%)
	Bachelor degree: 75 (30.1%)
	Higher degree: 33 (13.3%)
	Professional qualification: 34 (13.7%)
Employment	Full-time/Self Employed: 25 (10.0%)
	Part-time/Self Employed: 31 (12.4%)
	Retired: 193 (77.5%)

Participants were asked to rate their confidence with computers and with using the Internet on 7-point Likert items (not at all confident = 1 to very confident = 7). The median rating for confidence with computers was 6.0 (semi-interquartile rating (SIQR): 0.5), which was significantly above the midpoint of the scale (Wilcoxon one sample signed rank test T = 11.16, p < .001). The median rating for confidence with the Internet was also 6.0 (SIQR: 0.05), also significantly above the midpoint of the scale (Wilcoxon T = 13.17, p < .001).

Participants were asked whether they had any experience of personal robots, 39 (15.7%) reported that they had. The most frequently mentioned type was robotic vacuum cleaners (mentioned by 32 participants); virtual assistants (e.g., Alexa, Siri) were mentioned as robots by 9 participants; robotic lawn mowers (4 participants); industrial/manufacturing robots (2 participants); information robots at airports, robotic mops, robotic swimming pool cleaners, robotic turtles for education were all mentioned by one participant each.

3.3 Materials

The online study was deployed using the Qualtrics online survey tool (www.qualtrics.com). The study comprised three sections:
1. Information page, informed consent
2. Robot videos and Almere Questionnaire
3. Demographic information and thanks.

1. Information page, informed consent: the study opened with an information screen about what would be involved in participating in the study, information about confidentiality and anonymity and how to withdraw from the study if wished. An informed consent form then followed.

2. Videos of personal robots and Almere Questionnaire

Participants were shown three videos of different types of personal robot (abstract, pet and humanoid, those illustrated in Figure 1), each video was approximately one minute long (videos available from the authors). Each video comprised publicly available footage of the robot and showed a number of functions typical of that robot. To orient the participants, each video was preceded by a short text introduction to the robot type. These introductions were all approximately 75 words long and with the same amount of information (see Table 3).

Each video was followed by two multiple choice attention check questions which asked for specific concrete details of the video content, to enable us to check that participants had watched the video carefully. Participants then completed a 39 item questionnaire adapted from the Almere questionnaire (Heerink et al., 2010). Our questionnaire was two items shorter than the original Almere questionnaire (which comprised 42 items), as the original questionnaire included three statements about intention to use the robot in the next few days. As this was not a possibility for participants in this study, these statements were replaced by one statement "I would use the [name] robot if offered one".

The questionnaire consisted of 39 statements about the robot on a 7-point rating scale from Strongly Disagree (coded as 1) to Strongly Agree (coded as 7). Heerink and colleagues asked older people to rate these statements after they had interacted with a robot for a short period of time (e.g., I think the [name] robot is useful to me), whereas in this study participants had only seen the robot in the video, so the formulation of the statements was changed to the hypothetical form (e.g., I think the [name] robot would be useful to me). This resulted in only minor changes to the wording of the statements in the Almere questionnaire.

3. Demographic information and thanks
Participants were asked demographic questions and thanked for their participation in the study.

Table 3: Text introductions to the three personal robot videos.

Afobot is a tabletop personal robot. It has a screen that will rotate towards you when you speak to it and will understand your voice commands (like Alexa and Siri). It can assist in a range of activities of daily life such as reminding you of appointments or taking your medicines. It can quickly connect you to your family and friends via voice or video calls and can take and send photos for you.
MiRo is a pet-like personal robot. It can move around independently, but will also be attracted by human movement and sounds. You can train it to respond to particular actions like clapping your hands as you might a pet. It also responds to being stroked by moving its head, ears, and tail and changing colour. It also makes animal-like sounds. It can show different emotions with these features and goes to "sleep" automatically to recharge itself.
Sanbot is a human-like personal robot with a head and arms and a screen. It can move around independently and can recognise different people using face recognition. It will also understand voice commands. It can assist in a range of activities of daily life such as reminding you of appointments or taking your medicines. It can quickly connect you to your family and friends via voice or video calls and monitor your health by linking with a smartwatch.

4 RESULTS

To investigate RQ1(Are the Almere model constructs appropriate to describe older people's attitudes to three types of personal robots?), we first investigated whether the rating for each of the attitude statements within each Almere construct were consistent with each other. Cronbach's alpha, a measure of internal consistency, was calculated for each construct, but separately for each robot type. A Cronbach's alpha of at least 0.80 is considered adequate consistency for this kind of data (Nunnally & Bernstein, 1994).

