The contribution of people's attitudes and perceptions to the acceptance of eldercare robots

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Abstract

The number of people aged over 65 years is increasing worldwide, and this is placing increased demand on healthcare services. Engineers have proposed that eldercare robots may be able to meet the increasing healthcare needs of the aging population; however eldercare robots have not yet been widely adopted. Reasons for this are likely multifaceted, but one reason may be insufficient attention to the psychological aspects of the human robot interaction (HRI) in eldercare.

Technology acceptance models indicate that people's perceptions of technology attributes (particularly perceived usefulness) predict technology acceptance more strongly than more objective design parameters. However, little research to date has investigated the importance of perceptions to the acceptance of eldercare robots. The central thesis of this PhD is that older people's perceptions will influence their acceptance of healthcare robots. Specifically, three main perceptions are studied - older people's perceptions of their own unmet needs, their attitudes towards robots in general, and their perceptions of the robot's mind. It is proposed that more positive attitudes and perceptions of robots will predict better acceptance of healthcare robots.

This thesis contains four peer reviewed publications. One is a discussion paper on the importance of assessing the unmet needs of eldercare stakeholders in order to develop more useful and acceptable robots. Three publications present the results of three different Human Robot Interaction (HRI) trials conducted with prototype healthcare robots. All three studies employed autonomous service-type robots and older participants, and two of the three HRI trials were conducted within real-world eldercare environments.

The key findings of the HRI studies were that people's perceptions of robots and 'robot mind' predicted robot acceptance. In all three studies, participants' 'pre-interaction' generic robot attitudes predicted acceptance of specific robots. This suggests that even people who have never used robots before can hold mental models of robots that influence robot acceptance. Additionally, people's robot attitudes improved after interacting with the robot, and these changes also predicted robot acceptance. This suggests that a positive HRI is important for robot acceptance. Compared with people who perceived robots as possessing more mind, people who perceived robots as having less mind were more likely to use a robot. Furthermore, despite robot-users perceiving less robot-mind at baseline, they perceived the robot to have even less mind after interacting with it. While this result suggests that people may hold unrealistically high perceptions of a robot's mind which may be a barrier to acceptance, it also suggests that these perceptions are revised downwards after actually experiencing a robot's capabilities.

In conclusion, older people's perceptions and attitudes towards robots do predict eldercare robot acceptance. Future implications of this work are that building robots that meet the specific unmet needs of older people and paying more attention to users' perceptions of robots may increase the acceptance of eldercare robots. Future research should investigate whether interventions designed to promote realistic and adaptive perceptions of robots in older people can increase the acceptance of eldercare robots.

Dedication in Memoriam

‘They broke the mould’.

This thesis is dedicated to my remarkable grandmother, Pauline Stafford, who died during my PhD candidature (b.1920:d.2009).

Communist. Feminist. Munitions manufacturer. Bomb dodger. Activist. Teacher. Artist. Musician. Traveller. Sailor. Fluent in English, French, and Italian - and apparently your German was pretty gut. Wife. Mother. Grandmother. Friend of many. Lover of history, people, literature, Shakespeare. Fascinated by……everything. Including robots. Eventually.

From robot sceptic to robot champion. Always a champion of education, you emotionally supported me in my PhD and although initially resistant, you quickly embraced the idea of healthcare robots for older people. And it turns out you bullied your friends into embracing the idea also.

The reactions of your friends were very revealing when I had to inform them that you’d died. When they figured out which granddaughter I was, they invariably exclaimed, “Oh, you’re the one with the robots!” They told me you would get quite cross when they couldn’t immediately see the *myriad* benefits of having a robot of one’s own. Apparently you had forgotten that your first response upon learning my PhD topic was on eldercare robots was - “Oh no, I wouldn’t want one of those”.

I miss you.

Also to my favourite aunt, Bridget Stafford (b.1952: d. 2013). You lost your cruel war with motor neurone disease in the last year of my PhD. I watched two grandparents die of cancer. Motor neurone is worse. Over two years you suffered the indignity and frustration and terror and grief of slowly becoming a paraplegic and losing your speech. Food, which was once such a pleasure, became an exhausting chore. Now accompanied with the threat of choking. Until you got the stomach plug. Then we would feed you through a tube. Sometimes you wanted to eat some soft food just so you have the feel and flavour of food in your mouth again. The frustration and exhaustion of trying to make yourself understood as your speech deteriorated. The fear that something would go wrong and you wouldn’t be able to communicate that to us. The complete and total loss of privacy and independence – of having to ask other people to do every little thing for you; to brush your teeth, to give you a sip of water, to adjust your glasses on your nose, to toilet you. Simply going to the toilet involved two other people and an electric hoist.

However you won many daily battles against the disease with your smile and love of people, plants and life. You were the perfect aunt with the biggest heart. You helped me in times of need, which I felt privileged to be able to reciprocate in a small way, and you were always interested in, and supportive of my studies. As you became increasingly disabled, you thought a healthcare robot that would reduce your dependence on other people couldn't come soon enough.

I miss you also.

And also, sadly, Dan Wegner, a co-author on the third paper in this thesis; 'Does the robot have a mind? Mind perception and attitudes towards robots predict use of an eldercare robot'. By all accounts, like my Aunt Bridget, you endured a motor neurone condition with great fortitude. I never met you, but would have loved to. Your sense of humour was legendary, and your work was far from restricted to making people *not* think about white bears. Your research umbrella also covered transactive memory, action identification, illusions of conscious will, as well as your work on mind perception which features in this thesis. Sincere condolences to your family, friends, and colleagues.

Acknowledgements

My PhD thesis tried to kill me. Several times over.

I'm glad I didn't know this at the beginning as I wouldn't have missed this adventure for the world.

I would like to express particular gratitude to …

…….my long-suffering supervisors; Dr Liz Broadbent and Dr Bruce MacDonald

thank you

I'm grateful to have had you both as my supervisors. Particular thanks to Liz, who, as my primary supervisor, has borne the brunt of…um….me.

Liz - with your support and collaboration - I think I've learned more about myself on this doctoral journey than I have about robots. (And I've learned quite a bit about robots.)

And to…….

……. the University of Auckland and Healthbots/Uniservices for the scholarships which have facilitated my work. I am conscious of the privilege of having had the opportunity to meet remarkable people, remarkable robots, and have remarkable travel. My scholarship funded travels have taken me to conferences in Romania, Italy, China, and robot lab visits in Australia and Singapore. There are so many highlights, but one that is right up there is drinking cocktails under the midnight stars on an Italian beach, discussing robot ergonomics with a United Nations of robotocists.

……the rest of the Healthbots team; it's been a privilege working with you in the retirement village trenches. Special thanks to 'my' engineers; Chandimal, Tony, Xingyan, Abdelaziz, and Chandan. It was sometimes frustrating, often fun, and always fascinating. My understanding of other disciplines, and how they interact, has been immensely broadened. Also grateful thanks to the Healthbots academic staff; in particular, Catherine Watson, Karen Day, Kathy Peri, and Ngaire Kerse, for illuminating conversations, occasional forbearance, and multi-faceted support.

…………the person who stocked the 007 PhD office with so many lovely, fun, and fascinating people; Jo, Debbie, Lisa, Jordan, Francesca, Margot, Natalie, Jade, Fiona, Arden, Puspa, Rebekah, and my special PhD buddies Kate and Mathijs. The support and wisdom of people a few offices over; Karolina, Terry, Heidi, and HoD Sally Merry, has also been greatly appreciated

…………the power brokers aka secretaries; Ngere and Ranjeeni. You give me life essentials - food and jokes.

………the residents at Selwyn Village. Particularly; Tom Pallas, Noel Tubman, Heather Astill, Nola Harris, Joe Craven, Mary Collins, Roberta Whelan, Pat and Rev Jenny Blood, Bruce and Edna Lovett – and Charlie the robot's favourite – Anne. Apologies to the many wonderful people I've missed out. Your input and support was critical and greatly appreciated. Thank you for allowing the Healthbots team (especially the robots!) to intrude into your homes and lives.

……the amazing staff at Selwyn Village. Especially at Kerridge Rest Home; Claudia the entertainment officer, Penny the nurse, and the wonderful caregivers. Despite being so busy, the caregivers always took….well, good care of us, and ensured we were perma-fuelled with tea and biscuits.

…..the robots. In particular Cafero; in his various personas as Selwynie in the first HRI trial (even though I can no longer bear to listen to Für Elise; an overly popular song choice in 'his' entertainment module) and Charlie in the third HRI trial.

…..my father, Ben. You have supported me in very practical ways; teaching me how to build adventure playgrounds (aka cages) for my pet rats, and getting me to change a dozen Range Rover tyres in the Papua New Guinea jungle. The latter skills helped me win a crate of beer in a tyre-changing competition. Strangely, the guys I beat in the competition failed to cheer up even when I gave them the crate of beer. Nasty tasting stuff, beer. I hope some of these problem solving skills you taught me are evident in this PhD thesis. I still don't like beer. I am thinking of getting another pet rat..

…….. and to my people: Andrew, David, Jane, Kumeshni, Lynda, Lucy, Marcia, Meg, Nick, and last but so not least, Tara. *Possibly* I could have achieved what I have without your love and support. It is not a hypothesis I would ever care to test.

Finally, this work would not have been possible without the joint support of the R&D program of the Korea Ministry of Knowledge and Economy (MKE) and Korea Evaluation Institute of Industrial Technology (KEIT) [KI001836: Development of Mediated Interface Technology for HRI], the New Zealand Ministry of Business, Innovation and Employment (MBIE), and the former New Zealand Ministry for Science and Innovation (13635). I thank the Electronics and Telecommunications Research Institute (ETRI) for their valuable contributions and help with the research. I would also like to thank Yujin Robot for their technical support and our colleagues from the University of Auckland Healthbots research team for their on-going support.

Publications of the PhD candidate

Lead author publications

As the PhD candidate's four thesis publications are referred to frequently in the preambles, segues, and discussion of this thesis, shorthand titles are provided for ease of comprehension. These are provided in bold italics under the full references. The PhD candidate's lead author publications are listed below in the order in which they appear in this thesis.

Stafford, R. Q., Broadbent, E., Jayawardena, C., Unger, U., Kuo, I. H., Igic, A., Wong, R., Kerse, N., Watson, C., MacDonald, B. A. (2010). *Improved robot attitudes and emotions at a retirement home after meeting a robot.* Paper presented at the RO-MAN 2010 International Symposium on Robots and Human Interaction, Viareggio, Italy. pp. 82-87.

DOI: http://dx.doi.org/10.1109/ROMAN.2010.5598679

Shorthand title used throughout this thesis: ***Improved attitudes study***

Stafford, R. Q., MacDonald, B. A., Li, X., & Broadbent, E. (2014). Older people's prior robot attitudes influence evaluations of a conversational robot. *International Journal of Social Robotics*, 1-17.

DOI: http://dx.doi.org/10.1007/s12369-013-0224-9

Shorthand title: ***Prior attitudes & drawings study***

Stafford, R. Q., MacDonald, B. A., Jayawardena, C., Wegner, D. M., & Broadbent, E. (2013). Does the robot have a mind? Mind perception and attitudes towards robots predict use of an eldercare robot*. International Journal of Social Robotics*, 1-16.

DOI: http://dx.doi.org/10.1007/s12369-013-0186-y

Shorthand title: ***Robot mind study***

Stafford, R. Q., MacDonald, B. A., & Broadbent, E. (2012). *Identifying specific reasons behind unmet needs may inform more specific eldercare robot design*. Paper presented at the 4th International Conference on Social Robotics ICSR, China. pp. 148-157.

DOI: http://dx.doi.org/10.1007/978-3-642-34103-8_15

Shorthand title: ***Unmet needs paper***

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Please indicate the chapter/section/pages of this thesis that are extracted from a co-authored work and the title and publication details or details of submission of the co-authored work.

Thesis sections:	
Publication :	Stafford, R., Broadbent, E., Jayawardena, C., Unger, U., Kuo, I. H., Igic, A., Wong, R., Kerse, N., Watson, C. I., MacDonald, B. M. (2010). *Improved robot attitudes and emotions at a retirement home after meeting a robot.* Paper presented at the RO-MAN 2010 International Symposium on Robots and Human Interaction, Viareggio, Italy.\
Nature of contribution by PhD candidate	Assisted in designing trial, measures, and ethics application; assisted with usability of human-robot interface; recruited participants; conducted trial; analysed results; wrote paper
Extent of contribution by PhD candidate (%)	80

CO-AUTHORS

Name	Nature of Contribution
Elizabeth Broadbent	contributed to trial design, data analysis and paper writing
Chandimal Jayawardena	Contributed to robot programming and paper editing.
Uli Unger	DEVELOP FACES & SOFTWARE FOR ROBOT.
Tony Kuo (Kuo I H)	Written the software with others, help running the trial, revised the paper
Aleksandar Igic	Voice Production
Richie Wong	Help with software
Ngaire Kerse	Contributed to trial design, participant and [illegible] recruitment, [illegible]
Catherine Watson	Voice Production
Bruce MacDonald	[illegible] Robot content, Editing.

Certification continued on next page............

PhD Candidate	Rebecca Stafford
Publication ;	Stafford, R., Broadbent, E., Jayawardena, C., Unger, U., Kuo, I. H., Iglo, A., Wong, R., Kerse, N., Watson, C. L., MacDonald, B. A. (2010). *Improved robot attitudes and emotions at a retirement home after meeting a robot.* Paper presented at the RO-MAN 2010 International Symposium on Robots and Human Interaction, Viareggio, Italy.\

Certification by Co-Authors

The undersigned hereby certify that:

- the above statement correctly reflects the nature and extent of the PhD candidate's contribution to this work, and the nature of the contribution of each of the co-authors; and
- the PhD candidate was the lead author of the work and wrote the text.

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Stafford, R. Q., MacDonald, B. A., Li, X., & Broadbent, E. (2013). Older People's Prior Robot Attitudes Influence Evaluations of a Conversational Robot. *Journal of Social Robotics*[01/08/2013 In submission- accepted with minor revisions]

Nature of contribution by PhD candidate	Study design, measure construction and compliation, ethics application, recruitment, design software robot faces, conduct manipulation checks of robot faces, conduct main HRI study - including administration of 'pen and paper' and physiological measures, data entry and analyses, write paper.
Extent of contribution by PhD candidate (%)	80%

CO-AUTHORS

Name	Nature of Contribution
Bruce MacDonald	contributed to study design and paper writing
Xingyan Li	Develop software robot faces, integrating robot hardware and software, set up robot for experiment, technical support during trial.
Elizabeth Broadbent	contributed to study design, analysis and paper writing

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- the PhD candidate was the lead author of the work and wrote the text.

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Journal publication
Stafford RQ, MacDonald BA, Jaywardena C, Wegner DM, Broadbent E (2013) Does the robot have a mind? Mind perception and attitudes towards robots predict use of an eldercare robot. International Journal of Social Robotics

Nature of contribution by PhD candidate	Study design, recruit participants, conduct trial including demonstrating and assisting participants interact with the robot, administration of measures, data collection, entry and analyses, write paper.
Extent of contribution by PhD candidate (%)	80

CO-AUTHORS

Name	Nature of Contribution
Bruce MacDonald	Gaining study funding, study design, editing paper
Chandimal Jayawardena	Programming robot, robot problem solving, editing paper.
Dan Wegner	Study design, editing paper
Elizabeth Broadbent	Gaining study funding, study design, data analyses, editing paper

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Nature of contribution by PhD candidate	Concept, write paper
Extent of contribution by PhD candidate (%)	80

CO-AUTHORS

Name	Nature of Contribution
Elizabeth Broadbent	Edit paper
Bruce MacDonald	Edit paper

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Co-author publications

Broadbent, E., Jayawardena, C., Kerse, N., Stafford, R. Q., & MacDonald, B. A. (2011). *Human-Robot Interaction research to improve quality of life in elder care - An approach and issues*. Paper presented at the Workshops at the Twenty-Fifth AAAI Conference on Artificial Intelligence.

Broadbent, E., Kumar, V., Li, X., Sollers, J., Stafford, R.Q., MacDonald, B.A., & Wegner, D. M. (2013). Robots with display screens: A robot with a more humanlike face display is perceived to have more mind and a better personality. *PLoS ONE, 8,* e72589.

Broadbent, E., Kuo, I. H., Lee, Y. I., Rabindran, J., Kerse, N., Stafford, R., & MacDonald, B. A. (2010). Attitudes and reactions to a healthcare robot. *Telemedicine and e-Health, 16,* 608-613.

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Igic, A., Watson, C. I., Stafford, R., Broadbent, E., Jayawardena, C., & MacDonald, B. (2010) Perception of synthetic speech with emotion modelling delivered through a robot platform: an initial investigation with older listeners. Paper presented at the 7th Australasian Language Technology Association Workshop, Sydney, Australia.

Jayawardena, C., Kuo, I., Datta, C., Stafford, R. Q., Broadbent, E., & MacDonald, B. A. (2012). *Design, implementation and field tests of a socially assistive robot for the elderly: HealthBot version 2.* Paper presented at the 4th IEEE RAS & EMBS International Conference on Biomedical Robotics and Biomechatronics (BioRob). pp. 5990-5995.

Jayawardena, C., Kuo, I. H., Unger, U., Igic, A., Wong, R., Watson, C. I., Stafford, R. Q., Broadbent, E., Tiwari, P., Warren, J. (2010). *Deployment of a service robot to help older people*. Paper presented at the IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS). pp. 5990-5995.

Kuo, I. H., Jayawardena, C., Broadbent, E., Stafford, R. Q., & MacDonald, B. A. (2012). *HRI evaluation of a healthcare service robot. In Social Robotics* (pp.178-187). Springer Berlin Heidelberg.

Kuo, I.-H., Rabindran, J. M., Broadbent, E., Lee, Y. I., Kerse, N., Stafford, R. Q., & MacDonald, B. A. (2009). *Age and gender factors in user acceptance of healthcare robots.* Paper presented at the 18th IEEE International Symposium on Robot and Human Interactive Communication, RO-MAN 2009.

The Healthbots project: Contributions of the PhD candidate

The results of this PhD are very much a team effort: the Healthbots team.

Healthbots is a joint research project between UniServices, the commercial branch of the University of Auckland, and the Electronic and Telecommunications Research Institute in Korea (ETRI).

The aim of the Healthbots project is to combine ETRI's Robot expertise with the University of Auckland's research capabilities; while partnering with Korean and New Zealand Companies. The research objective is to evolve the healthcare available for older people by custom designed robotic technology. Applications are being designed to help with repetitive tasks such as vital sign monitoring, dispensing of medications, and fall detection. These objectives are being achieved by research into the areas of health informatics, speech generation, vital signs monitoring, robots in organizations, medication management support, psychological factors, wireless propagation, indicators to falls in older people, and integration.

The multi-disciplinary Healthbots team consists of over 20 researchers; bringing expertise from a range of disciplines including electrical and computer engineering, health psychology, gerontology, speech production, health informatics, and computer science.

The PhD candidate's role within this complex collaborative project could be broadly divided into two areas: designing, conducting and analysing Human Robot Interaction (HRI) trials, and assisting the engineers develop the robot software.

The PhD candidate made a variety of contributions to the three HRI studies described in this thesis. These included collaborating with other Healthbots members, reviewing the literature, trial design, measure selection/creation, participant recruitment, pilot testing, liaising with retirement village staff, conduction of trials, administration of measures, collecting, entering and analysing data, and writing publications. Note, while the PhD candidate played a key role in these project events, important input was provided by other Healthbots team members.

The PhD candidates' views and ideas about eldercare robots were informed in assisting the engineers develop the robot software. This assistance took the form of analysis of software requirements, developing the storyboards, robot script development, implementations of the software, and 'elder-friendly' usability testing – including continuity and error checking.

Of all the robot's healthcare modules, the PhD candidate was particularly involved in the development of the robot's entertainment module. In addition to the work described above, creating the robot's entertainment modules involved reviewing the literature, consultation with older people on their entertainment preferences, collation of entertainment material, and pilot testing to assess entertainment value and acceptability of the material.

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Acronyms

ECM-IT - Expectation-Continuation Model of Information Technology use

HCI – Human Computer Interaction

HRI – Human Robot Interaction

IT – Information Technology

NARS – Negative Attitudes towards Robots Scale

RAS – Robot Attitudes Scale

TAM – Technology Acceptance Model

UTAUT – Unified Theory of Acceptance & Use of Technology

Prologue

Conversation between the PhD candidate and a rest home resident

Location: Kerridge Rest Home, Selwyn Village, Auckland, New Zealand.

Year: 2012

PhD candidate: Can I ask why you don't want to use the robot?

Rest home resident: It's too much effort to learn how to use it

PhD candidate: But it's quite easy to use. I'll show you how

Rest home resident: But it doesn't do anything that's of use to me

PhD candidate: So you don't see it being worth your time and energy learning how to use the robot, as you don't see it as being of any use to you - is that right?

Rest home resident: Yes

PhD candidate: So what would the robot need to do, for you to go to the effort of learning how to use it?

Rest home resident: (pause)....................your robot would need to spring-clean my brain before I could answer that question

It is 2013…….

There seems to be something significant about the year 2013 - at least from an HRI perspective. Microsoft's Bill Gates is often (mis)quoted as saying there will be a robot in every home by 2013. In his Scientific American article titled "A robot in every home" (Gates, 2006), Gates cites the plan of the South Korean Ministry of Information and Communication to have a robot in every [South Korean] home by 2013.

In his 2006 article, Gates stated that although it is impossible to tell exactly how robots of the future will be employed, possibilities include physical assistance and even companionship for the elderly. He describes a futuristic scenario of an office worker who remotely controls a network of household robots from his computer. Via his networked P.C., the office worker monitors his home security, delegates domestic chores, and even supervises the care of his bedridden mother. Regarding robot appearance, Gates thought it was unlikely future robots would look like the humanoid C3PO of Star Wars fame; rather that they would be so specialised and ubiquitous that they would not even be referred to as robots.

Gates was not the only technology expert to look ahead to 2013. In 1988 The Los Angeles Times hired more than 30 futurists and technical experts to collaborate on describing a day in the life of a family 25 years hence – in 2013 (Yorkin, 1988). In the futuristic family scenario, 11 year old Zach has 'Max' – a robo-pet smarter than the family dog. Max taught Zach to read and now helps him with his homework. However the robo-star of the family is 'Billy Rae'- a US$5,000 four foot tall domestic robot. After some early teething problems, such as serving the family cat-food for breakfast, Billy Rae is now an irreplaceable part of the family's lives.

The engineers and academics that collaborated on the futuristic article were confident mobile domestic robots would be established in homes by 2013. Beham Bavarian, then assistant professor and director of the UC Irvine Robotics Research Lab, proposed these domestic robots would be doing everyday chores such as cooking and cleaning. Robot capabilities would include speech generation and perception. Bavarian projected that robots “could look like anything from R2D2 from Star Wars, to a cylindrical thing with two arms and light sensors” (Yorkin, 1988, p. 18).

The experts’ confidence about the state of 2013 robotics appears derived from optimistic extrapolations from the (then) current state of robotic science. Robotic projects already underway in 1988 included a fully autonomous robot destined for Mars, a robotic prison guard, a horse robot, a companion robot for frail older citizens, and a robot nurse that could talk, monitor a patient’s condition, and call for assistance. The technology experts proposed robots would be the next technology item made for households after the PC.

It is now 2013 and eldercare robots are not widespread. We do have *some* robots. We have surgical robots Zeus and Da Vinci (Pott, Scharf, & Schwarz, 2005), robotic vacuum cleaners (Hornyak, 2012), and robots are commonplace in industry (Gates, 2006; Shibata & Wada, 2010) and the military (Sparrow, 2007). NASA’s robot, Explorer, has exceeded its expected life span on Mars and is now entering its 10th year (Webster, 2013). But eldercare robots are far from commonplace. The seal robot Paro makes an effective eldercare companion (Robinson, MacDonald, Kerse, & Broadbent, 2013) and has sold a promising 1,500 units (Shibata & Wada, 2010), but this is a negligible proportion of potential demand.

These predictions of a 2013 eldercare robot utopia appear partly driven by an assumption that mainstream robot production will be enabled by technology progress, anticipated labour shortages, and the increasing costs of maintaining aging populations. However, not only are eldercare robots not commonplace, but these assumptions of the necessity and desirability of robotic care for older people are not universally accepted. Some people find the idea of robots looking after older people unacceptable on some levels (Flandorfer, 2012; Neven, 2011; Sharkey & Sharkey, 2011; Sparrow & Sparrow, 2006; Turkle, 2012).

This thesis examines the assumptions of the necessity of eldercare robots, as well as the reasons why they are not commonplace as anticipated by some. Methods of increasing the acceptance of eldercare robots are considered, including an overview of research on theoretical models of technology acceptance. Little research has been done on psychological aspects related to eldercare robots in this regard. The thesis presents three studies and a review on psychological aspects of robot acceptance in eldercare.

Chapter 1. Eldercare robots - Are they necessary, useful, or even wanted?

As this thesis explores psychological determinants of eldercare robot acceptability, the first task is to define some key terms. ‘Acceptability’ in an eldercare robot context has been defined as the robot being willingly incorporated into the older person’s life (Broadbent, Stafford, & MacDonald, 2009). The next key term to define is ‘robot’. The definitions below, from both popular and scientific sources, show the variety of conceptual understandings of the agents known as robots.

Etymology: robot

From Czech robot, from robots (“drudgery, servitude”). Coined in the 1921 science fiction play R.U.R. (Rossum’s Universal Robots) by Karel Čapek and taken into the English translation without change (Wicktionary, 2013)

robot (plural robots)

n **1** a machine programmed to perform specific tasks in a human manner, esp. one with a human shape. **2** a person of machine-like efficiency (Collins Paperback Dictionary, 2003, p. 713)

The physical manifestation of a system in our physical and social space (Duffy, 2003, p. 177)

1 a machine that looks like a human being and performs various complex acts (as walking or talking) of a human being; also: a similar but fictional machine whose lack of capacity for human emotions is often emphasized. **2** an efficient insensitive person who functions automatically. **3** a device that automatically performs complicated, often repetitive, tasks. **4** a mechanism guided by automatic controls (Merriam Webster Dictionary, 2013, online)

1 A machine built to carry out some complex task or group of tasks, especially one which can be programmed. **2** (*chiefly science fiction*) An intelligent mechanical being designed to look like a human or other creature, and usually made from metal. **3** (*figuratively*) A person who does not seem to have any emotions. **4** A style of dance popular in disco whereby the dancer impersonates the movement of a robot (Wicktionary, 2013, online)

A very powerful computer with equally powerful software housed in a mobile body and able to act rationally on its perception of the world around it (Ichbiah, 2005, p. 9)

Chapter outline

The first section of this chapter, **1.1**, explores if eldercare robots are actually necessary. Trends in the aging population are examined, as are gaps in eldercare. Section **1.2** assesses if robots are sufficiently useful to address eldercare resource gaps. The next section **1.3**, questions whether, regardless of whether robots can usefully bridge the gap, do people want them to? An extension of this question examines what eldercare stakeholders want, and do not want, in a robot and robot functions. The last section, **1.4**, looks at possible reasons eldercare robots are not as commonplace as predicted.

1.1. Are eldercare robots necessary?

A clinical psychologist with a distinguished Human-Robot Interaction (HRI) pedigree[1], Professor Sherry Turkle from MIT, observes that it is standard for presentations about the necessity of eldercare robots to begin with a United Nations slide on global population aging (Figure 1). This slide is used to illustrate the inability of the dwindling proportion of younger people to care for the growing proportion of older people.

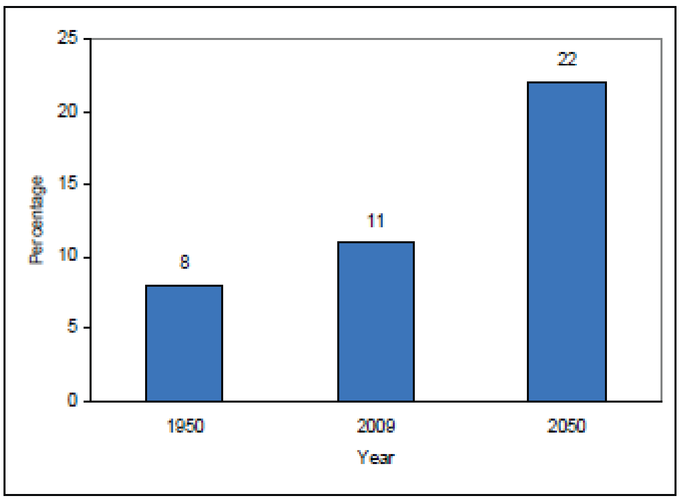

Figure 1. Proportion of population aged 60 or over: world, 1950-2050 (United Nations,2010)

Turkle (2012) believes these slides dramatise the impact of the aging population[2], but she does not question the slides' contents. Turkle questions the leap from the slides' contents to the inevitability of

---

[1] Sherry Turkle witnessed the inception of the ELIZA psychotherapy software programme. Professor Turkle has also worked with Cynthia Breazeal's socially interactive robot Kismet, and conducted eldercare HRI studies with companion robots; the seal-like Paro and the lifelike My Real Baby.

[2] Indeed, in their survey of the economic costs of population aging, (Denton & Spencer, 2000) concluded the effects of population aging are predictable, slow, and some time off. Further, old age dependency ratios are based on the simplistic assumption that all people aged 15 - 64 are in the work force and all people aged 65+ are not.

robots caring for older people. The assumption is that eldercare resource gaps arise from the inability of decreasing numbers of younger people to care for increasing numbers of older people. However the internationally rising unemployment rates (Allen & Wearden, 2013) suggest eldercare personnel gaps arise more from a lack of funding to train and pay for caregivers, rather than insufficient numbers of younger people per se. This argument is further undermined by the fact that sometimes older people get insufficient care for reasons other than insufficient numbers of carers. In some cases there *are* sufficient eldercare resources, but the needs of older people go unmet due to inadequate access to, and distribution of these resources (e.g. Horrocks, Somerset, Stoddart, & Peters, 2004).

Population trends

Examining the trends and issues of the aging population may shed further light on this argument.

A global portrait of an aging population

The current global population aging is a result of declines in both mortality and fertility. In almost all developed countries the fertility rate is below replacement level. In less developed countries the fertility decline started later than in developed countries, but has since declined at a faster rate. In all regions people are increasingly likely to survive until older ages, and, once there, they tend to live longer than previously (United Nations, 2010). Despite regional differences, the old-age dependency ratio is increasing globally (Figure 2). Internationally, fewer younger people are supporting more older people, and at an increasing rate. Implications include higher taxes and other demands on the working population (those in the economically active ages of 15-64) in order to maintain a stable flow of benefits to the older group (typically aged 65 plus).

The fertility decline has meant a corresponding sharp decline in the proportion of dependent-young (the number of children in a population under the age of 15 years, per 100 people aged 15-64 years). However, as supporting the dependent-old generally costs more than supporting the dependent-young (United Nations, 2010), cost savings from reduced youth dependency may not be sufficient to offset the increase in costs of old age dependency. However, another demographic shift, the increasing disability-free life expectancies (how many years of life are spent in good health) may help offset the relative cost of old-age dependency (Sanderson & Scherbov, 2010).

Other trends associated with global aging include more family caring for aging parents, a gender imbalance, and elder under-employment. Increasing numbers of young-old adult children (64-74 years) are caring for one or more oldest-old (85+) family member. The aging gender imbalance is reflected in older women outnumbering older men in most countries. This imbalance is particularly marked in the oldest-old population. Elder under-employment is increasing as labour force participation amongst older people is declining worldwide. Although this is usually a sign of higher levels of social security coverage, lower elder-employment also results from a shortage of employment opportunities, discrimination against older workers and job seekers (Bendick Jr, Brown, & Wall, 1999) and obsolete skills and knowledge. As unemployment is associated with adverse health outcomes (Jin, Shah, & Svoboda, 1995; Price, Choi, & Vinokur, 2002) this may be a future eldercare issue.

Successfully meeting the challenges of unprecedented global aging will allow all people to age with dignity and security, and continue to participate in their societies with full rights (United Nations, 2010). Amongst other solutions, this means more eldercare facilities and services are required. Public eldercare facilities are most common in developed countries, but they are becoming more common in less developed countries (United Nations, 2010). And while the *rate* of aging increase is predicted to decelerate after 2035, Lutz, Sanderson, and Scherbov (2008) suggest there is still a need for institutional adjustments to cope with the unprecedented global aging.

A New Zealand portrait of an aging population

The New Zealand statistics department provides snapshots of the lives of older New Zealanders based on national census results and other surveys (Statistics New Zealand, 2013). New Zealand's population profile reflects the international trend for decreasing mortality and fertility. The old age dependency ratio increased gradually from 14 older people per 100 working age people in the mid-1960s, to 20 per 100 in 2011. The ratio is projected to increase to 36–39 older people per 100 younger people in 2026, and 39–51 per 100 in 2061. This demographic transition also means that older people are getting older. The biggest change is found in the old-old group (85+ years). In 1996 this group made up 4.8% of the total elderly population, in 2051 this group is projected to make up 22.3% of the elderly population; bringing the number of people aged 85+ to 255,000 people.

The global gender imbalance in older people is also reflected in New Zealand. The gap is narrowing slightly but the female dominance is particularly marked in the old-old group. The 2051 gender projections for the 85+ group are 162 women for every 100 men. While both men and women are tending to live longer; in 1996 an average 65 year old man and woman could expect to live another 15.4 and 19.0 years respectively – a 3.6 year advantage to women.

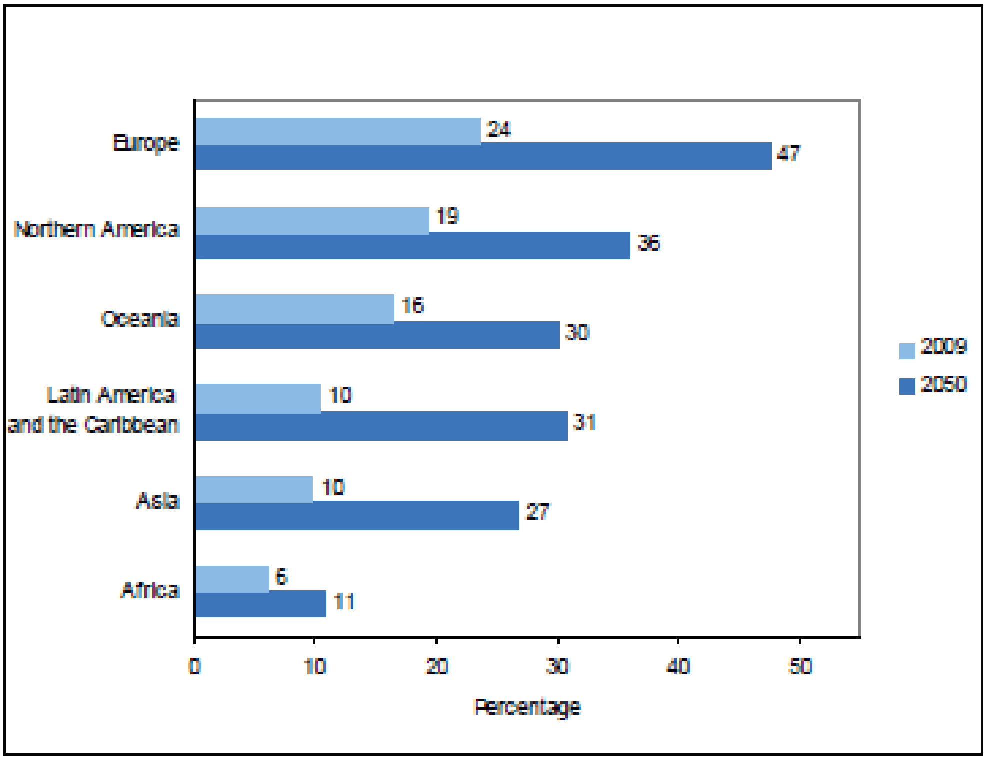

Figure 2. Old-age dependency ratios (the number of people aged 65+ for every 100 people of working age, 15-64) in major areas in 2009, and the projected ratios for 2050 (United Nations, 2010)

The place of origin of older New Zealanders is changing. In 1996 almost a quarter of older respondents indicated they had not been born in New Zealand. The most common place of origin for these people was the United Kingdom or Ireland. In contrast, in the younger generations, fewer people come from this region and more come from the Pacific Islands and Asia. Consequently there will be a shift in the cultural and ethnic profile of New Zealand older people as younger people become older.

In 2001 a quarter of New Zealand's older population lived in Auckland (115,000) followed by Canterbury (66,500), and Wellington (46,900). Because Auckland's population is over a million; although 26% of older people live there, they only account for 1 in 10 Auckland people. In other areas with smaller general populations, a smaller proportion of older people than in Auckland can make a dramatic difference to a region's age profile. An increasing trend is that, compared with younger people, older people are more likely to live in urban rather than rural areas. Living in urban areas typically allows better access to eldercare services.

New Zealanders of today are dying of different health conditions than they did 50 years ago. Better control of health risks such as respiratory tuberculosis, anaemia, and hypertension, means people are now unlikely to die young from these conditions. Now people are more likely to die of cancer, heart disease and cirrhosis of the liver - conditions more prevalent in old people (Prosser, 1998).

However, a disturbing cause of death in older people is the high rates of suicide. The latest report from New Zealand's Chief Coroner states that men over the age of 85 have the highest rates of suicide of the entire New Zealand population (Anderson, 2013). With a view to preventing suicide in older people, an investigation is underway to better understand the reasons behind these disproportionately high rates. However, preliminary research indicates that, over and above depression, social isolation is the biggest predictor of older men killing themselves (Tolley, 2013).

The main New Zealand census does not cover disability details; however, the household disability survey (not including residential care) - conducted as part of the 1996 New Zealand census - does. Disability was defined as any long term limitation in activity resulting from a condition or health problem. People were not considered disabled if their limitation was nullified by the use of an assistive device such as a hearing aid. There was little difference between older and younger people in self-reported intellectual or psychiatric disability, but older people reported about three times as many sensory and physical disabilities as younger people.

Where do older people live? Who do they live with?

Types of elder accommodation could be broadly divided into eldercare facilities or ‘aging in place’. The latter category usually refers to older people continuing to live in the home they lived in during their working years. The subcategory of Independent living usually refers to a domestic environment where an older person or couple can cater for their own needs without substantial assistance or caregiving. This may refer to both an older person who is aging in place and one who is living independently within some form of eldercare facility, residential care, or retirement village. Eldercare facilities may cater for a wide range of older people from independent living through to hospital and dementia care. However, many older people prefer to stay living in their own homes (Barba, 2002; Lawton, 1985).

Reflecting this preference, most older people are living in their own homes - whether by themselves or with other people. In 1996, 53.9% of older New Zealanders reported living independently with a spouse or partner (this percentage is almost unchanged from 10 years previously), 10% of older people were living with their children, and 6.9% were living with non-related people. The latter includes living in eldercare facilities and hospitals. Even in the old-old category, only one in four people were living in residential care. This shows both the diversity of living arrangements and also that the majority of older people are *not* living in eldercare facilities. Consequently older people who are independent living and/or aging in place should not be neglected as potential eldercare robot consumers.

In 2001 333,000 older New Zealanders were living by themselves. This is an increase from the one in five older people living alone in 1966, and is projected to increase to 482,000 people in 2021. As women tend to outlive their husbands, they are more likely to be living by themselves. As the old-old are more likely to have disabilities that require more care; people in their 90s are less likely to be living alone.

Fewer older people are living with their children or other relatives – a downward trend that started in the 1960s. Reasons for this shift may include a greater proportion of older people being healthier and more able to live on their own, less cohesive family ties – both socially and geographically, and increased eldercare services. In 1996 only 2% of older people were in hospitals. This number has deceased over the decades as hospital care is replaced with residential care.

Community living vs. eldercare facilities

Aging in place or community living is generally preferred to moving to eldercare facilities. Eldercare facilities can be seen as 'a last port of call'; a place where elderly dependent people go to await death (Nay, 1995). There are many advantages to aging in place. Continuity of domestic environments is considered key to adaptive identities (Twigger-Ross & Uzzell, 1996). Other advantages include familiarity of routines that are adapted to the older person and social support from friends and family (J. A. Hancock, 1987). Moreover, moving home can be a major life stressor (Nay, 1995), and many people may simply not wish to move at all. Resistance to change is a human characteristic not restricted to older people (Samuelson & Zeckhauser, 1988). If older people do move from their own homes, certain characteristics predict who will make a smoother transition to eldercare facilities. These characteristics include having had more choice in the decision to move (Mikhail, 1992), being less frail and stressed (Horowitz & Schulz, 1983), and having sufficient support and resources (Eckert, 1983).

Aging in place may be a popular option, but is not without its problems. Necessary infrastructures may not be available or are no longer accessible. Older people may have altered physical, sensory, and cognitive needs through illness or normative aging, which may necessitate home help. Even if sufficient home support can be obtained, support from other people can be counterproductive. Home help can feel intrusive, and older people receiving home help may feel a loss of autonomy and self-esteem (Scopelliti, Giuliani, & Fornara, 2005). As being independent and "not being a burden" is important to many older people (Hirsch et al., 2000) even receiving help from friends or family can be challenging. Independent living older people may enjoy emotional support from their social networks, but find it harder to ask for practical support (Lewis, 1997).

There are important eldercare issues specific to independent living and residential care, but there are some eldercare issues common to both. An eldercare problem represents an opportunity for eldercare robots to assist.

Common eldercare issues

Loneliness and depression

In 2010 a New Zealand survey found 11% of older people reported feeling lonely all, most, or some of the time (Statistics New Zealand, 2010). Older women were more likely to report feeling lonely than men. Compared with living alone, or even living in a larger household, both men and women were least likely to be lonely when they lived in a two-person household. There was an inverse correlation between loneliness and age. The older people were, the less likely they were to report feeling lonely. An international review of depression in community-living older people found women and those with financial difficulties were more severely affected than others (Beekman, Copeland, & Prince, 1999). Overall, the review authors concluded that depression in older people was common with an average prevalence of 13.5% - although the prevalence in the reviewed studies ranged from 0.4 - 35%.

One possible explanation for the wide range in prevalence of reported loneliness is that people tend to underreport potentially stigmatising issues. Reasons for this include not wishing to be perceived as weak, needy, or incompetent (Hirsch et al., 2000; Neven, 2011). This human predisposition for socially desirable responding, or impression management, can vary between individuals, generations, and cultures (Lalwani, Shavitt, & Johnson, 2006). There is some evidence that older people are more predisposed to certain types of socially desirable responding than younger people (Sherbourne & Meredith, 1992). Despite the possibility that self-reported rates of elder-loneliness are lower than the true rates, the self-reported rates *are* strongly correlated with worse physical and mental health. This association is so strong some researchers consider that reducing loneliness should be an important therapeutic target (Luanaigh & Lawlor, 2008). However due to possible underreporting, the association between elder-loneliness and health may be even stronger than is currently realised.

Eldercare personnel

A rationale for eldercare robots often mentioned in conjunction with aging populations is a shortage of eldercare personnel (Oulton, 2006; Super, 2002). Although this is not uniform globally (Fleming, Evans, & Chutka, 2003; Simonazzi, 2009), the personnel shortages include caregivers and medical professionals (Sargen, Hooker, & Cooper, 2011). Causes of this eldercare shortage include the ageing population – with fewer younger people to look after increasing numbers of care-intensive older people, financial pressures, increased consumer demand, family fragmentation and the bureaucratisation of long term eldercare (Simonazzi, 2009).

Carers can abuse

A common objection to robot eldercare is that it is likely to be inferior to human care (e.g. Sparrow & Sparrow, 2006; Turkle, 2012). However, while it is important to acknowledge the many caring and dedicated caregivers, rates of elder-abuse by caregivers can be high. A review of elder-abuse found 6%

of older people reported experiencing physical abuse in the previous month, and nearly a quarter reported psychological abuses (Homer & Gilleard, 1991). Another study found sixteen percent of eldercare facility staff admitted psychologically abusing residents (Cooper, Selwood, & Livingston, 2008).

Elder abuse is not restricted to eldercare facilities. The most likely abusers of older people were those with whom they were living (Kleinschmidt, 1997). This means that, of reported cases, abusers were most likely to be spouses of the older person, followed by adult children. However, much elder abuse goes unreported (Cooper et al., 2008). Reasons for non-reporting by victims include not recognising maltreatment, guilt or embarrassment, being unaware of available resources, or a belief that help will not be forthcoming even if they do report the abuse (A. Moon & Williams, 1993).

Carers can be abused

It is not just older people with unmet eldercare needs. Some caregivers may abuse older people, but caregivers can be subject to abuse from older people (Phillips, de Ardon, & Briones, 2001). Mental and physical health issues such as dementia, psychiatric conditions, and alcohol abuse can create behavioural problems that make high-needs older people challenging to care for (Homer & Gilleard, 1991). A nursing home study found assistants were physically assaulted on average 9.3 times per month and verbally abused 11.3 times per month (Goodridge, Johnston, & Thomson, 1996). A rest home study found almost 14% of residents had abused staff. The most common form of abuse was hitting (56.7% of incidents), followed by kicking (13.3%), punching (10%), biting (6.7%), and scratching (6.7%). Abusers were more likely to be male, need assistance in activities of daily living, and have a degree of confusion (Meddaugh, 1987).

Carer stress

Spouses and adult children often provide unpaid caregiving for frail or unwell older family members. Often when one member of a couple has dementia, it is common for the healthier spouse to (at least initially) care for their partner. Caring for people with dementia can be demanding and distressing. A systematic review found dementia caregivers have high rates (22.3%) of depressive disorders (Cuijpers, 2005). Compared with younger carers, the health of older carers may be more adversely affected by the demands of caring for people with dementia (Pinquart & Sörensen, 2007).

Carers have high rates of psychological distress and low rates of support to address their distress (Goodridge et al., 1996; K. Walters, Iliffe, Tai, & Orrell, 2000). Up to a third of caregivers report health consequences such as sleep deprivation and fatigue. They also report prioritising their caregiving responsibilities over their own medical needs. However, some protective factors have been identified. Adverse effects of caregiving appear to be offset by higher education, access to resources, being employed, and being able to take breaks or access respite care (Arnsberger, Lynch, & Li, 2012; Colin, Caranasos, & Davidson, 1992).

High levels of eldercare needs

As older people tend to have higher levels of care needs compared with younger adults (United Nations, 2010), assessments of elder needs may help indicate if eldercare robots are a necessity or not. Additionally, detailed information on eldercare-needs may indicate the areas where robotic assistance could be of most value. Widely used measures of the needs of older people are the Activities of Daily Living (ADLs: Katz & Akpom, 1976) and Instrumental Activities of Daily Living (IADLs: Lawton & Brody, 1969). ADLs assess limitations in daily living such as bathing, transfer from bed, and toileting. IADLs assess limitations in routine activities such as shopping, housekeeping, and using the telephone. However, as the ADL and IADL measures are oriented to assessing elder needs that can met by the available services of eldercare organisations (Reynolds et al., 2000), they may not fully represent an older persons unmet needs.

To help redress this, British researchers conducted a study to determine the needs of community-based older people and carers (K. Walters et al., 2000). The 24 most common elder needs related to; accommodation/looking after the home, food, self-care, company/intimate relationships, daytime activities, abuse/neglect, intentional and unintentional self-harm, managing finances, medical information, mobility/falls, incontinence, eyesight/hearing, memory, psychological distress, psychotic symptoms, alcohol, behaviour, and caring for someone else. The two most common carer needs were information and psychological distress.

Older people not only tend to have many care needs, they also tend to have high rates of *unmet* needs. However, in order to develop or deploy resources to effectively meet elder needs, first the needs must be identified. Correctly identifying and prioritising unmet elder-needs can be difficult. One barrier to effective prioritisation of elder-needs is the differing perceptions held by different eldercare stakeholders. For example, a British study found older people reported their three most frequent unmet needs related to eyesight/hearing, psychological distress, and incontinence. In contrast, carers considered the top three unmet elder needs related to mobility, eyesight/hearing, and accommodation: and health professionals considered the top three unmet elder needs related to daytime activities, accommodation, and mobility (K. Walters et al., 2000).

In summary, the *necessity* of eldercare robots is debatable (Neven, 2011; Turkle, 2012); but it is less debatable that there are concerning discrepancies between eldercare needs and eldercare resources. It is possible these discrepancies could be met by non-robotic means, such as more investment in eldercare personnel (Turkle, 2012) and better allocation of existing resources (Horrocks et al., 2004). However, these discrepancies exist now, and are likely to worsen as the world's population continues to age. This strongly suggests there is a need for supplementary eldercare both now and in the future.

However, can eldercare robots usefully supplement eldercare? And do people want them to?

1.2. Are eldercare robots useful?

People want useful robots. Participants rated the most important characteristics of a domestic robot as being practicality and usefulness (Lohse, 2011). The most frequent comments people made about CHARLEY, a companion humanoid robot that was on public display, were (apart from the robot being creepy), queries about how was the robot useful (M. Walters et al., 2012). Over 100 respondents to a mail survey indicated they would be willing to have a robot in their homes as long as it was useful and easy to use (Ezer, Fisk, & Rogers, 2009).

In determining if eldercare robots are useful, it is important to determine which *type* of eldercare robot is being referred to. The range of robots that could potentially help older people is extensive. Even a robot vacuum cleaner could be considered an eldercare robot if it helped an older person maintain their independence (Broadbent, Stafford, et al., 2009). In an emerging field such as eldercare robotics, an initial lack of nomenclature is likely inevitable, but can be confusing.

In recognition of this, several reviews have provided definitions for different categories of assistive social eldercare robots. Broekens et al. (2009), while acknowledging there may be overlap between categories, initially divided robots that are designed to support older people into two groups. The first group consists of robots that provide physical assistance, e.g. smart wheelchairs and exoskeletons. This group are usually not intended to be perceived as social entities.

The second group are the 'social robots' that *can* be perceived as social entities that communicate with the user. Broekens et al. subdivided these social eldercare robots into a further two types. The first type of social robot is referred to as a service-type robot. Such robots are intended to support older people in their daily functions, such as eating, bathing, toileting, getting dressed, mobility, household maintenance, and safety monitoring. The second type of social robot is a companion type robot. The primary purpose of companion robots is to enhance mental health and psychological well-being. These categories have since become widely adopted into the HRI literature.

But can these eldercare robots fill the current and projected eldercare gap? Several reviews of assistive robots and their effectiveness have been published in the last 10 years (e.g. Fong, Nourbakhsh, & Dautenhahn, 2003). While some of these reviews have focused on socially assistive eldercare robots, the use of differing selection criteria demonstrates the incomplete agreement of the concept of 'eldercare robot' (Herstatt, Göldner, Tietze, & Rehder, 2012). Some reviews include all robots that might help older people stay in their own homes (e.g. Broadbent, Stafford, et al., 2009). Other reviews have excluded companion robots (one of these reviews did not give a rationale for this exclusion - Pearce et al., 2012; whereas another stated that companion robots were excluded as they do not promote an older person's independence - Flandorfer, 2012). In contrast, some eldercare robot reviews focus exclusively on companion robots (e.g. Shibata & Wada, 2010).

Of the reviews that included both service type and companion eldercare robots, most of the located studies consisted of companion robot studies (notably Paro the seal robot), with few service-type robot studies located (Bemelmans, Gelderblom, Jonker, & de Witte, 2010; Broekens et al., 2009). Despite variation in the eldercare robot selection criteria; there was considerable consensus in the reviews' findings. The most notable being that there is little empirical evidence for the effectiveness of eldercare robots (Bemelmans et al., 2010; Broekens et al., 2009; Flandorfer, 2012; Pearce et al., 2012). Other review findings include that many of the reviewed robots are still in the developmental phase. Fully developed robots described in the reviews are either research platforms, such as Phillip's robotic iCat, or commercial products. Of the commercialised robots, a few, such as Paro are still commercially available, but others, such as the Sanyo's robot dog Aibo, Mitsubishi's Wakamaru – a socially assistive domestic robot, and Sanyo's Hopis – an eldercare vital signs device, have been discontinued (Borland, 2006; Foulk, 2007; Miller, 2007).

While most of the eldercare HRI studies included in the reviews reported positive outcomes, the review authors concur that the data validity is compromised by methodological limitations - including generalisability issues. As cultural differences have been found in responses to robots (Bartneck, Nomura, Kanda, Suzuki, & Kennsuke, 2005; Cortellessa, Koch-Svedberg, et al., 2008) it may be a limitation that most studies have been conducted in Japan (Bemelmans et al., 2010; Broekens et al., 2009). Most studies with older participants were situated in care-intensive eldercare facilities which may limit generalisability of results to independent living older people (Broekens et al., 2009). Further, the common use of images of robots in studies, rather than actual robots, may also limit generalisability of results to real-world HRI contexts. People may respond differently when interacting with a robot compared with viewing pictures and videos of robots (Flandorfer, 2012; Kidd & Breazeal, 2010).

Other common methodological limitations described in the reviews include small sample sizes (Broadbent, Stafford, et al., 2009; Broekens et al., 2009; Pearce et al., 2012), short duration of trials, a lack of equivalent control groups, and a lack of randomisation (Bemelmans et al., 2010; Fong et al., 2003; Shibata & Wada, 2010). Although there were some exceptions where older people were able to use the robots alone (e.g. Kidd, Taggart, & Turkle, 2006), generally researchers were present when an actual robot was being deployed. The presence of researchers during HRI studies meant the Hawthorne, or measurement effect, may be a confound (Broekens et al., 2009), and people may have been responding to the presence of the researchers rather than the robot. The typically short trial duration also means novelty effects cannot be ruled out. This may be particularly true of eldercare facilities where there is insufficient variety in the recreation options. Another common limitation of eldercare HRI studies is insufficient assessment of sociodemographics that may be important to robot acceptance. These include age, ethnicity/culture, education and technology experience (Flandorfer, 2012).

However methodological issues are not unexpected in an emerging field such as eldercare robotics. Consequently the reviewers suggest the limited but promising results, combined with the eldercare resource gap, warrant further research on eldercare robots. In addition to recommending the HRI method limitations be addressed, the eldercare HRI reviewers recommend future research on a range of HRI aspects including more assessment of sociodemographic variables that impact acceptance of robots (Flandorfer, 2012); replication of existing studies and more assessment of service-type robots (Broekens et al., 2009; Pearce et al., 2012); further development of psychometric measures to better assess the effectiveness of eldercare robots; more research on how existing user perceptions influence robot acceptance; and in-depth assessment of the needs and expectations of a range of eldercare stakeholders (Broadbent, Stafford, et al., 2009; Flandorfer, 2012). However, Flandorfer (2012) advises being mindful of aging stereotypes when assessing elder needs. The views of older robot study participants may be different from those of younger robot designers.

What eldercare robots are there? What can they do?

A description of all eldercare robots that have been developed and are under development is beyond the scope of this thesis - readers should refer to reviews on this topic for more detail (e.g. Broadbent, Stafford, et al., 2009; Broekens et al., 2009; Diehl, Schmitt, Villano, & Crowell, 2012; Flandorfer, 2012; Fong et al., 2003; Nejat, Sun, & Nies, 2009; Pearce et al., 2012; Shibata & Wada, 2010). However, some examples of eldercare robots from Broeken's categories are provided below.

Paro appears to be the most studied of the eldercare robots (Kolling et al., 2013). The companion seal robot has pressure-sensitive sensors covered with soft white anti-bacterial fur. It responds to touch, makes crying noises, and can 'learn' its name. A number of studies have found benefits from the use of Paro. Older people's use of Paro was found to decrease their levels of urinal stress hormones (Saito, Shibata, Wada, & Tanie, 2002). A year-long Paro study in an eldercare facility found the robot facilitated communication between the residents (Wada, Shibata, Saito, Sakamoto, & Tanie, 2005a). Residents also continued to use Paro throughout the year - demonstrating the robot's functionalities had enduring appeal beyond any initial novelty. A recent randomised controlled study showed use of Paro significantly reduced loneliness in older rest home and hospital residents, compared with people in an active control group (Robinson et al., 2013). Considering the strong association between elder-loneliness and poor health, this is an important finding.

One controlled Paro study found older people responded less to a switched-off Paro than to a switched-on Paro (Taggart, Turkle, & Kidd, 2005); suggesting the robot's movements, responsiveness, and vocalisations add to its effectiveness as a companion. In contrast, a similar controlled study using a different robot companion, the robot cat NeCoRo, found both the robot cat and a non-robotic version had a calming effect on patients with dementia (A. V. Libin & Libin, 2004). However, compared with the more impaired people, higher functioning people played for longer with the robotic cat.

Commercial industry may dominate in number of robot patents filed in the last 30 years, but university publications dominate the robotic literature (Herstatt et al., 2012). Numerous universities internationally are running their own robotics projects. Some eldercare robot examples include researchers at the Georgia Institute of Technology developing a robotic nurse to bathe older people. Carnegie Mellon researchers are developing HERB - short for Home Exploring Robot Butler. HERB is designed to do domestic cleaning, as well as to fetch and carry household objects. Another robot, Hector, is being developed by the University of Reading in England. Hector is being designed to issue medication reminders, help people find missing objects, and provide assistance in the event of a fall (Bilton, 2013). Australia's La Trobe University is trialling NECs PaPeRo robots with older people with mild dementia. The small robot can transport itself and move its head, light up its eyes, and play music and Bingo. It is programmed to recognise up to 10 faces and detect if people have low mood - in which case it can alert family or caregivers (La Trobe University, 2013). Results of the trial are not yet available.

The commercially available benchtop robot Autom is an interesting example of non-stigmatising marketing. The intentionality of this marketing strategy is unclear, but despite the robot being trialled with older people, Autom is marketed as a *lifestyle* robot, rather than an eldercare robot (Biggs, 2012). Autom has speech production, a moving head and eyes, a camera, and a colour touch screen. The benefits of Autom were assessed in a controlled weight loss study with independent living older people. The participants in the Autom condition lost no more weight compared with controls over the six week study period, but they developed a stronger relationship with the robot, and adhered to Autom's dietary and lifestyle advice for longer than people in the computer or paper log conditions (Kidd & Breazeal, 2008).

Phillips robotic research platform, the cartoon-like iCat, has been used in a number of studies to assess the association of a range of HRI variables with robot acceptance. Human HRI variables assessed included demographics and attitudes: Robot HRI variables assessed included perceived personality (e.g. Bartneck, Van Der Hoek, Mubin, & Al Mahmud, 2007; Heerink, Kröse, Evers, & Wielinga, 2010). For example, older people who used an iCat programmed with good social skills were more expressive and felt more comfortable, compared with people who used an iCat with poor social skills (Heerink, Krose, Evers, & Wielinga, 2006).

Compared with the number of publications on companion robots, there are relatively few publications on trials with service-type robots. One such publication describes the service-type robot, 'Nursebot Pearl', a result of a multidisciplinary collaboration between the University of Pittsburgh and Carnegie Mellon University. Pearl is a mobile robot designed to remind people of routine daily activities such as taking medications, eating, drinking, and toileting, and guide them to appointments. Features of the 1.2 metre tall robot include an actuated head, touch screen, stereo camera, and speech production and recognition. Pearl prototypes have been piloted in an eldercare environment (Pollack et al., 2002), however the project is no longer active (Carnegie Mellon Robotics Institute, 2013).

The Care-O-bot, part of the European Commission funded SRS project, is another service-type robot. Early prototypes were not intended for eldercare (Parlitz, HÃgele, Klein, Seifert, & Dautenhahn, 2008), but later models of the Care-O-bot has been piloted in an eldercare facility (Fraunhofer, 2011). The robots primary task in the pilot study was to ensure residents were hydrated. However data has not been provided about the robots effectiveness at this task. The latest version of the networked Care-O-bot3 is designed to fetch and carry objects, facilitate human-human communications, act as a healthcare portal, and attend someone if they fall. Functional limitations of the robot are bridged by human teleoperators. Recently, brief trials of the Care-O-bot3 have been conducted in real home and smart home environments (SRS project, 2013).

In summary there are very few developed eldercare robots that are commercially available (Kolling et al., 2013). There is evidence for the usefulness or effectiveness of companion robots in eldercare (albeit mainly Paro), but little evidence for the usefulness of socially assistive service-type robots. One reason for this is there are few fully developed service-type eldercare robots to assess. Another reason is that the little available data on eldercare robot effectiveness is often compromised by research method limitations.

To help progress the development of effective eldercare robots, researchers have sought to gather data on what eldercare stakeholders would find useful in such a robot. However, a precursor to that question is – do eldercare stakeholders actually want eldercare robots?

1.3. Do older people and other eldercare stakeholders want eldercare robots?

Sherry Turkle (2012) is uneasy that people *do* appear to want robots - even to the extent of preferring robots to people. She observed some older people develop deep attachments for Paro and the My Real Baby robotic dolls. However Turkle considers the robots provide an unauthentic poor quality relationship, and is concerned they may displace authentic human companionship. However Turkle has no concerns about functional [service-type] robots that assist older people and keep them safe. Turkle considers tasks such as delivering medications, reaching for groceries on high shelves, and monitoring human safety, as acceptable for eldercare robots.

However, when assessing if people want eldercare robots, it is important to consider what *type* of people might want them. Regardless of how useful a robot may be, older people are unlikely to be the purchasers (Mahoney, 1997; Schulz et al., 2013). As older people are often embedded in complex social environments, the needs of all stakeholders in the eldercare environment should be considered (Hirsch et al., 2000). Eldercare stakeholders can include older people, their family and friends, formal and informal caregivers, health professionals, and eldercare facility staff. At a more removed but still important level, the public, governments, and other investors are also eldercare stakeholders. This distinction is important as different eldercare stakeholder groups may not only vary in whether they do or do not want eldercare robots; but also vary in their *reasons* for wanting or not wanting them.

Turkle's concerns about a human predilection for robots may be unfounded. Regardless of which eldercare stakeholder groups are the primary purchasers of assistive technology; poor sales of fully developed assistive robots do not suggest strong demand. A review of the viability of ten commercially available rehabilitation robots (three mountable wheelchairs, five vocational workstations, and two mobile bases), concluded none of the robots have been a commercial success (Mahoney, 1997).

At the time of the report's publication 225 robots had been sold at an average price of US$19,020 (Mahoney, 1997). The number of devices sold is low considering the estimated 100,000 to 500,000 people in the United States of America who could benefit from rehabilitation robots. This small market share is not restricted to rehabilitation robots. Since the commercial launch of Paro in 2005, 1,500 units have been sold (of which an estimated 1,300 have been sold in Japan: Shibata & Wada, 2010). While Paro's sales figures are promising, they are unlikely to represent market share.

It is difficult to decipher from the available literature the reasons for the relative lack of commercial success of assistive robots. As most of the rehabilitation robots reviewed by Mahoney (1997) were not being actively marketed, it is possible the relatively poor sales represent lack of consumer awareness rather than lack of consumer demand. There are examples of robots that have either been used in or intended for use in eldercare that are no longer commercially available. One such example is Hopis - a furry toy-like robot marketed as being suitable for older people. The robot was capable of measuring vital signs such as blood sugar, blood pressure and temperature. However poor sales have led Sanyo to withdraw Hopis from the market (Foulk, 2007). Yet poor sales did not seem to be the reason behind Sony's withdrawal of the robot dog Aibo. Sony has sold 150,000 Aibo units since its market release in 1999. While not specifically designed for eldercare, results from HRI trials with older people suggest Aibo was beneficial as a companion robot (Banks, Willoughby, & Banks, 2008). Yet, along with the more humanlike robot Qrio, Sony withdrew the robot dog from commercial sale in 2006.

Despite the relative lack of commercial success, a reader could acquire an impression from some HRI literature and mainstream media that the prevalence of some eldercare robots is higher than it is. This may be due to the sometimes uncritical relaying of promotional information supplied by robot developers (Paepcke & Takayama, 2010). For example, a recent review of eldercare robots portrayed Mitsubishi's small yellow humanoid robot, Wakamaru, as an example of a "developed and tested socially assistive robot" (Flandorfer, 2012). The review lists Wakamaru's social interaction capacities as the ability to speak in "natural conversation" and shake hands. Wakamaru's functionalities are described as reminding users to take their medications and call for help. However, sometimes more detailed information on the commercial fate of robots can be obtained from the grey literature. An online source elaborates that of the one hundred $14,000 Wakamaru robots Mitsubishi manufactured, orders were only received for 25 of these. Furthermore, sales were not completed on all orders (Miller, 2007).

The commercial situation paints a rather bleak picture of the state of eldercare robotics. But this does not necessarily reflect the future state. Other methods of assessing consumer attitudes may more accurately illustrate the future potential of eldercare robots. Indeed, a number of studies have been conducted to assess the opinions of eldercare stakeholders on this topic. These studies have used a variety of methods. Some involve people interacting with an actual robot, although most are conducted in the absence of an actual robot. Other methods include participants being shown photographs or videos of robots, or no images at all. Focus groups may be used, and/or online, or pen and paper surveys.

Studies assessing attitudes towards eldercare robots also vary in the number of eldercare stakeholder groups who are canvassed. Some studies assess just one eldercare stakeholder group, such as older people. Others include additional groups, such as carers, family, health professionals, and eldercare service and facility management. This variation in research methods provides a depth of data but can also produce conflicting findings.

The findings from these studies are mixed on whether people want assistive robots. Some people are enthusiastic about the idea, whereas others are resistant (Giuliani, Scopelliti, & Fornara, 2005b). Some older people are emphatic they find the idea of robots objectionable, e.g. “If it is possible, I would prefer no robot at all. Anyway, I would prefer a small machine rather than simulacra [of a human]’’ (Wu, Faucounau, Boulay, Maestrutti, & Rigaud, 2012). Some results suggest robot attitudes are mediated by personal context (Scopelliti et al., 2005). One study found mixed-age people with disabilities were positive about generic assistive devices, but negative about the concept of robotic assistance (Dario, Guglielmelli, Laschi, & Teti, 1999). In contrast, another study found people with profound disabilities (mean age 42 years) were enthusiastic about the idea of a healthcare robot, even preferring it to human care. They perceived a robot would restore independence without the ‘hassles’ that can come with human caregivers (Mahani & Eklundh, 2009).

Like older people, eldercare facility staff can also have mixed responses to the concept of eldercare robots. Focus groups conducted within a retirement village found some staff were positive. For example, “[if robots did basic tasks] the caregivers could spend a lot more time with the residents as well instead of doing these [basic tasks]. . . . That’s the place we miss out on” (Broadbent, Tamagawa, et al., 2011). However, other staff were more concerned about reliability; “Are [the robots] reasonably reliable, or is it likely to have a hissy fit and bounce off the walls at some stage?’’. And some staff were concerned about job losses; “And then you have to be very careful how [many] robots you need otherwise you’re just taking, you know, your job away..” .

A recent study showed a slight majority of staff participants preferred a robot to a human (Mitzner, Kemp, Rogers, & Tiberio, 2013). After 14 eldercare personnel watched a video of PR2, Willow Garage's research robot, eight of them indicated they would prefer a robot over a human assistant. Reasons given for preferring a robot included "[the robot] can reduce the number of tasks…", however five of the staff said they would prefer a human to a robot assistant, "...I know what humans do, but a robot, I don't…", and one staff member had no preference.

Public attitudes towards eldercare robots are also important. As well as members of the public being potential eldercare robot purchasers, public opinion may influence government policy around eldercare. An example of public reaction to an upcoming eldercare robot study was provided in responses to an online article (Hill, 2011). Of the ten responses given before the comments field was closed, only one comment was positive; "the aim of enabling staff to spend more quality time with patients is laudable…". Examples of the negative comments include; "I am of the opinion that old people are dehumanised enough in our society. This is just another step that shows [older people] are not even worthy of human contact in their declining years. Disgusting.", "I think it's pretty unlikely that old, demented people are going to have an improved quality of life by being poked and prodded by robots. What old people want/need, just like the rest of us, is human interaction and affection". Two comments expressed concern about the effectiveness of robots in eldercare, e.g. "…Not sure it is a good idea with dementia patients they might smash them and I bet [the robots] aren't cheap".

However, despite the predominantly negative nature of these online comments, the self-selected nature of them should be taken into account. It cannot be assumed that self-selected commentary is representative of the general population. People who use the internet may differ in their robot opinions than those who do not. People who visit that particular website may differ from those who do not. People who leave online comments may have stronger opinions than those who do not, and people who comment online later may have been influenced by other people's earlier comments (Li & Hitt, 2008).

There are a number of reasons why determining people's 'true' attitudes towards robots can be difficult. Sometimes participants perplex robotocists by providing apparently conflicting information about their robot preferences. For example, a man with dementia reported he did not like the seal robot Paro while simultaneously playing with it. Wada, Shibata, Musha, and Kimura (2005) hypothesised that the man was conflicted as he both liked the robot but was embarrassed to be playing with what looked like a child's toy. If this is an accurate interpretation, it illustrates researcher concerns that even a useful eldercare device may not be accepted if people perceive it as infantilising (Turkle, 2012), or stigmatising them as elderly, infirm, or disabled (Hirsch et al., 2000).

Older participants can provide other types of information that may mislead eldercare HRI researchers. For example, older people can make positive comments about eldercare robots, yet have no desire to actually have one (Neven, 2011). Reasons for this can include participants not wishing to offend the HRI researchers by being impolite about the robot (Wu, Fassert, & Rigaud, 2012). In other cases people may see the robot as an interesting novelty, but do not see it usefully meeting any of their needs (Giuliani et al., 2005b).

While some older people may not be enthusiastic about assistive technologies (including robots), they are more likely to be accepting if they perceive the benefits of use outweigh the costs (Beer et al.; Pain et al., 2007; Tinker & Lansley, 2005). Perceived 'costs' relates not only to financial cost, but also to psychological costs such as stigma, as well as perceived difficulty and effort involved in using the technology (Hirsch et al., 2000; W. A. Rogers & Fisk, 2010; Wu, Faucounau, et al., 2012). The benefit of maintained or increased independence is often cited by older people as a reason to use assistive technologies which they otherwise would not use (Hirsch et al., 2000; Pain et al., 2007; Tinker & Lansley, 2005). Asked to imagine a future scenario in which they were frail and needed assistance; 83% of survey respondents at a robotics show said they would accept a robot if it increased their independence. Possibly reflecting heightened concerns about loss of independence; the older the survey respondents were – the more likely they were to say they would accept an assistive robot (Arras & Cerqui, 2005).

Costs and benefits of robot use may be weighted differently by different eldercare stakeholders. Older people may be particularly interested in robot benefits relating to independence. Adult children may buy robots for their aged parents if they perceive the robots will keep their parents safer and provide companionship (Tufel, 2013). Governments and eldercare organisations may invest in eldercare robots if they perceive the robots will reduce eldercare costs (Schulz et al., 2013). Eldercare stakeholders may be unaccepting of eldercare robots when they either perceive insufficient benefits to robot use and/or the costs are too high. Therefore it seems important for robot acceptance to foster adaptive perceptions of *both* costs and benefits of eldercare robot use in potential users. To do this, first an understanding is required of what eldercare stakeholders consider the costs and benefits of robot use. What do people want and not want in an eldercare robot?

What do eldercare stakeholders want a robot to look like and do?

While not everyone wants an eldercare robot, if they *did* have one - what would they like it to look like and do? Many older people report a preference for a smaller discreet robot (Broadbent, Tamagawa, et al., 2009; Scopelliti et al., 2005; Wu, Fassert, et al., 2012). Using a generative design approach, younger people (mean age = 42 years) identified 99 discrete tasks they would like a domestic robot to do (Sung, Christensen, & Grinter, 2009). The 99 tasks were categorised into Time-consuming, Drudgeries, House-sitting, and Personal Attendance. Participants did not want overly intelligent domestic robots. They wanted a robot to only be as sufficiently autonomous as required to be effective at its tasks. Older people also tend to prefer a robot that is not too autonomous or anticipatory, preferring a robot that only acts as directed by the human user (Huttenrauch, Green, Norman, Oestreicher, & Eklundh, 2004; Scopelliti et al., 2005). Mixed-age participants who interacted with both more and less responsive versions of a Peoplebot, found the more responsive robot both more autonomous and less acceptable (Syrdal, Dautenhahn, Koay, & Walters, 2009).

A variety of eldercare stakeholders have also been consulted on what constitutes useful robot tasks. A European study asked mixed-aged people with disabilities and their carers what capabilities they wanted a domestic robot to have (Dario et al., 1999). The most commonly requested robot tasks were tidying and cleaning the kitchen, heating and serving food to a bed-ridden person, and changing bed linen. Mitzner et al. (2013) found eldercare staff had no preference either way for human or robot assistance with Instrumental Activities of Daily Living (IADLs) except they preferred robot assistance over human assistance with light housework tasks. Whereas for the Activities of Daily Living (ADLs) the staff preferred robot assistance in transfer tasks, such as transferring older people from bed to chair, but preferred human assistance with feeding tasks. They mostly preferred a human assistant for medical tasks, with the exception of preferring a robot for checking vital signs. For some tasks, such as changing catheters and bandages, the staff had no preference either way.

A retirement home study assessed the opinions of older people, their families, and staff on eldercare robots (Broadbent et al., 2011). Residents were more positive towards robots than their families and staff. Caregivers liked the idea of a robot checking on residents' safety and helping with entertainment. Residents thought they would appreciate robot help with medication management and reminders. Managers liked the idea of a robot that could repeatedly orient forgetful residents as to time and place. However concerns were expressed about privacy, the robot harming and frightening psychologically and physically fragile residents, and the reliability of the robot. Both residents and caregivers were concerned about robots replacing people. From a list of possible robot tasks, all participants identified fall detection, summoning assistance, and monitoring people's location as useful robot tasks. However the residents rated the most useful robot tasks as detecting if someone had fallen, summoning assistance, turning appliances off and on, making phone calls to health professionals, monitoring the location of people with dementia who may wander and giving medication reminders (Broadbent, Tamagawa, et al., 2009).

Older people in differing domestic environments can have differing ideas of what constitutes a useful robot task. After being shown a video of the robot PR2, independent living older people were asked what types of domestic tasks they would like robot assistance with (Beer et al., 2012). Participants reported they most preferred a robot to clean, organise, and fetch objects, but they did not want a robot to sort mail or do the laundry or wash dishes. Showing the importance of eliciting underlying reasons for robot preferences, it appeared participants did not want a robot doing water-oriented tasks due to concerns about the robot getting wet, as distinct from not wanting assistance with these tasks.

As well as providing further evidence that individual robot task preferences may depend on individual context and study methods, these examples demonstrate the importance of understanding the *reasons* why people do or do not want particular robots or particular robot functionalities. Through lack of knowledge about robots, people may have misunderstandings about a robot's functionalities and limitations. These misunderstandings may constitute barriers to acceptance of robots. Conversely, if HRI researchers are aware of these mistaken perceptions, it may be possible to correct them, and increase robot acceptance in doing so. A related issue is that researchers have noted the difficulty some older people and other eldercare stakeholders have in suggesting useful tasks for robots. This is considered likely due to a lack of understanding of robot capabilities and usefulness, and may change with experience (Forlizzi, DiSalvo, & Gemperle, 2004; Mitzner et al., 2013; Scopelliti et al., 2005; Wu et al., 2013).

Despite the variation in robot preferences reported in the HRI literature, there are some themes. One theme is that many (but not all) people report *not* wanting a humanlike robot. Of over 2,000 respondents attending a robotics pavilion at technology show, 47% indicated they would *not* like a humanoid design for a robot, 19% said they would, and 35% were undecided. There appeared to be an age effect: 29% of people under the age of 18 wanted a robot of humanoid design, compared with only 10% of people aged 65 years plus (Arras & Cerqui, 2005). Some older people consider a robot is a machine, not a human, and it should look like what it is (Wu, Faucounau, et al., 2012). Other comments include older people disliking the 'falseness' of a robot that has an "unpleasant aspect of a false human''. However, this sense of falseness is not restricted to humanlike robots: ''to communicate with Paro is to communicate with nothing'' (Wu, Fassert, et al., 2012). The presence of a face is a strong cue for humanlikeness, and some older people have indicated a preference for a robot without a face (Broadbent, Tamagawa, et al., 2009; Cesta et al., 2007). This may be related to a common fear expressed by both caregivers and older people that robots will replace humans (Arras & Cerqui, 2005; Broadbent, Tamagawa, et al., 2009; Wu et al., 2013).

However, there may be other reasons people tend to prefer machinelike robots. People may feel more certain about how to interact with a clearly machinelike agent and more uncertain about how to interact with an unfamiliar agent that appears part machinelike and partly lifelike.

An interaction between humanlikeness and familiarity may be seen in a study where people could indicate how closely two different robots could approach them (Koay, Syrdal, Walters, & Dautenhahn, 2007). One robot was more humanlike and one more machinelike. Initially participants allowed the machinelike robot to approach more closely than the more humanlike one, but after five weeks participants had no difference in their preferred approach distance for the two robots This indicates that, compared with the machinelike robot, the participants may have initially been more uncertain about the behaviour of the more humanlike robot and thus were reluctant to let it approach them as closely as the more familiar machinelike robot. However over time participants may have become more familiar with the more humanlike robot, thus allowing it to approach as closely as the machinelike robot.

Another theme is people want a robot's appearance to 'afford', or match, its functionalities (Hirsch et al., 2000). If a robot's appearance is congruent with its functionalities this may improve acceptance in two ways. Firstly, a robot's appearance gives users cues on how to interact with it. Cues may reduce aversive uncertainty. Secondly, a robot that 'looks like what it does' may give users confidence in both the robot and its functionalities. For example, after retirement village residents viewed images of different robots, they thought the fluffy toy-like robot 'Hopis' was more suitable for companionship, and the robotic telepresence 'Intouch' was more suitable for healthcare tasks (Broadbent, Tamagawa, et al., 2009).

Considering the commercially withdrawn Hopis is actually a robotic healthcare device, the incongruence between its toy-like appearance and healthcare functionalities may at least partly explain its commercial failure.

A caveat to soliciting the robot preferences of users is that the most preferred robot features may not be the most effective. Results from an exercise robot study showed participants preferred an exercise robot programmed with a more fun personality compared to one with a more serious personality. However, participants did more exercise with the 'serious' robot (Goetz, Kiesler, & Powers, 2003). These findings suggest several HRI design considerations. One is the importance of matching robot form to function. A friendly personality may be the most 'effective' personality for a robot companion, but less effective for a robot where compliance with the robots functions is desirable, e.g. medication management.

Another design consideration is that HRI studies should include objective measures of robot effectiveness in addition to self-report. Multiple measures of acceptance can help resolve conflicting data. Like the exercise robot study, the benefits of multiple measures was demonstrated in the Paro study where the man reported he did not like the seal robot, but video of his affectionate behaviours towards the robot suggest otherwise (Wada, Shibata, Musha, et al., 2005).

Older people are diverse

Older people can hold different views of robots from other groups of eldercare stakeholders. An Italian study assessed the eldercare robot views of young, middle-aged, and older people (Scopelliti et al., 2005). Older people were found to be more concerned than younger people that a robot be unobtrusive and fit in with the décor. They also felt more strongly that technology would enable them to be independent, yet they were also more mistrustful of technology. However this type of age-related finding is not universal. Broadbent, Tamagawa, et al. (2009) found older people were more positive about robots compared with their families and eldercare facility staff.

Older people may have some different robot preferences from other eldercare stakeholder groups: but they are also a diverse group within themselves. Flandorfer (2012) cautions robotocists against the application of aging stereotypes in a ‘one size fits all’ design approach. To assess differences *within* the older generation that may impact technology acceptance, Giuliani et al. (2005b) examined attitudes to technological assistance and coping strategies in people aged 62-94 years. Showing the importance of perceived benefits of use, participants were found to be open to accepting assistant technologies if they perceived the technology as being better than alternatives, such as help from friends. However, even within this older age bracket, older age and lower education was associated with increased likelihood of putting up with unmet needs rather than attempting to problem solve with technologies.

Older-age gender differences in robot attitudes have been found. After interacting with an iCat, male rest home residents were more likely than females to want to own the iCat (so they could figure out how to programme it!). In contrast, the female residents were more likely to express they did not want any assistive technology until it was absolutely necessary. They feared premature use of such devices would result in premature loss of independence (Heerink, Kröse, Evers, & Wielinga, 2006).

However as the male participants also had significantly more experience with computers, it is plausible that these older-age gender differences detected by Heerink, Kröse, et al. (2006) may reflect prior experience with technology rather than gender per se. However, while Kuo et al. (2009) also found that men were more positive than women towards a healthcare robot, there was no significant difference between women and men in their self-reported computer experience.

However it seems likely that these reported gender differences in response to robots result from something other than chromosomal differences. Differing gender responses may be due to the different type of study robot or its functionalities, differences in the measures used, or the younger age of participants in Kuo et al.'s study compared with Heerink et al.'s study. Regardless of the cause, as the majority of older people are women, gender differences may be an important consideration for eldercare robot designers and should be investigated further.

In summary, there is not a unanimously positive response to the concept of eldercare robots. While some eldercare stakeholder groups appear more accepting of eldercare robots than others, there is also a lot of variability within stakeholder groups. Despite this, there are some distinct acceptability themes around the concept of eldercare robots. Themes of *non*-acceptability include: fear of being stigmatised as elderly or disabled, fear of robots replacing people, and unawareness of the benefits of robot use. As it can be difficult to imagine the qualities of a product of which you have no experience (Beer et al., 2012), some of the negativity may be explained by the fact that most people have not interacted with a socially assistive robot. People's attitudes may become more positive if they actually experience a robot's functions. Indeed, some eldercare HRI studies that have used actual robots have had positive responses (e.g. Pollack et al., 2002; Robinson et al., 2013; Shibata & Wada, 2010). In an extreme example, Sherry Turkle (2012) found some older participants formed such strong attachments to the companion robots Paro and My Real Baby that they did not return them at study completion.

This suggests eldercare robots may become more acceptable if more people try using them and experience their benefits. However this does not explain why there are so few eldercare robots available for people to try in the first instance. Taking into account the facts that care-intensive aging populations have been forecast for some decades, that robots are well established in factories and the military and even NASA's Explorer now has its own robot companion on Mars – where are the eldercare robots?

1.4. Why have the predictions of ubiquitous robots not come to pass?

A recent review of eldercare robots concluded the low prevalence of such robots is simply a consequence of the early stage of eldercare robot development, and they are not yet sufficiently technologically advanced to provide eldercare services at acceptable levels (Flandorfer, 2012). However, the reasons for low prevalence of eldercare robots appear to be more complex than this. It is accurate that not many eldercare robots have been made commercially available, but a few have been. And of these, a number, including Wakamaru, Aibo, and Hopis, have been withdrawn from sale. Of the commercial eldercare robots that are still available; sales do not match expected demand. The sale of 1,500 Paro units neither matches expected demand nor matches iRobots sales of over 6 million Roomba vacuum cleaners (Hornyak, 2012).

The reasons for the low prevalence of eldercare robot are likely to be many, but one identified barrier to successful robot commercialisation is high price (Blackman, 2013). Paro retails for approximately EUR$4,500 and the flagship Roomba retails for US$500 (TopTen Reviews, 2013). Cost is particularly marked as a commercial barrier when the benefits of robot use are perceived as inadequate or there are cheaper comparable products (D. Bernstein, Michaud, & Silvia, 2010; Mahoney, 1997). Some more expensive copycat versions of Roomba have been withdrawn from sale (D. Bernstein, Michaud, & Silvia, 2010). Johnson & Johnson's US$25,000 stair-climbing iBOT wheelchair is reportedly an exemplar of an otherwise desirable robotic device that is being discontinued due to being prohibitively expensive. Many individuals who would benefit from the iBOT cannot afford it, and healthcare providers are unwilling to purchase it (Linfoot, 2011). A recent review noted that eldercare robots must be perceived as cost effective to be attractive to eldercare providers (Bemelmans, Gelderblom, Jonker, & de Witte, 2012).

Understanding the reasons why formerly commercially available assistive robots have been discontinued may be valuable in designing acceptable robots. Unfortunately robot manufacturers rarely make this information available. While some robots such as Hopis, Wakamaru, and iBOT, have reportedly been discontinued due to lack of sales, the reasons for the withdrawal of other robots is unclear. Sometimes these reasons may be surmised from the grey online literature. Sony reported the withdrawal of the robot dog Aibo was in order to refocus on more profitable lines (Borland, 2006). An inspection of some Aibo blogs suggests the complex US$2,000 robot dog was somewhat unreliable (e.g. Aibo-Life Bot-House, 2013). The costs of servicing Aibo warranties may have eroded Sony's profit margins. Even if commercial robots are still available, poor sales may still be a problem. Mahoney (1997) observed issues that commonly slow down or prevent a product's commercial success appeared applicable to rehabilitation robotics. These issues included interfaces with poor usability, lack of real-world trials, robots being too expensive (and/or having inadequate cost-benefit ratios), poor business organisation, and insufficient capital.

Lack of marketing may be one reason for poor sales. Mahoney (1997) noted of nine organisations with commercially available rehabilitation robots; only two were actively marketing their products. Lack of *effective* marketing may be another reason for poor sales. The influence of ineffective robot marketing became evident during an HRI trial with independent living older people (Neven, 2011). During the trial, the older participants gave researchers positive feedback about an entertainment robot, yet they were not interested in having the robot for themselves. Participants reported seeing the study robot advertised on television as being suitable for the lonely elderly and did not wish to be associated with such a stigmatising product.

Another possible barrier to the commercialisation of eldercare robots is complex regulatory eldercare requirements. The eldercare HRI environment is not just physically and socially complex; meeting eldercare regulations can be time consuming and expensive for robot developers. Some robot companies may have underestimated the amount of capital required, and consequently re-directed their research efforts into simpler markets with cheaper entry requirements. Developing a viable integrated system such as a domestic robot requires expertise in many sub-fields, which may be easier to commercialise in their own right. For example, eldercare software such as medication management programmes may be cheaper and simpler for companies to provide on PCs and tablets, rather than robots.

Bill Gates had some ideas as to the prevalence gap between ‘real’ robots and factory robots (about one factory robot for every 10 human workers in automobile manufacturing). He suggested the technical challenges of deploying robots in more complex and variable eldercare environments, compared with fixed factory environments, have been underestimated. He also felt engineers have underestimated the difficulty a robot faces in orienting itself to objects in a room; in generating and responding to speech; in grasping objects of varying mass and fragility; and even replicating simple human tasks such as telling the difference between a window and an open door.