Table 4 presents the Cronbach's alpha results for the 11 Almere constructs we measured with more than one statement (as noted above, Intention to Use was measured by only one statement). It is interesting that the consistency measure is very similar across the three robots for most of the constructs; only on Perceived Ease of Use and Social Presence was it very different. However, a number of the constructs failed to reach an adequate level of consistency for any of the three robots: Facilitating Conditions, Perceived Adaptability, and Perceived Ease of Use. Social Influence and Social Presence failed to reach consistency for MiRo, and Anxiety just failed to reach consistency for both Afobot and MiRo. Only on six of the 11 constructs was consistency reached for all three robots (we will include Anxiety as consistent, as this was marginal). Thus, the statements in the Almere questionnaire, for these participants and these robots, do not always provide consistent measures of the constructs they are designed to measure.

Therefore, to investigate whether there is an alternative to the Almere constructs, that is a statistically reliable set of underlying meaningful constructs in older participants' attitudes to the personal robots, a Principal Components Analysis (PCA) was conducted on the Almere Questionnaire responses, again for each personal robot separately (see Table 5).

For Afobot and Sanbot, three componennts [3] produced the most appropriate solutions (in terms of proportion of variance accounted for and semantic grouping of items): for Afobot 62.1% of the variance in responses was accounted for, and for Sanbot 64.7%. These are very adequate proportions of the variance accounted for.

[3] We will use component to refer to the results of the PCA to avoid confusion with the theoretically derived constructs in the Almere questionnaire.

Table 4: Cronbach's alpha for each of the Almere model constructs for each personal robot.

	Afobot	MiRo	Sanbot
Anxiety	0.79	0.79	0.81
Attitude	0.91	0.91	0.91
Facilitating Conditions	0.75	0.70	0.75
Perceived Adaptability	0.59	0.62	0.53
Perceived Enjoyment	0.92	0.94	0.94
Perceived Ease of Use	0.60	0.33	0.75
Perceived Sociability	0.88	0.87	0.88
Perceived Usefulness	0.89	0.90	0.92
Social Influence	0.80	0.77	0.82
Social Presence	0.86	0.63	0.90
Trust	0.91	0.90	0.90

The three components can be summarized as:

Positive User Experience (PUX): includes the usefulness and adaptability of the robot, as well as the pleasure of interacting with the robot.

Anxiety and Negative Usability (AnxNegU): includes anxieties about knowing how to interact with the robot, and usability issues, but in a negative sense (i.e. that it would be difficult to learn to use and the person would need help)

Social Presence (SocPres): the sense that the robot is a living, sentient being.

For MiRo, two components produced the most appropriate solution, accounting for 56.4% of the variance. However, the components were very similar to those of the other two robots, the difference being that the SocPres items grouped with the PUX items rather than creating a separate component.

Thus, there are meaningful groupings of the attitudes statements, based on the participants own ratings, which are meaningful and create a simpler model for studying attitudes to personal robots for older people than the complex set of contstructs proposed by TAM.

Table 5: Components extracted from PCAs on responses to Almere Questionnaire for each personal robot.

	Afobot	MiRo	Sanbot
Positive User Experience (PUX)			
I think it would be a good idea to use the [X] robot	x	x	x
The [X] robot would make life more interesting	x	x	x
It would be good to make use of the [X] robot	x	x	x
I would use the [X] robot if offered one	x	x	x
I think the [X] robot would be adaptive to what I need	x	x	x
I think the [X] robot would only do what I need at that particular moment	x	x	x
I think the [X] robot would help me when I considered it to be necessary	x	x	x
I would enjoy the [X] robot talking to me	x	x	x
I would enjoy doing things with the [X] robot	x	x	x
I would find the [X] robot enjoyable	x	x	x
I would find the [X] robot fascinating	x	x	x
I would find the [X] robot boring [reversed]	x	x	x
I would think the [X] robot would be nice	x	x	x
I think the [X] robot would be useful to me	x	x	x
It would be convenient for me to have the [X] robot	x	x	x
I think the [X] robot would help me with many things	x	x	x
I think my family and friends would like me using the [X] robot	x	x	x
I think it would give a good impression if I were to use the [X] robot	x	x	x
I would find the [X] robot pleasant to interact with	x	x	
When interacting with the [X] robot I would feel like I'm talking to a real being		x	
It would feel as if the [X] robot is really looking at me		x	
I could imagine the [X] robot to be a living creature		x	
I would think the [X] robot is a real being		x	
The [X] robot would seem to have real feelings		x	
I would consider the [X] robot a pleasant conversational partner		x	
I would feel the [X] robot would understand me		x	
Anxiety-Negative Usability (Anx-NegU)			
If I were to use the [X] robot, I would be afraid to make mistakes with it	x	x	x
If I were to use the [X] robot, I would be afraid to break something	x	x	x
I would find the [X] robot intimidating	x	x	
I have everything I would need to use the [X] robot (R)	x	x	x
I know enough about the [X] robot to be able to make good use of it (R)	x		
I think I would know quickly how to use the [X] robot (R)	x	x	x
I would find the [X] robot easy to use (R)	x	x	x
I think I would be able to use the [X] robot without any help (R)	x	x	x
Social Presence (SocPres)			
When interacting with the [X] robot I would feel like I'm talking to a real being	x		x
I could imagine the [X] robot to be a living creature	x		x
I would think the [X] robot is a real being	x		x
The [X] robot would seem to have real feelings	x		x