However Gates (2006) was optimistic about personal robots of the future. The increased availability and decreasing price of processing power and hardware would help offset these robot design challenges. He considered major progress had been made in the toughest robotic areas of visual recognition, navigation and machine learning. Gates proposed the next major barrier to robotic progress was similar to that faced by computing 30 years ago – a lack of standard operating software that would allow popular application programmes to run on a variety of robotic devices.

Resolving technical issues is critical to robot acceptance. Robots must do what they are supposed to do, and do it reliably and safely. But human issues are equally critical - eldercare robots cannot be commercially viable unless people actually want them and their functionalities. Some eldercare stakeholders do want eldercare robots but many do not. Most objections to eldercare robots are conceptual and made in the absence of an actual robot. There are examples of older people being more accepting of robots after they have interacted with them. Conversely, Sony's entertainment robot 'IfBot' is an example of an eldercare robot that older people used for a month and then rejected (Belew, 2007). It may be important to distinguish between acceptable robot hardware and acceptable robot software. Staff reported the rest home residents stopped using the IfBot because "they got bored" with it. This suggests that, rather than that the robot itself necessarily being unacceptable, that the robot's entertainment software was insufficiently varied to entertain beyond a month-long novelty period. However without more detailed information this explanation cannot be verified.

One reason people appear unwilling to accept an eldercare robot is they do not perceive sufficient benefits from robot use (Scopelliti et al., 2005). The inadequate matching of robots and their functions to user needs has been identified as a barrier to successful commercialisation (Bemelmans et al., 2010; Mahoney, 1997; Neven, 2011). Erin Rapacki (2011), product marketing manager for Adept Mobile Robots, agrees. She states that robots are extremely difficult to build well, and in order for them to be profitable, they must be matched to a problem. Rapacki also suggests that if more robotics researchers focused on solving real-world problems, then the field of personal robotics would be further along than it currently is.

Relative lack of investment may also help explain the relative lack of personal robots. As robots are difficult to build well, they also tend to be expensive to build well. Henrik Christensen (2011), Chair of the US Centre of Robotics and Intelligent Machines, has some opinions on this. In charge of setting up and co-coordinating robotics research in the USA and worldwide, Christensen believes the gap in prevalence between personal and military robots comes down to funding. Several hundred million US dollars have been spent on developing military robots in the US, compared with the approximately 15 million spent on personal robots. Christensen considers Europe to be more advanced than the US in personal robots. This is partly due to EU policy prohibiting the European Commission from funding research into military robots, and partly due to US desires to minimise human casualties in Afghanistan.

Another robotics industry leader believes a lack of user- and solution-focused design is impeding the commercial progress of personal robots. Dmitri Grishin, founder of Grishin Robotics, believes the field of personal robots is less advanced than the available technology warrants (Grishin, 2012). He points out that good robot concepts, such as the robotic lawnmower, were already present in the 1960’s and 70’s, but were ahead of their time and had insufficient supporting infrastructure. Grishin concurs with Rapacki (2011) in proposing that current robot design is overly technology-focused and insufficiently solution-focused. He suggests robot designers get user feedback early and avoid overcomplicating the technology. Increasing robot complexity with inadequate justification can increase cost and unreliability of robots without any increase in benefits for the user.

Benefits of robot use, or usefulness, appear important for robot acceptance. Online sources suggest Wakamaru's lack of acceptance may have been due to its limited usefulness (Miller, 2007). The robot could not negotiate multi-story homes and its conversational abilities were limited. Despite Wakamaru being promoted as having eldercare medication management capabilities, it had few functions beyond online weather forecasts and email. Mitsubishi intended to develop an arm for Wakamaru - hoping to enhance the robot's usefulness with the ability to carry drinks and open doors. To date this redesign has not occurred. Wakamaru robots are currently available for hire within Japan as corporate novelties (Mitsubishi Heavy Industries Ltd., 2013).

Conclusion

Developing commercially viable robots is a complex, expensive, multidisciplinary, multifaceted undertaking. It is likely that all major components of an eldercare robot's development, such as solution-focused technology, negotiating eldercare regulations, adequate funding, and marketing, need to be adequately addressed to achieve an acceptable and commercially viable eldercare robot. More understanding of what makes robots acceptable to older people, their families, carers, health professionals, managers of eldercare services, and investors, is required. This information can then be fed into the robot design to help create more acceptable eldercare robots.

Of the many possible variables that contribute to the development of acceptable robots, there appears to be a research and literature focus on the 'R' of the HRI: a focus on the technology and usability aspects of personal assistive robots. This focus reflects the engineering dominance in the HRI field (Bartneck, Kulić, Croft, & Zoghbi, 2009) and is critical work, but an unbalanced technology focus may be inadequate for developing acceptable eldercare robots. As there appears to be a relative lack of research on psychological contributions to robot acceptance, it is possible robot acceptance may be enhanced with more focus on the ‘H’ of the HRI.

Consequently, the next chapter examines models intended to assist designers determine what human aspects of the complex human technology interaction influence users to accept or reject technologies. The validity of these models is assessed, as is their ability to generalise to an eldercare robot context. Additionally the methods used and HRI variables selected to evaluate the models are examined. The results of some eldercare HRI studies that have used these models are also presented and discussed.

Chapter 2. Creating acceptable eldercare robots – models and evaluation of acceptability

Preamble

In order to help address the eldercare resource gaps, robots need to be developed that are acceptable to eldercare stakeholders. But how can researchers tell when a robot *is* acceptable? How can researchers determine which of the many aspects of a complex HRI are acceptable and which need improving? As HRI is an emerging multidisciplinary field, there is a need for appropriate theoretical models and knowledge of acceptance-related HRI variables to guide cross-discipline HRI researchers in developing acceptable robots.

Chapter outline

Section 2.1 of this chapter examines models that may be useful for improving understanding of robot acceptance. The focus of the section is on the seminal Technology Acceptance Model (TAM) and its more complex offspring; the Unified Theory of Acceptance and Use of Technology model (UTAUT). Two other potentially useful technology acceptance models are highlighted; the Technology Diffusion Model and the Expectation-Confirmation Model of continued IT usage (ECM-IT).

There is a need for HRI researchers to better understand *which* of the many HRI variables contribute most to the acceptability or not of robots. To meet this need, several guides to HRI evaluation have been published in the last ten years. Several of these guides have drawn on models of technology acceptance. The applicability of these evaluation methods to an *eldercare* HRI context is discussed in section 2.2.

2.1. Technology Acceptance Models - background

A Google Scholar check on the 12th September 2013 revealed 17,042 citations for Davis's (1989) paper outlining the development of scales that predicted user acceptance of computer systems. The scales formed key components of a model that became known as the Technology Acceptance Model (TAM). The model title has become a generic label for models associated with predicting and explaining acceptance of technologies.

Davis's motivation for developing the TAM was twofold. The first motivation was the persistently poor uptake of information technology by white collar workers. The second was the lack of quality measures for key determinants of user acceptance. Davis synthesised the TAM from a range of cross-disciplinary theories and studies. Sources included: work on the impact of perceived usefulness on system utilization; expectancy models (DeSanctis, 1983; Vroom, 1964); Bandura's self-efficacy theory (Bandura, 1982); the cost-benefit paradigm from behavioural decision theory (Beach & Mitchell, 1978; E. J. Johnson & Payne, 1985); studies in the adoption of innovations; and studies on how people evaluate information. Davis also drew on marketing and human-computer interaction research.

An important TAM feature is that it is users' *perceptions* of a technology's usefulness and ease of use, rather than more objective measures of these attributes, which are considered the critical predictors of acceptance. In synthesising this cross-disciplinary research, Davis (1989) proposed two key determinants of technology acceptance. These were 'perceived usefulness' of the technology and ‘perceived ease of use’. Davis defined *perceived usefulness* as “the degree to which a person believes that using a particular system would enhance his or her job performance”; and he defined *perceived ease of use* as “the degree to which a person believes that using a particular system would be free of effort”. In brief, technology acceptance was predicted by how useful and easy to use a technology was perceived to be.

Davis felt existing research on human computer interaction (HCI) had neglected two key areas. One was the excessive focus on *objective* measures of usability. While objective ease of technology use is important, it may not be as important as users’ *subjective* perceptions of ease of use. The second key area of neglect was that research and development on technology *usefulness* had been minimal compared with research on technology ease of use[3].

Although both perceived usefulness and ease of use appear to be important predictors of technology acceptance, they may not be equally important. During research assessing the fit of the TAM, Davis (1989) found that perceived usefulness was more strongly correlated with self-reports of current and future system usage than perceived ease of use. This suggests that while users are willing to endure a difficult-to-use system that delivers important functionality, they are less willing to use an easy-to-use system that delivers little or no functionality.

Despite the combined predictive power of both perceived usefulness and ease of use, Davis (1989) thought it likely there were more important predictor variables to be discovered. He encouraged further research in this area, as well as further research into determining the precursors to perceptions of

[3] The terms ‘ease of use’ and ‘usability’ are often used interchangeably.

technology usefulness and ease of use. Two potential precursor variables nominated for further research were intrinsic motivation and affective attitudes.

Davis also called for more research into the application of technology acceptability measures in applied settings (1989). By this he meant an increase in the repeat use of *subjective* measures "throughout the technology development and implementation process, from the earliest needs assessment through to concept screening and prototype testing, to post-implementation assessment" (p. 335). Davis cautioned that while system evaluation is important, so is determining reasons for *lack* of acceptance. Both types of information are useful in designing interventions to improve technology acceptance.

Following his own recommendations, Davis (1993) continued to develop the TAM. He next drew on Fishbein and Ajzen's (1975) theories on attitudes, specifically drawing on their description of behavioural attitudes. These attitudes were conceptualised as expectancy-value model of beliefs weighted by the consequences. Davis proposed that a potential technology user's 'behavioural attitude' mapped onto overall attitude toward *using* the system, and this in turn was the primary predictor of use. He further proposed that overall attitude towards use was determined by the two previously identified technology beliefs of perceived usefulness and ease of use.

In turn, Davis considered that perceived usefulness and ease of use were directly influenced by the external stimuli of the technology's features (i.e. what the technology looks like). As Davis considered features of the technology to have an indirect effect on users' attitudes via visual perceptions of usefulness and ease of use, he advised designers to optimise technology acceptability by ensuring technologies *appeared* useful and easy to use. Davis proposed that perceived ease of use of a technology could be enhanced by making it easier to use the existing functions. He proposed perceived usefulness could be enhanced by adding additional functions. There are some possible limitations to these methods for promoting acceptance. It is unclear how simply adding more functions to a technology will increase perceived usefulness. The model also makes no allowance for the influence of ‘internal stimuli’, such as the possibility of users possessing pre-existing technology attitudes, or ‘pre-factual attitudes’ (Bagozzi, 2007), which may influence acceptance.

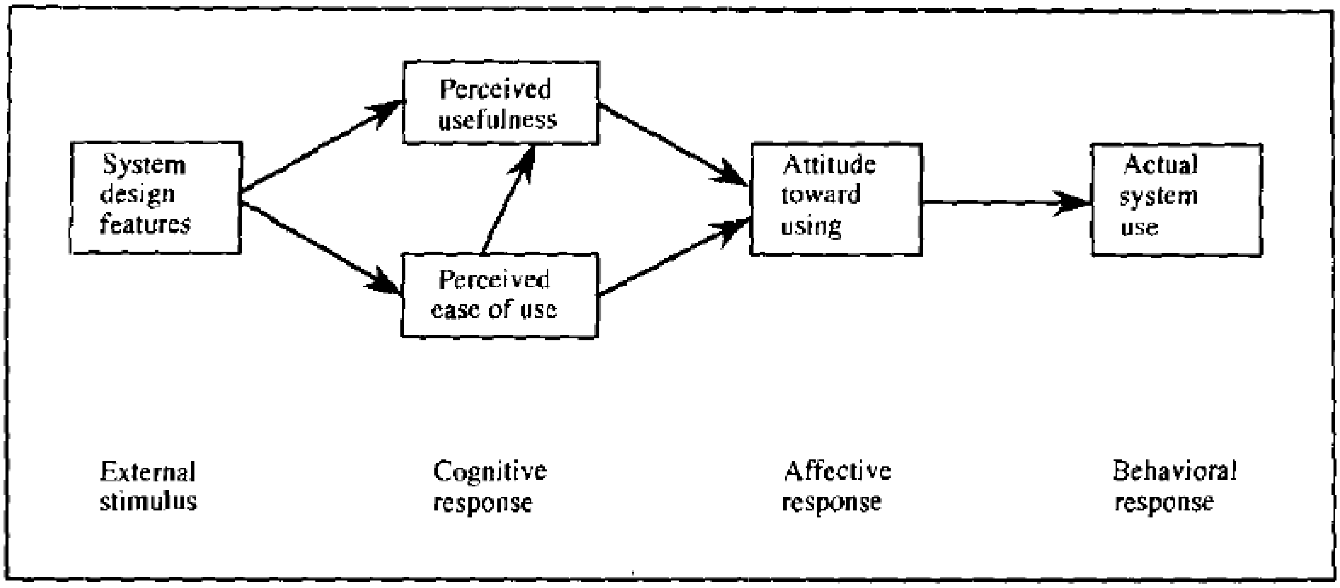

Figure 3. Technology Acceptance Model: TAM2 (Davis, 1993)[4]

[4] From “User acceptance of information technology: System characteristics, user perceptions and behavioral impacts” by F.D. Davis, 1993 (Fig 1). *International Journal of Man-Machine Studies, 38*, p. 476, © 1993 reproduced with kind permission from Elsevier Press

Despite the addition of attitudes towards using the technology, the TAM was incomplete. In 2000 Davis and his colleague Venkatesh collaborated in developing an extended TAM model they called TAM2 (Venkatesh & Davis, 2000). The variable ‘subjective norm’ was taken from the Theory of Reasoned Action (Fishbein & Ajzen, 1975) on the grounds that even if people do not personally wish to use a technology, they may do so anyway if influential people think they should. For the purposes of TAM2, the variable ‘subjective norm’ was defined as whether use of a new information system was perceived as voluntary or mandatory within a work setting.

After conducting four IT field trials, Venkatesh and Davis found (somewhat confusingly) that when technology use was *mandatory*, ‘subjective norm’ was more predictive of technology use than perceived usefulness and ease of use. However when the technology use was *voluntary*, ‘subjective norm’ was no longer a predictor of use. Therefore, in a voluntary context, the key predictors of technology acceptance reverted to being the variables of perceived usefulness and ease of use. To clarify, this implies that when people feel they have to use the technology - they will use it: regardless of how useful or easy to use they think it is. Conversely, when technology use is voluntary, perceived usefulness and ease of use are important to acceptance.

Can technology acceptance models generalise to eldercare robot acceptance?

This operationalisation of the variable ‘subjective norm’ in TAM2 is questionable, and the findings appear somewhat redundant (i.e. people who have to use the technology tend to use it). Nonetheless, mandatory vs. voluntary use may be a useful variable to consider in an eldercare HRI context. There may be some potential eldercare robot users for whom the use of the robot *cannot* be mandated (e.g.

older people and their families) and some potential users who *are* mandated to use the robot as part of their employment contracts (e.g. caregivers).

This implies that perceived usefulness and ease of use may be more important to older users who likely have a choice of using the robot or not, and less important for ensuring robot use amongst employees who are required to use the robot. However, as Davis (1993) points out, the goal of technology acceptance research is not to coerce people into using technologies that are 'un-useful' and difficult to use. Rather, robotocists may benefit from being mindful that if people who have little choice over their technology use, *are* using, or appear to have 'accepted' the technology, that does not necessarily mean they are finding it useful or easy to use.

TAM strengths and limitations

Even critics acknowledge the contribution of TAMs to furthering understanding of technology acceptance. The key merits of the TAM are considered to be that the TAM is both parsimonious (making it relatively easy to apply) *and* predictive of technology acceptance (e.g. Bagozzi, 2007; Legris, Ingham, & Collerette, 2003). Another TAM contribution is the focus on users' subjective perceptions, rather than objective measures. A third TAM contribution is the determination that, of the two major predictors - perceived ease of use and perceived usefulness - the latter is the more important variable. However despite the TAMs considerable contributions to the field of technology acceptance, the model is not without limitations. Some TAM limitations are more general in nature, and some limitations may be more specific to an eldercare HRI context.

A general limitation is the questionable operationalisation of some constructs. As discussed in the previous section, the variable 'subjective norms' may not be well defined in the TAM. Another TAM2 variable which may not be well operationalised is attitudes (Figure 3). In the TAM2, technology attitudes are defined as 'behavioural attitudes towards technology use'. As this operationalisation relates to attitudes towards the *use* of the technology, attitudes towards the technology *itself* may not be addressed. A merit of the TAM, its parsimony, may also be a limitation. There are variables which have been shown to be predictive of technology acceptance, such as age of the user (Czaja et al., 2006), which are not included in the model.

Another general TAM limitation is that the core construct of 'technology acceptance' is not defined. (Davis, 1989, did however present two outcomes; 'self-reported use' and 'self-reported continued use', that presumably indicated technology acceptance.) In the absence of a firm definition of what constitutes 'acceptance', different researchers have to operationalise acceptance as best they can. This may impede the progress of technology acceptance research in several ways. It may impair comparisons between studies with different operationalisations of technology acceptance. Secondly, if acceptance is inadequately operationalised it may invalidate study findings.

Issues around the operationalisation of 'acceptance' highlight another possible TAM limitation. Despite Davis proposed the variables of 'use' and 'continued use' were related but discrete outcomes (i.e. there were some differences between the variables that predicted whether someone would *start* using a technology, and the variables that predicted whether they would *continue* to use the technology). These differences included perceived ease of use being a significant predictor of use for naïve users, but not for current users (Venkatesh & Davis, 2000). However the TAM does not accommodate these differences. As currently the vast majority of older people and eldercare stakeholders are not current robot users, this lack of consideration of these differences may be a limitation in the application of the TAM to the development of acceptable eldercare robots.

There are also research method issues that may limit the generalisability of TAMs to an eldercare context. One is that the majority of TAM studies have been conducted with young people and with simpler technologies such as cell phones, computers and information systems, rather than robots (Bagozzi, 2007; Flandorfer, 2012; Heerink et al., 2010). Another issue is that most of the studies have been conducted in work settings with employees as participants. This may generalise well to an eldercare robot context where robots are intended for deployment in an eldercare service environment, and the intended users are employed caregivers or health professionals. But it may be a limitation if the eldercare robot is intended for a non-organisational environment and the intended users are older people.

The Unified Theory of Acceptance and Use of Technology (UTAUT)

Perhaps mindful of some TAM limitations, Davis and Venkatesh continued searching for ways to enhance the prediction of technology acceptance. The next stage was to synthesise eight models of user acceptance into one. The resulting model was termed the Unified Theory of Acceptance and Use of Technology (UTAUT:Venkatesh, Morris, Davis, & Davis, 2003).

In addition to the TAM, the eight models the UTAUT is derived from include the Theory of Reasoned Action (Fishbein & Ajzen, 1975), the Motivational Model (Vallerand, 1997), the Theory of Planned Behaviour (Ajzen, 1991), the Model of Personal Computer Utilisation (Thompson, Higgins, & Howell, 1994), and the Innovation Diffusion Theory (E. M. Rogers, 1995). A number of other variables that might moderate or mediate technology acceptance were selected from the literature. Potential moderators added to the UTAUT were age, gender, technology experience, and the variable ‘subjective norm’ (from TAM2). A further four UTAUT additions were the potential mediating variables of voluntariness, performance expectancy, effort expectancy, facilitating conditions and social influence.

However, some of the ‘new’ UTAUT variables appear similar in construct to the TAM and TAM2 variables. Venkatesh et al. 2003 defined performance expectancy as the degree to which a person believes that using a particular system will enhance his or her job performance. Effort expectancy is defined as the degree of ease of system use. The variable of facilitating conditions was defined as the degree to which an individual believes that an organisational and technical infrastructure exists to support use of the system, and the variable of social influence was defined as the degree to which an individual perceives that other influential people believe he or she should use the system.

These UTAUT definitions for performance expectancy and effort expectancy are almost identical to those given for, respectively, perceived usefulness and perceived ease of use from TAM (Davis, 1989). Although not explicitly stated, it appears as though existing TAM constructs have been relabelled rather than all new constructs created. Confusingly, and possibly reflecting a lack of construct validity, examination of the definitions of voluntariness and social influence suggest *both* constructs have been operationalised in a way similar to that of subjective norm from TAM2.

To validate the new UTAUT, Venkatesh et al. (2003) conducted four workplace IT adoption studies. Results showed that the addition of the four moderators and four mediators did increase the proportion of usage variance explained. The finalised UTAUT model (Figure 4) accounted for 70% of the variance in intention to use the technology (the percentage of variance in actual usage behaviours accounted for by the UTAUT was not reported). The study results also indicated that, like the TAM, some initially significant predictors of usage (e.g. effort expectancy aka perceived ease of use) became non-significant over time.

Despite some possible overlap in the constructs of voluntariness and subjective norms, Venkatesh et al. (2003) retained both variables in the UTAUT. Variables *not* retained in the final version of the UTAUT include ‘attitude toward using a technology’. Similar to the TAM operationalisation of attitude, the UTAUT attitude construct is defined as an individual’s overall affective reaction to using a system. The rationale given for removing ‘attitude’ is that despite it being typically the strongest predictor of intention to use the technology, Venkatesh et al. found that the attitude variable (as operationalised by them) only significantly predicted acceptance when other constructs related to performance and effort expectancies are *not* included in the model. Venkatesh et al. conclude this indicates that any significant associations detected between ‘attitude’ and technology usage are spurious only, and result from the omission of other key predictors. However an alternate explanation is that the UTAUT ‘attitudes’ construct has been mis-operationalised as being very similar to performance and effort expectancy, and thus contributes little unique variance to the model.

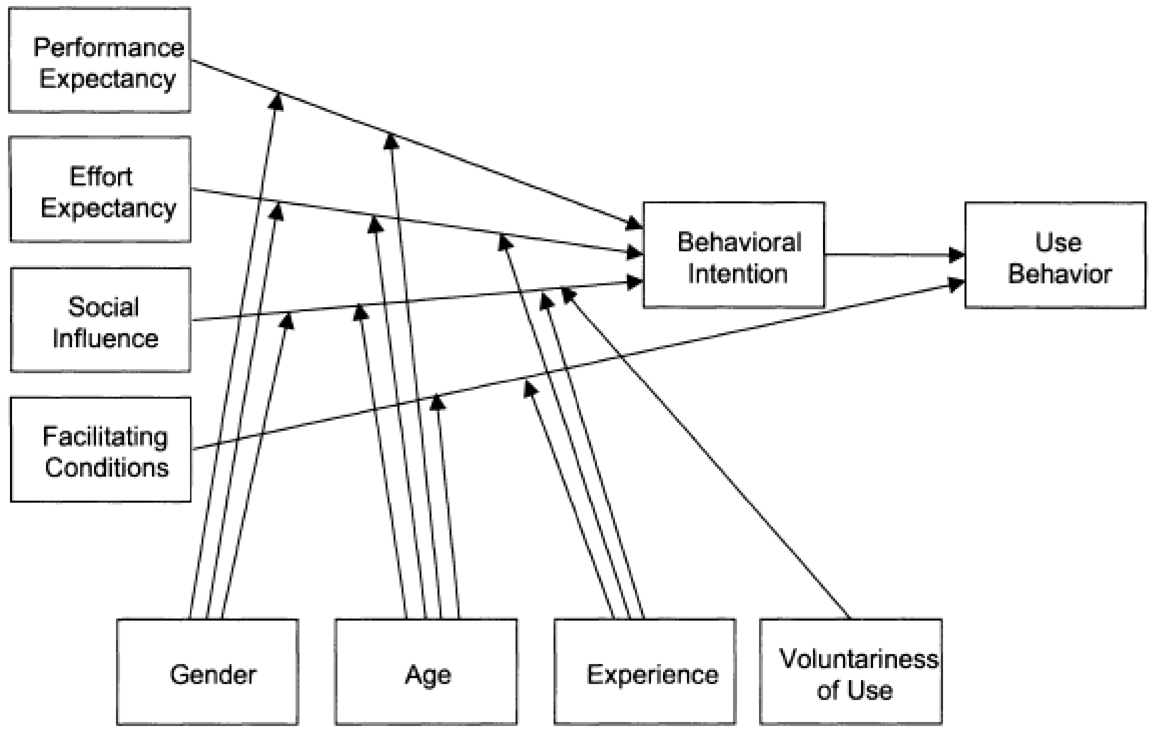

Figure 4. The UTAUT research model (Venkatesh et al., 2003)[5]

Age and gender effects were detected amongst the results of the UTAUT validation studies. Specifically performance expectancy (aka TAM perceived usefulness) was found to be more important to men and younger workers. In contrast, effort expectancy (aka TAM perceived ease of use) was found to be more important to women and older workers, but this importance decreased with increasing technology

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[5] From "User acceptance of information technology: Toward a unified view" by V. Venkatesh, M.G. Morris, G.B. Davis, and F.D. Davis, 2003, *MIS Quarterly*, (Fig 3) p. 447, © 2003 reproduced with kind permission of the regents of the University of Minnesota

experience. It is possible the relationship between age, gender and technology acceptance was moderated by technology experience (i.e. if older males had more prior technology experience than older women, this may have influenced their greater acceptance of similar technologies), however there is insufficient sociodemographic information presented in Venkatesh et al.'s paper to explore this. Regardless, age moderated all key relationships in the model. It is interesting that, considering that the age range of participants was probably not that wide age, age effects *were* found. Although age data were not provided, all participants were employees and therefore the majority could be expected to be less than 65 years old.

UTAUT strengths and limitations

Two key strengths of the UTAUT are that is it highly predictive of people's intentions to use technology and the inclusion of sociodemographic factors such as age, gender and technology experience. However, like the TAM, the UTAUT is not without limitations. As acknowledged by its authors, the UTAUT is predictive but not explanatory, i.e. it does not identify underlying mechanisms that influence predictors of acceptance. Venkatesh et al. (2003) identify the variables of computer literacy, societal effects, and gender roles, as candidates for research into these underlying mechanisms. They also suggest research on identification of causal antecedents of the UTAUT constructs. Possible antecedents proposed for further study include system characteristics, self-efficacy, task-technology fit, behavioural expectation, habit, and individual ability constructs such as 'g' (general cognitive ability).

The UTAUT has the strengths of the TAM such as its emphasis on users' perceptions and expectations of the technology but also contains some of the same limitations. As Venkatesh et al. (2003) acknowledge; like the TAM, the UTAUT has been designed for and validated within an organisational context and with information systems technologies, which may limit generalisation to other contexts. Additionally, like the TAM authors, despite the UTAUT authors recognising differences between naïve technology users and continuing users, they do not accommodate these differences in the models. A further TAM similarity is that the operational validity of some UTAUT constructs is questionable. Bagozzi (2007) is critical of the reliance of the TAM (and the theories of Reasoned Action and Planned Behaviour that the TAM is derived from) on "naïve and over-simplified notions of affect and emotions". Bagozzi advises caution with regard to research conducted with, or based on, these models or their constructs

Despite these criticism and limitations, technology acceptance models like the UTAUT and TAM have their strengths and have made considerable contributions to the field of technology acceptance. Not the least of which is to orient the thinking of technology designers to creating technologies that are acceptable to users, as well as the assessment of acceptance.

HRI studies based on the TAM/UTAUT

De Ruyter, Saini, Markopoulos, and Van Breemen (2005) appear to be amongst the first researchers to incorporate the UTAUT, and the concept of technology acceptance, into the design of an HRI study. The study assessed how people responded to two conditions of the interactive robotic iCat. In one condition the iCat was socially expressive and in the other condition it was socially neutral. Participants were 15 women and 21 men (age, occupation and ethnicity not reported) with "at least some basic experience of using email and the internet”. They were randomly assigned to one of the two iCat robot conditions. The ‘Wizard of Oz’ method[6] was used to operate the iCat.

Participants were given two tasks to complete with the iCat’s support. The tasks were to record some TV programmes using a DVD recorder and purchase several items via an online auction. The interaction was video recorded and questionnaires administered immediately after the interaction. To measure technology acceptance the item ‘intention to use’ was adapted from the UTAUT. Participants were asked how much they would (hypothetically) like to use the iCat at home after the experiment. Although the effect sizes were not reported, compared with people in the socially neutral iCat condition, participants in the socially intelligent iCat condition were significantly more interested in using the iCat in their own home. They also reported significantly more satisfaction with the DVD recorder.

However, the findings reported by De Ruyter et al. (2005) may need to be considered in light of a lack of participant sociodemographics. Not all variables from the UTAUT were assesed and missing information inluded participants’ ages and details of prior technology experience: both variables that have been shown to predict technology acceptance. It is possible that participants’ level of technology experience may have influenced their acceptance of the iCat. De Ruyter et al. noted that several participants struggled with the technologies, but did not say which iCat condition they were in.

The Almere model

Marcel Heerink’s research team from the Windesheim Flevoland University of Applied Sciences in Almere, The Netherlands, developed a model of robot acceptance. Named the Almere Model, the new

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[6] The ‘Wizard of Oz’ method refers to the use of a robot that appears autonomous; but in reality is being partly or completely remotely controlled by a human operator.

model was based on the UTAUT. Heerink et al. (2010) chose to modify the UTAUT rather than using the original model as they theorised that some aspects of the UTAUT may not generalise well to the eldercare robot context. These aspects inlcude the UTAUT not having been developed with elderly users and not accommodating aspects of interactions with more social embodied technologies such as robots and on-screen characters.

Construction of the Almere model included adding further variables to the UTAUT. One such variable was 'attitude'. As Venkatesh et al., 2003, had removed the attitude variable from the UTAUT, this was the first incorporation of both the UTAUT and an attitudes construct into an eldercare HRI context. Heerink et al. operationalised the attitude construct as "positive or negative feelings about the appliance[7] of the technology". The three attitude items in the Almere questionnaire were; I think it's a good idea to use the robot, the robot would make my life more interesting, and it's good to make use of the robot. Similar to the UTAUT attitude construct, the operationalisation of the Almere attitude construct appears to reflect attitudes towards *using* the technology and not attitudes towards the technology itself. Examination of the Almere attitude items suggest the first and last of the three attitude items relate to intentions to use the robot, and the middle item appears to relate to perceived benefits of use, or, rephrased, perceived usefulness. Similar to the UTAUT attitude items, the Almere model items appear less to reflect attitudes towards the robot as a whole, but more reflect some overlap with the variables of intention to use, and perceived usefulness.

[7] "…the *appliance* of the technology" is taken to mean the application, or use, of the technology.

In validating the Almere model, Heerink et al. (2010) conducted four studies using social agents and older people. Structural equation modeling was run on the pooled results. Two of the four studies were conducted with the iCat, one with a video of a Robocare robot, and one with a screen agent. In the first iCat experiment, the Wizard of Oz iCat had two conditions; socially expressive (e.g. using the participant's name and making eye contact) and not socially expressive. After an introductory session, older participants interacted with the iCat for approximately three minutes. Participants could use the iCat to set an alarm and get the weather forecast, or directions to the nearest supermarket. Questionaires were completed after the HRI. Results showed that, compared with people in the less expressive iCat condition, participants in the *more* socially expressive iCat condition had more intention of using the iCat, and found their iCat was more enjoyable to use and had more social presence.

In the second experiment; older participants were allocated to watch one of two short HRI videos. The videos showed a cylinder-shaped mobile Robocare robot interacting with an eldery actor. In one video the robot was responsive to the user and anticipated their needs (e.g. reminding them when they forgot their medications) and in the second video the robot was *not* anticipatory and only responded to the user upon request. A questionnaire was administered to participants after they viewed the video. Study results indicated, compared with peoples' ratings of the less responsive robot, people who viewed video of the more responsive robot had higher intentions to use that particular robot, scored more highly on the attitude variable, and rated the robot as more enjoyable and more useful. However, people in the more responsive robot condition also reported significantly more anxiety. This suggests that anticipating user needs may not be a completely desirable characteristic for an eldercare robot. However, as participants did not use the robot themselves, it is possible this finding is an artefact of the video methodology.

Heerink et al.'s (2010) third study measured actual use of an iCat in a retirement village over seven days. This study did not use a Wizard of Oz scenario as is typical for iCat trials; rather, participants interacted with the iCat via a nearby touch screen interface. Using the touch screen, users could select TV programmes, the weather forecast or a joke. At the start of the study, the 30 retirement home participants had a three minute introductory interaction with the iCat and then completed a questionnaire. The iCat was subsequently placed in a tearoom within the retirement village where participants and passers-by could use the robot as they chose.

The questionnaire was administered after the brief introductory session, but before the iCat was placed in the tearoom. The acceptance outcome variable 'intention to use' was included in the questionnaire. Results showed participants' intentions to use the iCat were predicted by perceived ease of use and attitudes. This means that the residents who had more positive attitudes towards the iCat and thought it would be easy to use, were also more likely to report intending to use it. People's intentions to use the iCat were positively correlated with how long they spent using it later in the tearoom. Similar to the second experiment with the Robocare robot videos, attitude also significantly predicted intention to use the iCat.

The fourth Almere study involved 30 older users (65-89 years) who owned computers. An on-screen cartoon character, Steffie, was installed on participants' computers. Steffie had been developed to assist older people in using the internet for tasks such as email, health insurance, cash dispensers, and railway ticket machines. After installation of 'Steffie', participants were given an introduction to the character's functions and asked to complete a questionnaire. Participants' usage of the character was assessed over the next 10 days. Study results showed participants' intention to use the screen character again was predicted by perceived usefulness and the attitude variable.

Results from the four studies were pooled to create the final Almere model, which differed from its parent UTAUT model in several ways. The acceptance outcome, or dependent, variable of 'actual use [of the technology]' has been removed as an outcome and replaced by 'intention to use'. Heerink et al. (2010) consider the Almere model demonstrates the importance of the attitude variable as it was one of the most significant predictors of intention to use the technology. They further suggest there may be "different types of attitudes" that should be investigated. Similar to De Ruyter et al.'s (2005) iCat study, Heerink et al. did not include the UTAUT moderators of age and technology experience in the Almere model despite the focus on eldercare robots and the use of older participants. (However, they do recommend these variables for future research.)

Overall, while these studies and models have limitations, which are inevitable in complex exploratory research, the findings suggest that concepts from technology acceptance type models can be usefully employed in an eldercare HRI context. Other models which may help address some UTAUT limitations are the Diffusion of Innovations and Expectation-Confirmation models. The applicability of these models to an eldercare HRI context is discussed in the next section.

Theory of Innovation/technology diffusion

Although the model of technology diffusion (also referred to as the diffusion of innovations) was one of the six models the UTAUT was synthesised from, the original technology diffusion model has some features which were not incorporated into the UTAUT. These missing features may be pertinent to the eldercare HRI context.

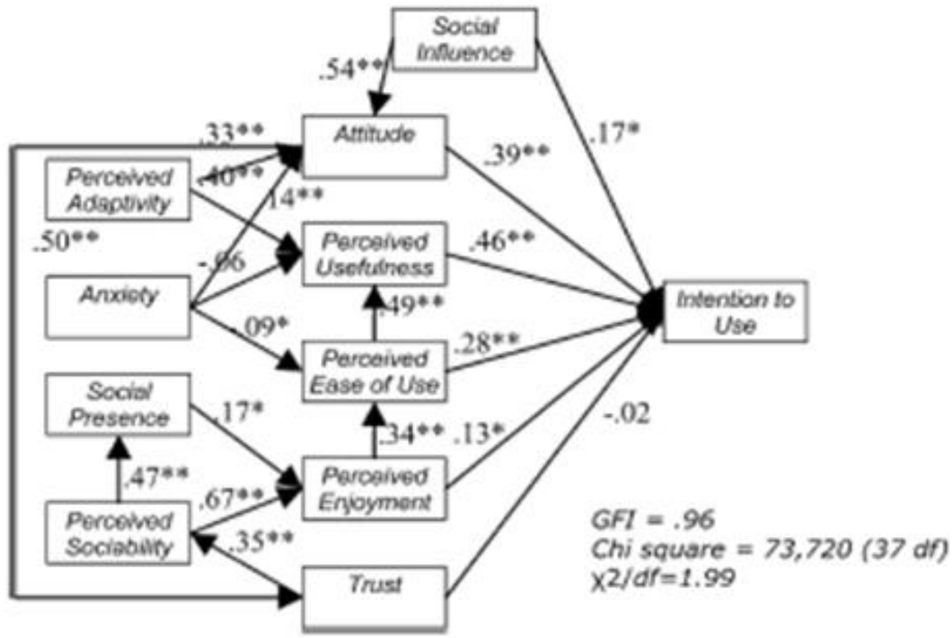

Figure 5. The Almere Model; final path estimates (Heerink et al., 2010)[8]

**p< 0.05, **p< 0.005*

The theory of diffusion of technology refers to the spread from the technology source to an adopter; of ideas, technical information, and actual practices within a social system. The spread is usually via communication and influence, and the form of these communications can alter an adopter's probability of adopting a system (E. M. Rogers, 1995). People like what they know, they tend to be cautious about

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[8] From "Assessing acceptance of assistive social agent technology by older adults: the Almere Model," M. Heerink, B. Kröse, V. Evers and B. Wielinga, 2010, *International Journal of Social Robotics*, (Fig.8) p. 372. © 2010, reproduced with kind permission from Springer Science+Business Media B.V.

novelty and change, and the rate of adoption tends to decrease the more radical the technology (Greve, 1998). As older people tend to be less familiar with technologies, and robots are ‘discontinuous’[9] technologies (Flandorfer, 2012), this technology diffusion issue appears relevant to eldercare robots.

A factor commonly associated with diffusion of innovations is adopters’ perceptions of benefits and costs. The costs of innovation adoption can be financial; or non-financial – such as perceived risks associated with adopting the technology (Wejnert, 2002). Direct costs usually relate to the financial situation of the adopter. *Indirect* costs may be less obvious, but can still significantly decrease adoption. Examples of indirect costs include technical uncertainty – such as how much training is required (Gerwin, 1988), or social uncertainty – such as anticipation of conflict or disapproval resulting from adoption (Rosero-Bixby & Casterline, 1993). The innovation diffusion barrier of both direct and indirect costs may be very applicable to an eldercare robot context. For example, the indirect cost of stigma has been identified as a barrier to older peoples’ adoption of some assistive technologies (Hirsch et al., 2000).

The *type* of adopter is also proposed to be associated with the rate of technology adoption. The innovation adopter categories proposed by E. M. Rogers (1995) have worked their way into common lexicon. The five categories are innovators, early adopters, early majority, late majority, and laggards. Characteristics of the people in the innovator category include being the youngest of the five categories in age, having high tolerance for risk, being very social, and having close links to scientific resources and other innovators. Like the innovator group, early adopters tend to be young in age. They also tend to have more financial resources, higher education, and be more sociable than later adopters.

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[9] Terms that are used interchangeably with ‘discontinuous’ to describe innovations that substantially different from existing technologies include ‘disruptive’ and ‘radical’.

The third category of technology adopters, the early majority, tends to be slower to adopt innovations compared with innovators and early adopters. People in the fourth category, the late majority, are sceptical about innovation and will only adopt after the majority of society has already done so. They also tend to have lower social status and have less discretionary income. The last self-explanatory adopter category, the laggards, are the last people to adopt an innovation. They tend to have an aversion to change and be of the older generations. Laggards tend to have lower social status, have less discretionary spending, and be least sociable - often only in contact with close friends and family.

However, as well as user characteristics influencing adoption rates, E. M. Rogers (1995) noted adoption is also influenced by charateristics of the innovation itself. Some of these are relative adavantage, compatibility, complexity, and triability. Relative advantage relates to whether the innovation give an advantage to adopters over non-adopters. Compatability relates to how easy is it for the user to assimilate the innovation into their life. The complexity of an innovation refers to the tendency for people who percieve that an innovation is difficult to use are unlikely to adopt it. And the innovation characteristic of trialability suggests that people who are are able to ‘try before they buy’ are more likely to adopt the innovation.

Some overlap of innovation diffusion constructs and TAM and UTAUT constructs are evident. This is to be expected, since the innovation diffusion theory was one of the theories from which the TAM was derived. However, some characteristics, such as trialability may be important in an eldercare context involving unfamiliar discontinuous technologies such as robots. Furthermore, older age is associated with the technology adoption category of laggards. While this is not explanatory, the categorisation supports the notion that older people may need a different approach to younger people when it comes to encouraging adoption of new technologies. The innovation diffusion theory also supports the notion that encouraging acceptance of discontinuous innovations, such as eldercare robots, may require a different methodology from that of continuous innovations, such as a new model of cell phone, or a new computer software programme.

Expectation-Confirmation Theory

Although derived from the TAM and innovation diffusion theory, amongst others, another model that may assist in addressing limitations of the UTAUT and Almere models is a modified expectation confirmation model. Bhattacherjee (2001) synthesised expectation confirmation theory from the consumer behaviour literature, innovation diffusion theory (E. M. Rogers, 1995), the TAM (Davis, 1989) and the theory of planned behaviour (Ajzen, 1991). The resulting model was called the Expectation-Continuation model of IT use (ECM-IT: Figure 6).

Two key aspects of the ECM-IT are the role of users' expectations of technology use and a distinction between first time and current users. Satisfaction (or not) with the technology will be determined by whether the users' expectations are met, unmet, or exceeded. The specific distinction between first time and existing users is that *existing* technology users will have their expectations formed by actual experience of the technology. In contrast, novice, or first time users, not having this prior experience will have had their expectations formed by other sources such as friends and family, the media and marketing materials. This distinction between novice and current users was noted by the TAM and UTAUT authors, but not incorporated into their technology acceptance models. No HRI studies have been located that have used the ECM-IT.

Models- conclusion

Models can provide a useful theoretical basis from which to assess human-technology interactions, but do not usually address the specifics of *how* to measure them. Determining *which* variables of the complex and variable HRI are important to acceptance can be daunting in an emerging multi-disciplinary field. Researchers have identified problems with interdisciplinary knowledge transfer and a lack of human-centred HRI evaluation methods and measures as a barrier to progress in human-interactive robotic intelligent systems (Burke, Murphy, Rogers, Lumelsky, & Scholtz, 2004). To redress this lack, several researchers have complied HRI metric toolkits.

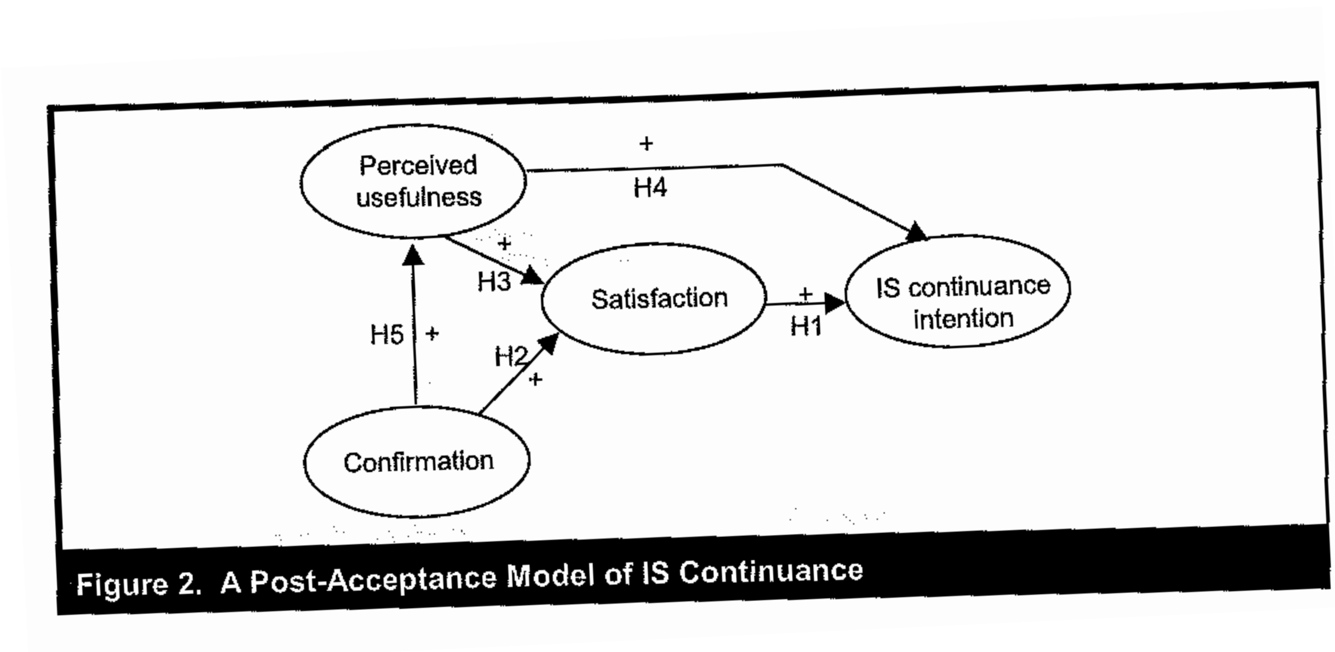

Figure 6. The ECM-IT: A post-acceptance model of information system continuance (Bhattacherjee,2001)[10]

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[10] From "Understanding information systems continuance: An expectation-confirmation model" by Bhattacherjee, 2001, MIS Quarterly, 25 (Fig 2) p. 356, © 2001 reproduced with kind permission of the regents of the University of Minnesota

2.2. Evaluation of robot acceptability

There are numerous challenges in evaluating the acceptability of interactive robots. As discussed in the previous section, the outcome 'technology acceptance' has not actually been defined in the technology acceptance models. It can be concluded from the operationalisation of technology acceptance model outcomes that acceptance can be inferred from intentions to use the technology as well as actual use of the technology. In contrast the definition of eldercare robot acceptance used in this thesis- that older people willingly incorporate the robot into their lives - reflects adherence, or long term continued use of a robot, constitutes full acceptance.

But regardless of how robot acceptance is determined; intentions to use, actual use, or long term use, how do researchers determine *which* HRI variables should be assessed in order to evaluate robot acceptability? Which of the *many* HRI variables predict acceptance?

While results from technology acceptance model research provide strong evidence for perceived ease of use and perceived usefulness being the dominant predictors of technology acceptance, there are two issues with these variables. One is that the models were not developed for embodied technologies such as robots in complex eldercare environments. It is possible that there are variables that predict robot acceptance that are unique to the HRI context, and these unique variables may be missing from existing generic technology acceptance models. Additionally, technology acceptance models have been criticised for being predictive, but not explanatory. This criticism is acknowledged by Davis (1993) and Venkatash (2003) who suggest a range of additional possible predictor variables to be studied, as well as suggesting that the antecedent predictors of perceived usefulness and ease of use should be determined.

A further barrier to determining which are the critical HRI variables requiring evaluation, is the diversity of HRI contexts. An HRI environment could be anything from a kindergarten to a privately owned home to an eldercare facility to a shopping mall to the army. Robot users could range from children to older people to soldiers.

In consideration of the impossibility of developing HRI evaluation methods that address all possible HRI scenarios, Steinfeld et al. (2006) focused on developing an HRI assessment toolkit for a search and rescue robot-human team scenario. However, despite the HRI context, most of the HRI variables that Steinfeld et al. propose for evaluation refer to more technical aspects of the robot (e.g. manipulation, communications; delay, jitter, bandwidth, system performance, situation awareness, navigation etc.) and there is relatively little consideration of human user.

However, Steinfeld et al.'s (2006) HRI evaluation toolkit does offer some human-centred HRI variables, or user-metrics, for evaluation. Although not intended for an eldercare robot context, some of these HRI variables may be particularly relevant to eldercare HRI. Under the 'user metrics' section, Steinfeld et al. discus how performance shaping factors (PSFs) can influence human behaviour and performance. PSFs include operational factors, equipment factors, task factors, external environmental factors, and personal factors. The latter includes stress, motivation, and training. This may be important for eldercare robot acceptance. Inadequate training for older people has been identified as a barrier to acceptance of assistive technology (Magnusson, Hanson, & Borg, 2004).

Another user-metric listed by Steinfeld et al. (2006) is 'human role'. Five different human HRI roles are proposed; supervisor, operator, mechanic, peer, and bystander (Scholtz, 2003). People in different HRI roles may require different information. While the specified roles reflect the authors' search and rescue focus, the concept of multiple human HRI roles is applicable to the eldercare environment with its multiple eldercare stakeholder categories. For example potential older users may have quite different motivations for using (or not) healthcare robots compared with the motivations eldercare service providers may have for purchasing (or not) eldercare robots. Practical and informational resources provided to eldercare stakeholders about eldercare robots should accommodate these different motivations.

Multi-disciplinary methodology challenges are apparent in the HRI category of 'social metrics', where Steinfeld et al. (2006) consider the difficultly of determining whether engineering, psychological, or sociological metrics are best for assessing robot 'social effectiveness'. In consideration of the diverse HRI literature, Steinfeld et al. suggest five social assessment HRI metrics; interaction characteristics, persuasiveness, trust, engagement, and human compliance. The latter metric of human compliance may be influenced by robot social characteristics such as appearance and social norms. Assessment of effectiveness of robot design characteristics can be assessed by human compliance with a specified HRI task. For example, in an eldercare environment, the effects of different robot appearances could be measured against an older person's compliance with a robot's medication management programme.

Under the 'operator performance' category, Steinfeld et al. (2006) list the HRI metric of 'accuracy of mental models of device operation'. This metric describes how stimulus-response compatibility, design affordances, and operator expectations, can all impact human performance. The benefits of matching robot interface displays and controls to human mental models may include reductions in mental transformations of information, faster learning, and reduced cognitive load. This may be relevant to an eldercare context for several reasons. One reason is robot design that 'affords', or promotes, intuitive use will likely improve acceptance amongst older people who have low levels of technology experience. Another complementary reason is some older people may have a high cognitive burden due to fatigue and dementia type conditions. Minimising the cognitive burden of using a robot may increase robot acceptance for these users.

While researchers such as Steinfeld et al. (2006) have published HRI evaluation tools that have task-oriented contexts such as search and rescue, other researchers, such as Kahn et al. (2007) have published evaluation tools that are oriented to a social human-like robot context. Kahn et al. begin justifying their focus on humanlike robots by acknowledging there are situations where a humanlike robot may be *dis*advantageous. For example, a machinelike, rather than humanlike, robot may be more suited to helping an older person with personal hygiene tasks where privacy is paramount, such as toileting. Another reason *not* to build humanlike robots is to avoid the dangers of the uncanny valley (Mori, 1970) – a phenomena that describes how people may respond negatively to an agent that is almost, but not quite, human. However Kahn et al. propose there are advantages to humanlike robots. One advantage is that human-like robot design may optimise intuitive human-robot communication, and another is that humanlike robot design may confer more ‘companionship’ benefits than non-human looking robots.

To assess the “success” of humanlike robots, Kahn et al. (2007) propose six psychological benchmarks; autonomy, imitation, intrinsic moral worth, moral accountability, privacy and reciprocity. Kahn et al., do not define success in a humanlike HRI context, rather they state that determining the correct HRI benchmarks will help answer the fundamental question of what it is to be human. Reflecting this philosophical mind-set, the proposed benchmarks are described from a human, not robot, perspective.

For example, ‘autonomy’ in this framework refers to human perceptions of robot autonomy, not whether the robot is actually autonomous or not.

The discussion of the first benchmark of autonomy presents philosophical rather than practical issues. These include consideration of the associations between autonomy and morality, and the proposal that we will understand under what conditions people perceive humanoid robots as autonomous, when we understand under what conditions people attribute autonomy to themselves and others. The second benchmark is imitation (whether and how people will imitate robots). The third benchmark is intrinsic moral value. Kahn et al. (2007) claim that understanding whether people will accord humanoid robots intrinsic moral value, will illuminate the moral underpinnings of the HRI. The practical implications of this are not discussed, but some complex scenarios are presented as a method of assessing how much intrinsic moral value people believe robots have. The proffered scenarios involve people needing to choose between their own self-interest or a robot’s interest; such as whether a human should go out socialising in the evening or stay home with a humanoid robot who claims to be traumatised after a burglary.

The fourth ‘success’ benchmark is whether people will come to hold robots morally accountable for their behaviour. Again, no practical implications are offered, but the authors suggest this will increasingly become an issue as robots become more humanlike. A fifth benchmark question relates to privacy. Can humanoid robots, even if they are not networked with a survaillance system, infringe on human privacy? A rationale for the inclusion of the the sixth and last benchmark of reciprocity (i.e. “do unto others as you would have them do unto you”), is that reciprocity is commonly considered a central feature of the moral life.

In summary, the orientation of Kahn et al.'s (2007) paper is philosophical, with an emphasis on human perceptions of robot morality. Limitations of the paper include neither empirical support nor the provision of practical implications for these proposed HRI success benchmarks. However the paper appears more intended to stimulate debate around these concepts rather than to offer concrete solutions.

Another set of HRI evaluation guidelines that has focused on humanoid robots has been produced by Weiss, Bernhaupt, Lankes, and Tscheligi (2009). The authors synthesised the HRI evaluation literature (including Steinfeld et al.'s, 2006, HRI assessment toolkit), to produce an evaluation framework for human-robot collaboration with a humanoid robot. The authors also incorporated the UTAUT into their framework. Abbreviated to USUS, the framework has four evaluation goals; robot usability, social acceptance, user experience, and societal impact. Weiss et al. consider these factors as being most important to the integration of humanoid robots into a human working environment.

It is unclear why Weiss et al. have focused on humanoid robots (nor is 'humanoid' defined), but, like Kahn et al. (2007) they suggest a humanoid robot form may provide a more socially-intuitive HRI interface than a non-humanoid one. Weiss et al. acknowledge this claim is largely untested and also acknowledge opposing claims that a non-humanlike robot form is best as humanoid features may generate unrealistic expectations, or even fear, of a robot's abilities.

Weiss et al (2009) use the term 'metrics' to describe the HRI variables that will determine whether a particular evaluation goal is met. Usability - one of the four USUS evaluation goals – contains six metrics; effectiveness, efficiency, learnability, flexibility, robustness, and utility (Weiss et al., 2009).

Another of the USUS evaluation goals – social acceptance - contains seven metrics. Four of the seven social acceptance metrics are derived from the UTAUT; performance expectancy, effort expectancy, self-efficacy, and attitude toward using technology. The latter metric of attitude is defined (similar to the UTAUT attitude construct) as “the sum of all positive or negative feelings and attitudes about solving working tasks supported by the robot”.

The third USUS evaluation goal of user acceptance has five metrics; emotion, human-oriented perception, feeling secure, co-experience with robots, and embodiment. The inclusion of embodiment is justified on the grounds that robot variables such as morphology impact on social expectations.

The fourth and last USUS evaluation goal - societal impact of humanoid robots – has four metrics; quality of life, health and security, working conditions and employment, cultural context and education. Weiss et al. mention the importance of educating people about robots to reduce the fear of being replaced. Although eldercare robots do not need to be humanoid; the latter metric of societal impact may have application for eldercare robots considering the complex social environment many older people live in.

The USUS framework also describes three types of HRI study environments; laboratory based, the Wizard of Oz technique, and field-based. Researchers are cautioned that while field-based studies are useful for testing a system in a realistic usage context, the additional variables make interpretation and analysis of data more difficult. Lastly, the USUS describes four user assessment methods; standardised questionnaires, physiological measurements, focus groups, and in-depth interviews. Overall, the USUS framework contains extensive HRI metrics, some of which appear relevant to an eldercare context, but (arguably beyond the scope of the framework) provides few methodologies for evaluating these HRI constructs and variables.

Other researchers, such as Bethel and Murphy (2010), have bridged the gap between theory and practical application. Their goal is to assist multi-disciplinary HRI researchers design better quality studies. In their review of HRI methodologies, not only do Bethel and Murphy highlight that existing HRI frameworks and evaluation tools tend to be technology focused, but they also tend to lack practical and validated implementation methodologies. Consequently, their review both advises increased measurement of psychological HRI aspects and suggests methodologies for application of these evaluation tools

Bethel and Murphy (2010) make two key recommendations for HRI experimental design and study execution. These are the use of larger sample sizes and triangulation of measures (the use of three or more study measures). Larger sample sizes will increase the likelihood of obtaining a more representative sample of participants. Larger sample sizes also increase the likelihood of detecting significant effects.

Triangulation of measures has several benefits. As all measures have their strengths and limitations, the use of multiple types of measures will help ‘plug gaps’ in the limitations of other measures. A second benefit is, due to the complexity of the HRI, the use of multiple measures will give a more comprehensive understanding of study events.

In recommending multiple measures, Bethel and Murphy (2010) describe the strengths, limitations and potential pitfalls associated with five methods of HRI evaluation. The methods are self-assessment, observational or behavioural measures, psychophysiology measures, interviews, and task performance metrics. Self-assessments, or self-report, can provide valuable information, but are also subject to confounds. These include, through lack of awareness, participants unintentionally misreporting their ‘true feelings’ about an object or interaction. Another potential confound is socially desirable responding, or impression management. This also describes situations where participants misrepresent themselves, but in this case they do so to present themselves favourably to researchers and peers, or to avoid responding in ways that cause them embarrassment.

The second recommended HRI assessment method is behavioural measures. These are defined as observing behavioural patterns in people in particular context to obtain information about a particular construct (B. Johnson & Christensen, 2004). While a benefit of behavioural measures is that they are more objective than subjective self-report measures, even behavioural measures are not free of potential confounds. The Hawthorne or measurement effect describes the phenomenon where the sense of being observed causes a person to alter their natural behaviour (Adair, 1984). The main advantage of the fourth recommended method - psychophysiology measures such as blood pressure and salivary cortisol - is that they are objective. It is difficult for people to consciously manipulate physiology measures.

The fifth recommended HRI assessment method is interviews. Like self-report, interviews can be rich sources of data but are also subject to similar confounds such as socially desirable responding. The sixth and last assessment method of performance metrics measures how well a person or team performs or completes a task. Bethel and Murphy (2010) make a number of other HRI methodology recommendations. These include; awareness of self-selection bias (participants who volunteer for HRI studies may not be representative of the general population and therefore their responses may not be representative); consideration of the HRI study environment (it should as closely as possible approximate the intended robot deployment environment); and also being aware that measures from social and individual psychology, and even from HCI, may not necessarily generalise well to HRI.

Conclusion

There are several models of acceptance that may be useful for understanding human acceptance of eldercare robots. Early results from HRI studies using the UTAUT and Almere models suggest promise for these models in an eldercare context. However there are issues with operationalisation of constructs, particularly robot attitudes. Additionally the models may not sufficiently address differences between older technology users and younger users, between novice and existing users, or differences between less familiar discontinuous technologies such as robots and more familiar continuous technologies such as computers or cell phones. The inclusion of aspects of other models, such as innovation diffusion and ECM-IT, may provide options for addressing aspects unique to the eldercare HRI.

There are a number of HRI variables that are recommended for assessment in order to determine the success of an HRI. Despite not being oriented to eldercare, some of these may be applicable to an eldercare environment. If eldercare robotocists have access to reliable and valid measures of robot acceptance, this may help progress the field by facilitating cross-study comparison. However, generic HRI variables, measures, and methods should be critically examined to assess their generalisability to a specialised context such as eldercare.

Despite some limitations, a common theme is that understanding peoples' expectations and perceptions of socially assistive robots, and their attitudes towards these robots, appears to be important to understanding their acceptance of robots. Consequently, people's attitudes towards robots and the role of these attitudes in the acceptance of robots are examined in more detail in the next chapter.

Chapter 3. Human attitudes towards robots

Preamble

As discussed in chapter one, it is common for people to hold attitudes about robots, even though they may have little knowledge or experience of robots. Qualitative reports indicate that there are mixed responses to the concept of eldercare robots. Some people have positive attitudes towards eldercare robots, others have negative attitudes. The proportion of people who have negative responses appears significant, and may be a barrier to the acceptance of eldercare robots. Indeed, Nomura, Kanda, and Suzuki (2006) noted high levels of (generic) negative robot attitudes during exploratory studies. Anticipating these negative attitudes may be a barrier to people engaging with robots they developed the Negative Attitudes towards Robots scale (NARS) specifically to better study the phenomenon.

Chapter outline

Section 3.1 of this chapter will review other studies that have assessed people's robot attitudes. The review will include the methodologies, contributions and limitations of these robot attitude studies. There will be a particular focus on the validity of operationalization of robot attitudes, and assessment of robot acceptance. (As the focus of this thesis is on the specific HRI context of eldercare robots, only studies with adult participants are included.)

As discussed in chapter one, qualitative reports also indicate negative attitudes towards robots are commonly associated with perceptions of robots as humanlike. Consequently, section 3.2 will examine theory and research that might explain this phenomenon, including anthropomorphism and the uncanny valley. Other topics include the possible origins of people's robot attitudes. Finally, the implications of robot attitudes in relation to robot acceptance are discussed.

3.1. Review of studies of robot attitudes in adults

Measures of robot attitudes

Attitudes are intangible positive or negative evaluations of an object of thought (Weiten, 2004). People's attitudes towards robots must be inferred from peoples' emotions or feelings towards robots, behaviours towards robots, and/or cognitions about robots. Consequently there are a variety of methods to assess people's attitudes towards robots. These methods include self-reports of affect/emotions, or intentions to use a robot, through to behaviour assessment and physiological measures. The studies of robot attitudes that follow are grouped by the methods they have used to assess attitudes towards robots.

UTAUT and robot attitudes

Ezer, Fisk, and Rogers (2009) used the UTAUT principles to assess people's robot acceptance in a mail survey. There were three, five-point Likert-style robot attitude items: Bad-Good; Unfavourable-Favourable; and Negative-Positive. There were also three, five point Likert-style items for 'intentions' (robot acceptance). The three intentions items were: Not Buy It-Buy It: No Intention-Strong Intention; and Unlikely-Likely. In the survey, participants were asked to respond to their idea of a domestic robot. Results for the mixed-age participants showed that age and robot experience were not related to robot acceptance. However, higher levels of technology experience were associated with higher robot acceptance. The results support the concept that people who are generally more familiar with technology are more accepting of robots. It may be that robot experience was not correlated with robot acceptance as too few people have experience with robots, or the robot experience participants did have, was not congruent with their mental schema of the domestic robot they were asked to imagine. It is unknown if this operationalization of robot attitudes would translate to an actual HRI.

Heerink et al.'s research group have combined the UTAUT with eldercare, and incorporated embodied robots. Prior to publication of Heerink et al.'s (2010) paper describing their Almere model of robot acceptance, Heerink, Kröse, Evers, and Wielinga (2009) published another paper containing additional detail on one of the iCat studies that was to later inform the Almere model. The methodology of this eldercare HRI/iCat study included both measures of attitudes and a behavioural measure of robot acceptance – how long participants used the iCat for. The study procedure involved older people being administered questionnaires containing a modified version of the UTAUT (later termed the Almere mode) following a brief interaction of the iCat. The questionnaire attitudes items were the same three items described in the Almere model (i. I think it's a good idea to use the robot, ii. The robot would make life more interesting, and iii. It's good to make use of the robot). After completion of the questionnaire, participants were given the option of using the iCat in a public tearoom over a seven day period.

Results from hierarchical regression showed robot attitudes and perceived ease of use of the robot were the only two (of six) variables to significantly predict intentions to use the iCat. In turn, intentions to use the iCat significantly predicted the robot acceptance outcome of how many minutes the participants actually spent using the iCat in the tearoom (however, the other two variables included in that regression, facilitating conditions and social influence, did not).

This finding that people's intentions to use a robot significantly predicted their actual robot usage is important. For practical reasons there is often no opportunity to measure people's degree of technology acceptance by assessing if they use, or continue to use, the actual technology. Consequently in the TAM and UTAUT, the outcome variable of ‘intention to use’ is used as a convenient substitute for actual use of the technology. However there are some issues with this assumption. In psychology it is well accepted that intentions are imperfect predictors of behaviours - to the extent the phenomenon is known as the intention-behaviour gap (Kollmuss & Agyeman, 2002; Sutton, 1998). For example, a meta-analysis of meta-analyses indicated that behavioural intentions explain, on average, 28% of the variance in actual behaviour (Sheeran, 2002). In Heerink, Kröse, et al.’s (2009) study, the correlation between participants’ intention to use the iCat and how many minutes they actually spent using it was $r = .63$, $p <.00$. While this is a strong correlation, the strength of the association between the two variables is not at multicollinearity levels, i.e. the two variables are distinct, non-interchangeable, variables. Therefore peoples’ reported intentions to use a robot are predictive of, but not the same construct as, actual use of a robot.

While these findings need verification, they have two important implications for assessing acceptance of robots. One is that it appears that intentions to use a robot can sometimes be a valid interchangeable measure for use, or acceptance, of a robot. However the second implication is that while intention to use a robot may predict use of a robot, it does not mean that someone who indicates they intend to use the robot will definitely do so. This suggests that intention to use a robot *is* be a valid measure of acceptance, but is a weaker, less proximal, indication of acceptance compared with actual use of a robot.

Negative Attitudes towards Robots Scale: NARS

Tatsuya Nomura of Ryukoku University, Japan, developed the NARs to better understand the apparently high levels of negative attitudes towards robots (Nomura, Kanda, et al., 2006). The NARS items were derived from surveys, and measures of computer anxiety (Hirata, 1990) and communication apprehension (Pribyl, Keaten, Sakamoto, & Koshikawa, 1998).

The NARS was back-translated into English and validated in an HRI study (Syrdal et al., 2009). Factor analyses of the NARs resulted in some items being deleted to obtain a satisfactory Cronbach's Alpha of .80, and a tentative re-formulation of three NARs subscales. The resulting measure retained the three subscales and 11 items. The first subscale, Future/Social influence, contained three items: "1. I feel that if I depend on robots too much, something bad might happen"; "2. I am concerned that robots would be a bad influence on children"; and, "3. I hate the idea that robots or artificial intelligences were making judgements about things". The second subscale, Relational attitudes, contained five items: "4. I would feel uneasy if robots really had emotions"; "5. I feel comforted being with robots that have emotion"[11]*; "6. I would feel relaxed talking with robots"*; "7. If robots had emotions I would be able to make friends with them"*; and, "8. I would feel paranoid talking with a robot". The third and last subscale, Actual interactions and situations, contained three items: "9. I would feel very nervous standing in front of a robot"; "10. I would feel uneasy if I was given a job where I had to use robots", and, "11. Something bad might happen if robots developed into living beings. (Response options are not reported in Syrdal et al., but in the Japanese version, Nomura et al., 2006, response options are on a Likert scale from 1- strongly disagree, to 5 - strongly agree)

However, as can be seen from the items listed above, there are a number of issues inherent in the NARS which may impair its validity as a measure of robot attitudes. One issue is the assumption that

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[11] The three items marked with an asterisk are reverse scored.

robots have emotions. This both makes the measure specific to robots that have (or are perceived to have) emotions, and creates double barrelled questions. For example, item 5 “I feel comforted being with robots that have emotions”, is both asking participants to decide if they feel comfortable with robots that have emotions, as well as asking them to agree with the statement that robots have emotions. There are assumptions that the robot can both talk and converse (items 6 and 8), which precludes robots without these humanlike characteristics. As the NARS both presents robots as having humanlike characteristics of emotions and speech, and predominantly presents them negatively (e.g. items 1, 2, 3, 8, 11) it is possible the measure itself may have a priming or framing effect (Schacter & Buckner, 1998), and influence people’s responses (Tsui, Desai, Yanco, Cramer, & Kemper, 2011). Despite these possible confounds, the NARS has been used in a number of robot studies which have produced some interesting results.

In an early study, Nomura et al. (2006) used the NARS to assess associations between peoples’ negative attitudes towards robots and their communication behaviours. The robot research platform used was Robovie - a 120cm tall humanoid-type robot - and participants were comprised of 22 male and 31 female Japanese university students. Prior to meeting Robovie, participants completed measures of gender and age, the NARS, and an item on whether they had previously seen ‘acting robots’. Participants then entered a room where they were instructed to stop at a marked line and talk to the robot in front of them. During the video recorded interaction, the robot asked participants if they had recently experienced anything negative, and instructed participants to touch it.

Nomura, Kanda, et al. (2006) reported that, compared with people who had *not* previously seen “an acting robot”, people who *had* previously seen a robot stood 10% further away from the robot when they first entered the room, and took slightly longer to respond to the robot when it asked them a question ($p < .01$). There was also some gender differences found. Other results showed some associations between some NARS subscales and how the participants responded to the robots question, e.g. whether they talked about something related to themselves, n = 9, something not related to themselves, n = 39, or whether they did not speak, n = 3. However, due to translation issues, the results of the Japanese study are not easy to interpret. Furthermore there is a lack of outcomes that demonstrate association between negative robot attitudes and acceptability of the robot. Nomura et al. acknowledge results from the Japanese student participants may not generalise well to different populations.

Nomura, Kanda, Suzuki, and Kato (2008) extended the earlier 2006 study by adding a newly developed measure; the Robot Anxiety Scale. The scale has three subscales: Subscale 1 – anxiety toward communication capability of robots (example item - whether the robot might talk about irrelevant things in the middle of a conversation); Subscale 2 – anxiety towards behavioural characteristics of robots (e.g. what kind of movements the robot will make): and Subscale 3 – anxiety towards discourse with robots (e.g. how I should talk to the robot). Deviations from Nomura et al.'s (2006) methodology include the Robot Anxiety Scale being administered both before and after the interaction (however the NARS was only administered once - prior to the interaction: Nomura et al. propose attitudes are unlikely to alter over the short term). The state trait anxiety scale (STAI: Spielberger, Gorsuch, & Lushene, 1970) was also administered prior to the HRI.

Nomura et al. (2008) used a similar study methodology to their earlier 2006 study. 22 male and 16 female Japanese University students had a brief interaction with the robot platform Robovie. Participants were initially instructed by researchers to greet the robot. During the HRI the robot asked participants to tell it “one thing that recently happened to you”, and then instructed participants to “touch me”. Nomura et al. report their results suggest robot anxiety and negative attitudes towards robots are associated with behaviours such as time spent talking to the robot and touching it. Higher levels of the STAI, as measured at baseline, were associated with other baseline measures including more negative attitudes on the first subscale of the NARS, and more anxiety on the third subscale of the Robot Anxiety Scale. Limitations of both the 2006 and 2008 studies include the constructed nature of the HRI. Participants were instructed to speak to the robot and touch it, rather than a more naturalistic methodology of observing how people chose to respond to the robot.

Other research groups have also used the NARs. As part of the European Commission LIREC project (LIving with Robots and integrated Companions) Syrdal et al. (2009) used the English translation of the NARs to explore how robot behaviour variables impact on peoples responses. The methodology included programming a Peoplebot to behave in either a socially ignorant or socially responsive fashion during a simple HRI. Socially ignorant robot behaviours included taking a straight path in front of the participant (as opposed to the socially responsive behaviour of avoiding the participant), moving fast at all times rather than slowing around the participant, and waiting for the participant to ask for a pen to complete the measures rather than delivering the pen before it was requested.

Study participants were 14 men and 14 women aged between 18 – 55. All were recruited from a British University. The study method included participants evaluating the robot’s behaviour and personality after interacting with each of the socially ignorant and socially responsive versions of the robot. The NARs was administered once, but is it not clear from the Syrdal et al. (2009) publication at what time point this measure was completed (i.e. before or after the HRI).

Results indicated participants felt no difference in comfort or enjoyment levels between the two differently programmed robots. However, the higher overall NARs scores (more negative attitudes) were significantly correlated with higher enjoyment of the interaction. Participants with more negative NARs scores were also more likely to rate the personality of *both* the socially ignorant and socially responsive versions of the robot as more autonomous. For the socially responsive robot only, participants with more negative attitudes towards robots, not only rated it as more autonomous, but also as being less predictable, less controllable, and less considerate.

This last result was unexpected by Syrdal et al. (2009). It disconfirmed their hypothesis that socially responsive behaviours would be desirable in a socially interactive robot. They suggest this resulted from people being wary of more sophisticated robots. Despite this explanation for these unexpected findings, Syrdal et al. appeared to have concerns about the validity of the NARS. Syrdal, Nomura, Hirai, and Dautenhahn (2011) did not use the NARs in a subsequent survey of robot attitudes. The rationale provided for this omission was that the measure may not generalise well to a non-Japanese population

Despite these possible limitations, Syrdal et al.'s (2009) findings from the more and less socially responsive robot study indicate that the NARs could be used to assess associations between negative robot attitudes and other variables. However, similar to the Nomura et al. (2006, 2008) studies, methodological limitations of Syrdal et al.'s study include a lack of acceptance measures. This lack means it is unclear what the implications for robot acceptance are for the association between holding more negative attitudes towards robots and also finding it more autonomous. A further limitation of the study is that manipulation checks were not conducted. Consequently it is unclear if participants did perceive the robot's behaviours to be socially responsive and socially ignorant. For example – did participants perceive the robot bringing them an unrequested pen as a socially responsive or socially ignorant behaviour?

The NARs has also been used to assess associations between negative attitudes towards robots and the distance people like to have between themselves and a robot (Takayama & Pantofaru, 2009). This US study had 30 people of mixed gender aged 19 - 55 years (mean 28.9 years). Participants each had two robot-related tasks. They were instructed to approach a prototype PR22 robot as far as they felt comfortable, and then to allow it to approach them. Measures of the participants' personalities and the NARs were administered after participants had done both robot-approach tasks. Takayama & Pantofaru found that people who preferred a greater distance between themselves and the robot, also held more negative attitudes towards robots and had higher levels of neuroticism.

Bartneck et al. (2005) used the NARS to assess cross-cultural attitudes towards robots. A survey of 24 Dutch, 19 Chinese and 53 Japanese participants indicated that Dutch and Chinese participants held more negative attitudes on the 'social influence of robot' NARS subscale. An example item from this subscale is "I am concerned that robots would have a bad influence on children". However there are some methodological issues that cast doubt on the validity of the results. The issues include the 'Chinese' participants being Dutch Chinese, and there is no indication of whether they were born in the Netherlands or were immigrants; the ethnicity of '"the other" Dutch participants is not provided; there are very uneven numbers in the participant groups; "most" of the participants were university students (which may limit the generalizability of the results to other populations); and there are no outcome measures. The latter issue means that it is unclear if the results are due to cultural differences in attitudes towards robots, or the differences are due to cultural interpretations of the NARS (Syrdal et al., 2009).

Robot Attitudes Scale (RAS) and drawings

Emotions towards robots and a new measure of robot attitudes, the Robot Attitudes Scale (RAS), were used in a survey of retirement village staff and residents (Broadbent, Tamagawa, et al., 2009). The 11 item RAS assesses general attitudes towards robots. The items are on 8 point Likert scales with semantic opposites as anchors. The items are friendly-not friendly, useful-not useful, trustworthy-untrustworthy, strong-weak, interesting–not interesting, advanced-basic, easy to use-hard to use, reliable-unreliable, safe-unsafe, simple-complicated, and helpful-unhelpful. The Positive and Negative Affect Schedule (PANAS: D. Watson et al., 1988) was also used to survey participants' emotions towards robots.

Results showed that, compared with staff, residents were found to have significantly more positive attitudes towards robots and less negative emotions. However there was no difference between the two groups on positive emotions towards robots. The RAS Cronbach's alpha in this study was a high 0.92. The more negative staff response to robots may be explained by comments staff made during the study; indicating they were fearful of losing their jobs to robots.

A later HRI study also used the RAS in a blood pressure taking scenario with older participants. (Kuo et al., 2009). There were two age groups of mixed-gender participants in the study; 29 participants aged 40 - 64 years (mean 55.90 years), and 28 participants aged 65 and older (mean 73.07 years). Participants were a community sample recruited via GPs, and the majority were New Zealand European in ethnicity. The Peoplebot used in the trial had a moving face displayed on its monitor, and had a blood pressure device and cuff attached to it. The study procedure involved participants completing initial baseline measures before meeting the robot. The baseline measures included the RAS and participants' drawings of their idea of a healthcare robot. They next interacted with the robot and took their blood pressure with the robot's assistance (instructions and blood pressure results were both spoken by the robot and displayed on the robot's monitor).

After the interaction, participants completed more measures, including viewing video of their HRI. While watching the video, participants noted their thoughts and feelings that occurred at specific time points during the interaction. The most common thoughts participants reported related to difficulties with the blood pressure cuff, the comprehensibility of the robots instructions, and dislike of the robot's voice. Other frequent comments related to how the robot was unlike or like a human, and the robots facial features. However there was no difference in reported attitudes from before to after the trial, or between the two age groups. Hierarchical regression analyses showed that age, gender, and computer experience did not predict Quality of the Experience (i.e. how fun and natural the robot was: Berry & Hansen, 1996), but baseline emotions and attitudes did (Broadbent et al., 2010).

However Kuo et al. (2009) did find a gender difference. Men had significantly more positive attitudes than women in relation to the usefulness of healthcare robots and their future potential. In contrast, the expected age differences were not found. Aside from a non-significant trend for the older age group to be more uncomfortable with the robot taking their blood pressure, the lack of differences between the two age groups was unexpected considering the age-related differences reported in the technology acceptance literature (Charness & Boot, 2009; Venkatesh & Davis, 2000).

Kuo et al. (2009) proposed one explanation for this is that, unlike much of the related literature which compared young people with older people, their study compared middle-aged people with older people. In relation to the gender results, prior computer experience was not associated with gender, so that does not explain why men were more accepting of the concept of healthcare robots. However this result may arise from the particular computer experience item used in the study. Inspection of the response options for this item shows participants were asked to rate their level of computer experience from 1 ‘not at all’ to 8 ‘extremely’. These response options are subjective, and the use of response items with more objective descriptions of computer skills, such as using email, internet banking etc., may give different results.

There were several interesting results from the participants’ healthcare robot drawings. A distinctive feature of the drawings was that people either drew a humanlike robot or a box-like robot. Furthermore, people who drew a humanlike robot had significantly greater increases in both diastolic and systolic blood pressure. As both groups interacted with the same robot, this result indicates that preconceptions of robots as more humanlike are associated with stress and heightened physiological arousal. There was a non-significant trend for the participants who drew larger drawings to have greater increases in systolic blood pressure during the HRI. This finding is in line with previous work with drawings in health care settings where drawing size is correlated with more anxiety about the drawing object and more adverse outcomes (Broadbent, Ellis, Gamble, & Petrie, 2006; Broadbent, Petrie, Ellis, Ying, & Gamble, 2004). Drawings may be a useful method for measuring robot related anxiety, but more research is needed to assess if these results generalise to different HRI contexts.

HRI studies indicate that peoples’ attitudes and perceptions of robots are associated with their responses to robots. While ‘general attitudes’ or perceptions may be useful in predicting responses to robots, understanding specific attitudes or perceptions – such as perceived usefulness and ease of use – may also be necessary for developing acceptable eldercare robots.

Emotions towards robots

There has been a small amount of research on the influence of people's emotions, or affect, towards robots on their robot acceptance. There is some evidence that negative emotions (but not positive) can cause people to rapidly recalibrate negative evaluations of out-groups (Monteith,1993). Affective evaluations may be faster than cognitive evaluations, suggesting they are more readily accessible (Verplanker, Hofstee, & Janssen, 1998).

In their 2008 study described previously, Nomura et al. developed the 11 item Robot Anxiety Scale as they believed negative emotions towards robots were an important research. Compared with negative attitudes towards robots, emotions may be more sensitive to psychological changes in response to even a brief HRI. However the validity of the Robot Anxiety Scale as a measure of affect or anxiety has not been established. There may be some cross-cultural issues, and the items (as translated into English) do appear to have construct overlap with the NARS. The two measures were significantly correlated in the study.

A different study manipulated a robot's behaviours to assess the effects on human emotional responses. 45 New Zealand university students were tasked with leading a B21r robot along a 16 metre marked path (Broadbent, MacDonald, Jago, Juergens, & Mazharullah, 2007). The students were randomised into either a 'good' or 'bad' robot condition. In the bad robot condition the robot was programmed to perform erratically in following participants. In the good robot condition the robot was programmed to follow participants consistently. After the HRI, participants completed a five section questionnaire in addition to their sociodemographics. The later included participants' previous robot and technical experience. Measures included the well validated Positive and Negative Affect Schedule (PANAS: D.

Watson, Clark, & Tellegen, 1988), a Quality of the Experience measure (used in a previous HRI study: Wang, Lignos, Vatsal, & Scassellati, 2006), and a measure of social interaction designed for human-human interaction. An exemplar social interaction item is participants were asked to rate the extent to which they influenced the interaction (Berry & Hansen, 1996). Like the Kuo et al (2009) BP healthcare robot study, participants also viewed video tapes of their interaction and noted thoughts and emotions they experienced at different points.

Results of the good/bad robot study included differences in emotions in response to the interaction. Participants in the *bad* robot condition thought the robot influenced the interaction more than they had. They also had decreased positive emotions and increased negative emotions. In contrast, participants in the good robot condition thought *they* influenced the interaction more than the robot and had increased positive emotions (but no change in negative emotions). Furthermore, compared with participants in the bad robot condition, participants in the *good* robot condition thought robots would be more useful in hospitals and rated the quality of the HRI experience more highly.

These results suggest that a robot's behaviour can not only influence peoples' emotions, but also their perceptions of the robot. Broadbent et al. (2007) suggest their results indicate that perceptions of a robot's reliability and predictability are important for acceptance of robots in a healthcare context. However due to the non-healthcare nature of the study task (guiding a robot around a course), Broadbent et al. also suggest that generalisation of the results needs to be done with care.

Behavioural measures

Despite having previously used the NARs in their study of cultural differences in robot attitudes (Bartneck et al., 2005). Bartneck, Van Der Hoek, et al. (2007) did not use the NARS in a more recent study. They used a very different methodology to assess people's attitudes towards iCats with different personalities. Drawing on Milgram's classic 1963 study on obedience to authority, 33 male and 16 female participants (aged 18 - 59, mean 24.6 years) from a Dutch University were asked to play Mastermind with assistance from an iCat. Participants were allocated to one of four iCat personality conditions which varied on 2 (intelligence) x 2 (agreeableness). Participants were instructed that, at the end of the study, they were to turn off the robot using a slow voltage dial. Participants were not informed that when they did actually begin to turn off the iCat, the robot would start pleading with them not to be turned off.

Outcome measures used in Bartneck, Van Der Hoek, et al.'s (2007) study included 'hesitation' (how long participants took to turn off the iCat), and various ratings of the game attributes, the robot's attributes, and the HRI relationship. The main finding was that there was no difference in how long participants took to turn off the two *less intelligent* iCat conditions - regardless of whether it was agreeable or disagreeable. In contrast, participants took almost three times as long to turn off the *agreeable* version of the more intelligent iCat as they did the *disagreeable* version of the more intelligent iCat. Limitations of the paper include that it is not reported if this reported difference is statistically significant, nor what the effect size is. A further limitation is there are no direct measures or manipulation checks of the independent variables of interest, i.e. the iCat's perceived intelligence and agreeableness.

Bartneck, Van Der Hoek, et al. (2007) offer several explanations for their findings. These include reciprocity, and a discussion of the differences between the Christian tradition where things either have a soul or not; compared with the Buddhist tradition, where there is no clear distinction and even non-living things can have a soul. Bartneck et al. recommended further research on the issue, including the use of an animacy measure to determine associations between intelligence and lifelikeness. However a final limitation of this study is that it is implied that the (presumably significant) differences in how long participants took to turn off the iCat with differing personalities are caused by something inherent in the robot. However as the study is not controlled it is possible that similar results would have been obtained if *any* object, such as a computer or a microwave oven had been programmed to manifest similar behaviours.

Like Takayama and Pantofaru's (2009) study with the PR22 robot, Koay et al. (2007) used approach distances to assess people's attitudes to a more humanlike or a more machinelike Peoplebot. The more humanlike Peoplebot had mechanical-looking arms and a metal mask-type face. The machinelike version had no arms and a small camera in place of a head. Eight hours of HRI sessions were spread over a five week period. The longer duration of this trial allowed assessment of any habituation effects. Results showed the 12 university staff and student participants were more comfortable with the robot approaching closely after the five week period. The habituation effect was particularly marked with the more humanlike robot. At the beginning of the trial participants preferred the more humanlike Peoplebot to be further away from them than the machinelike robot, but by the end of the five weeks, participants had no preference.

Behavioural outcomes have been used both to assess acceptance of robots, and demonstrate the influence of robot attitudes on robot acceptance (Heerink et al., 2010).

3.2. To be [humanlike] or not to be [humanlike]

Section 3.1 describes general robot attitudes, but does not include the central concept of humanlikeness in robots.

What is a humanlike robot?

It is not clear what constitutes a ‘humanlike robot’. Robots come in many shapes and sizes, and their behaviour may vary as much as their degrees of freedom and the programmes available to operate them. With a few arguable exceptions such as the humanoid Geminoid (Nishio, Ishiguro, & Hagita, 2007), there is a currently a considerable gulf between a humanlike robot and a human-identical robot. However is a human-identical, or even humanlike, robot desirable or not? Despite some HRI researchers suggesting a humanoid form is the optimal form for a socially assistive robot (Kahn et al., 2007; Mori, 1970) a substantial proportion of potential robot-users state they do *not* want a robot to be humanlike (e.g. Arras & Cerqui, 2005; Khan, 1998; Lachs & Pillemer, 1995; Wu, Fassert, & Rigard, 2012).

However, generally details are not available on what specific *ways* a robot should not be humanlike. In other words – when people say they do not want a humanlike robot – what do they actually mean by that? Dautenhahn et al. (2005) found that although a majority of participants wanted a robot companion to communicate in a humanlike manner, a similar majority did not want a robot companion to have a humanlike appearance or behaviour. While useful, these categories of communication, appearance and behaviour are still general. This lack of specificity of what constitutes a humanlike robot does not just originate from lay participants. In defining a humanoid robot, DiSalvo, Gemperle, Forlizzi, and Kiesler (2002) propose that ‘humanoid’ does not necessarily mean a robot looks like a human; rather that it looks more like a human than anything else. Similar to Dautenhahn et al., DiSalvo et al. consider that robot humanlikeness will be determined by characteristics in addition to physical appearance, such as expression, communication, and behaviour. Considering robots are very diverse in their appearance, functionalities, and behaviour; in order to design acceptable robots, more research is needed on which specific aspects of humanlikeness in robots tends to cause discomfort in humans.