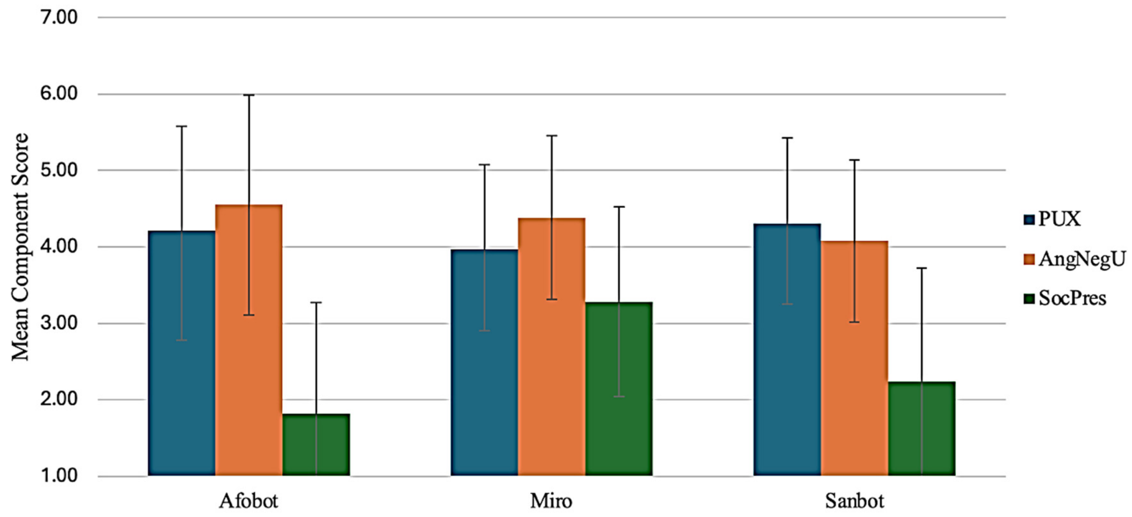

Figure 2: New Almere-derived component scores for the three personal robots.

Table 6: Summary of repeated measures ANOVA on the new components for the three robots.

Source	F value	df	p value	Effect size (ηp²)
Robot type	39.15	1.99, 492.70	< 0.001	0.136
Almere component	317.35	1.68, 415.75	< 0.001	0.561
Robot x Almere	189.06	3.78, 937.15	< 0.001	0.433

To investigate RQ2 (How do attitudes to the three robots differ on the most appropriate set of constructs?), participants' scores on the proposed three component structure of the Almere items was calculated for all three robots (although this was not the best solution for MiRo, the three component model was used for this robot to allow comparison with the other two) with the AnxNegU component ratings reversed, so that a high rating always indicates a positive attitude (in the case of AnxNegU, not being anxious or knowing how to interact with the robot). Fig. 2 illustrates the mean component ratings.

A repeated measures analysis of variance (ANOVA) was then conducted on the component ratings for the three robots. The results are summarized in Table 6. Overall, there was a significant difference with a large effect size between the three robots. MiRo had the most positive ratings, post hoc analysis showed this was significantly higher than either Afobot or Sanbot which did not differ significantly from each other. There was also a significant difference between the three components. PUX and AnxNegU had significantly higher ratings than SocPres. There was also a significant interaction between robot and component. As can be seen from Fig. 2, this was largely caused by SocPres being much higher for MiRo than the other two robots.

5 DISCUSSION AND CONCLUSIONS

This study investigated how to measure the attitudes of older people to a range of personal robots, using a large sample of older people in the UK and three different personal robot types. The study had the dual aims of moving towards a robust measure for measuring such attitudes and conducting a preliminary investigation into the attitudes of older people to three different types of personal robots. The research built on and extended the work by Heerink and colleagues on their Almere model.

The first analysis investigated whether the constructs in the Almere model, which were derived theoretically from the TAM model of technology acceptance (Davis, 1989) would show internal consistency with a large UK sample of older people, given that Heerink and colleagues had worked with older people in the Netherlands. Heerink et al. (2008, 2009, 2010) themselves note the need for testing with larger samples of participants and participants in difference circumstances.

Six of the 11 constructs showed adequate consistency of items and consistency across three different types of personal robots, which was encouraging . However, there were constructs which showed low consistency (Facilitating Conditions, Perceived Adaptability, Perceived Ease of Use, marginally Anxiety) or inconsistent results (Perceived Ease of Use, Social Presence). Some of these issues may have been due to differences between the particular robots and the robot types, although one would hope for consistency of items across a range of robots.