So why *are* some people uneasy about the idea of humanlike robots?

The answers to that question may help in the development of more acceptable robots.

Media portrayals of robots

Some answers may come from popular media depictions of robots. When lay people are asked about robots they tend to refer to fictitious robots from science fiction films, TV programmes, and literature (Khan, 1998; Kriz, Ferro, Damera, & Porter, 2010; Ray, Mondada, & Siegwart, 2008; Scopelliti et al., 2005). This suggests that people's concepts of robots largely arise from exposure to fictitious media representations, combined with little experience of real robots. In recognition of this, and also in recognition of the possible impact of these media representations on robot acceptance, several researchers have analysed media portrayal of robots.

Khan (1998) noted common robot themes in science fiction media were 'the dangerous machine'; the desire for life or consciousness; the 'too intelligent' robot; and human fear of being replaced by robots in both domestic and industrial settings. As part of the study, Kahn asked a small group of participants what words they associated with the word 'robot'. The most frequent responses were; "strange thing", TV, horror movies, industrial robots, and programmed machines. A larger group of participants were asked to draw a robot for their home. The resulting drawings showed mechanical looking robots with few realistic human features, and were clearly influenced by media depictions of robots.

Another HRI researcher analysed how robots are portrayed in popular American films, such as Star Wars, Transformers, AI, Short circuit, and RoboCop (Kriz et al., 2010). Robots were found to be commonly portrayed as possessing cognitive capacities such as vision, spatial cognition, and language. They were *less* commonly portrayed as possessing social capacities such as stereotyping/prejudice, conformity, and close relationships.

In an interesting extension of Kriz et al.'s (2010) study, engineering students were seated in front of a stationary Peoplebot and asked what capabilities they thought the robot possessed. The participants' responses mapped very closely to the typical capacities possessed by fictitious robots in popular film. The four capabilities participants rated the Peoplebot as being most likely to possess were cognitive ones; short term memory, vision, spatial cognition, and language. The five capabilities participants rated the Peoplebot as being *least* likely to possess were social ones; prosocial behaviour, conformity, aggression, stereotyping and close relationships. The results strongly support the notion that people's expectations about robots are informed by popular media. In particular that robots are high in cognitive capabilities and low in social capabilities.

However Kriz et al. cautioned that participant responses may have been influenced by the specific robot (a Peoplebot) used in the study. Another possible limitation of this study is that responses from the engineering student participants may not be typical of the wider, less-technical, population. More studies with different robots and different populations are required to endorse or disconfirm these results.

Anthropomorphism and agency

The human predilection for anthropomorphism may also underpin people's discomfort around the concept of humanlike robots. Anthropomorphism is the attribution of humanlike qualities to a non-human agent or object. The proposed ‘function’ of anthropomorphism is that it helps people understand and predict the world around them, and the people, agents, and objects contained within it (Epley, Waytz & Cacioppo, 2007). The proposed mechanism of anthropomorphism is when faced with some unknown agent; people will access readily accessible known rules or schemas about human behaviour and apply them to the agent.

Perceptions of anthropomorphism arise from an interaction between the human observer and the object or agent under observation. In an HRI context, characteristics of both the human and the robot will interact to influence if, and how, the human anthropomorphises a robot.

Robot characteristics that promote anthropomorphism

Physical features

A robot’s appearance can affect perceptions of humanlikeness. DiSalvo et al. (2002) asked participants to rate the humanlikeness of images of humanoid robot heads – some real and some fictitious. Results showed that the presence of a nose, eyelids, and a mouth contributed the most to perceptions of robot humanlikeness. However regardless of which particular facial features a robot head possessed, the *more* facial features they had, the more humanlike it was rated as being. This latter result suggests that while some anthropomorphic cues may be stronger than others; generally they may act in a summative fashion.

However, it seems that robots do not need to have any realistic human facial features, or even a humanlike form, to be anthropomorphised. People can anthropomorphise even clearly non-humanoid and machinelike robots, such as their Roomba vacuum cleaner (Forlizzi & DiSalvo, 2006). On the grounds that humanlike robots appeared to be unacceptable to some people, a guiding design principle of the Care-O-bot was that it be non-anthropomorphic (Parlitz et al., 2008). However, when the robot was trialled in a rest home some residents referred to the Care-O-bot as 'he' (Fraunhofer, 2011). These findings have several implications for robots. One is that that there may be a dose effect with perceptions of anthropomorphism, or humanlikeness, in robots. While even the most minimal of cues can trigger anthropomorphic perceptions, the more cues there are, and/or the stronger the cues, the stronger the perceptions of humanlikeness may be. Another implication of this is that features common to robots – such as apparently agentic movement – are such strong anthropomorphic cues (Nass, Steuer, Henriksen, & Dryer, 1994). This implies it may be impossible to 'design-out' anthropomorphism in robots (Duffy, 2003). Consequently rather than robotocists aiming to design non-anthropomorphic robots, a better goal may be to aim for robots with 'adaptive' anthropomorphic features: robot features that optimise people's robot acceptance rather than alarm them.

Movement

An agent's movement can contribute to perceptions of lifelikeness and agency, but so can the *type* of movement. Participants who evaluated the different head tracking behaviours of a mechanical robotic torso, rated the robot's more erratic behaviours as more enjoyable and as having more intentionality, despite rating the robot's smooth tracking behaviour as more natural (Wang et al., 2006). Similar to the matching hypothesis (Kalick & Hamilton, 1986) Wang et al. suggest this unexpected result (that despite the robot with the more erratic movements being rated as *less* natural compared with the smoother-moving robot, it was also rated as *more* enjoyable and having more intentionality) may be due to the robots more erratic behaviour being congruent with its unnatural mechanical appearance. However, another (complementary) explanation is that the robot's unpredictable behaviour triggered anthropomorphic perceptions. In support of these interpretations, another study found the more closely a non-human agents' movement approximated human movement, the more mind people attributed to the agents, including robots (Morewedge, Preston, & Wegner, 2007).

There are a number of features common to robots that may predispose humans to perceiving robots as anthropomorphic, humanlike, or as possessing intentionality or mind.

Interactivity

Speech is a uniquely human characteristic that greatly enhances communication. Many socially interactive robots are equipped with this mode of interactivity and the use of natural language will likely promote anthropomorphic perceptions (DiSalvo et al., 2002). However the language does not have to be verbal. The non-verbal emotionally-responsive squeaking of the social robot Kismet is sufficient to encourage people to converse with it (Breazeal & Scassellati, 1999).

Uncertainty and unpredictability

Novel objects or agents are more likely to trigger perceptions of anthropomorphism or perceptions of an agent's mind. People attempt to reduce aversive uncertainty by accessing readily available schemas of human social rules to predict the behaviour of the novel agent (Bering, 2002; Waytz, Gray, Epley, & Wegner, 2010). For similar reasons, compared with predictable agents, agents that behave unpredictably are also more likely to trigger perceptions of agency or intentionality (Waytz, Morewedge, et al., 2010).

The novelty of robots could be one of several reasons why people are predisposed to anthropomorphise them. Most people have not previously interacted with a robot and therefore have little certainty about how a robot might behave. This uncertainty may trigger perceptions of anthropomorphism as people apply better known rules about human behaviour to the robot. This may enable them to better predict the robots behaviour and reduce aversive uncertainty. A logical extension of this explanation is that, as people become more familiar with robots and robot behaviour, they may anthropomorphise them less.

Malevolent agents

Agents, and even fellow humans, that produce adverse outcomes are likely to be perceived as having more intentionality, compared with agents that produce neutral, or even positive outcomes (Knobe, 2008; Morewedge, 2009). A person will perceive more pain if they believe someone hurt them intentionally, rather than by accident, and people are more likely to believe in an agentic God when they are contemplating suffering rather than salvation (K. Gray & Wegner, 2010).

This may be an important consideration for robotocists. If a robot is unreliable, users may ascribe more intentionality to it. In a bi-directional fashion, if people are more anxious at the prospect of interacting with a robot, they may perceive the robot as being more agentic. The proposed explanation for this tendency to attribute more mind in response to negative, rather than positive events, comes from evolutionary psychology. This is based on the concept that immediate survival is more dependent on understanding the causes of adverse events (in order to avoid them), than it is on understanding the causes of positive events (S. E. Taylor, 1991).

Human characteristics that promote anthropomorphism

Although a robot’s appearance and behaviour can affect people’s anthropomorphic perceptions, individual people can respond quite differently to identical robots. For example, two older men responded very differently to the robotic cat NeCoRo. One man was quite indifferent to the robot and the other man was enthusiastic – patting the robot and talking to it (E. V. Libin & Libin, 2003). Another study found family members anthropomorphised identical Roomba vacuum cleaners to varying degrees, from ignoring it through to talking to it (Forlizzi & DiSalvo, 2006). This suggests that characteristics of the individual human user influence human anthropomorphic perceptions, as well as robot characteristics.

Motivation for anthropomorphism

Motivation to understand an agent's behaviour is considered a key driver of anthropomorphism (Waytz, Gray, et al., 2010). Therefore the prospect of interacting with an unknown agent may heighten perceptions of anthropomorphism. Eyssel, Kuchenbrandt, and Bobinger (2011) found people ascribed more human personality characteristics to a version of the social robot Flobi that was more unpredictable, *but* only if they thought they were about to interact with it. Anthropomorphism may also be motivated by a desire to increase social bonding (Waytz, Gray, et al.). People who are lonely are more likely to ascribe mental states to pets and machines (Epley, Akalis, Waytz, & Cacioppo, 2008).

An 'advantage' of anthropomorphising uncertain agents (including other humans) is that, compared with figuring everything out from first principles, anthropomorphism is a relatively fast and energy-conserving process (Waytz, Gray, et al., 2010). This may explain why people are more inclined to resort to anthropomorphism (rather than generate more cognitively demanding causal explanations), when they are under cognitive load or when their cognitive reserve is compromised. People with Alzheimer's disease have been found to make more teleological, or anthropomorphic, attributions to agents, compared to healthy controls (Lombrozo, Kelemen, & Zaitchik, 2007).

Individual characteristics

While humans generally are prone to anthropomorphising, there are individual characteristics that enhance this tendency. These include cognitive impairment, loneliness, and less familiarity with technology -in general as well as robots. As these characteristics are also common to older people, it may mean that compared with younger people, older people are more strongly predisposed to anthropomorphise robots. This, combined with the anthropomorphic characteristics of robots, has important implications for the design and deployment of eldercare robots.

However, while anthropomorphism gives some clues as to why some people feel discomfort at the prospect of humanlike robots, it does not fully explain the issue.

The uncanny valley

Peoples discomfort with the idea of humanlike robots is not a modern phenomenon. In 1970, a Japanese researcher, Masahiro Mori, published a paper on the phenomenon he termed the Uncanny Valley. Mori proposes that people are increasingly satisfied with robots that become increasingly humanlike and more familiar – but only up to a certain point. That point is reached when robots become almost, but not quite, humanlike. It is proposed that it is this 'almost but not quite human' gap, that causes people discomfort, or a sense of uncanniness. Mori suggests the function of the sense of uncanniness resulting from the uncanny valley may be that of self-preservation. For example a sense of aversive uncanniness may be induced by an organism acting oddly due to disease or infection, and therefore the uncanniness is a threat signal to avoid that organism. Considering the current impossibility of bypassing the uncanny valley altogether by creating a human-identical robot[12] (which Mori states is the ultimate purpose of robotics), Mori recommends robot designers avoid the uncanny valley by erring on the side of designing clearly non-humanlike robots. However, as robots inherently contain anthropomorphic cues, Mori's

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[12] An unchallenged assumption of Mori's uncanny valley theory is that humans will be comfortable with robots that are indistinguishable from humans.

suggestion is likely to be a difficult task, requiring greater understanding of specific robotic anthropomorphic cues and their influence on humans.

However the notion of a robotic uncanny valley is not uncontested. Hanson (2006) digitally merged the faces of a very humanlike and a very non-humanlike robot, and had participants rate the resulting images on humanlikeness and machinelikeness, and also on familiarity and eeriness. Results showed no 'valley' or increase in eeriness as the robot faces became almost humanlike. Hanson proposed that while there *can* be eeriness or uncanniness in response to robot faces, it is more likely to arise from poor aesthetic design, rather than arising from a robot being almost, but not quite, human-identical.

Yet another explanation for some people's discomfort with humanlike robots is both simple and complementary to the other explanations. As a commonly expressed fear is that robots will take away human jobs and replace human contact, it may be that the more humanlike a robot is perceived to be, the more likely it is also perceived to be capable of replacing people.

Conclusion

Preliminary research suggests robot attitudes may be an important variable to reinstate in a model of robot acceptance. There are some validity concerns with available measures of robot attitudes. While technology acceptance models appear useful for the development of eldercare robots, there appear to be factors common to older people and robots which the technology acceptance models do not address. In particular, people's perceptions of humanlikeness in robots and their relation to robot acceptance. Changes may need to be made to models of technology acceptance to accommodate the characteristics of the eldercare robot HRI.

Chapter 4. Central thesis; and aims and focus of thesis and thesis publications

Preamble

Eldercare robots are not the commonplace ubiquitous machines that were predicted –especially in consideration of the available technology and the apparent niche market. The preceding chapters review reasons for this lower than expected prevalence. Reasons appear to be multifaceted, and include insufficient investment in research and development of eldercare robots, and the complex eldercare environment being challenging for both robots and robot developers to navigate. Another reason for the relatively low prevalence of eldercare robots may be insufficient understanding of human aspects of the eldercare HRI.

Consequently, the preceding chapters also examined models, constructs, and variables associated with human acceptance of technology and robots, including the TAM, the UTAUT, and the Almere model. A common theme in these models was that people's technology and robot attitudes influenced acceptance. Next, HRI studies that assessed people's robot attitudes were examined. There is early evidence that people's robot attitudes influence acceptance of robots, as do people's perceptions of humanlikeness in robots. These findings are valuable contributions to the emerging and complex HRI field. However, there are some methodological issues which may limit their applicability for the development of real-world acceptable eldercare robots. Common limitations include the recruitment of younger people rather than older, robot studies that do not include an actual robot, or the use of Wizard of Oz robotic systems rather than autonomous robots, and the use of measures and constructs of unproven or questionable validity. Sometimes robot studies have no measures of robot acceptance, or the outcome measures may have little real-world application. Alternately, robot acceptance is measured, but it is not compared with other variables, therefore the influences or implications of the results are unclear. The thesis studies described next aim to build on this promising previous work while addressing some of the limitations.

Overall thesis aim

The overall aim of this thesis is to broaden knowledge of the psychological predictors of human acceptance of eldercare robots

Thesis focus

The focus is on people's attitudes towards robots in real-world eldercare contexts.

4.1. Central thesis

That older people's perceptions will affect their acceptance of healthcare robots; specifically their perceptions of their unmet needs and their perceptions of robots

Thesis publications: methodologies and aims

This thesis contains four publications.

Improved attitudes study

The first publication, “Improved robot attitudes and emotions at a retirement home after meeting a robot” (Stafford et al., 2010) describes a cross-sectional eldercare HRI study conducted in a retirement village. Eldercare facility staff and residents interacted with a Cafero robot with demonstration healthcare functions for 30 minutes. Measures of robot attitudes and affect were administered before participants saw the robot, and again when they had finished interacting with the robot. Participants also rated the quality of their interaction with the robot.

The primary aims of the *improved attitudes study* were to assess whether or not people’s robot attitudes changed from before to after meeting the robot, and whether people’s attitudes towards robots predicted ratings, or acceptance, of the robot. A further aim was to assess whether participants perceived robots as humanlike or machinelike, and if these perceptions were associated with acceptance.

Prior attitudes & drawings study

The second publication in this thesis, “Older people’s prior robot attitudes influence evaluations of a conversational robot” (Stafford, MacDonald, Li, & Broadbent, 2014), describes a cross-sectional repeated measures study with 20 people aged 55 years and over. Participants had six interactions with a Peoplebot robot installed with a psychotherapy programme. For each of the interactions, the robot had a different face condition displayed on its monitor. The six face conditions varied on gender, machine/humanlikeness, and face or no face. Baseline measures included robot attitudes and drawings of what participants thought a robot therapist's face might look like. After each of the six interactions, participants gave an overall rating of the interaction and indicated how much they would like to use that particular version of the robot again.

There were several aims of the *prior attitudes & drawings study*. One was to assess if the finding from the previous study (that peoples' baseline robot attitudes predicted acceptance of the robot), could be replicated with a different robot and a different population. Another was to assess if participants found some robot's face displays more acceptable than others. Further aims related to the participants' robot drawings. These aims were to assess people's concepts of what a robot therapist face would look like, and to assess if any drawing variables were associated with robot acceptance.

Robot mind study

The third study, "Does the robot have a mind? Mind perception and attitudes towards robots predict use of an eldercare robot" (Stafford, MacDonald, Jayawardena, Wegner, & Broadbent, 2013) used an improved version of the Cafero eldercare robot used in the first thesis study (the *improved attitudes study*). The robot was deployed for a between-within groups two week study in a retirement village apartment building. All residents in the building were invited, but not required, to use the robot. Measures administered both at baseline and at trial completion included attitudes towards robots and perceptions of robot mind.

The primary aims of the *robot mind study* included assessment of any baseline differences between people who chose to use the robot over the two week trial period, and those who did not; and whether these differences were associated with use, or acceptance, of the robot. Differences of interest included whether or not there were differences in baseline attitudes towards robots and perceptions of robot mind. Further aims include assessing whether or not there were changes in these robot attitudes and perceptions over the two week trial; and if so, how did they change?

Unmet needs paper

The fourth and last paper in the thesis, "Identifying specific reasons behind unmet needs may inform more specific eldercare robot design" (Stafford, MacDonald, & Broadbent, 2012) is a discussion paper. The overall aim of the paper is to assist robotocists in developing more acceptable robots. The paper argues that robots are more likely to be accepted if they are perceived to be useful; and robots are more likely to be perceived as useful, if they are perceived to meet users' unmet needs. Furthermore, knowing the specific reasons for users unmet needs will help design acceptable robotic solutions. However obtaining this information can be difficult, and there is little guidance on how to achieve this. Therefore the specific aim of the paper is to provide some general and specific methodological guidelines to assist in determining specific reasons for unmet needs of eldercare stakeholders, drawing on psychological approaches.

Chapter 5. Improved robot attitudes after interacting with a healthcare robot in a retirement village [*improved attitudes study*]

5.1. Preamble to study one – the *improved attitudes study*

Research described in the introductory chapters of this thesis provides preliminary evidence that people's robot attitudes are associated with acceptance of eldercare robots. As expected in an embryonic field, these initial findings have some methodological limitations and potential confounds. These include: the use of measures of robot attitudes that may reflect overlap with other constructs such as 'intentions to use', rather than assessing attitudes towards robots; the use of non-target user groups such as students; either no robot used at all - or a non-autonomous Wizard of Oz style HRI; and some studies have no acceptance outcomes - making it difficult to assess the implications for robot acceptance. This study attempts to address some of these limitations while being informed by this earlier research.

Some gaps in the research relate to the stability of people's robot attitudes. While there is evidence that robot attitudes are associated with HRI outcomes, there is little research on if, and how, robot attitudes change as a result of people actually interacting with a robot. It has been suggested that people's robot attitudes are unlikely to change in the short term (Nomura et al., 2008; Nomura, Suzuki, Kanda, & Kato, 2006). In order to assess changes in people's robot attitudes, these need to be assessed (at least) twice: once at baseline, prior to the interaction; and again, after the HRI. There is little research into the existence of peoples' pre-factual, or baseline, robot attitudes; or how these attitudes might be associated with robot acceptance.

Baseline robot attitudes are not usually considered in HRI studies. Bartneck et al. (2009) advised researchers not to administer psychological measures prior to an HRI on the grounds that people cannot hold opinions about a robot they have not yet interacted with. While some technology acceptance models do not consider pre-factual technology attitudes (e.g. Davis, 1989; Venkatesh et al., 2003): others do (Bhattacherjee, 2001).

There is also little research on the role of human emotions in robot acceptance. No studies have been located that have used validated measures of emotions in an eldercare HRI context.

Consequently, this study explores these little researched areas of pre-interaction attitudes and emotions towards robots, changes in these variables as a result of an eldercare HRI, and their associations with robot acceptance.

5.2. Publication one: Improved robot attitudes and emotions at a retirement home after meeting a robot

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Abstract

This study investigated whether attitudes and emotions towards robots predicted acceptance of a healthcare robot in a retirement village population. Residents (n = 32) and staff (n = 21) at a retirement village interacted with a robot for approximately 30 minutes. Prior to meeting the robot, participants had their heart rate and blood pressure measured. The robot greeted the participants, assisted them in taking their vital signs, performed a hydration reminder, told a joke, played a music video, and asked some questions about falls and medication management.

Participants were given two questionnaires; one before and one after interacting with the robot. Measures included in both questionnaires were the Robot Attitude Scale (RAS) and the Positive and

Negative Affect Schedule (PANAS). After using the robot, participants rated the overall quality of the robot interaction. Both residents and staff reported more favourable attitudes ($p < .05$) and decreases in negative affect ($p < .05$) towards the robot after meeting it, compared with before meeting it. Pre-interaction emotions and robot attitudes, combined with post-interaction changes in emotions and robot attitudes, were highly predictive of participants' robot evaluations ($R = .88$, $p < .05$). The results suggest both pre-interaction emotions and attitudes towards robots, as well as experience with the robot, are important areas to monitor and address in influencing acceptance of healthcare robots in retirement village residents and staff. The results support an active cognition model that incorporates a feedback loop based on re-evaluation after experience.

5.2.1. Introduction

Many countries in the world are facing aging populations (United Nations, 2010). One consequence of this is a greater proportion of older people living with care-intensive chronic illness, combined with a growing shortfall in health professionals (Murray, 2002) and caregivers (Super, 2002).

One possible solution is for robots to help care for older people. A variety of physical and social robotic devices have been deployed in the health arena. These range from hospital transporters (Ichbiah, 2005), to surgical robots (Howe & Matsuoka, 1999), and physical and mental rehabilitation robots (Krebs et al., 2003; Mataric, Eriksson, Feil-Seifer, & Winstein, 2007).

Some robots have been shown to be effective. Robotic telepresence increased patient satisfaction after surgery (Ellison et al., 2004), the seal-like social robot, Paro, was associated with cognitive improvements in older dementia patients (Wada, Shibata, Saito, Sakamoto, & Tanie, 2005b), and the robot dog AIBO reduced loneliness in rest home residents (Banks & Banks, 2002). However acceptance of many robotic health devices has not been adequately assessed and others have not been successful. SANYO's Hopis, a health and vital signs assessment robot (Belew, 2007) was a commercial failure. Yorisoi Ifbot, an entertainment and companion robot, was eventually ignored by its older users (Foulk, 2007).

Acceptance has been defined as the healthcare robot being willingly incorporated into the person's life (Broadbent, Stafford, et al., 2009). Studies on acceptability of retirement home robots are limited, and the commercial failure of Hopis and Ifbot demonstrate the importance of determining which factors make a robot acceptable to older people.

Technology Acceptance Models (TAM) determine which variables predict acceptance of new technologies. The proposed variables include emotions and attitudes towards technology, as well as demographics such as age, gender, and technology experience (Venkatesh et al., 2003). A limitation in TAM studies is that technology acceptance is not assessed over a long term. Technology acceptance studies typically involve trials of computers and cell phones, as well as younger participants. As older people can be less accepting of new technologies than younger people (Giuliani, Scopelliti, & Fornara, 2005a), the ability of TAM findings to generalize to robot acceptance in older people is not clear.

A recent review on acceptance of healthcare robots for older people (Broadbent, Stafford, et al., 2009) found the following human factors were associated with acceptance; age, gender, prior experience with technology and robots; education, and staff role. Robot factors include; the robots' appearance; the degree to which the robot is perceived as humanlike or machinelike; size; gender; personality; and how adaptive the robot is to the users' needs. Trials with the retirement home robot Pearl showed the importance of personalizing the robot to the user's physical and sensory abilities; such as walking and hearing (Pineau, Montemerlo, Pollack, Roy, & Thrun, 2003).

Initial trials suggest that attitudes towards technology are significant predictors of both post-trial attitudes and future use (Hartwick & Barki, 1994). However, there has been little research on the influence of emotions and attitudes on acceptance of healthcare robots particularly for older people and associated caregivers. Findings so far suggest emotions and attitudes do impact on the human-robot interaction (HRI) and are associated with acceptance. In older people, Heerink, Kröse, Wielinga, and Evers (2008) found expectation of enjoying the robot interaction was associated with acceptance. Nomura et al.

(2008) reported that people with more negative attitudes and anxiety about robots have more emotional conversations with the robot. Cortellessa, Loutfi, and Pecora (2008) found people can hold attitudes about robots from viewing domestic robots on videotapes. Other research suggests that a more sociable robot may make older people feel more comfortable and expressive (Heerink, Kröse, et al., 2006).

Broekens et al. (2009) identified common methodological problems in older-care robot research, including a lack of control groups, a lack of replication of existing findings, a lack of long term studies, and the need for larger samples. Another issue is failing to assess staff reactions to older-care health robots, which may be important in a retirement setting (Broadbent, Stafford, et al., 2009).

This study builds on earlier research that investigated what retirement village residents and staff want in a healthcare robot (Broadbent, Tamagawa, et al., 2009). This paper specifically focuses on attitudes and emotions towards robots. While previous research has shown attitudes and emotions are important for technology acceptance; these variables are understudied in relation to robots. The aims of the study are listed in Table 1.

Table 1. Questions about human attitudes and emotions to robots

How do retirement village residents and staff rate a healthcare robot?
Do attitudes and emotions change after meeting the robot?
Do attitude and emotions, and changes in these variables, predict better robot ratings?

5.2.2. Method

Recruitment

Study approval was obtained from the University of Auckland Human Participants Ethics Committee (number 2009/434). 32 residents and 21 staff were recruited from Selwyn Village: a non-profit retirement complex in Auckland, New Zealand. The 26 acre village has around 650 residents, and provides progressive care from independent living units through to hospital and dementia care. Using an alpha level of .05 (i.e., $p < .05$ is required to achieve significance) and power of .80; the sample size of 53 allows moderate effect sizes to be detected between variables.

The robot

The Healthbots project is a joint development between the University of Auckland, ETRI, and Yujin Robot. The overall goal of the project is to develop healthcare robots that are acceptable to older people, their families and staff.

Figure 7. Robot used in the retirement home trials

The mobile robot (Figure 7) has a differential drive, which is powered by a 24v Li-Polymer battery. The architecture of the robot consists of four layers; hardware, robot software framework, robot application programming interface (RAPI), and service applications. RAPI allows rapid service application development, by isolating complexities of low-level control and navigation tasks from the service application layer.

The robot uses the StarGazer robot localization system for navigation (Hagisonic.Co.Ltd, 2008). StarGazer requires passive landmarks installed on the ceiling of the robot work-space. Therefore, in the experimental environment (described in section II B), landmarks were installed with approximately 1m separation. A map of the area was built using the built-in map building module of the robot. During the trials, once the destination location was entered using a remote controller, the robot could autonomously navigate to designated places (such as the charging station, participants' chair etc.) while avoiding obstacles.

For this experiment, seven service application modules were developed; greeting, vital signs measurement, medication reminding, schedule reminding, falls detection, entertainment, and evaluation. Each module was represented by a pictorial touch button on the robot's computer screen (Figure 8). Participant responses were received via the touch screen and the robot responded to participants with synthesized speech.

Service application front-end was developed with Flash and ActionScript 2.0 and the back-end was developed with C++. The vital signs devices attached to the robot were the Omron digital automatic blood pressure monitor M10-IT®, and the Masimo SET® for pulse oximetry.

The robot's synthetic speech was generated through diphone concatenation type synthesis implemented with Festival speech synthesis system (P. Taylor, Black, & Caley, 1998) and used a New Zealand accented diphone voice developed at the University of Auckland (C. I. Watson, Teutenberg, Thompson, Roehling, & Igic, 2009). Expression was added to the synthetic speech through an intonation modelling technique described in Igic et al. (2009) called 'Say Emotional'.

The robot greeted the participant by name and asked how they were feeling. The vital signs measurement module included blood pressure and blood oxygen saturation. Medication management, schedule reminding and fall detection modules handled dialogs with participants in respective areas, and gathered data. The entertainment module allowed participants the option of hearing a joke and songs of their choice. A ‘patting’ module allowed the participants to pat the back of the robot - causing it to turn towards them and say ‘Hi’. The evaluation module collected participant feedback on robot functionalities through a controlled dialog. Finally, a ‘goodbye’ module enabled the participant to terminate the interaction.

Figure 8. Robot’s main menu screen showing touch buttons

The Setting

The trial was conducted in the carpeted lounge of a display home set within the retirement village complex.

Measures in Questionnaire One

The first questionnaire and first blood pressure assessment was administered to participants prior to meeting the robot. The blood pressure assessment was used to indicate participants' pre-interaction anxiety levels.

1) Demographics: Participants were asked their age, gender, ethnicity, and level of education. Residents were asked about their living situation. Staff were asked to describe their employment role and how long they had worked at Selwyn Village.

2) Computer Knowledge: Participants were asked to rate their level of experience at basic computer tasks such as email and internet searches on a numeric scale. The possible answers ranged from 1= 'not at all' to 8 = 'extremely'.

3) Robot Knowledge: Participants were asked to rate their level of knowledge of robots. The possible answers ranged from 1= 'nothing' to 8 = 'quite a bit'.

4) The Positive and Negative Affect Schedule (PANAS:D. Watson et al., 1988): This popular measure has previously been used in HRI studies (Broadbent et al., 2007; Preucil, Pavlicek, Mazl, Driewer, & Schilling, 2006). The base scale consists of two ten-item mood scales, one composed of positive emotions or affect (PA), e.g., 'interested', and the other composed of negative affect (NA), e.g., 'scared'. Based on findings from a prior study (Broadbent et al., 2007) an additional negative emotion of 'embarrassed' was added. Participants were asked to what extent they felt these emotions as they were about to meet the robot. The purpose of this measure was to assess participants' positive and negative affect specific to the robot. PANAS scales are internally consistent and sensitive to fluctuations over time. For internal consistency, the pre-interaction PA subscale had a Cronbach's α of .92; the NA subscale had a Cronbach's α of .84; suggesting the items are measuring the same underlying construct

5) Robot Attitude Scale (RAS): Developed from the preliminary study at the same retirement home (Broadbent, Tamagawa, et al., 2009), the RAS consists of 12 pairs of robot attribute opposites such as, friendly - unfriendly; advanced - basic. Participants rated their expectations of the robot on an eight

point scale, with the attribute opposites as anchors. RAS items are summed to create an overall scale. Lower scores are associated with more favourable attitudes towards robots. The Cronbach's α was .93. There is an additional item to measure 'humanlikeness'; for this item low scores = more humanlike and high scores = more machinelike. The purpose of the RAS was to assess participants' attitudes towards the robot they were about to meet.

Measures - Questionnaire Two

The second questionnaire was administered to participants immediately after interacting with the robot.

1) Robot Rating: Participants were asked to rate their experience of the robot interaction overall using a scale from 0 = 'poor' to 100 = 'excellent'. This item's purpose is to indicate how acceptable participants found the robot. Staff were also asked to indicate how they thought residents would rate the robot after using it.

2) The Positive and Negative Affect Schedule (PANAS): The PANAS was repeated in the second questionnaire to detect any change in emotions from before to after meeting the robot. Participants were asked to what extent they felt these emotions during the interaction with the robot. Post-interaction, the PA subscale had a Cronbach's α of.85 and the NA subscale had a Cronbach's α of .74.

3) Robot Attitude Scale (RAS): The RAS was repeated in the second questionnaire to detect any attitude changes from before to after meeting the robot. Cronbach's α was .92 post-interaction.

Neither the pre- or post-interaction PA, NA, and RAS scales were significantly correlated ($p > .05$) indicating they are assessing distinct constructs.

Procedure

Participants were invited to an individual appointment at the show home, and seated in the lounge. The robot was stored out of view down the hallway. The researcher was seated next to the participants throughout the trial. After informed consent was obtained, participants were given the first questionnaire to complete. This was followed by the researcher measuring participants' blood pressure. Via remote control, the researcher then brought the robot into the lounge, where it stopped in front of the participant. The researcher then explained to the participant how to use the robot. Starting with the robot greeting, participants worked through the robot modules in a standardised order. After using the robot, participants were given the second questionnaire to complete. Participants then sent the robot away by touching the ‘goodbye’ button on the robot’s computer screen.

Statistical Analysis

Data analysis was carried out using SPSS for Windows 16. The data normality was checked using the Kolmogorov-Smirnov test. All significance tests are two tailed at the .05 level ($p < .05$). To produce ‘change’ variables (the change in measure scores from before to after meeting the robot) pre-interaction PANAS, RAS and humanlikeness scores were deducted from their respective post-interaction scores.

5.2.3. Results

Demographics

The mean age of the residents was 80.66 years, SD = 6.29 with a range from 68 to 92 years. The staff mean age was 46.48, SD = 9.60, ranging from 26 to 62 years. Nine of the residents (28.1%) were male; with only one (4.8%) male member of staff. All but one of the residents identified as New Zealand European, compared with just over half of the staff (52.4%). The remainder of staff ethnicities was evenly composed of ‘other European’, ‘Pacific Island’ and ‘other’. 30 (93.8%) of the participant residents lived in independent living units; the remaining two were in the higher dependency rest-home part of the retirement village.

Residents and staff did not differ significantly in education level or knowledge of robots ($p > .05$). However staff reported significantly higher levels of computer knowledge (M= 5.57, SD = 1.69), than residents (M = 3.64, SD = 2.15, $t\ (52) = 3.48$, $p < .01$, with a large effect size (eta squared = .19). Level of computer or robot knowledge was not associated with overall robot rating ($p > .05$). Education level was inversely associated with overall rating, $r = -.28$, $p < .05$).

Differences between Groups in Robot Rating

Participants gave the robot a mean overall rating of 80.28, SD = 16.90, Md = 80.00, with a range from 20 to 100. A Mann-Whitney U test showed no significant difference between staff (Md = 80, n = 21) and residents (Md = 90, n =32) in their overall ratings of the robot interaction, U = 259, z = -1.42, r = .20, p >.05.

In the post-interaction questionnaire, staff were asked how they thought residents would rate the robot overall. Interestingly, staff thought residents would rate the robot significantly lower, Md = 80, n = 21, than residents actually did, Md = 90, n = 32, U = 116, z = -3.96, p <.01, r = .54.

Correlations between Robot Rating and Attitudes and Emotions

As seen in Table 2, three of the eight pre- and post- interaction attitudes and emotions were significantly correlated with robot rating. More favourable robot attitudes, both pre- and post-interaction, were associated with higher robot ratings. The r value for the association between robot rating and robot attitude after HRI was almost twice that of the r value between robot rating and robot attitude and positive affect before meeting the robot. This result suggests while pre-interaction attitudes and emotions are important for robot acceptance; the attitudes held after experiencing the robot are more strongly associated with robot acceptance.

Changes in Attitudes and Emotions after a Human-Robot Interaction

A repeat MANOVA assessed the impact of group (residents or staff) and time (before and after the robot interaction) on participants' emotions and robot attitudes. Four emotion and attitude variables were used: robot attitude, humanlikeness, positive affect, and negative affect. The results suggest that after meeting the robot, there were significant improvements in participants' attitude towards robots (F, 27) = 25.04, partial eta squared = .48, Figure 9) as well as decreases in negative affect (F (1, 27) = 4.30, partial eta squared = .14, Figure 10). There was no change (p > .05) in positive affect or perceptions of humanlikeness.

Table 2. Spearman's Rho correlation coefficients between pre- and post-interaction attitudes and emotions, and robot rating[13]

Variable	*r*
Pre-interaction robot attitude	-.37*
Pre-interaction humanlikeness	-.21
Pre-interaction positive affect	.36*
Pre-interaction negative affect	-.20
Post-interaction robot attitude	-.63**
Post-interaction humanlikeness	-.09
Post-interaction positive affect	.15
Post-interaction negative affect	-.08

There was no significant interaction between group and time, Wilks Lambda = .92, F (4, 24) = .54, p > .05, partial eta squared = .08. The non-significant main effect (p > .05) suggests the changes in robot attitude, F (1, 27), = 3.59, and negative emotion, F (1, 27) = .27, were not different between residents and staff.

Impact of education levels, pre - interaction emotions and attitudes, and changes in emotions and attitudes, on robot rating.

Hierarchical multiple regression assessed the ability of pre-interaction emotions and attitudes, as well as the change in these emotions and attitudes, to predict how participants rated the robot, while controlling for education levels.

[13] * p < .05 **p < .01

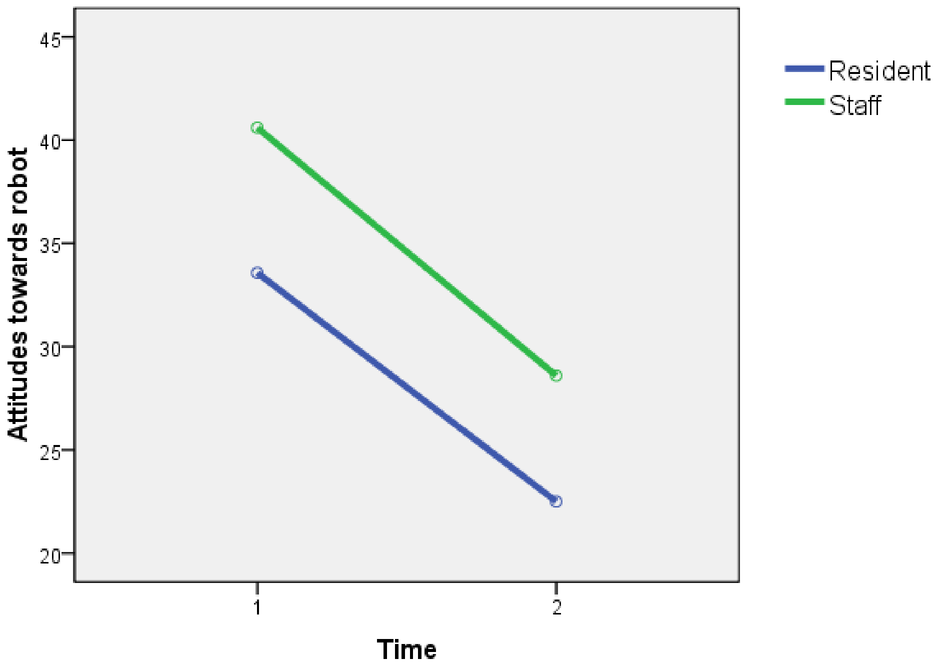

Figure 9. Reductions in negative attitudes towards the robot in residents and staff from time 1 (pre-interaction) to time 2 (post-interaction)

The total variance in robot rating explained by the model as a whole was high; 84.7%, $F(9, 20) = 12.35$, $p < .01$. In the final model (Table 3), education level was not associated with robot rating, in contrast with previous research (Giuliani et al., 2005a). Change in negative affect contributed the most unique variance to robot rating. Change in humanlikeness was the only non-significant change variable. While pre-interaction humanlikeness was significant, its beta value was small. The results suggest robot attitude, both before and after the HRI, is an important predictor of robot rating. In contrast; while changes in emotions towards robots were strong predictors of robot rating; pre-interaction emotions towards robots were not. The results also support previous technology acceptance studies showing both emotions and attitudes independently predict technology acceptance (Venkatesh et al., 2003).

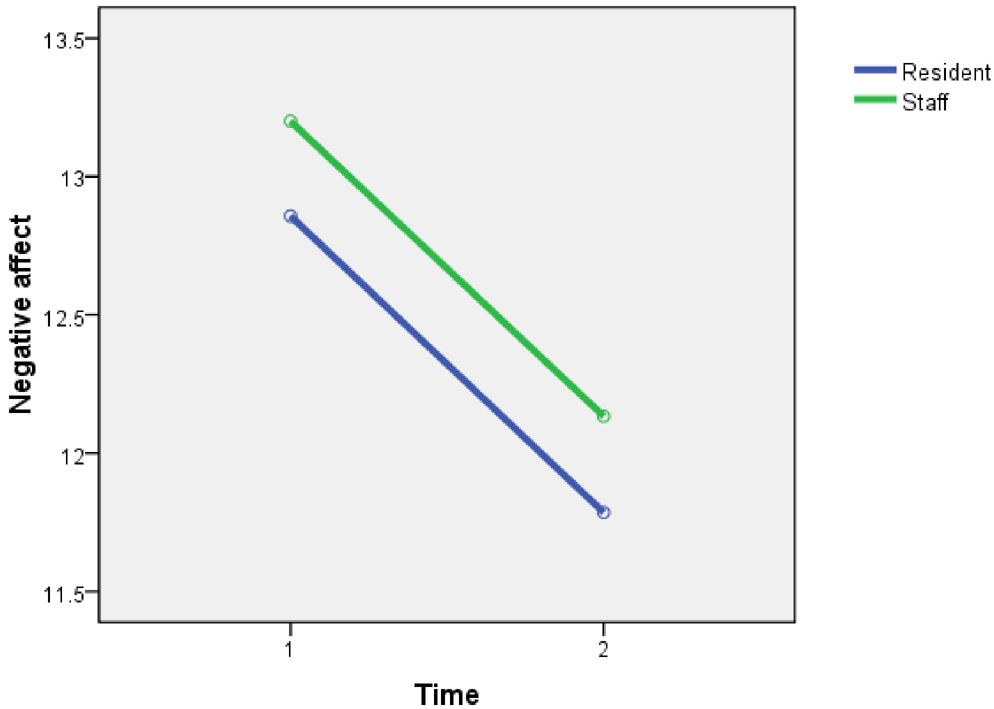

Figure 10. Improvements in negative affect towards the robot in residents and staff from time 1 (pre-interaction) to time 2 (post-interaction)

Humanlikeness

The humanlikeness item had no significant correlations with attitudes, emotions, or blood pressure. The one exception was, for staff only, reporting the robot as more humanlike after meeting it was associated with higher post- interaction positive affect, $r = .53$, $p < .05$.

For residents only, higher heart rate before meeting the robot was associated with reporting the robot as more human-like and less machinelike *after* meeting it ($r = .38$, $p < .05$); suggesting an association between heightened anxiety and perceiving the robot as more humanlike. In contrast, participants who were expecting the robot to be *more* humanlike before they met it, tended to give it higher ratings after they used it (beta = -.27, p < 05).

Table 3. Final hierarchical regression model showing unique contribution to variance (beta value) in robot rating by individual variables[14]

Variable	*beta value*
Education level	-.16
Pre-interaction robot attitude	-.88**
Pre-interaction humanlikeness	-.27*
Pre-interaction positive affect	-.20
Pre-interaction negative affect	.54
Change robot attitude	-.86**
Change humanlikeness	-.26
Change positive affect	-.70**
Change negative affect	.97**

5.2.4. Discussion

Participants rated the robot a high 80% in terms of overall quality of HRI. This is a positive result, and suggests participants found the robot acceptable. There was no difference in how residents and staff rated the robot, though staff thought residents would rate the robot lower than residents actually did.

Since this study was cross-sectional, with no manipulation of variables, we cannot be specific as to why the robot was rated so highly by participants. But it seems plausible that the high rating can be partly

[14] * $p < .05$ ** $p < .01$

attributed to the robot being designed in response to older peoples' expressed preferences (Broadbent, Tamagawa, et al., 2009). The robot was also designed to be easy to use for people with physical and sensory impairments and low technology experience. User-design examples include; clear instructions, uncluttered screen interface, large iconic touch-screen buttons, high visual contrast for discrete touch-screen elements, multi-modal robot communication (speech and large text), and the robot's slow and indirect approach to participants.

There were improvements in robot attitude and negative affect from before to after meeting the robot. This may reflect both a high level of anxiety in naive users prior to meeting the robot, as well as reflecting a positive experience in using the robot.

Changes in robot attitudes and emotions after meeting the robot explained a large amount of variance in robot rating. Improvements in robot attitude, and positive and negative affect predicted higher ratings. Of the four highly significant ($p < .01$) attitude and emotion variables that predicted robot rating; three were change variables and only one was a pre-interaction variable. While initial robot attitudes and emotions are important in terms of robot acceptance, changes in attitudes and emotions that occur during the HRI may be more important.

Perceived humanlikeness of the robot was associated with higher ratings of the robot by staff, yet also with elevated heart rate in residents. This suggests that perceived humanlikeness may be a good feature, but may also provoke anxiety depending on demographic context. The complex relationship between humanlikeness and acceptance has been found in other robot research (Gee, Browne, & Kawamura, 2005).

Focusing on both pre-existing attitudes and emotions towards robots, as well as the changes in these variables, may aid in maximizing an eldercare robot's acceptance. Educational materials to improve potential users' attitudes and emotions towards robots could be developed and disseminated at a retirement village. The robot experience could also be designed to foster positive robot attitudes in users and reduce negative affect.

Strengths of this study include; ecological validity - the trial's retirement home setting means results may generalize to other retirement homes in similar cultures; the interdisciplinary nature of the Healthbots research team brings expertise from engineering, psychology, gerontology, medicine, and health informatics to an emerging and complex field; the study design demonstrates the value of assessing attitudes and emotions both before and after a robot interaction; the study had a reasonably large sample size for HRI research - which typically has very few participants; this is not a Wizard of Oz study, as is often the case; additionally it is part of an on-going robot development project, where results of previous stages are fed into the design of the next phase.

There were several limitations in this study. The robot trials were a brief interaction with demonstration modules only, so it is unknown how well the results will generalize to longer trials. This study was not a controlled trial; therefore it is unknown how the robot would rate compared with, for example, a human caregiver or a computer telepresence. There were some robot malfunctions during the trials. This may have caused some participants to rate the robot more negatively than they otherwise would have. A self-selection bias is also possible; people who volunteered to take part in the robot trial may have had more positive robot attitudes and emotions, than residents and staff who did not volunteer.

Conclusion

This research demonstrates people do have attitudes and emotions towards robots that are important predictors of how they accept robots, but these are flexible and can change through experience with robots. The research results support an iterative cognition model for robot acceptance.

Future research could investigate whether similar results are found with robot trials of longer duration; compare a healthcare robot against another similar healthcare delivery option; develop and trial robot educational materials to promote positive robot attitudes and emotions amongst residents and staff in retirement homes; and further assess which aspects of robot design and programming optimise the human-robot interaction.

5.3. Study one segue – the *improved attitudes study*

Possible limitations of the *improved attitudes study*

A possible limitation of this study is that we were unable to use the traditional technology acceptance outcome measure of 'intention to use'. This study method included two self-report measures of acceptance administered after the HRI. One was "how well would you rate the interaction with the robot overall?", and the other intention to use outcome was, "how much would you like to use this robot again?" The latter item is more similar to the well validated 'intention to use the technology' outcome from technology acceptance models.

However, participants in the *improved attitudes study* found the 'intention to use' item inappropriate. When they were asked how much they would like to use the robot again, many participants responded with comments similar to "Well, it was fun using the robot, but it was a demo. I'd like to use the improved version, but I don't need to use this one again." Consequently participants' 'overall rating of the interaction' was used as the primary self-report measure of robot acceptance.

This issue has been noted in other HRI studies that have used outcome measures based on the UTAUT. Rest home residents found a similar item inappropriate when they were asked how much they would like to interact with a meal-companion robot again (McColl & Nejat, 2013). The question did not make sense to the residents as they knew the robot was being removed after the trial and there would be no opportunity to use it again. The UTAUT is a generic technology acceptance model, and as suggested by Venkatesh et al. (2003), some technology acceptance items may need to be adapted to fit specific contexts.

Other HRI studies that have administered psychological measures both before and after an interaction

Since the *improved attitudes study* was published in 2010, two other publications have been located that describe HRI studies that also employed a 'before and after' assessment. Lohse (2011) designed an HRI study to assess gaps between users' expectations of a robot's performance and its actual performance. The study protocol involved 31 participants with a mean age of 24.2 years. They were given a written task scenario outlining how they were about to teach a new domestic robot the layout of a home. After reading the scenario participants rated their expectations of the robot's characteristics and performance, as well as the importance of each characteristic. The measure consisted of a series of 17 semantic differential Likert scales with items such as; friendly-unfriendly, autonomous-not autonomous, useful-not useful, funny-serious. After guiding a Bielefeld Robot Companion (BIRON) through a study house, participants again rated the robot's characteristics.

Robot characteristics that the participants rated most important at baseline were 'practical' and 'useful'. After participants had 'taught' the robot the house layout, the difference was calculated between participants' pre-HRI expectations and their post-HRI opinions of the robot's performance and characteristics. The largest gaps between expectations of the robot and actual performance were for the items; fast-slow, practical-impractical, and useful-useless. This indicates participants found the robot slower and less useful than expected. Lohse (2011) suggest this may be explained by the prototype robot lacking the functionalities expected of a commercial product.

As participants rated practicality and usefulness as the most important robot characteristics, the results support Davis's (1989) proposal that perceived usefulness is a major determinant of acceptance. However, as Lohse's (2011) study did not contain any acceptance outcome measures (i.e. participants were not asked to rate the robot, or how much they would like to use it again), associations between these robot expectation/performance gaps and robot acceptance cannot be determined. Lohse's et al.'s results do however concur with the findings of the *improved attitudes study* that people's attitudes and perceptions of robots can change in a short time period as a result of a robot interaction. Although Lohse's et al.'s study was not targeted at eldercare, the use of younger participants in their study means their results may not necessarily generalise to an older population.

While not using the model of Expectation Confirmation Model of IT use specifically, another HRI study has been located that combined the methodology of before and after measures, with manipulation of expectations. Noting that some robot companies appear to over-sell the benefits of their robotic products, Paepcke and Takayama (2010) sought to determine the influence of raising or lowering people's expectations of a pet robot's abilities on their perceptions of those abilities after use. To test this, 24 participants (mean age 30.46 years), were allocated to one of four conditions in a 2 x 2 HRI trial design (expectation setting: high vs. low, and pet robot type: Aibo vs. dinosaur robot Pleo). The experimental procedure started with manipulation of the participants' expectations of the robots, after which (similar to Heerink, Kröse, et al.'s, 2009, study with the iCat placed in the tearoom) they could interact with the robot for as long as they chose. Participants' perceptions of the robot's abilities were measured both before and after the interaction.

Results showed high or low expectations made no difference to participants' perceptions of the robots' people-perceiving capabilities, or how much time they chose to spend interacting with the robot. However, compared with people in the low expectation groups, participants in the *high* expectation setting believed their robot had significantly *less* touch-sensing capacity, and was less competent. These results suggest that a high expectation setting did not lead to higher perceptions of the robots actual abilities (i.e. there did not appear to be a confirmation bias effect), rather it appears that people in the high expectation setting were disappointed with the robot's actual abilities. Paepcke and Takayama (2010) conclude that robot acceptance may be optimised by decribing robots to potential users in ways that avoid disapointment when people actually interact with the robot.

Results from Paepcke and Takayama's (2010) expectation manipulation study support the findings from the *improved attitudes study* that people's robot attitudes can be rapidly modifed. Furthermore, their results imply that people do not even need to interact with a robot for this to occur: people's robot attitudes and consequent evaluations can be altered with simple framing effects.

However, while the expection manipulation appeared to influence participants' subjective perceptions of the robots' competance and abilities, the manipulation influence did not extend to the study's more objective measure of acceptance – how long participants played with the robots. A possible explanation for this result may lie in the choice of acceptance measure. For many middle-aged adults, playing with a pet robot may not be a natural default, or preferred, behaviour (Premack, 1965): i.e. when not under instruction and left to their own devices, middle-aged adults may not choose to play with a toy-like robot dinosaur or dog at all. Akin to 'floor effects', improbable behaviours may be relatively insensitive to expectancy manipulations. A compatible explanation is that each of the four study groups only had six participants. The study may have been under powered to detect significant differences in length of time participants spent playing with the robots.

Chapter 6. Older people's prior attitudes influence evaluations of a conversational robot [*prior attitudes & drawing study*]

6.1. Preamble to study two – the *prior attitudes & drawings study*

This study also assessed robot attitudes, but added a new measure of expectations. We asked people to draw what they expected the robot's face to look like. The aims were to explore if the finding from the *improved attitudes study* - that people's prefactual robot attitudes predicted robot acceptance - could be replicated within a different HRI context. Compared with the previous study, this study had a different population (community living older people vs. retirement village residents) interacting with a different robot (Peoplebot vs. Cafero) with different functions (therapist/conversational vs. healthcare) in a different setting (university vs. retirement village). Additionally, we wanted to assess whether people's robot drawings, as a more implicit measure of their prefactual robot attitudes, were associated with their acceptance of the robot. A further aim was to assess what type of display on a robot's screen was more acceptable to older people: a human or machinelike face, a male or female face, or no face.

6.2. Publication two: Older people's prior robot attitudes influence evaluations of a conversational robot

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Abstract

As the population ages, healthcare robots may help meet increasing demands for mental and physical health services. However more understanding is required of how to make robots acceptable to older people. This study aimed to assess how older peoples' robot attitudes and drawings were related to their reactions to a conversational robot. We also assessed whether altering the robot's virtual face affected peoples' responses. 20 participants aged over 55 conversed with a Peoplebot robot for 30 minutes. During the interaction the robot displayed six different face conditions on its monitor in a randomized order. The six robot conditions varied on two dimensions; i/ facial appearance (humanlike, machinelike, or no face), and ii/ robot gender. Measures included the Robot Attitudes Scale, drawings of a robot's face prior to the interaction, blood pressure (BP) and heart rate, and evaluations of the robot. Results suggest participants did not evaluate the robot's six display conditions differently. However, there was a trend for men to evaluate the robot more highly than women did. Participants' positive attitudes towards robots before the robot interactions were

associated with positive robot evaluations after the interactions. Larger drawings were associated with higher systolic BP after interacting with the robot. These findings suggest that (at least in the short-term) people's pre-existing mental models of robots may be more important for acceptance than the gender, human or machinelikeness, or even the presence or not of a robot's virtual face. More research is needed on participant gender differences in reactions to eldercare robots. Compared with creating different robot faces to meet individual preferences, promoting positive attitudes towards robots may be a cost-effective method of promoting robot acceptance. Drawings of robots may be a useful, more implicit way of assessing anxiety towards robots in potential users.

6.2.1. Introduction

Older people can have many unmet needs due to the presence of mental and physical illnesses (G. A. Hancock, Reynolds, Woods, Thornicroft, & Orrell, 2003). Decreasing numbers of healthcare professionals is one reason some countries struggle to meet the healthcare needs of their older populations (Sargen et al., 2011). Technology based solutions, including healthcare robots, may be able to supplement care for older people. However few eldercare robots are commercially available (Mahoney, 1997). A greater understanding of robot and human variables associated with acceptance of eldercare robots may assist with individual and commercial acceptance.

Preliminary studies (Broadbent, Lee, Stafford, Kuo, & MacDonald, 2011) suggest that people's attitudes towards robots and drawings of robots can predict their responses to healthcare robots, including their blood pressure (BP). The face of the robot, as well as the robot's humanlikeness or machinelikeness, can also influence ratings (K. Gray & Wegner, 2012). However, more research is needed to assess how older people expect a socially interactive robot to look, and how their attitudes towards robots are associated with reactions to robots. This study aimed to assess how older people's robot attitudes and drawings of robots were related to their reactions to a conversational robot. We introduced different virtual robot faces in the study so we could further evaluate peoples' responses.

This paper's background section discusses related work - including possible advantages of robots for elder mental health support, technology acceptance models, and robot and human variables that impact acceptance of robots. The latter sub-section focuses on human expectations and attitudes towards robots, as well as the robot variables of humanlikeness and machinelikeness, gender, and robot faces. The background concludes with some methodological issues relating to assessment of eldercare robot acceptance, the research questions and study hypotheses. The next section presents the method, followed by the results, discussion, and conclusion.

Background

The potential for robotic delivery of mental health care

Whereas some robots are intended to help with more physical aspects of healthcare (e.g. RI-MAN:Mukai, Onishi, Odashima, Hirano, & Luo, 2008) robots may also be able to assist older people with mental health issues. Older people have high rates of psychopathology and emotional issues, such as depression, anxiety and loneliness (G. A. Hancock et al., 2003). Despite the high prevalence of these mental health issues, detection (and consequently treatment) can be difficult (Stafford et al., 2012). Older people often are not willing or able to report both mental and physical health problems. Reasons for this include older people not wanting to be a nuisance, pride, socially desirable responding, lack of awareness, and fear of stigma and institutionalisation (Horrocks et al., 2004; K. Walters, Iliffe, & Orrell, 2001).

Robotic mental health support could be delivered in a variety of ways. Loneliness and possibly depression may be alleviated via direct interaction with pet therapy robots such as Aibo (Banks et al., 2008) and Paro (Robinson et al., 2013; Wada, Shibata, Musha, et al., 2005), or indirectly by facilitating human to human interaction via elder-friendly versions of communication technologies such as Skype. Another example is that robots with monitors could support elder mental health with software games designed to entertain and practice memory such as Brain Fitness (Dakim, 2012).

A meta-analysis of computerised cognitive behavioural therapy programmes concluded that it is an effective treatment for adults with a range of anxiety and depressive disorders (Andrews, Cuijpers, Craske, McEvoy, & Titov, 2010). Such therapy delivered via robots may be an effective way to support older people with their mental health. Compared to computer or even human delivery of cognitive therapies, there may be some advantages to delivery by a robot. There is some evidence that the embodiment of a robot may provide a beneficial social presence over and above that of a computer (Kidd et al., 2006) while still retaining the non-human advantages of being a machine.

While some older people fear eldercare robots replacing people (Wu, Fassert, et al., 2012); in some contexts machine-care may have advantages over human care. For example, compared with disclosing health concerns to a human, older people may feel less like they are 'bothering' a machine. As people have been shown to disclose more information via computer than face to face

(Joinson, 2001); people may feel more able to disclose distress to a robot with less fear of negative evaluation.

Despite possible advantages to robotic eldercare; older people can be less accepting of new technologies than younger people (W. A. Rogers & Fisk, 2010). Further, older people have been shown to respond differently to robots compared with younger people (Ezer et al., 2009; Nomura & Takeuchi, 2011; Stafford et al., 2010). One implication of this is that older participants should be included in research to help develop and assess technologies, including robots, intended for elder-use (Beer et al., 2012; Heerink et al., 2010; Tapus & Mataric, 2008). Therefore, compared with technologies developed for younger users; more care may be needed in optimising the acceptability of eldercare robots. One approach to optimising acceptability is to exploit technology acceptance models (TAMs).

Technology Acceptance Models (TAMs)

The purpose of TAMs is to predict under which conditions technologies will be accepted. The primary determinants of acceptance, or intention to use the technology, are how useful and easy to use the technology is perceived to be (Davis, 1989). However, Davis - the author of the original TAM - notes that there will likely be additional variables that impact technology acceptance and further research is needed to determine these (Davis, 1993). TAMs are also general models, and not much is known about specific factors that contribute to acceptance of new technologies such as robots by older people (Bagozzi, 2007). Therefore, in addition to examining general perceptions of robot usefulness and ease of use; it may be useful to identify specific robot and human variables that impact acceptance of eldercare robots.

Which human and robot variables impact acceptance?

A human variable that is associated with acceptance of robots is peoples' attitudes towards robots. In a human robot interaction (HRI) study, retirement home residents interacted with a Cafero healthcare robot for half an hour (Stafford et al., 2010). The robot's demonstration healthcare functions included measuring blood pressure (BP), a hydration reminder, medication management, and entertainment. People's attitudes towards the robot improved significantly from before to after interacting with the robot. Positive robot attitudes before the interaction predicted positive evaluations of the robot after the interaction. Another healthcare HRI study using Cafero found older people who held less positive attitudes towards the robot before deployment in a retirement village, were significantly less likely to use it over a two week period, compared with residents who held more positive robot attitudes (Stafford et al., 2013).

However, unrealistically high expectations about a robot's abilities may negatively affect acceptance. From a robot variable perspective; Cynthia Breazeal designed the sociable robot Kismet to have an anthropomorphic but non-humanlike appearance to help match people's expectations of the robot to the robot's actual abilities, thus avoiding disappointment (Breazeal, 2000).

From a human variable perspective; Paepcke and Takayama (2010) manipulated participants' expectations of the abilities of robot pets AIBO and Pleo. People with low expectations reported less disappointment in the robots after interacting with them and higher evaluations of the robots' competence. Theoretical support for the role of pre-interaction expectations in robot acceptance comes from the expectancy-confirmation paradigm; widely used to understand consumer satisfaction and re-purchasing behaviour (Hong, Thong, & Tam, 2006). Bhattacherjee (2001) created the

Expectation-Confirmation Model in IT (ECM-IT) in recognition of the applicability of this paradigm to technology acceptance.

Compared with general robot attitudes; human perceptions of robot ‘trustworthiness’ could be considered a more specific robot attitude. Sanders, Oleson, Billings, Chen, and Hancock (2011) proposed trust as a key factor in successful robot-human teams. They further concluded that there was little evidence for the impact of human variables on trust. Rather, robot variables were considered the dominant determinants of perceived robot trustworthiness. Support for this model comes from a study where different robot forms (viewed as static images) were rated as having differing levels of trustworthiness by students. Additionally, trustworthiness ratings were positively correlated with theoretical willingness to use the robots depicted in the images (Schaefer, Sanders, Yordon, Billings, & Hancock, 2012).

A human’s perception of whether a robot is humanlike or machinelike can also influence acceptance of the robot. However it is unclear which design would be more acceptable for an eldercare robot. Some HRI researchers propose that socially interactive robots should be humanlike to afford more natural interaction (Duffy, 2003). Other research suggests humanlikeness in robots is undesirable (Broadbent, Lee, et al., 2011; Wu, Fassert, et al., 2012).

Some answers to this ‘humanlike or machinelike?’ robot design problem may lie in Mori’s 1970 Theory of the Uncanny Valley (Mori, 1970). Mori’s theory predicts that people will be increasingly comfortable with objects as they become more humanlike until a sense of unsettling uncanniness develops as the robot becomes almost, but not quite, humanlike. K. Gray and Wegner (2012) explored this theory by asking 120 people (mean age = 25 years) to watch short videos of the same social robot, Kasper, in two different conditions. In one condition the participants could see the more humanlike face of the robot; and in the other the more mechanical looking rear of the robot's head. Participants did indeed rate the more humanlike front of the robot as being more uncanny than the mechanical back of the robot. While this supports the notion that humanlikeness in robots is counterproductive to acceptance, the study was conducted with young participants in a non-healthcare context, which may not generalise well to an eldercare robot context. Further, the results may be specific to Kasper's face and not generalise to robot faces of different design.

A robots' physical form seems to be important for acceptance of robots, and the face of a robot, like the face of humans (Etcoff,1999), also appears to be critical in people reactions to it. So an important question is: should an interactive robot have a face? And if so: what should the face be like?

Some researchers have assessed the relationship between robot facial features and how humanlike the robot appears. DiSalvo et al. (2002) collected 48 static images of robots from popular media. The features of the robot's heads were counted and 20 participants (of unreported age) rated the heads on humanlikeness. Results showed the presence of robot facial features was important for perceptions of humanness. The features that contributed most to perceptions of humanness were the nose, eyelids, and mouth. However, the study did not assess whether degree of perceived humanness was related to acceptance.

The results from K. Gray and Wegner's (2012) 'front and behind' Kaspar study are aligned with the results from several studies that suggest older people would prefer a robot without a face (Broadbent, Tamagawa, et al., 2009; Cesta et al., 2007). However there may be further variables that determine whether people prefer a humanlike or machinelike robot - with or without a face. Preference may be impacted by context variables. For example, Goetz et al. (2003) found people preferred more humanlike-looking robots for more sociable tasks, and more machinelike robots for less sociable tasks. It also seems plausible that preferences are impacted by the aesthetics of a particular robot face. For example, Hanson (2006) tested the Uncanny Valley Theory by digitally morphing static images of a robot and a human. Results suggested it was not degree of robot humanlikeness per se that was associated with uncanniness or unease; but rather unaesthetic design.

While explicit human preferences are important, they are not the only consideration in the design of acceptable robots. For example, Goetz et al. (2003) found people preferred an exercise robot programmed with a fun personality compared with the same robot with a serious personality. However despite their preference for the fun robot, participants exercised more with the serious robot. This finding further supports the notion that context and context-relevant outcomes should be considered in designing acceptable robots.

Another factor that may impact acceptance is robot gender, which is strongly expressed in the face. A review of eldercare robots concluded that while there is some evidence to suggest perceived gender of a robot can impact human responses, there is insufficient research to advise on the optimal eldercare robot gender (Broadbent, Stafford, et al., 2009). It is also possible the gender of the human robot-user may impact acceptance. There is some evidence that men and women rate technologies differently (Sung et al., 2009; Venkatesh et al., 2003). In other work, Schermerhorn, Scheutz, and Crowell (2008) found male students (of unreported age) performed worse than female students on a difficult arithmetic task performed in front of a robot. The Peoplebot robot used in that study had an embodied camera-type ‘head’ and a male voice (voice origin unreported).

In assessing human-robot gender interaction, Siegel, Breazeal, and Norton (2009) used cash donation as an objective measure of the relative persuasive powers of a male and female robot. The physically androgynous Mobile Dexterous Social Robot was gendered by pre-recorded male and female human voices. The mean participant age was 35.6 (SD = 11.6). It was found that men donated more money to the female version of the robot, whereas the gender of the robot made no difference to women participants.

In a recent study, Eyssel, Kuchenbrandt, Bobinger, de Ruiter, and Hegel (2012) randomized 58 students (Mean age = 22.88, SD = 2.81) to viewing one of four videos of the androgynous robot FLOBI uttering a short sentence. The 2 x 2 robot conditions varied on whether the robot spoke with a male or female, humanlike or robot-like voice. Eyssel et al. reported that gender interactions were detected, including participants preferring the robot with the same-sex voice. However several of these reported gender differences were non-significant, e.g. $p = .20$.

As the HRI gender studies have been conducted with younger participants in a non-healthcare context, generalisability to an eldercare robot context may be limited. Furthermore, the robots were gendered by voice only and not by appearance. Results from non-HRI gender-preference healthcare studies may help with this research question. For example, B. L. Bernstein, Hofmann, and Wade (1987) found that the majority of 169 students (age range 17-74 years, M = 30.5, SD = 8.1) either had no gender preference for a counsellor or they preferred a male counsellor. However older age was associated with preferring a male counsellor. The exception was when the issue was of a personal or intimate nature, in which case students reported preferring a same-sex counsellor. In a UK study

(Horrocks et al., 2004), older women reported preferring a female doctor. Older men had no preference.

How to assess attitudes? Some methodological issues

The interaction between a human and a robot is complex. Determining and measuring acceptance-critical aspects of HRI, in a valid and reliable way, can be difficult. For example, an elderly man verbally reported he did not like Paro the social seal robot, yet video recordings of the man's affectionate behaviour towards the robot suggest otherwise (Wada, Shibata, Musha, et al., 2005). For these reasons the use of multiple data gathering methodologies, or data triangulation, is recommended (Bethel & Murphy, 2010). More implicit measures of people's attitudes, such as drawings, can corroborate self-report or help circumvent self-report limitations.

Drawings may be used as an alternative and complementary method to questionnaires to assess people's mental schemas about an object. Drawings have shown to be associated with anxiety and behaviour. For example, patient's drawings of damage to their heart predicted return to work after a heart attack (Broadbent et al., 2004). Larger drawings of the heart have been associated with more heart-focused anxiety in the same group (Broadbent et al., 2006). Furthermore, pictures of robots drawn by people aged over 40 have been found to predict outcomes in an HRI study (Broadbent, Lee, et al., 2011). People who drew a humanlike, rather than box-like robot at baseline, had greater increases in BP from before to after interacting with a healthcare Peoplebot. Larger drawings of robots were associated with more negative emotions after interacting with the robot.

Aims

This study aimed to determine some more specific factors that impact older people's acceptance of a conversational robot. In particular, to see if older participants would respond differently to different types of displays on the robot's monitor; some displays with faces, some without. Also to examine whether pre-existing attitudes towards robots and drawings of robots are related to acceptance of a conversational robot. The purpose of the latter aim is to build on earlier studies and assess if the previous findings can generalise to a community-dwelling older sample interacting with a conversational robot.

Research questions

I. Does the gender, humanlikeness or machinelikeness, or presence or absence, of a conversational robot's virtual face influence participants' responses to the robot?

II. What do people draw when asked to draw a robot therapist's face?

III. Are participants' attitudes towards robots and drawings of robots associated with their evaluations of a conversational robot, and their BP and heart rate, after interacting with the robot

Hypotheses

A. Participants would rate a virtual humanlike face on a conversational robot's monitor most acceptable, followed by a robot with no face on its screen, and a virtual machinelike face would be least acceptable.

B. People would draw a humanlike face to express their idea of a therapist robot's face.

C. Larger drawings of the robot would be associated with lower robot acceptance and increased BP and heart rate.

D. More positive robot attitudes before an interaction would result in greater acceptance of the robot

E. Men and women would rate a conversational robot of the same sex as more acceptable than a conversational robot of the opposite sex.

6.2.2. Method

Creation of the robot's display conditions

The robot's monitor displayed six different 'face' display conditions. Four of the six display conditions had virtual faces (along with a male or female voice). Two of the six conditions had no faces and a male or female voice only. Therefore the robot's monitor displays varied on two dimensions, i/ facial appearance (humanlike, machinelike, or no face) ii/ robot gender.

In this study the robot's six display conditions are referred to as; human-female face, machine-female face, human-male face, machine-male face, noface/female voice, and noface/male voice.

The human faces for the robot's display originated with standard faces on the software FaceGen Modeller from Singular Inversions. The faces were aged at approximately 40 years using the software settings. This agent age was considered appropriate for a conversational robot study with older participants. A Caucasian appearance was also selected for the faces, to match the expected participant group. Once the human faces were determined, a 'silver skin' was placed over them and the nose made more angular to provide more robotic or machinelike versions of the human faces.

However, with the agent's body not visible and without stereotypical feminine accessories such as women's clothing, long hair, or makeup, the machine-female virtual face looked more neutral in gender than female. Consequently (as seen in Figure 11) the size of the cheekbones and lips were enhanced to feminise the machine-female's face. Longer hair was also added to the human-female face to increase the perceived 'femaleness' relative to the human-male face. Xface, an open source 3D talking head based on the MPEG-4 standard was used to animate the virtual faces so they appeared to speak in a naturalistic way.

Manipulation check for the robot's virtual faces

Using participants aged 55 years and over, two iterations of manipulation checks were conducted to ensure that the robot's four virtual faces were perceived as significantly different in human/machinelikeness and gender. To ensure that the virtual faces *only* differed from each other on these variables of interest and not on emotional expression - scales were administered based on Ekman's basic emotions (Ekman, 1992). The faces are shown in Figure 11 and results of the second manipulation check indicated the emotional expressions of the four virtual faces were not significantly different ($p > .05$).

Manipulation check for the robot's male and female voices

The robot communicated with participants by generating speech with either a male or female Microsoft voice. Prior to the main study, manipulation checks were conducted with participants to ensure that the voices were perceived as significantly different in gender ($p < .05$). The checks also ensured the voices did not differ on a 10 item Likert scale that had semantic opposites of 'natural: humanlike' versus 'mechanical:robotlike' ($p > .05$).

Participants

A power calculation was conducted to determine the appropriate number of participants for the study. With power set at .8 and an α value of .05, the GPower 3.1 calculation indicated a sample of 19 people would be sufficient to detect a medium effect size (f = .25) in differences between participants' evaluations of the robot's six different display conditions. Twenty participants aged 55 years or over were recruited via email sent to University of Auckland departments. Potential participants were informed they would be asked to interact with a therapist robot. Participants were required to be fluent in English and able to type using a keyboard. The ages of the seven men and 13 women participants ranged from 55 - 71, M = 64.5, SD = 4.55. Seventeen participants identified as European New Zealanders, two as European Dutch, and one as Indian. Sixteen of the participants had a university degree. With a maximum possible score of eight, the mean of participants' computer knowledge was M = 6.32 (SD = 1.53), and the mean for their knowledge of robots was 3.37 (SD = 1.7, both n's = 19).

Procedure

Ethics approval was obtained from the University of Auckland Human Participants Ethics Committee (Ref.2009/367). During the study participants interacted with the ELIZA programme installed on a Peoplebot robot (Adept Mobile Robots), with an on-board Intel Pentium1300 MHz processor. ELIZA is an interactive software programme that simulates Rogerian psychotherapy (O'Dell & Dickson, 1984). The purpose of the programme was to provide a constant conversational platform to enable evaluation of participants' responses to the changing appearance of the robot's monitor display. ELIZA responds to participants with pre-formatted psychotherapy content triggered by key words typed by the participants. While useful, ELIZA is a very limited psychotherapy programme. As the Peoplebot/ELIZA combination is not equivalent to a human psychotherapist, in this study the robot is referred to as a ‘conversational robot’.

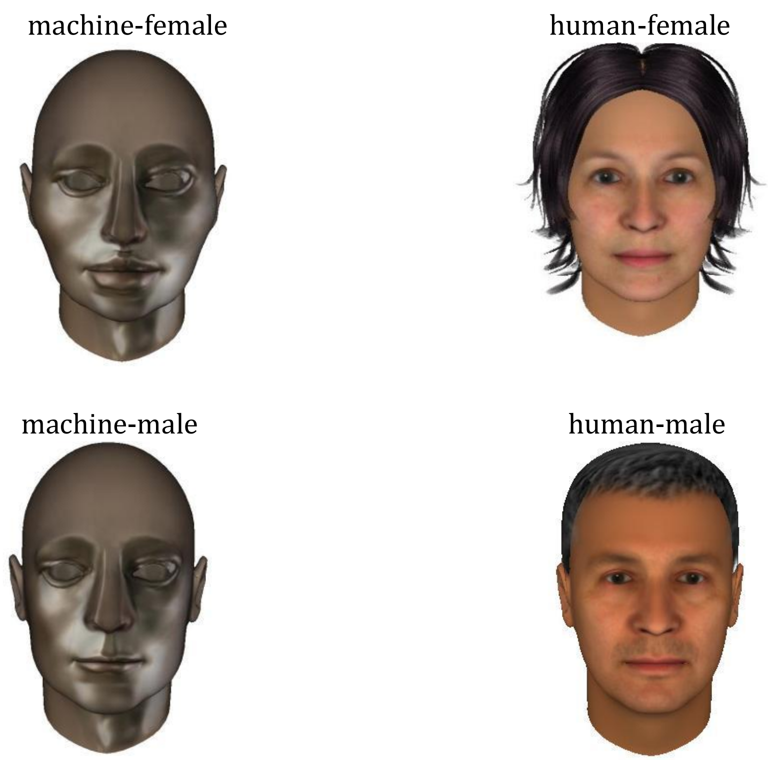

Figure 11. The final faces used for the four of six robot display conditions with virtual faces[15]

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[15] Note: The robot’s two display conditions without faces (no face/female voice and no face/male voice) are not shown, but had a blank blue screen instead of a face.

The Microsoft Speech SDK 5.1 was used to synthesize the robot's speech. For the robot's three female display conditions, Microsoft's 'Mary' voice was used. Microsoft's 'Mike' voice was used for the three male conditions. These two voices are available for download from the Microsoft website (Microsoft, 2012).

Text generated by the ELIZA programme was also displayed on the robot's monitor. As seen in Figure 12, participants communicated with the robot by typing on a keyboard attached to the robot. During the interaction the robot sequentially displayed the six different conditions on its monitor. The order of presentation of the display conditions was randomized for each participant.

The trial was conducted in a small office within the University of Auckland, New Zealand. Participants were met on the University campus by a researcher and escorted to the study room. They were informed about the study procedure including that they would be interacting with a robot installed with a basic psychotherapy programme and displaying different faces on its monitor. They were told they would interact with the robot by typing into a keyboard and the robot would communicate with them with speech and text.

On arrival at the study room participants were seated opposite the robot, which initially had a blank monitor display. Written informed consent was obtained. Participants then completed the baseline questionnaires. Next, participants were asked to interact for five minutes with each of the robot's six display conditions. Participants evaluated each of the conditions immediately after each interaction. Blood pressure and heart rate were measured both at the beginning and end of the trial.

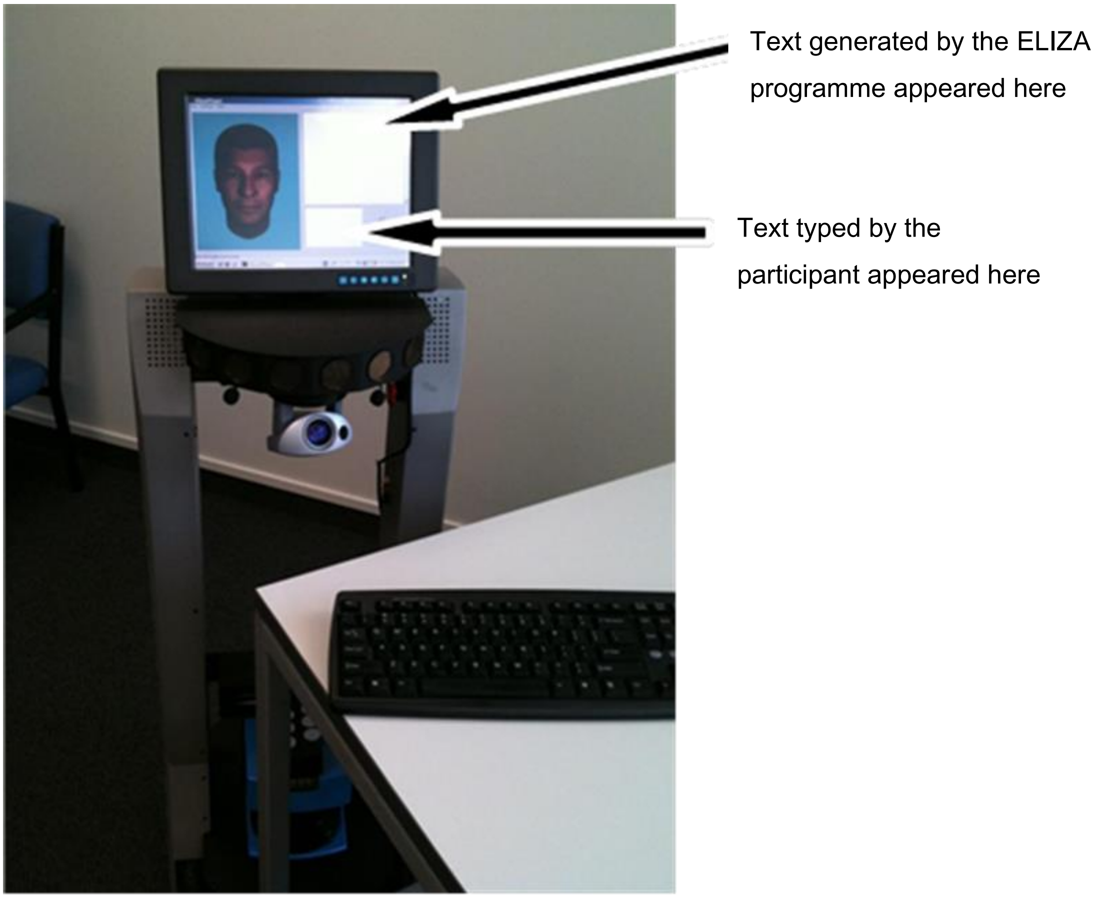

Figure 12. The trial set-up[16]

Measures

As outlined in Figure 13, different measures were administered at different stages of the trial.

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[16] Note: For the robot's two display conditions without a virtual face, the monitor screen was identical except for having a blank blue space where the human-male face is depicted in this figure

Pre-HRI measures

Demographics: Participants were asked their gender, age, ethnicity, education, and occupation.

Knowledge of computers and robots (Stafford et al., 2010): Participants were asked to circle a number to indicate how experienced they were at using computers; e.g. for email, typing things out, and finding things on the internet. The response options ranged from 1 (not at all) to 8 (extremely). They were also asked how much they knew about robots. The response options for this item ranged from 1 (nothing) to 8 (quite a bit).

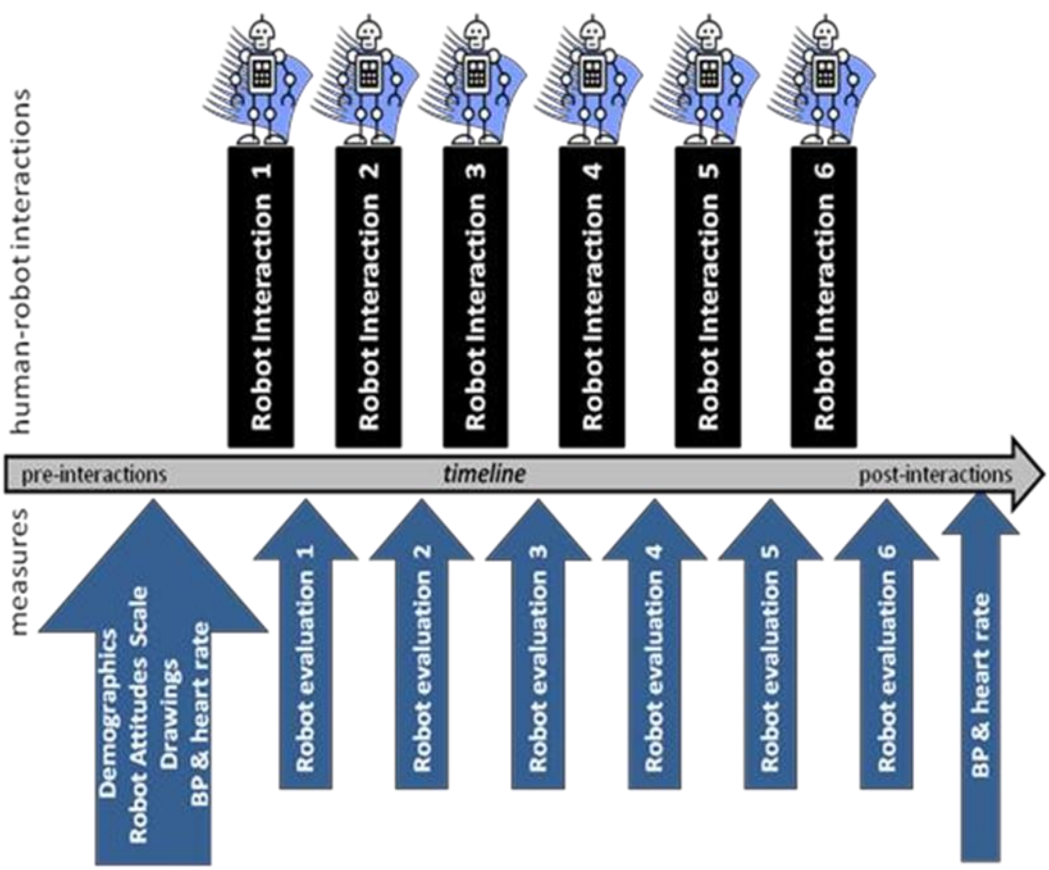


Figure 13. Diagram showing administration of measures in relation to pre-robot interactions, interactions with each of the six robot display conditions, and post-interactions.

Robot Attitudes Scale (RAS): This 12-item measure was developed in an earlier study (Broadbent et al., 2010). The written RAS instructions were ‘Please circle the number that best corresponds to how you feel towards the robot therapist you are about to use. I think the robot therapist will be:’. Participants then rated the robot on 12 attributes using an eight-point scale, with the attribute opposites as anchors. For example; friendly (1) - unfriendly (8). The other RAS items were; useful-useless; trustworthy-untrustworthy; strong-fragile; interesting - boring; advanced - basic; easy to use - hard to use; reliable - unreliable; safe - dangerous; simple - complicated; helpful - unhelpful; and controllable - uncontrollable. RAS items were summed to create an overall score (RAS-total) between 12 and 96. Higher RAS scores equate to less favourable robot attitudes. Cronbach’s α was .86.

Drawings of the robot’s face: The standardised drawing instructions were adapted from (Broadbent, Lee, et al., 2011). Instructions were placed above a 124mm(h) x 141mm(w) box on an A4 sized page. The instructions were – “The robot will have a face displayed on its computer screen. Please draw a picture of what you think the robot’s face will look like. We are not interested in your drawing ability; we are interested in your ideas about robot faces - a simple sketch is fine”. On the inside top left of the box was the text “My picture of a face that could be displayed for a robot therapist….”.

After the trial, researchers viewed the drawings and by consensus identified the drawings’ distinctive features.

Measures administered *after* interacting with each of the six robot display conditions

Robot evaluation: After each of the six interactions, participants completed two questions. These items were developed in Stafford et al., (2010). The two items asked participants to i/ provide an overall rating of that robot display condition - from 0 (very poor) to 100 (excellent) and ii/ to indicate how much they would like to use that version of the robot again, by writing a number from 0 (not at all) to 100 (excellent). Item ii/ is based on technology acceptance research indicating there is a strong relationship between intentions to use a technology and actually using it (Venkatesh et al., 2003). These two variables were highly correlated ($r = .92$, $n = 20$, $p < .001$), so were averaged to form a composite variable 'Robot evaluation'.

Perceived gender and human/machinelikeness of the robot's virtual faces: After each of the interactions, participants rated the four of six robot display conditions that had virtual faces (human-female face, machine-female face, human-male face and machine-male face) on gender and human/machinelikeness. Response options were on a 10 point Likert scale. Response options for perceived gender were: 1(male)-10(female): for human/machinelikeness: 1(machinelike)-10(humanlike). Note the robot's two monitor display conditions *without* virtual faces (no face/male voice and no face/female voice) were not rated on these items.

Statistical analyses were conducted using SPSS statistics 18. Data were assessed for normality using the Kolmogorov-Smirnoff statistic, and parametric or non-parametric statistical analyses run accordingly. A Friedman Test was conducted to assess differences in participants' evaluations of the robot's six different screen displays. A mixed ANOVA was conducted to assess differences between man and women in ratings of the robot's different displays (for this analysis, the evaluation data was ranked in order to convert it to a normal distribution). Spearman's correlation coefficients tested for associations between the continuous variables (the RAS, drawing details, physiological measures, and robot evaluations). Mann-Whitney U tests were conducted to assess differences in physiological measures between people who did and did not draw particular features on their robot faces. Significance was set at $p < .05$.