Therefore, a series of PCAs were conducted on the ratings to investigate whether there was a more meaningful set of underlying components. These analyses showed very similar grouping of attitude ratings for two of the personal robots, Afobot and Sanbot. Only one group of ratings, related to social presence, were different for MiRo. MiRo is an animal-like robot (its developers deliberately based MiRo's design on a number of small mammals kittens, dogs, rabbits, to make a "generic mammalian" form, Collins et al., 2015), whereas Afobot and Sanbot have more human-like qualities, which may account for this difference. Although Afobot does not look very human-like, it speaks in a human way. Therefore, we propose that all three components (Positive User Experience, Anxiety/Negative Usability, and Social Presence) may be useful high level components of attitudes to personal robots which can be helpful in studying robotic technologies to support older people. Further research and psychometric development of a scale (DeVellis, 2003) incorporating these components is needed, using different robots within each type, particularly to tease out the role social presence as a separate component in pet robots such as MiRo.

An analysis with the new sets of components, to investigate differences in the attitudes of the UK sample of older people towards the three personal robots. There were highly significant differences between the robots overall and on all three components. Of particular interest was the fact that MiRo received the most positive ratings, due to significantly higher social presence ratings (an interesting point, given the issues of how social presence grouped with other attitudes for MiRo). This was not surprising, as MiRo was explicitly designed to interact with the user at an emotional level and to have numerous characteristics of a pet animal. Thus, the attitude components do clearly discriminate between these three different personal robots of three different types.

The research has several important limitations that require discussion. Firstly, participants only viewed videos of the personal robots and did not interact with them face-to-face. This has several consequences. Participants did not get a chance to explore the robot's behaviour themselves and its reactions to their own behaviour. This may be particularly important of issues of perceived adaptability, which would have been hard to judge from just watching a video. In addition, as we wanted to keep the videos short in an online study which included a lot of ratings and questions for the participants, so each video only included one example of each robot type. This had both advantages and disadvantages. It meant that the participants were reacting to a specific personal robot, so the ratings are not a combination of reactions to potentially slightly different robots within one type. However, they only represent one example of that robot type and further research is vital on each robot type and between robot types to understand commonalities and differences (a point also made by Heerink et al., 2008, 2009). Finally, although we tried very hard to make the videos comparable and show a range of situations and functions for each personal robot, we used publicly available videos, so the three videos were not a tightly controlled set and this may have introduced differences we are not completely aware of.

Another limitation was that the study was conducted online, rather than face-to-face, which would have enabled us to recruit a more diverse sample of older people. However, the study required data from a large number of participants for the analyses we wished to conduct, and we did not have the resources or stamina to undertake face-to-face sessions with nearly 250 older people. In addition, as the study was conducted towards the end of the COVID-19 pandemic, we were also very concerned that if we planned for face-to-face sessions, another social distancing situation might arise and we would not be able to proceed with the study. Finally, we were concerned that older people might be reluctant to participate in face-to-face sessions because of the risk of COVID-19 infection. However, we chose the three personal robots in the study because we do have each of these robots in our laboratories. We are planning smaller scale follow-up studies in which older people will actually interact with the robots. This will allow us to compare the attitudes developed from watching videos to the attitudes developed from live interaction. An investigation of such differences will be of interest in itself, as in the future older people may well choose a personal robot from watching a video on television or the Internet, rather than being able to interact with it live.

A final limitation is that the sample of older people was an opportunistic one. As the study was conducted online and required people to be able to access the questionnaire software and watch videos embedded in the questionnaire, this may mean the sample is biased towards participants more proficient and comfortable with technology. Certainly, the fact that participants rated themselves as significantly above the midpoint of the scale on confidence with computers and the Internet suggests this. We used the Prolific participant recruitment website, which also requires a certain confidence with the internet and interest in new technology, but we also made considerable efforts to recruit older participants through other routes as well, in order to create a more heterogeneous sample. The wide range of occupations of participants showed that they were quite a diverse range of British society. However, they were also relatively young older people – the majority were in their 60s, so this is definitely a study about the attitudes of "young old" UK people to personal robots.

In conclusion, this study has made a contribution towards developing a questionnaire to easier measure older people's attitudes to personal robots. It has extended the work on the Almere model with a large sample of older people in the UK, showing an underlying grouping of attitudes to personal robots which may be useful in future work. Given that it is highly likely that older people will increasingly be using personal robots to support themselves in the future, having simple methods for developing a clear understanding of their attitudes to such technology is very important. The study has also made a initial contribution to understanding the attitudes of older people in the UK to three types of personal robot that they may find useful and companionable in the near future.

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