6.2.3. Results

Do people respond differently to the different faces of a conversational robot?

Was the manipulation of the robot's virtual faces effective? - As expected, there were significant differences between participants' ratings of the robot's four virtual faces on gender and human/machinelikeness. However (unlike the manipulation check) in this main trial participants rated the human-female face as being significantly more female ($M = 7.5$, $SD = 1.73$) than the machine-female face ($M = 4.8$, $SD = 2.79$, $p < .05$). This was considered acceptable for the purposes of the main study, as the machine-female face was still rated as being significantly more female than the two male virtual faces; human-male ($M = 1.5$, $SD = .61$) and machine-male ($M = 1.9$, $SD = 1.17$, p's $< .05$).

How did participants evaluate the different robot display conditions? - The results of a Friedman Test (Table 4) indicated there were no significant differences detected in participants' evaluations of the robot's six different display conditions, $X2(5, n = 20) = 2.25$, $p > .05$. Consequently, for the remainder of the analyses, the evaluation scores for the robot's six display conditions were averaged to give an overall evaluation of the robot for simplified analyses.

Table 4. Statistics describing participants' evaluations of the six different robot display conditions

Condition displayed on robot's monitor	Median	Mean	SD
Human-female face	25.0	27.8	24.3
Machine-female face	25.0	27.8	23.2
Human-male face	12.5	27.6	27.2
Machine-male face	7.5	25.4	28.0
Noface/female voice	16.3	24.6	24.7
Noface/male voice	16.3	24.2	24.3

Did men and women evaluate the robot display conditions differently?

A mixed 2 (men and women) X 2 (robot male, robot female) X 3 (robot humanlike, machinelike, or no face) ANOVA was conducted using participant gender as a between subjects factor and robot facial appearance and robot gender as within subjects factors. The results indicated that there was no main effect for robot gender $F(1,18) = .265$, $p = .613$), and there was no main effect for robot facial appearance ($F(2, 36) = .185$, $p = .832$). However, there was a non-significant trend for a between-subjects effect between men and women, such that men tended to rate all the conditions (estimated marginal mean rank 13.44, SD 1.76) higher than women did (estimated marginal mean rank 8.92, SD 1.29), $F(1,18) = 4.30$, $p = .053$). There was a medium sized between-subjects effect size of $r = .44$. There were no significant interaction effects (all p values >.05).

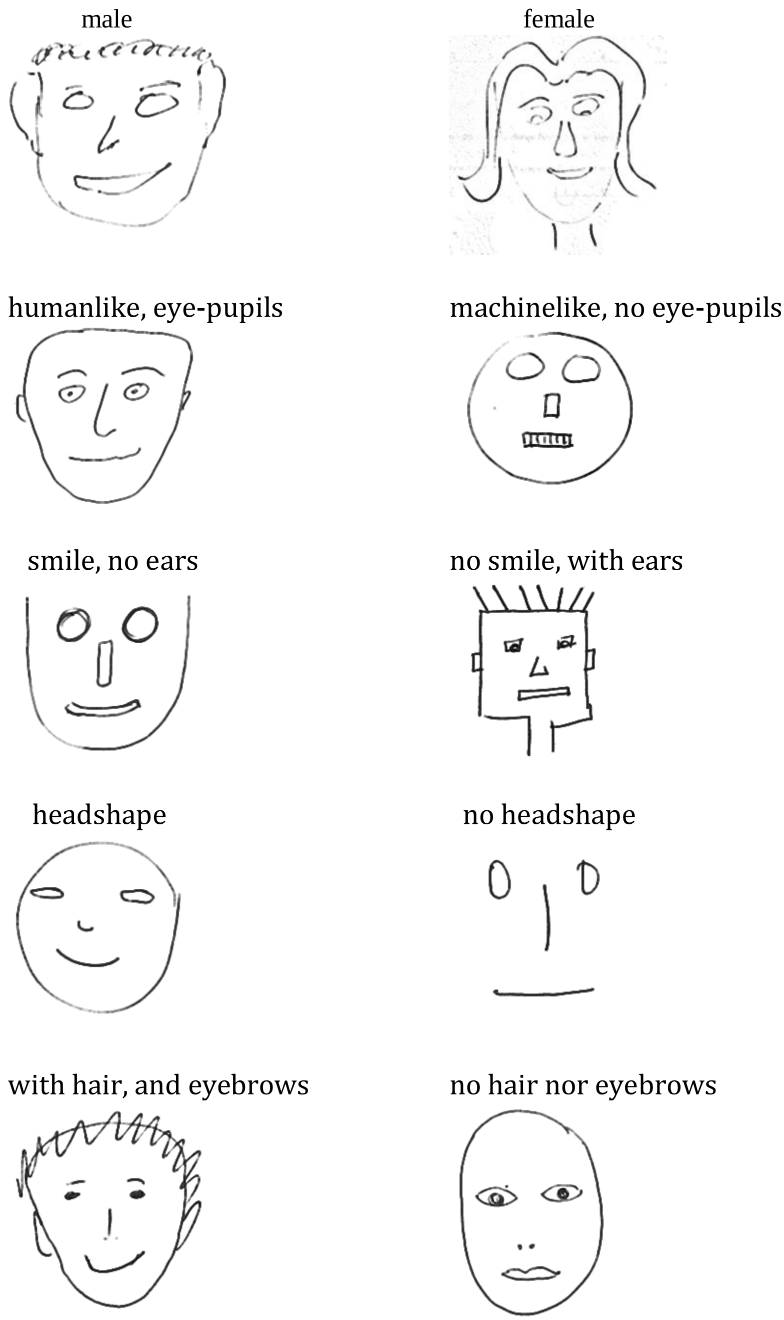
What do people draw when asked to draw a robot therapist's face?

Drawing descriptives: The mean width of the drawings was M = 65.2mm (SD = 29.05); the mean height was M = 64.0 (SD = 24.03); and mean area was M = 4789.3mm2 (SD = 4157.15; all n's = 20. The mean number of robot facial features drawn was M = 5.45, SD = 1.96, range = 6 (from 3 to 9). Counts of whether or not participants drew particular facial features can be seen in Table 5. Examples of drawings showing particular facial features can be seen in Figure 14.

Table 5. Counts and percentages of robot therapist facial features drawn by participants

	Is the facial feature present in the drawing?		
Feature	Yes		No
Eyes	20	(100%)	0
Nose	19	(95%)	1
Mouth	18	(90%)	2
Head-shape containing features	16	(80%)	4
Smile	11	(55%)	9
Eyebrows	9	(45%)	11
Ears	9	(45%)	11
Eye pupils	8	(40%)	12
Hair	7	(35%)	13
Neck	3	(15%)	17

Figure 14. Some examples of robot drawings demonstrating gender dimorphism, human vs. machinelikeness, and the presence or absence of particular facial features



Did participants draw male or female, humanlike or machinelike robot therapist faces? Researchers rated participants' drawings of a robot therapist face on both gender (male, female or 'gender-neutral') and whether they were humanlike or machinelike. As seen in Table 6 the majority of faces were categorised as predominantly male, with gender-neutral a close second and only two drawings were rated as being female. Almost two thirds of the drawings were rated as being humanlike rather than machinelike. There was agreement amongst the six researchers on face gender and human/machinelikeness for all drawings except four. In these cases, the faces were re-examined and a consensus reached.

Table 6. Counts of researcher ratings of the gender (male, female, or gender-neutral) of the participant's robot therapist face drawings and whether the faces were humanlike or machinelike

Drawing categories	Male	Female	Gender-Neutral	Totals
Machinelike	2	0	5	7 (35%)
Humanlike	8	2	3	13 (65%)
Totals	10 (50%)	2 (10%)	8 (40%)	20 (100%)

Do participants' robot attitudes and robot drawings correlate with their evaluations of the robot, their blood pressure or heart rate?

Robot Attitudes Scale (RAS): Half of the robot attitude items reported before interacting with the robot (including RAS-total) were significantly and strongly correlated with post-interaction evaluations of the robot. As seen in Table 7 more positive robot attitudes at baseline were associated with higher robot evaluations.

Table 7. Spearman correlations between pre-interaction RAS Items and the post-HRI evaluation scores[17]

			correlations between RAS items and robot evaluation	
RAS items	M	SD	rho	P
RAS- total	36.65	10.73	-.64**	.002
RAS- useful(1)-useless(10)	3.35	1.09	-.52*	.02
RAS- strong(1)-fragile(10)	3.20	1.45	-.49*	.03
RAS- interesting(1)-boring(10)	2.30	1.34	-.50*	.03
RAS- advanced(1)-basic(10)	3.85	1.69	-.69**	.001
RAS- reliable(1)-unreliable(10)	3.00	1.26	-.73**	.000
RAS- helpful(1)-unhelpful(10)	3.40	1.23	-.69**	.001
RAS- friendly(1) – unfriendly(10)	3.20	1.67	-.21	.34
RAS-trustworthy(1)-untrustworthy(10)	2.80	1.61	-.32	.16
RAS- easy to use(1)- hard to use(10)	3.15	1.35	-.20	.41
RAS- safe(1)- dangerous(10)	1.55	0.69	-.24	.31
RAS- simple(1)-complicated(10)	3.35	1.31	-.16	.38
RAS-controllable(1)-uncontrollable(10)	3.50	1.79	-.21	.38

*p<.05 **p<.01

There were no significant correlations between participants' robot attitudes and participants' *initial* heart rate and BP. However, elevated heart rate post-interactions was associated with pre-interaction perceptions of the robot as less trustworthy (r = .53, p = .02) and less controllable (r = .56, p =

[17] Note i. Lower RAS scores mean more positive robot attitudes. Note ii. all n's =20

.01). The RAS-total score was not significantly associated with any pre- or post-interaction physiological measures.

Drawings of a robot therapist's face: There were no significant correlations between i/ drawing width, height, area, or total number of features drawn, and ii/ robot evaluation ($p > .05$).

With one exception, Mann-Whitney U tests showed no significant differences between people who did or did not draw particular facial features and their robot evaluations ($p > .05$). The exception was people who drew hair on the robot's head ($Md = 32.5$, $n = 7$) were more likely to evaluate the robot more highly after using it than people who did not draw hair ($Md = 7.9$, $n = 13$, $U = 17.5$, $z = -2.2$, $p = .03$, $r = .49$). There was also a non-significant trend for people who drew a neck to evaluate the robot more highly ($p = .08$).

There were no significant associations between drawing features and diastolic BP ($p > .05$), but the larger people's robot therapist drawings were - the more elevated their systolic BP was at the end of the trial ($r = .53$, $p = .02$, $n = 20$).

Ears were the only facial feature of the drawings associated with any physiological measure. As seen in Table 8 people who drew ears were more likely to have a lower heart rate at both pre- and post-interactions, compared with those who did not draw ears.

Table 8. Mann-Whitney U Test statistics showing differences in heart rate between participants who did and did not draw ears in their picture of a robot therapist face

Ears drawn?	Heart rate (*pre*-interactions) Median	n	u	z	p	r
No	80.0	11	23.0	-2.01	.04	.45
Yes	64.0	9				
	Heart rate (*post*-interactions) Median					
No	73.0	11	19.0	-2.13	.02	.48
Yes	61.0	9				

6.2.4. Discussion

There was no significant difference in participants' evaluations of the six different conditions displayed on the robot's monitor; regardless of whether the robot's face was male or female, human or machinelike, or even if there was a face at all. However when examining participant gender differences; there was a non-significant trend for men to evaluate the robot more highly than women did. Participants' evaluations of the robot in this study were low compared with evaluations of a Cafero healthcare robot in a retirement village setting (Stafford et al., 2010). The difference may be explained by participants in this study being younger and more highly educated than the retirement village residents. They may have had high expectations of a 'therapist robot' but with their greater familiarity with technology, were disappointed with the low level of technical sophistication exhibited by the ELIZA programme on the Peoplebot. Additional methodological differences between the two studies included the use of different robots (Peoplebot Vs. Cafero) with different functions (conversational vs. healthcare).

In relation to drawings - half of participants drew a male robot therapist face, and 40% drew a gender-neutral one. Only 10% drew a robot's face that was identified as female. Most people drew a humanlike, rather than machinelike face. All people drew eyes on the robot's face. All but one participant drew a nose, and most drew a mouth and head-shape. About half of participants gave their robot's face a smile, eyebrows, ears and eye pupils. Less than half drew a neck or hair on the robot's head.

This study's participants likely acquired at least some of their concepts of what a robot looks like from popular media. It may be interesting to 'reverse engineer' this study's drawing results by comparing them with the robot features coded from images of popular media and research robots. DiSalvo et al. (2002) found 81.3% of the 48 'humanoid' robot images they surveyed had eyes, 18.8% had eyelids, 16.7% eyebrows, 29.2% noses, 62.5% a mouth, and 43.8% had ears. Similar to this study, Di Salvo et al. (2002) found eyes were the most common robot facial feature.

This study's robot drawings contained a considerably higher proportion of noses and mouths than DiSalvo et al.'s 48 robot images, and almost the same proportion of ears, but fewer eyebrows. This suggests that people have higher expectations of robot faces having noses and mouths than would be expected from the robot faces typically portrayed in the media. Alternatively, this study's instructions to draw the "face of a therapist robot" may have triggered schemas of more humanlike and less media-typical robots.

Participants who reported more positive pre-interaction robot attitudes also reported higher robot evaluations after interacting with it. Perceptions of the robot as less trustworthy and less controllable were associated with higher post-interaction heart rates. People who drew hair in their pictures also rated the robot more highly. People who drew ears had a lower heart rate both before and after the interactions. Larger drawings of robot therapist faces were associated with higher post-interaction systolic BP.

Therefore hypothesis A. was not upheld as no differences were found in participants' responses to the robot's different face displays. Hypothesis B. was upheld as the majority of participants' drawings were humanlike. As larger robot drawings were associated with higher post-interactions systolic BP, but *not* diastolic BP nor heart rate, hypothesis C. was partially upheld. As participants' positive pre-interaction robot attitudes were associated with positive evaluations of the robot, hypothesis D. was upheld. As men and women did not have a same-sex preference for the conversational robots, hypothesis E was not upheld.

Some of this study's results are consistent with other studies, and some are not. Considering there is evidence that people evaluate different robot faces differently (DiSalvo et al., 2002; Goetz et al., 2003), it was surprising that differences in the robot's display conditions in this study did not appear to affect participant's robot evaluations. There are several possible reasons for this. As the trial was sufficiently powered to detect moderate effect sizes; it's possible a significant but small effect went undetected due to an insufficient number of participants.

Another (complementary) reason is a five-minute interaction with each of the six different display conditions may not have been long enough for differences in participants' responses to be elicited. Further, the ELIZA programme may have acted as a confound by not responding sufficiently consistently across the six conditions. It is also possible the faces used in this study were too similar to provoke moderate differences in participant responses. Some of this study's results differing from that of other studies could also be due to participant age differences. Results from HRI studies with younger participants may not generalise well to older people (W. A. Rogers & Fisk, 2010).

Some of the individual RAS items that were associated with participants' evaluations of the robot have been identified as important in other acceptance studies. One RAS item of particular interest is 'useful-useless'. In this study people who expected the robot to be more useful also evaluated it more highly. This finding is consistent with models of technology acceptance where perceived usefulness is considered a key determinant of technology acceptance. As these naïve expectations were captured via administration of the first measures before participants had used the robot; these results support Davis's (1989) emphasis on the importance of *perceptions* of usefulness rather than more objective measures of usefulness.

As both perceived usefulness and perceived ease of use are considered key predictors of technology acceptance, the 'easy to use - hard to use' RAS item is also of interest. In this study, in contrast to previous technology acceptance research (Davis, 1989, 1993; Venkatesh et al., 2003) perceptions of the robot's ease of use were not significantly correlated with robot evaluation scores.

A third RAS item of interest is 'trustworthy-untrustworthy'. Despite other researchers proposing that perceptions of robot trustworthiness are important for acceptance (J. D. Lee & See, 2004; Sanders et al., 2011), this study found no significant association between perceptions of robot trustworthiness and post-trial evaluations of the robot.

There are several possible explanations for these anomalous results for the RAS items relating to ease of use and trustworthiness. In relation to perceptions of ease of robot use – this highly educated sample may have had high comfort levels in relation to technology use. Additionally, as part of the procedure, the researcher explained the robot's simple operating requirements to participants before they completed the pre-interaction measures. Consequently ease or difficulty of use of the robot may not have been a salient cognition for participants. In support of this explanation, Hong et al. (2006) note the impact of perceived ease of use may diminish as users adjust to a technology. Further, Davis (1993) found that while perceived ease of IT use was predictive of technology acceptance; it was only half as influential as perceived usefulness.

In relation to perceptions of robot trustworthiness; pre-interaction perceptions of the robot as being less trustworthy were not significantly associated with robot evaluation or initial heart rates, but were significantly correlated with higher heart rate after the interactions. It is possible that perceptions of robot untrustworthiness provoke anxiety in response to a robot interaction. In light of this finding, closer examination of the data in Table 7 show that of the non-significant correlations between RAS items and robot evaluation; 'trustworthy-not trustworthy' had the highest r value (-.32) and the p value closest to significance (.16). This suggests that the correlation between perceptions of robot trustworthiness and higher robot evaluations may have reached significance with higher participant numbers. These physiological and self-report results for perceptions of robot 'trustworthiness' support both the concept that trustworthiness perceptions are associated with robot acceptance, and the importance of multiple data gathering methodologies in HRI research.

People who draw more humanlike robot features such as hair and ears may have more humanlike mental schemas of robots. Drawing these features was associated with better robot evaluations and lower heart rate. Previous research is divided on whether humanlikeness in robots negatively or positively impacts on acceptance. This division may have arisen because the answer to the question “Should a robot be humanlike or not?” is “it depends”. Whether people regard robot humanlikeness as a negative or a positive factor may be an interaction between a person’s robot schemas, or pre-existing mental models of robots, and the specific HRI context; in this case a conversational robot.

Eldercare robots could perform a variety of social or more task-oriented roles; and it is likely people prefer an eldercare robot’s appearance to be consistent with its role (Broadbent, Tamagawa, et al., 2009). In this study, results from the drawings suggest that participants’ perceptions of the therapist robot as humanlike were both positive and associated with higher robot acceptance. This may mean that perceptions of humanlikeness are consistent with perceptions of a conversational robot. That larger robot drawings were associated with higher systolic BP concurs with previous research findings that larger drawings are associated with increased anxiety. Similarly to this study, Broadbent, Lee, et al. (2011) found a trend for larger drawings of a healthcare robot to be associated with greater increases in systolic BP during an HRI.

Compared with women in this study, men tended to rate the robot higher across all conditions. The medium effect size associated with that finding suggests the standard significance benchmark of $p < .05$ may have been reached with a larger sample size. The sample size of seven men and 13 women implies generalizations of the gender results should be done with caution. However this study’s gender-related findings are similar to those of a healthcare robot study with a larger sample ($n = 57$) of mixed age participants (Kuo et al., 2009). Compared with women in that study, men were found to hold significantly more positive robot attitudes. This study’s gender result concurs with other research that suggests men are more accepting of technologies (Venkatesh et al., 2003).

The limitations of this study may include being underpowered to detect small differences in participants' responses to the different robot conditions. Participants may have become tired after interacting with six different versions of the robot. Participants were not asked to rate the two versions of the robot without virtual faces on gender and humanlikeness. If they had responded to these items, results may have indicated whether virtual faces added to perceptions of robot gender and human/machinelikeness over and above the gendered voices. The RAS was not re-administered after baseline in order to minimise participant burden. This limited the number of outcomes able to be analysed.

There are pros and cons to quantitative and qualitative analyses. In this study there was more emphasis on quantitative analyses of the drawings (for example counts of facial features and drawing size) rather than qualitative analyses. Although the presence or absence of a smile - qualitatively suggestive of friendliness - was considered a distinctive feature across the drawings; other qualitative aspects were not analysed in this study. Quantitative assessments are useful for quantitative statistical analyses; but more qualitative assessments may be more useful for a one on one in-depth analysis. For example, if a potential robot user drew a frightening looking robot it may be beneficial to have an in-depth interview to understand the source of these perceptions.

Study strengths include triangulation of data methodologies. These included self-report items, drawings and physiological measures. Multiple data collection methodologies are recommended for HRI research, and drawings may be a useful and more implicit measure to use concurrently with self-report. Participants' drawing results may either endorse participants' self-reports or help circumvent self-report limitations such as socially desirable responding and memory biases. Further strengths include participant assessment both before and after the robot interactions. This enabled predictors of robot acceptance to be ascertained. The use of older participants supports work in the development of acceptable eldercare robots. The use of standardized drawing instructions enables comparison with other HRI research. Drawings of robots may be a useful way to index anxiety and changes in anxiety towards robots.

Sanders et al. (2011) claim robot variables are the dominant determinant of human acceptance of robots, and human variables make a negligible contribution if any. However, other HRI studies have found human variables are important for acceptance (e.g. Heerink, Kröse, Wielinga, et al., 2008). While not discounting the importance of robot factors; evidence that different individuals' perceptions of the attributes and acceptability of identical robots can vary (Forlizzi & DiSalvo, 2006; Paepcke & Takayama, 2010) supports the concept that human perceptions are also an important factor in robot acceptability. In this study, pre-existing subjective perceptions of robot humanlikeness appear to have larger effects on acceptability than more objective design parameters of robot humanlikeness.

It is possible that in this study, small differences in acceptance between the different robot faces went undetected. However results also suggest that, beyond basic aesthetic design as proposed by Hanson et al. (2005), differences in robot faces, such as human/machinelikeness, may only result in differential user responses of minor clinical significance. Future research could therefore focus on optimising attitudes towards robots and fostering context appropriate perceptions of robot humanlikeness in order to increase acceptance. Although care should also be taken not to raise people's expectations so high that they are disappointed with the robot.

It is plausible that participants' prior experience with human therapists could influence their responses to a 'robot therapist'; as could prior experience with online computer therapies, especially ones that feature screen agents or static or moving images of real people. These variables were not measured by the authors and may be an interesting area for future research.

Even though numbers of participants used in this study were relatively small, this is not dissimilar to previous work in either drawings (Kaptein et al., 2011) or HRI research (Bartneck, Verbunt, Mubin, & Al Mahmud, 2007; Beer et al., 2012; Caine, Fisk, & Rogers, 2006; Callari, Ciairano, & Re, 2012; Kiesler & Goetz, 2002).

Furthermore, other research groups in addition to the authors have already published a number of studies on quantitative analysis of drawings (Broadbent et al., 2006; Broadbent et al., 2004; Daleboudt, Broadbent, Berger, & Kaptein, 2011). Despite this, future research should include larger sample sizes to better detect differences in responses to different robot faces, as well as detect gender differences in participant responses.

A larger sample size would also allow broader knowledge of older people's drawings of robots. However, the type of robot image drawn is likely to be influenced by the specific HRI, the study context, and drawing instructions. In this study the instructions were to draw a robot's face. The instruction in a prior HRI study involving robot drawings was to draw a healthcare robot (Broadbent, Lee, et al., 2011), and consequently the drawings were quite different from the ones in this study. And robot drawings are likely to be different again if participants are asked to draw a companion robot, or a medical robot, or the face of a multi-functional service type robot. More research is needed to assess which of these exploratory results generalise to other HRI contexts, and which are specific to specific HRI contexts.

However, while details of robot drawings, such as facial features or body shape, are likely to vary depending on HRI study context, this study's results have demonstrated that drawing size was positively correlated with physiological arousal (indicating anxiety). This is an important and useful finding. This result is congruent with previous robot and non-robot drawing studies that have found larger drawing sizes are positively correlated with poorer outcomes and anxiety in relation to the drawing subject. This suggests that this result is likely to generalise across a wide variety of HRI contexts, and therefore be a useful and generalisable tool for assessing robot-related anxiety. Note that while the results cannot prove precisely what mental states the physiological measures correspond to; physiological arousal, such as elevated heart rate and blood pressure, is associated with elevated stress and anxiety (De Vente, Olff, Van Amsterdam, Kamphuis, & Emmelkamp, 2003).

A possible limitation of the study is that drawings of a robot's screen face may not generalize to robots with embodied 3D heads. However, displaying a head or face on a robot's monitor or screen is one of several methods for manifesting a robot's face. Each different method for manifesting a robot's face will likely have its advantages and disadvantages. While an embodied 3D robot head may have benefits that a robot's '3D' screen head does not (Bainbridge, 2011; Kidd & Breazeal, 2010; Tapus, Tapus, & Mataric, 2009); it will also be relatively expensive to construct, and be limited in its scope for customisation. In contrast, a robot's screen face readily lends itself to customisability, including the option of no face. The latter preference has been expressed by some older people in eldercare robot studies (Broadbent, Tamagawa, et al., 2009; Stafford et al., 2010), which is why in this study, two of the robot's six screen display conditions were without faces.

Advantages of screens and monitors on robots include provision of additional functions, more interaction modalities, and customisability. Perhaps in recognition of these advantages, a number of socially assistive robots have screens. Although the Peoplebot's monitor is optional, some other robots with screens include Fraunhofer's Care-O-bot-3 (Fraunhofer, 2012), Yujin Robot's Cafero and IRobiQ (Robot, 2007), the EU CompanionAble project's Hector (IMSS, 2012), the NurseBot project's Pearl (Pollack et al., 2002), and the shopping robot TOOMAS (Gross et al., 2009). Therefore understanding what constitutes an optimal display on a robot's screen appears to be an important emerging HRI area to research.

Additional suggestions for future research include longer interactions. This may assist in detecting differences in participant responses to different robot faces. More research is also needed on differences between older men and women in their ratings of robots. It may be of interest to assess if younger people's drawings of robots differ from older people's drawings. Interventions could be designed to manipulate older people's robot attitudes and assess the impact on acceptance of eldercare robots.

Future HRI studies could administer drawings both before and after interactions, to assess whether changes in drawing size and features mirror any changes in anxiety about robots or physiological changes. A subsequent study has been performed to try and address some of these limitations (Broadbent et al., 2013). Rather than using the ELIZA programme, the subsequent study uses a robot healthcare interaction with a larger sample size of younger participants, and with a smaller number of faces that were only one gender and without hair.

Conclusion

This is the first time older people's expectations of a virtual robot therapist face have been assessed via drawings. The results of this study suggest drawings can indicate perceptions about robots which are related to acceptance. In subsequent work, they may be a useful methodological tool to assess changes in participants' perceptions of robots after an intervention designed to promote appropriate robot attitudes.

Results of this study corroborate earlier studies showing that pre-interaction robot attitudes are positively correlated with acceptance. The results demonstrate that these earlier findings relating to robot attitudes and drawings can generalise to a different community sample of middle-aged to older adults, and to a robot with a conversational function.

Although some participant gender effects were found, no differences in acceptance between the robot's six different face displays were detected. In contrast large effect sizes were detected for the associations between pre-interaction robot attitudes and post-interaction acceptance. This contrast suggests, alongside developing aesthetically pleasing and context-appropriate robot faces, it may be cost effective to direct research towards promoting contextually-appropriate robot attitudes. Support is also provided for the importance to robot acceptance of subjective perceptions of a robot's capacities. Assessing people's mental schemas of robots via attitudes and robot drawings may be important methods for predicting acceptance of robots, and form a basis for future interventions to enhance acceptance.

6.3. Study two segue – the *prior attitudes & drawings study*

Comparison of results between the *prior attitudes & drawings study* and the *improved attitudes study*

The results of the *prior attitudes & drawings study* replicate a key finding of the *improved attitudes study* - that people's prefactual robot attitudes are associated with their acceptance of a robot. This finding was replicated with a different robot with different functions, with a different older population, and in a different environment. Further replication of findings from the *improved attitudes study* in this *prior attitudes & drawings study* can be seen in the significant associations of participants' baseline robot drawing variables with post-HRI robot acceptance outcomes.

Support for the use of "overall rating of the HRI" as a proxy for 'intentions to use'

Results from the second *prior attitudes & drawings study* support the use of the item 'overall rating of the interaction' as a comparable outcome measure to 'intention to use' in the first, *improved attitudes study*. In the first study, the acceptance item 'how much would you like to use this robot again' was unable to be used for analyses. The majority of participants found the item confusing due to the robot only being a demonstration version. They wanted to use the improved version of the robot, but had no desire to use the prototype study robot again. In contrast, in the *prior attitudes & drawings study*, the outcome item "how much would you like to use this version of the robot again?" *was* acceptable to participants. Furthermore, in the *prior attitudes & drawings study*, participants' responses to that item ("How much would you like to use this version of the robot again?") *and* their responses to the 'overall rating of the interaction' were correlated to a multicollinearity level; indicating they are comparable constructs.

Other recent research on people's responses to different robot face displays

A recent publication describes a study that built on the methodology of the *prior attitudes & drawings study*. In this more recent study (Broadbent et al., 2013), 30 participants (Mean age 22.5 years) each interacted with three different versions of a Peoplebot in a blood pressure taking task. Similarities between Broadbent et al.'s study and the prior attitudes and drawings study include the use of a Peoplebot with different types of face displays on its monitor. The *types* of faces used were similar to those used in the *prior attitudes & drawings* study: a human face, a silvery robotic/machinelike face based on the human face, and no face.

Although the Peoplebot's faces were developed using a similar approach in both studies, they had different 'base faces' (in the *improved attitudes study* the base faces were 'average faces' in the software programme: in Broadbent et al.'s study the base face was a photograph of a male student). Consequently the resulting faces looked similar but not identical.

The results were also different between the two studies. In the *prior attitudes & drawings study*, regardless of the robot gender, no significant preference was found for the Peoplebot's human face, machinelike face, or no face display. In contrast, robot face preferences *were* found in Broadbent et al.'s (2013) study. Participant's in that study significantly preferred the human face display for a healthcare robot. The robot's no-face display was the next preferred, and the machinelike face was least preferred. There were no significant differences in participants' blood pressure readings between the three different face displays.

This difference in results could be attributed to a number of method differences between the two studies. These include Broadbent et al.'s study having younger participants rather than older, the study robots having different functions (blood pressure task vs. conversational/therapist), and Broadbent et al.'s study being a repeated measures design, rather than between groups, and having more participants and fewer face display conditions. This latter study difference meant that, compared with the *prior attitudes & drawings study*, Broadbent et al.'s study was better powered to detect significant differences in face preferences.

A further difference between the two studies is that of manipulation checks. In the *prior attitudes & drawings study* manipulation checks *prior* to the main trial ensured that the robot's faces did not significantly differ in emotional expression; whereas in Broadbent et al.'s (2013) study, the personality of the robot's faces was assessed *during* the trial.

This method difference does provide a possible explanation for the difference in findings. Broadbent et al. found 'eeriness', a measure of aversive uncanny valley effects, was not associated with the degree of humanlikeness of the robot faces, but rather was associated with negative perceptions of the face's personalities. Although perceived personality and perceived emotion are not interchangeable constructs; as the faces in the *prior attitudes & drawings study* were 'matched' on perceived emotional expression prior to the main trial, this may explain why in contrast to Broadbent et al.'s findings, participants had no preferences between the robot's face displays. However, this is speculation only. The eeriness and personality of the robot face displays were not assessed in the *prior attitudes & drawings study*, and as described above, there were many method differences between the two studies that may also explain the difference in results.

Chapter 7. Does the robot have a mind? Mind perception and attitudes towards robots predict use of an eldercare robot [*robot mind study*]

7.1. Preamble to study three – the *robot mind study*

The Cafero robot used in the first *improved attitudes study* had been upgraded based on two types of feedback. One type was feedback from participants in the *improved attitudes study*. The other type was the development of robot solutions in response to issues that become apparent during deployment in a real-world eldercare environment.

In the *improved attitudes study* participants only used the robot for approximately 30 minutes (also the case in the *prior attitudes & drawings study*). Therefore, a key aim of the next *robot mind study* was to assess if the findings that robot attitudes predicted robot acceptance could be replicated in a longer term trial. In this *robot mind study*, the improved version of the Cafero robot was deployed in a retirement village for two weeks. This study had several key objectives in addition to assessing the effects of longer exposure to the robot. As intentions to use a technology can be weak predictors of actual behaviour (Davis, 1989), we wanted to use the measure of actual use of the robot as a more objective and proximal measure of robot acceptance.

Lastly, a new, two-dimensional measure of mind perception was administered in the *robot mind study*. Mind perception may help explain why some people are uncomfortable with the concept of humanlike robots. Use of the Mind Perception Questionnaire (H. M. Gray, Gray, & Wegner, 2007) may help assess underlying mechanisms that influence people's acceptance of robots.

7.2. Publication three: Does the robot have a mind? Mind perception and attitudes towards robots predict use of an eldercare robot

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Abstract

Robots are starting to be developed for aged care populations and some of these have been made into commercial products that have been well received. However, little is known about the psychological factors that promote acceptance or rejection of robots by older people. Finding out more about these psychological determinants of robot uptake and acceptance is the primary focus of the study described in this paper. A healthcare robot feasibility study was conducted in a retirement village. Older people (n = 25) were invited to use a prototype robot with healthcare functions over a two week period. Questionnaires were completed before and after the period. It was found that residents who held significantly more positive attitudes towards robots, and perceived robot minds to

have less agency (ability to do things) were more likely to use the robot. It was also found that attitudes towards robots improved over time in robot-users. Our results suggest that the cognitions older people hold about robots may influence their decisions to use robots. The study results also validate participants' subjective self-reports of attitudes towards robots and perceptions of robot mind, against the objective measure of robot use. Interventions to foster adaptive cognitions could be developed and applied in the design, deployment and marketing of robots to promote their use and acceptance.

7.2.1. Introduction

The proportion of older persons compared to the proportion of younger persons in the global population is currently increasing (United Nations, 2012).These trends are particularly notable in the more developed regions, and especially in Japan, Germany, and Italy. There have been predictions of shortages of workers to care for this growing ageing population (Eaton, 2005; Sargen et al., 2011). It has been proposed that healthcare robots may be able to supplement support for older people, their families and caregivers (Bemelmans et al., 2010; Broadbent, Stafford, et al., 2009; Broekens et al., 2009). Many research organisations and companies are currently studying and/or developing eldercare robotic devices. A well-known example is Paro, a robotic seal, which has shown promising results in improving mental health (Klein & Cook, 2012; Shibata, Kawaguchi, & Wada, 2011). However, there are also unsuccessful cases where robots have not been widely adopted by aged-care populations, (e.g. Foulk, 2007; Mahoney, 1997).

More understanding is required of factors that minimise the rejection of eldercare robots and optimize their acceptance. There is some understanding of robot factors that promote acceptance; notably that the robot is perceived as both useful and easy to use. There is also some knowledge of human predictors of acceptance. However, known human predictors of technology acceptance tend to be fixed and/or historical demographics. For example, female gender and older age have been associated with low acceptance of novel technologies (Venkatesh et al., 2003). There are two issues with fixed demographic factors as acceptance predictors. One issue is fixed factors may predict non-acceptance of technology, but do not explain the underlying causes of non-acceptance. The second issue is that, by definition, fixed predictors are fixed. It is not possible to make older women more accepting of novel technologies by changing their gender and reducing their age. However, unlike demographics, psychological characteristics of potential technology users may be less fixed. Greater knowledge of potentially modifiable psychological factors associated with the acceptance and rejection of robots in an aged-care context is required. This may assist designers in creating acceptable eldercare robots to help meet the challenges of ageing populations.

Goals

The primary goal of the study described in this paper was to further knowledge of psychological factors involved in the acceptance of eldercare robots. Specifically we investigated whether the attitudes that older people hold about robots and their perceptions of the robot's mind could predict the use of a healthcare robot in a retirement village.

The study had several secondary study goals. These included testing the feasibility of deploying a prototype robot in a complex real-world eldercare environment. An additional goal was obtaining feedback from real-world older participants on the prototype robot and its healthcare functions or modules. The feedback will be used to further develop and improve the robot and its modules in an iterative fashion.

This paper's focus is on psychological factors and does not focus on the functional effectiveness of the robot. Assessing effectiveness was beyond the scope of this feasibility study, and robot functionality is an important but likely insufficient factor for acceptance. Several other publications focus on more technical aspects of this study, e.g. Kuo et al. (2011) and Jayawardena et al. (2012).

The introduction next provides an overview of related work in eldercare robots. The issue of increasing acceptance of eldercare robots is raised. Next, the potential for technology acceptance models to assist in increasing eldercare robot acceptance is examined. The next two sections propose two psychological factors as predictors of eldercare robot acceptance: attitudes towards robots and the theory of mind. The last section of the introduction provides the study's specific aims and hypotheses.

Eldercare Robots

For eldercare robots to have enduring commercial success, they must perform useful tasks that will promote continued usage once any novelty effects have worn off (e.g. Foulk, 2007). Past research using a variety of methodologies has identified potentially useful tasks for domestic eldercare robots. Identified tasks include chores such as vacuuming (Dautenhahn et al., 2005); cleaning in general, polishing and cleaning windows and walls, and moving heavy items (Khan, 1998). In another study, retirement village staff and residents rated detection of falls, lifting heaving objects and monitoring the location of people who wander away from the village, as the three most useful tasks for a hypothetical and unspecified eldercare robot. The study conducted focus groups with residents and staff using open ended questions to elicit preferences for robot functions and appearance in the absence of any robot. Subsequently a list of robot tasks was made from participants' responses (Broadbent, Tamagawa, et al., 2011). More personal tasks such as baby-sitting, pet-minding, and food preparation have been considered less suitable for robots (Khan, 1998).

Another approach to determining suitable robot tasks is to first assess the needs of older people, and subsequently develop technologies to address those needs (Cavallaro et al., 2013; Hirsch et al., 2000; Stafford et al., 2012). Much of the research on preferred robot tasks is based on surveys administered in the absence of an embodied robot. This is a valid approach; however physical interactions with embodied robots can also provide useful information about usability, and reveal changes in preferences and attitudes about robots and robot tasks (e.g. Koay et al., 2007).

A number of robots have been developed to perform different tasks in eldercare. Socially assistive eldercare robots aim to interact with older people to improve or maintain their physical and/or mental health (Heerink et al., 2010). Companion robots include the seal robot Paro (Shibata et al., 2011), the teddy-bear-like Huggable (Stiehl et al., 2006), and robotic cat NeCoRo (A. V. Libin & Cohen-Mansfield, 2004). The robotic dog, Aibo, has been shown to have similar benefits to a real dog in reducing loneliness in eldercare (Banks et al., 2008).

Other robots intended for eldercare include the mobile navigation and memory-aid robot Pearl (Pollack et al., 2002). Robot developers Fraunhofer IPA state the Care-o-bot 3 can safely navigate around humans, facilitate human-human interaction, and transport household objects to and from human users. They propose the Care-o-bot 3 may assist older people to continue living safely in their own homes (Graf, Parlitz, & Hägele, 2009).

This study used the robot Cafero - a multi-functional mobile robot with a touch-screen. Cafero has been adapted for eldercare by incorporating software for telephone calling, vital signs assessment, fall detection, medication management and entertainment (Stafford et al., 2010). Another eldercare HRI robot, Bandit, is a mobile robot platform with a humanoid torso. Bandit has been used for cognitive stimulation and as an eldercare exercise instructor (Fasola & Mataric, 2010; Tapus & Mataric, 2008). However most eldercare robots are either not yet commercially available, or are not widely deployed.

There is initial evidence for the effectiveness of robots in improving health outcomes in older people. A systematic review of the effects of robots in eldercare found 41 relevant studies - most of which focused on companion-type robots and Paro in particular (Bemelmans et al., 2010). The review concluded that while the effects on psychosocial and physiological outcomes are promising, larger randomised controlled trials are required to test efficacy. There is some limited evidence that robots are preferred to non-robotic devices in eldercare. For example Kidd, Taggart, and Turkle's (2006) study indicated that nursing home residents preferred the activated Paro compared with the turned-off Paro. Tapus and Mataric (2008) showed that Bandit was preferred to a non-robotic interface.

For eldercare robots to be effective they must not only be functional, but older people must be comfortable with their use. Acceptance in this context has been defined as the robot being willingly incorporated into the person's life (Broadbent, Stafford, et al., 2009). Consequently longitudinal human-robot interaction (HRI) studies are required to assess true human-robot acceptability. There are insufficient longitudinal eldercare HRI studies in a real-world environment (Bemelmans et al., 2012; Broekens et al., 2009), and despite the first electronic autonomous robot being created in 1948 (Holland, 2003), little is known about the variables that increase or decrease human acceptance of robots. This lack of knowledge of predictors of acceptance of eldercare robots is likely a barrier to their successful design, deployment and commercialisation; and a motivation for our study to explore psychological factors.

Technology Acceptance Models

Technology acceptance models have previously been applied in robotics research to study factors related to acceptance (Heerink, Kröse, Evers, et al., 2008; Heerink et al., 2010). Fred Davis (1989, 1993) is the author of the original Technology Acceptance Model (TAM). While anticipating the discovery of other technology acceptance predictors; Davis proposed perceived 'ease of use' and 'usefulness' of the technology as the major predictors. The much cited Unified Theory of Acceptance and Use of Technology model (UTAUT:Venkatesh et al., 2003) has built on Davis' parsimonious model by adding a variety of demographic and situational factors, such as age, gender, computer experience, and 'voluntariness' of technology use. Voluntariness was added in an attempt to address participant self-selection confounds.

Many studies have since shown technology acceptance models (including Davis' original TAM) to be predictive of technology acceptance (Bagozzi, 2007; Venkatesh et al., 2003). However the addition of many variables to UTAUT has been criticised for increasing the complexity of technology acceptance models without advancing understanding of how these variables contribute to technology acceptance. A deeper understanding of technology acceptance predictors is proposed to create truly acceptable technologies (Charness & Boot, 2009).

A further issue is that technology acceptance models may be limited in their ability to generalise to acceptance of eldercare robots. Potential limitations include technology acceptance studies being typically conducted with simpler technologies such as cell phones and computers, and rarely involving embodied agents such as robots. The studies rarely assess longer-term acceptance in a real-world setting (Broekens et al., 2009), and usually involve younger participants. Younger people may differ substantially from older people in terms of technology acceptance. Older people are less likely than younger people to have knowledge of similar technologies, such as computers, that they can generalise to robots. Older people have been found to be more reluctant to adopt novel technologies than younger people (Charness & Boot, 2009).

Eldercare robots that can provide users with easy to use and useful functionalities are more likely to be acceptable compared with robots that do not provide these things (Davis, 1993; Venkatesh et al., 2003). However, as identified by technology acceptance models, predictors of acceptance are *perceptions* of ease of use and usefulness, not objective measures of these factors. This suggests it is of limited use having a highly functional robot if it is not perceived as such by potential users. If people think a robot is worthless, they may be reluctant to even try using it. Hong et al. (2006) discuss how pre-use technology expectations are more likely to originate from manufacturers or mass media sources, whereas post-use technology expectations are more likely to originate from actual experience of the technology itself. If people are not willing to try using a technology then they cannot experience its functionality. Therefore uptake or initial use may be considered a critical if insufficient precursor to acceptance.

Fortunately, in exploring predictors of robot use, there are alternatives to adding more fixed demographic predictors to acceptance models. It may be helpful to investigate more explanatory and potentially modifiable predictors such as psychological variables. The general public view of robots might be characterised as having special status as artefacts with physical and/or cognitive humanlike qualities and this seems to trigger a range of preconceptions, which may be based on science fiction, movies, and television (Broadbent et al., 2010; Gee et al., 2005). Media images and messages may interact with a human predilection to anthropomorphise. Consequently people may perceive something different about robots, over and above other non-robot technologies such as computers or cell phones, which may affect robot uptake and subsequent acceptance.

Therefore to help identify predictors of eldercare robot acceptance we propose to explore two potential psychological factors in eldercare robot use: attitudes towards robots and perceptions of robots' minds.

Attitudes towards robots

For the purpose of this study we take our definition of 'attitude' from social psychology. Attitudes are positive or negative evaluations of objects of thought. Attitudes can be composed of affect (feelings towards the object), behaviours (predispositions to act in a certain way towards an object), and/or cognitions (the thoughts people hold about the object) (Weiten, 2004). In this paper, we are mostly interested in the cognition component. This is motivated by our interest in peoples' decisions to use a robot or not.

Robot-specific attitudes, possibly in addition to generic technology attitudes, may predict robot acceptance. Heerink et al. (2010) adapted the UTAUT to fit the context of an iCat robot within an elderly residence. Attitudes towards the robot were included in the model. The robot attitude items were; 'I think it's a good idea to use the robot'; 'The robot would make life more interesting'; and 'It's good to make use of the robot'. Results showed actual usage of the iCat by the 65–94 year old participants was predicted by the intention to use; and the intention to use was, in turn, predicted by perceived ease of use and attitudes to robots.

Generalisability of Heerink et al.'s (2010) results to the wider resident population may be impaired by some methodological limitations. One possible limitation is there was only a single administration of the questionnaire to participants (after they had used the robot in the introductory session). Therefore baseline robot attitudes and any changes in these attitudes over the week-long trial were unable to be assessed. A self-selection bias is also likely (and difficult to avoid) with participants having more favourable attitudes towards robots than non-participants. However, Heerink et al.'s results are supported by other studies that have also found attitudes towards robots are likely important for robot acceptance (Crawford, Grussing, Clark, & Rice, 1998; Gee et al., 2005; Goetz et al., 2003; Heerink, Krose, et al., 2006; Nomura, Kanda, et al., 2006; Syrdal et al., 2009).

This study employs the Robot Attitudes Scale, which focuses on general positive or negative thoughts about robots (Broadbent, Tamagawa, et al., 2011). Previous work with this scale has shown that attitudes towards robots predict ratings of the robot, and attitudes improve after interacting with the robot (Stafford et al., 2010).

Theory of Mind

A new area of investigation in HRI is peoples' perceptions of whether the robot has a mind. These perceptions may also affect acceptance of robots. H. M. Gray et al. (2007) examined the extent to which people agree that various characters, such as a baby, a dog, and a robot have a mind. The research found that people perceive the attributes of mind along not one dimension but two: mind experience and mind agency. The dimension of mind experience can be summarised as a character's perceived ability for 'feeling'; the capacity to feel hunger, fear, pain, pleasure, rage, desire, personality, consciousness, pride, embarrassment, and joy.

Conversely, mind agency can be summarised as a character's perceived ability for 'doing'; the capacity for self-control, morality, memory, emotion recognition, planning, communication, and thought. The robot character in Gray et al.'s study received a moderate score for agency (higher than the dog and some other characters) but lowest equal with God for capacity for experience. Recent research has suggested that higher perceptions of a robot's capacity for mind experience are tied to feelings of unease (K. Gray & Wegner, 2012).

The theory of mind perception is related to anthropomorphism, in that people attribute capacities of mind to non-human characters. Humans readily anthropomorphise non-human creatures, and even non-living objects, such as computers (Reeves & Nass, 1996). Anthropomorphism in humans is easily generated with even primitive social cues (Nass, Steuer, & Tauber, 1994). The greater the number and intensity of these cues; the stronger the impression the human may receive that their robot partner is a social actor and higher in agency. Features common to robots such as embodiment, movement, and speech may promote a sense of perceived agency in robots (Breazeal, Kidd, Thomaz, Hoffman, & Berlin, 2005; DiSalvo et al., 2002; Severinson-Eklundh, Green, & Hüttenrauch, 2003).

However different individuals in different contexts can perceive different levels of anthropomorphism for identical non-human agents. Epley, Waytz, and Cacioppo (2007) address contextual and psychological predictors of anthropomorphism within the Three Factor Theory of Anthropomorphism. Psychological components of the theory include the cognitive motivational mechanism of 'effectance'. The term describes the need to interact effectively with the environment. Ascribing familiar human characteristics to unfamiliar non-human agents may assist in both explaining and predicting the agent's behaviour. This strategy may serve to reduce anxiety about how the agent may behave in the future.

An extension of this work showed people expecting to interact with an unpredictable robot were more likely to anthropomorphise it than people who were expecting to interact with a predictable robot (Eyssel et al., 2011). In contrast, the cognitive motivational mechanism of 'sociality' describes the human need for social connectedness. For example, the more lonely people are - the more motivated they are to anthropomorphise non-human agents.

Similar to Epley et al. (2007); Takayama (2012) discusses how perceptions of robot agency may assist in understanding human-robot interactions. Whether agency is perceived as a positive or negative attribute may depend on context. A person who perceives little agency in a robot may have their own sense of agency enhanced by the use of a non-agentic 'robot-as-tool'. In contrast a person who perceives more agency in a robot may be more able to interact with it more easily via natural social behaviours. However, there is some evidence that higher levels of perceived agency in robots is not all positive. Heerink et al. (2010) conducted a study where older people watched videos of a robot programmed to be more or less responsive, or adaptive, to the needs of the human user. The older participants reported more anxiety in relation to a more adaptive robot than the robot that was programmed to be less adaptive. In a different study, preconceptions of a robot as more humanlike have been shown to negatively impact reactions amongst middle-aged and older people (Broadbent, Lee, et al., 2011). These findings suggest people may be more reluctant to use a robot if they perceive it as having a mind.

Therefore it appears possible that psychological factors related to attitudes toward robots and theory of mind are important in eldercare robot acceptance. This paper further explores these factors, and how they relate to eldercare robot use.

Aims and Hypotheses

This paper reports the results of a two week study of a healthcare robot in a retirement village. As technology up-take, or initial use, is a critical precursor to longer term acceptance; the main outcome is use of the robot. Therefore the aims were to test if the psychological factors; attitudes towards robots and the theory of mind; predicted robot up- take. Specifically our aims were to assess if:

1. Retirement village residents' initial attitudes towards robots could predict their use of the robot.

2. Retirement village residents' preconceptions of the robot's mind could predict their use of the robot.

We hypothesised that residents would be more likely to use the robot if they:

3. Had more positive attitudes towards robots.

4. Perceived the robot as having less mind.

Other observational results and participant ratings of the prototype robot and robot functions are reported elsewhere (Jayawardena et al., 2012; Tiwari, Warren, Day, & Datta, 2011).

7.2.2. Method

Participants

The study was conducted at Selwyn Village: a non-profit retirement complex in Point Chevalier, Auckland, New Zealand. The 26 acre village has approximately 650 residents, and provides progressive care from independent living units through to hospital and dementia care. This paper reports on the study in Lichfield Towers (Figure 15), a five story independent-living apartment complex within the retirement village. This building was chosen to recruit from because the independent-living residents were relatively mobile and capable of taking part in the study and providing feedback. Lichfield Tower's ground floor comprises a range of shared areas, including the foyer, dining room, pool room, television room and lounge. The foyer receives a high level of traffic from both residents and visitors from other village buildings, as well as visitors from outside the facility.

Information about the study was placed in the village newsletter and in the letterboxes of residents who lived in Lichfield Towers. The researcher knocked on each of the 48 apartment doors in Lichfield Towers with the aim of inviting all residents in the building to participate. As shown in the participant flow diagram (Figure 16), 25 residents consented to take part in the study. Residents were informed that the aim of the two week study was to have older people help test and give feedback on newly developed functions on a prototype robot. This feedback would assist the researchers develop and improve the robot and its functions.

Residents were told that the robot could take vital signs (e.g. blood pressure), remind about medication, make telephone calls, play some songs, and play memory games. Participants were invited to use the robot as much as they liked over the next two weeks, but were told they were not required to use it if they did not want to. Residents could choose to use the robot in their own apartment for half an hour a day and/or they could visit the robot in the public foyer of the building. An inclusion criterion for participants wanting the robot to visit their apartments was that they be taking medication daily. The purpose of this was to obtain feedback on the robot's medication management module.

The mean age of the 25 resident participants was 86.12 years, SD = 4.35, ranging from 78 to 95 years. Eighteen of the 25 participants were female. Four participants completed their formal education at age 12–13, twelve completed secondary school up to 15–18 years, two completed a technical or trade certificate, and six completed a polytechnic diploma or university degree (one had missing data). For the computer experience item, participants rated their experience at basic computer tasks such as email and Internet searches on a numeric scale. The possible responses ranged from 1 (not at all experienced) to 8 (extremely experienced). Residents' average level of computer experience was low at 2.29, SD = 2.24.

Procedure

Approval for the study was obtained from the University of Auckland Human Participants Ethics Committee. After obtaining residents' informed consent, baseline questionnaires were administered to participants before meeting the robot. The robot was then introduced to the building. During the study, the robot was taken to the apartments of residents who chose this option for 14 consecutive days for approximately 30 minutes between the hours of 7.30 am and 9 am. Morning visits were chosen as this was when residents typically took their regular medications. This meant participant could test the robot's medication management module, as well as using all the other robot functions. In the first visit, researchers showed participants how to use the robot. The robot also photographed these residents to program the robot's face-recognition software.

Figure 15. Lichfield Towers building, showing entrance and interior of its foyer

Between 11 am and 2 pm for the same 14 days, the robot was situated in a corner of the foyer on the ground floor of the building. These times were selected as outside these hours the public foyer had little foot traffic. During the trial the robot was attended by a researcher who demonstrated how to use the robot or offered assistance as required. Anyone who entered the foyer during this time was free to interact with the robot. People who used the robot in the foyer had the option of having the robot photograph them. The robot would then invite participants to type their name on the touch-screen keyboard. This participant input allowed the robot to register their faces. The robot could then recognise and greet participants by name via both speech and on-screen text.

As part of study procedures, video was taken of the interactions. The results of the video analysis are reported elsewhere (Kuo, Jayawardena, Broadbent, Stafford, & MacDonald, 2012). Follow-up questionnaires were administered after the robot was removed from the building at the end of the trial.

The Robot

The robot used in this study was the second version produced by the Healthbots project, which is a joint project between the University of Auckland, Electronics and Telecommunications Research Institute (ETRI), and Yujin Robot. The overall goal of the Healthbots project is to develop healthcare robots that are acceptable to older people, their families, and staff. The Healthbots project is an interdisciplinary collaboration of psychologists, engineers, computer scientists, and medical professionals (University of Auckland, 2012).

Software and Hardware

The Healthbots robot (Figure 17 & Figure 18) is a differential drive mobile robot, powered by a 24 V Lithium-Polymer battery. It consists of a rotatable touch-screen, microphones, ultrasonic sensors, bumper sensors, and a laser range finder. The commercial robot was provided by Yujin Robot together with our partners at ETRI in South Korea.

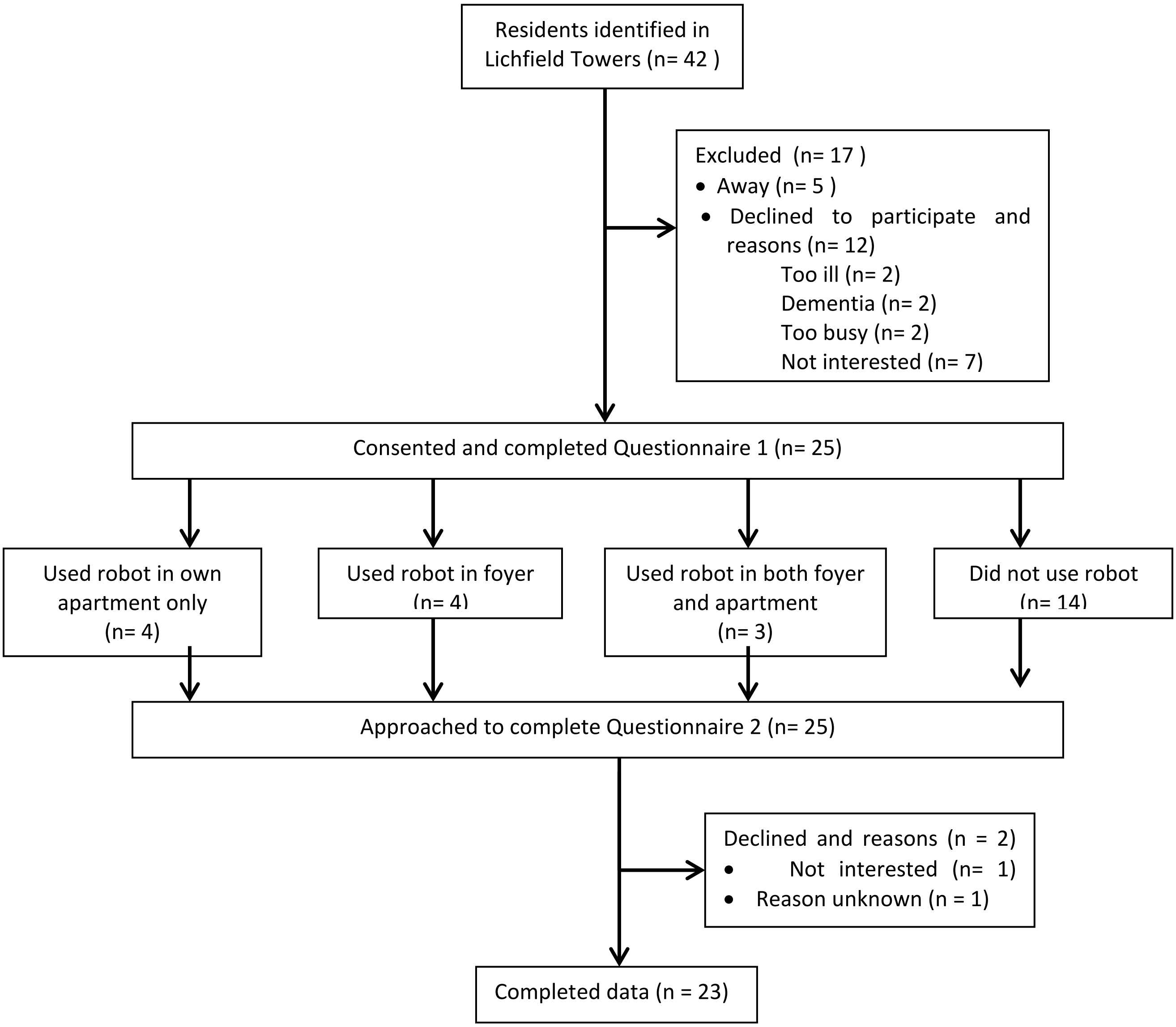

Figure 16. Participant flow diagram

The first version of the robot was deployed and tested through November – December 2009 (Jayawardena et al., 2010; Stafford et al., 2010). Building on results of the earlier study, our researchers designed and developed improvements and extensions to the robot's eldercare software functions. Software tools were developed to enhance the ability of roboticists, psychologists and healthcare experts to work together in iteratively refining the robot's interactive behaviour. A number of external services were developed for integration with web resources and to provide others a view of medications and vital signs data on a PC. The software version used for this study is an improved version of software used in the first Healthbots trial (Jayawardena et al., 2010). The front-end of the application was developed using Flash/Action Script 3.0 and the back-end was developed using C++. The robot software communicated with several web-services for information retrieval and update. Additional robot functionality was achieved via integration with third-party applications.

Several lessons related to the software development approach were learned during the field trials with the first version of the robot. Lessons included the importance of flexibility to meet individual preferences and usability needs (e.g. users may prefer a different screen colour, a larger font, layouts, images, videos, certain dialogues, voice accent, screen flows or application modules etc.).

Figure 17. Charlie - the Healthbots robot

Figure 18. A researcher demonstrating the robot to a retirement village resident

A key consideration in the software architecture design was rapid customisability. This provided the flexibility to respond to user preferences and usability needs. To improve the software continuously, an iterative approach was used throughout the software development cycle. This enabled the inclusion of real-time feedback from the SMEs, pilot groups, end-users, and other stakeholders. The software architecture was sufficiently flexible to accommodate new findings, suggestions, new requirements, etc. even during testing and deployment phases.

Robot Behaviour/Interactivity

The robot had three main response behaviours:

1. Public foyer setting: Respond to face recognition or touch-screen press to interact with users in the building foyer. Perform user-selected tasks on a touch-screen main menu. Participants in the public foyer were free to choose from any of the robot's service modules with the exception of medication management. The face recognition system is described in detail in Kuo, Jayawardena, Broadbent, and MacDonald (2011).

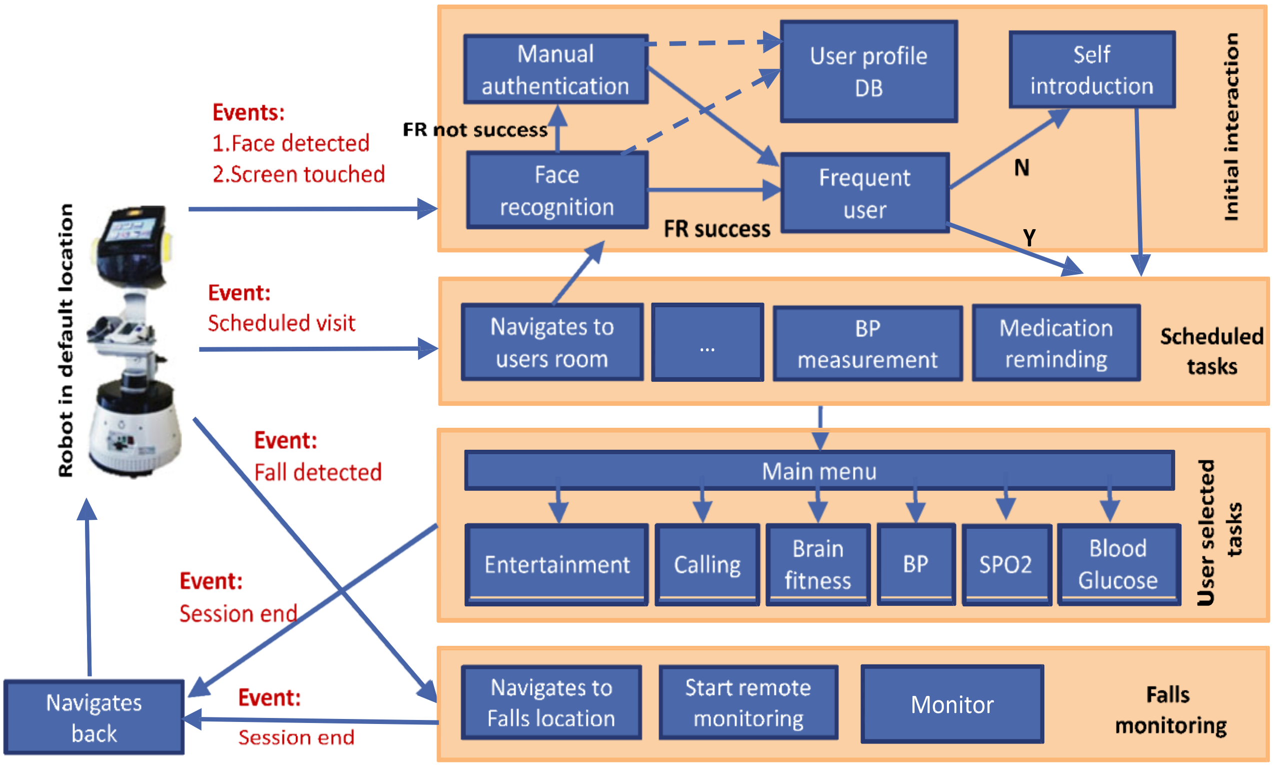

Figure 19. Scenarios employed on the robot[18]

2. Apartment setting: Respond to face recognition or touch-screen press to interact with users in their apartments. In the apartment setting the robot initially performed scheduled tasks (blood pressure measurement and medication reminding), and then offered the user the choice of other services.

3. Respond to fall events. This functionality was not used for this study. A subsequent study has been conducted on this aspect (unpublished).

Figure 19 illustrates the robot in the default position, the events that trigger the different behaviours, and the robot behaviours in each scenario. All three scenarios are embedded in the robot behaviour implemented by the robot software.

[18] Key: FR = face recognition, DB = database, BP = blood pressure, SPO2 = blood oxygen levels

By default, the robot was kept docked at its charging station in the foyer. If someone approached or touched the robot, either a 'Face Detected' or a 'Screen Touched' event was triggered. This starts the initial interaction phase, which includes face recognition, authentication, and self-introduction. At the end of the initial interaction phase, the robot displays the 'main menu'. At this junction users could select any available service (vital signs measurement, calling, entertainment, and brain fitness). The interaction session ends when the user finishes the session or no interaction is detected after a certain time period.

For the scheduled apartment visits within the multi-level Lichfield building, researchers transported the robot in the elevators between floors on a trolley. The robot then navigated down the corridor to the resident's apartment. The apartment door would be opened by the resident or a researcher. The robot next navigated inside the apartment and positioned itself in a pre-programmed location in front of the seated participant. It was beyond the scope of this feasibility study to have the robot navigate each apartment and locate the participant. However, the researchers or participant could use the robot's remote control to move it from the pre-programmed location as desired. Apartment HRI sessions were initiated as previously described in 'robot behaviour/interactivity 2'. At the end of the session, the robot would navigate outside the apartment and be returned by researchers to the default location in the public foyer.

Robot Functions: Service Modules

Seven prototype service application modules were developed; vital signs measurement, medication reminding, falls detection, entertainment, and telephone calling. Brain fitness games were also available on the robot. The modules were designed to be sufficiently intuitive so an older person who had never used a computer before could easily use them; yet adaptive enough so experienced users would not get frustrated. An example of the latter is that experienced users could bypass module introductions and instructions. Participants responded to the robot via the robot's touch-screen: the robot responded to participants via synthesised speech and on-screen text.

The vital signs measurement module assessed blood pressure, arterial stiffness, pulse rate, blood oxygen saturation, and blood glucose levels. Vital signs devices were attached to the robot via a USB hub, with a Bluetooth link for blood glucose monitoring. Participants could measure their own vital signs using the robot without assistance from the researchers. The robot provided optional instructions via speech, on-screen text, and/or demonstration video. Vital signs results were delivered via speech and displayed on the robot's screen.

The medication management module reminded users of their medication schedules and consisted of a sophisticated dialogue system connected to a back-end web service. The medication module was only conducted in apartments and not in the public foyer setting (details of the development and testing of the medication management module are published in Tiwari et al., 2011). As required by the University of Auckland Human Participants Ethics Committee, an MD researcher attended the robot in the apartments for the medication management sessions for this trial. A third-party software, BrainFitness from Dakim (2012), provided games designed to be an enjoyable way for older people to practice their cognition and memory. Entertainment sub-modules provided music videos, pictures, and quotes. The robot's calling module - developed using the Skype API - enabled participants to make telephone calls to friends and family.

Robot Speech

The robot's synthetic speech was generated through diphone concatenation-type synthesis implemented with Festival speech synthesis system (P. Taylor et al., 1998) and used a New Zealand accented diphone voice developed at the University of Auckland (C. I. Watson et al., 2009). Expression was added to the synthetic speech through an intonation modelling technique described in Igic et al. (2009) called 'Say Emotional'.

Navigation

For map building and navigation, the robot used the StarGazer robot localisation system (Hagisonic Co.Ltd, 2008). StarGazer is a robust, easy to use, and accurate commercial navigation system. The system requires small passive white dot landmarks. The unobtrusive landmarks are installed with approximately one metre separation on the ceiling of the robot work-space. A map of the area was built using the built-in map building module of the robot. The robot could then autonomously navigate to designated places (such as the charging station, participants' apartments etc.) and avoid obstacles using the pre-built map and landmarks. Landmarks were installed on the ceiling of all locations the robot traversed in the course of the study; public areas, corridors and apartments. Resetting the robot position was not required due to the robot being installed with the complete pre-built map.

Measures

Baseline Questionnaire

Demographics - Participants were asked their age, gender, level of education, and computer experience.

Robot Attitudes Scale (RAS:Broadbent, Tamagawa, et al., 2011): This 11 item scale was used to measure residents' attitudes towards robots. This scale was chosen as it had been developed in an earlier study at the same retirement village, and been shown to predict the quality of the residents' interaction with the robot (Stafford et al., 2010).

Table 9. Instructions and wording of the Robot Attitudes Scale and Dimensions of Mind Perception Questionnaire

Measure	Scale instructions	Example items
Robot Attitudes Scale	Please circle the number that best corresponds to how you feel towards the healthcare robot you are about to interact with. I think the robot will be…	1 2 3 4 5 6 7 8 Unfriendly Friendly 1 2 3 4 5 6 7 8 Useless Useful
Dimensions of Mind Perception	This survey asks you to make estimates of the abilities of the robot. Please rate the robot on each of the following scales. Try to indicate the degree to which you believe the robot has each of these capacities by using the numbers from 1 to 7 as a yardstick on which to measure the robot.	[Agency] How much is the robot capable of remembering things? 1 2 3 4 5 6 7 Has no memory Has memory [Experience] How much is the robot capable of experiencing physical or emotional pleasure? 1 2 3 4 5 6 7 Cannot feel pleasure Can feel pleasure

The primary purpose of using the RAS was to assess the strength of positive or negative attitudes toward robots; and to assess whether or not these attitudes were different between different groups, and if they changed as a result of interactions. A reduced eight item version of this scale was used for this study to minimise participant burden. The eight items chosen had the highest factor loadings (friendly: unfriendly, useful: useless, trustworthy: untrustworthy, easy to use: hard to use, reliable: unreliable, safe: dangerous, helpful: unhelpful, and interesting: boring). As per the original instructions, participants rated robots on each of the eight attributes using an eight point scale. The attribute opposites served as semantic anchors. RAS items are summed to create an overall score between eight and 64 where higher scores equate to more favourable robot attitudes. Cronbach's α was 0.90. The instructions and example items are shown in

Table 9.

Dimensions of Mind Perception (H. M. Gray et al., 2007) - Eleven items were used from this 18 item scale to minimise participant burden. The scale is composed of two subscales: mind agency (six items were chosen; perceived capacity of the robot to recognise emotions, have thought, memory, self-control, plan and be moral) and mind experience (five items were chosen; perceived capacity of the robot to feel pleasure, hunger, pain, and have personality and consciousness). We used the original response options, which are on a seven point scale with semantic anchors. The possible range of scores was from 6 to 42 for agency, and from 5 to 35 for experience. Instructions and example items are shown in

Table 9.

Follow-up Questionnaire

This included a second administration of the Robot Attitudes Scale and Dimensions of Mind Perception scale. It also included a question on whether the resident had used the robot or not. Participants who used the robot were asked to write a number indicating the quality of their overall experience of the robot interaction using a scale from 0 (poor) to 100 (excellent). They were also asked how much they would like to use the robot again using a scale from 0 (not at all) to 100 (very much). These two items had been used in a previous study and found to be acceptable to older users (Stafford et al., 2010). Robot-users were asked to rate how easy or hard they found the robot to use on a five point semantic scale. The response options were; very hard, hard, neither hard or easy, easy, and very easy. Participants were asked to rate the robot's usefulness for themselves on a four-point semantic scale. The usefulness response options were; not at all useful, a little useful, useful, and very useful. There was a fifth option of 'not useful for me but useful for others'. The latter item was included due to comments made during a previous study by the relatively high-functioning independent-living residents. A common comment was that while residents could not see the robot currently being useful for themselves - they could see it being useful for their future selves, or for other less independent residents.

Statistical Analyses

Statistical analyses were conducted with PASW Statistics Data Editor. Three mixed ANOVAs were performed. The within-groups variable was the two time points (baseline and follow-up) and the between groups variable was whether or not the participants used the robot. Non-significant Kolmogorov Smirnov tests ($p > .05$) indicate the distribution of scores for robot attitudes, and robot mind agency and experience, between the two groups (who used and did not use the robot) were sufficiently normal to justify parametric analyses. The first ANOVA used the Robot Attitudes Scale as the dependent variable, the second used perceived mind agency and the third used perceived mind experience. These analyses tested whether participants who used the robot differed from those who did not use the robot on attitudes and mind perceptions, and if there was a time by group effect. To increase statistical power for analyses of the two items; robot rating and intentions to use the robot again, two residents who completed all the measures and used the robot but lived in the rest-home part of the village were included.

7.2.3. Results

Use of Robot

Of the 25 residents who completed the baseline questionnaire; 11 *did* use the robot over the two week trial period and 14 did not. Of those who used the robot ($n = 11$), their use varied from once to 16 times (mean 5.5 times). Within this robot-user group, people who used the robot more often reported better attitudes towards the robot at follow-up ($r = 0.68$, $p < 0.01$), but there were no other significant correlations with other outcomes.

Neither age, gender, nor education ($p < 0.05$) were related to residents' choice to use the robot. However, a Mann Whitney U test revealed those who did use the robot had significantly higher computer experience (Md = 2, Mean = 3.40, n = 10) than those who did not use it (Md = 1, Mean = 1.50, n = 14), $U = 39.50$, $z = -2.06$, $p = 0.04$, and a medium-large effect size $r = 0.42$.

There was a significant group effect for robot attitudes. Residents who chose to use the robot had better attitudes towards robots at baseline than residents who did not use the robot, $F(1,16) = 6.70$, $p = 0.02$ (Mean 'did not use robot' 41.67 CI: 35.63 to 47.71; Mean 'used' 52.10 CI: 46.06 to 58.13); Partial Eta Squared = 0.30. There was also a significant time effect for attitudes. Overall there was a significant improvement in participants' attitudes towards robots from before to after the trial, $F(1, 16) = 9.99$, $p = 0.006$. (Mean before trial 44.44, CI: 39.77 to 49.11; Mean after trial 49.33, CI: 44.85 to 53.80), Partial Eta squared = 0.38. Lastly, there was a significant group by time interaction for attitudes, with greater increases in positive robot attitudes in the robot-use group (Figure 20), $F(1, 16) = 5.21$, $p = 0.04$, Partial Eta Squared = 0.25.

A significant group effect was found for perceived robot agency. There was a significant difference between residents who did and did not use the robot in perceived robot agency, $F(1, 9) = 5.49$, $p = 0.04$. Mean 'did not use robot' 22.33 (CI:17.23 to 27.44); Mean 'did use robot' 14.50, (CI: 8.90 to 20.10), with a large effect size of Partial Eta Squared = 0.38. Non-robot users perceived the robot as having higher agency than people who did use the robot (Figure 21), but there were no significant time ($p = 0.88$) or interaction effects ($p = 0.24$) for agency. For perceptions of robot mind experience, there were no significant differences detected between groups: robot using and non-robot using residents ($p = 0.28$), or over time ($p = 0.33$), or interaction effects ($p = 0.58$).

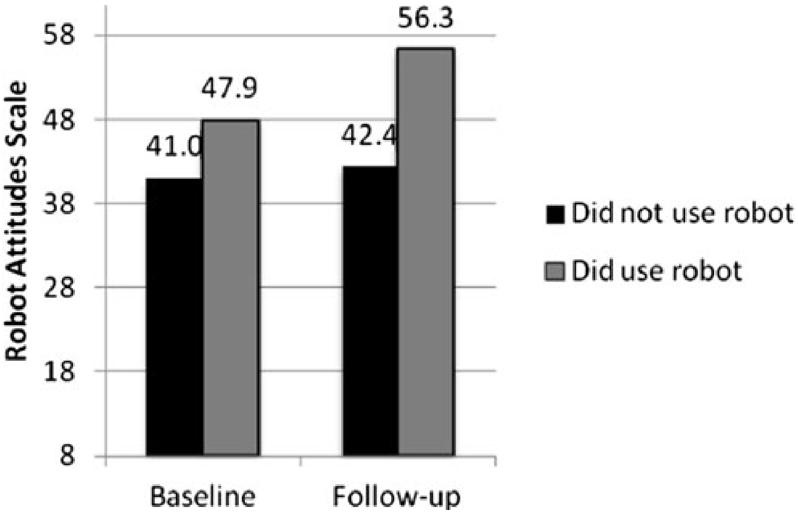

Figure 20. Attitudes towards robots were more favourable amongst people who used the robot compared to those who did not use the robot, and attitudes improved more in those who did use the robot[19]

Overall Rating, Intentions to Use Again, Ease of Use and Usefulness

Participants gave the robot interaction overall a mean rating of 78.50, SD = 15.47, CI: 67.44 to 89.56, Md = 80.00. The mean of 'intention to use the robot again' was 65.00, SD = 39.02, CI: 37.09 to 92.91, Md = 80.00. Of the nine respondents to the 'ease of robot use' question; four answered 'easy to use' and five answered 'very easy to use'. Of the 18 respondents who rated the robot's usefulness; four answered 'not at all useful', one 'a little useful', five 'useful', two 'very useful' and six 'not useful for me but useful for others'.

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[19] Mean 'did not use robot': baseline 40.99 (CI 34.39 to 47.59), follow-up 42.35 (CI: 36.02 to 48.68). Mean 'did use robot' baseline 47.89 (CI: 41.29 to 54.49), follow-up 56.30 (CI: 49.97 to 62.63)

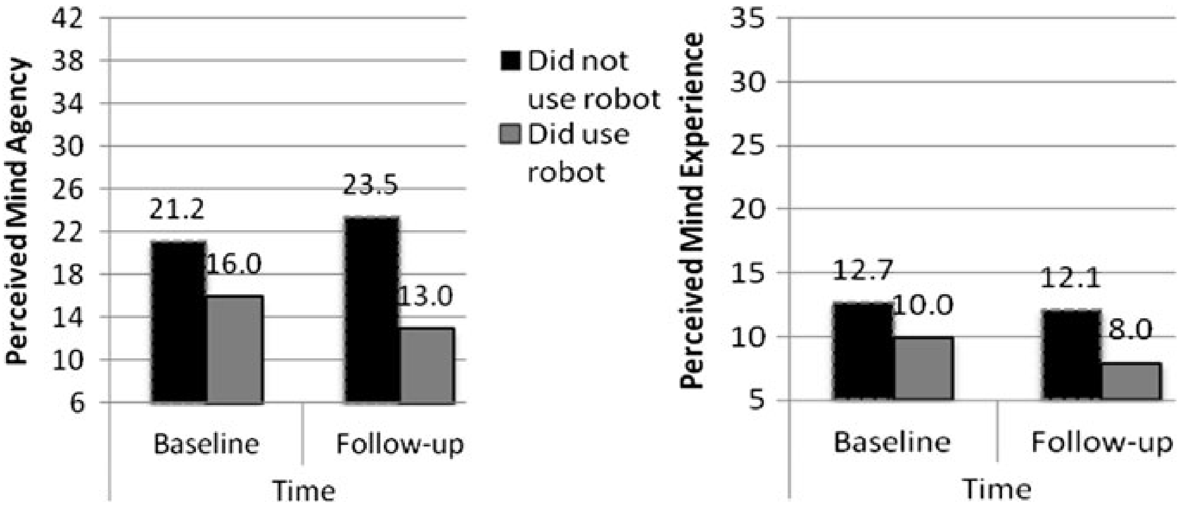

Figure 21. Participants who used the robot had lower perceptions of the robot's agency than those who did not use the robot[20]

To investigate predictors of the HRI rating and intentions to use the robot again amongst the small sample of users ($n = 11$), Pearson correlations and chi-square analyses were conducted. There were no significant associations between participants' age, gender, computer knowledge, and reported ease of robot use or usefulness, or with overall interaction rating or intentions to use the robot again ($p > 0.05$). There were however significant associations between perceived robot mind agency and robot mind experience (separately) with intention to use the robot again ($r = 0.68$, and $r = 0.62$ respectively, $p < 0.05$), but no significant associations with robot interaction rating.

7.2.4. Discussion

This study examined predictors of robot use in a small cohort of residents in a retirement village over a two week period. As predicted, people who chose to use the robot had more computer knowledge, held more positive attitudes towards robots, and attributed less mind agency to robots. The amount of mind agency and mind experience the residents perceived in robots also predicted how much robot-users intended to use the robot again.

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[20] There were no differences in perceptions of the robot's ability to experience things. Mean scores are presented at each time point

The study's secondary goals were met. Resident feedback was obtained on the robot and its functions that can be used to improve the robot. Results provide initial support for the feasibility of deploying robots in complex eldercare settings.

There are several possible reasons why people who attributed more agency to robots may have been less likely to use the robot in this study. One reason is that thinking a robot has more agency makes older people more wary of it and afraid to try it. Another possible reason is that they were disappointed when they saw the robot and therefore did not want to use it. However, inspection of Figure 21 suggests a trend that perceived agency decreased in those who *did* use the robot, and remained high in those who did not use it. This trend does not support the argument that non-users were disappointed that it did not appear have as much mind as they initially thought. The results suggest that people have preconceived ideas that robots have higher capacities to think and remember and be conscious than they actually do - an illusion that is dispelled when they actually use one. These ideas may originate from exposure to robots in the media, including books, television, film, and news reports, which often exaggerate the capabilities and dangers of robots.

Overall, participants in this study thought that robots had a higher capacity for agency than capacity for experience. This was similar to the mind dimension profile that participants ascribed to the social robot Kismet when given a written description and photo (H. M. Gray et al., 2007). In Gray et al.'s study, characters high in either dimension of mind experience or agency were more valued. In contrast, while all participants in this study perceived the robot to be low in the mind dimension of experience, those residents who expected the robot to be higher in agency were less likely to use it.

It may be that a robot perceived as possessing this type of high agency:low experience mind profile appears as an autonomous creature that has no sense of compassion or empathy. People may avoid such a robot as they fear that, at best, the robot may be indifferent to their welfare, and at worst actively inflict harm. This interpretation is in accord with Mori's (1970) suggestion that self-preservation is the function of uneasiness in relation to uncanny characters.

That higher ratings in this study of both robot mind experience and agency (separately) predicted intentions of using the robot again, concurs with Gray et al.'s (2007) results of both dimensions being valued; but are somewhat contrary to this study's finding that higher perceptions of robot agency were associated with non-use. It may be that if a robot is perceived to have an 'unbalanced mind' i.e. the capacity for agency but not for empathy, it is perceived to be missing the checks and balances that promote both predictable and desirable behaviour.

That robot-users were more likely to be those residents who perceived the robot as having both low agency and low experience, is congruent with previous reports from residents and staff (in the same retirement village as this study) that their preference was for a healthcare robot that did not look too humanlike as it was just a machine (Broadbent, Tamagawa, et al., 2011).

Like many previous technology acceptance studies, higher computer experience was associated with acceptance; but in contrast higher formal education was not. Many of this older generation of participants had their formal education terminated prematurely due to poverty and/or war. For older people the assessment of formal education may poorly reflect life experience. That all respondents rated the robot as easy, or very easy to use, suggests the goal of designing an 'older-user-friendly' robot was at least partially met.

The study results also contribute to knowledge about models of human acceptance of robots. The results replicate and strengthen previous findings that attitudes toward robots are important to acceptance and add a new predictor to the model - perceived robot mind. The study methodology has a number of strengths that support the application of the results to the development of individually and commercially acceptable eldercare robots.

The study's real-world setting is a considerable strength. Healthcare human-robot interactions are often complex; involving variable environments and multiple stakeholders (Kristoffersson, Coradeschi, & Loutfi, 2013). While laboratory robot studies are valuable and often necessary, studying HRI in real-world environments is likely key to an in-depth understanding of real-world robot acceptability. For a variety of technical, legal, ethical, practical, and resident health reasons, studying acceptance of eldercare robots in a retirement village is extremely challenging (Broadbent, Jayawardena, Kerse, Stafford, & MacDonald, 2011; Heerink, Kröse, et al., 2006; Stafford et al., 2010). This two week study was conducted in a real-world setting and used real-world retirement village residents as participants. Further, this study utilised a semi-autonomous robot with its attendant technical issues, rather than the Wizard of Oz scenario.

Further methodological strengths of this study include comparing subjective measures with objective measures. Psychological measures of robot attitudes were compared with an objective behavioural measure of whether participants chose to use the robot or not. This approach also enabled assessment of baseline differences between robot-users and non-users. Additionally this is the first time the theory of mind perception has been used to assess acceptance of healthcare robots in older people.

The study also had some limitations. Older participants often have limited capacity to complete lengthy questionnaires, so the number of measures needs to be restricted. Although a reasonable size by HRI standards, the sample size meant small effect sizes could not be detected. For this reason, longer-term trials with larger sample sizes are required to corroborate these results.

It is possible researcher presence acted as a confound. There was at least one researcher nearby when the robot was available for participant use. Researchers had to build rapport with some residents before they would consent to participate in the study. However the recruiting researcher was mindful of minimising socially desirable responding. This was achieved by emphasising that participants were being helpful whether they used the robot or not, and in order to best improve the robot we needed their honest, not polite, opinion when completing questionnaires. Given that 14/25 of participants did not use the robot it seems plausible this strategy to build rapport while simultaneously minimizing socially desirable responding was at least somewhat successful.

Further possible limitations for assessing robot acceptance include the robot being only available to all Lichfield Tower residents for three hours per day. Future research could include longer-term trials where the robot is permanently left in situ to assess how 24/7 availability impacts on acceptance. Future work could investigate why older users give high ratings to robots even if errors occur. It may be that residents blame themselves on these occasions rather than the robot.

That this feasibility study was not controlled is another limitation. Some of the robot’s functions such as Skype, entertainment and medication management could have been delivered via computer or tablet. While further research is needed, there is limited preliminary evidence that socially interactive robots may provide a ‘robot advantage’ over non-robot methodologies for motivating health behaviours. For example, in a six week study (Kidd & Breazeal, 2008), participants were allocated to one of three weight loss methodologies; a socially interactive robot, a computer, and a pen and paper log. There was no significant difference in weight loss between the three groups but participants in the robot group adhered to the programme for longer than the other two groups, and reported a closer relationship with the robot. A further advantage for some robots is mobility. Such robots may be able to visit older people with compromised mobility, as well as transporting objects between people.

It is useful to consider what influence the robot's form and function may have had on robot use. In our previous focus groups and questionnaires with this population (Broadbent, Tamagawa, et al., 2011), participants reported a preference for a non-humanlike robot and had high ratings of many of the functions we developed for the robot. In fact, that was why we chose this particular form and the functions for this robot. In this study we only had one robot at the village so could not test whether people would have used a different robot more or less often. This may be an area for future research to investigate. An understanding of specific design features that promote or decrease perceptions of robot agency could be used to formulate the appropriate robot design for a particular context. However Roomba owners vary greatly in how much agency or social relationships they perceive in their robotic vacuum cleaners of identical design (Forlizzi & DiSalvo, 2006). This suggests that subjective individual perceptions of robot agency, or intentionality (Dennett, 1987), may be as important as the objective physical design and behaviours of the robot.

This study's rapport building strategies used to promote recruitment may be of interest to HRI researchers. During the recruiting interviews it was noted that despite efforts to inform Selwyn Village residents about the study, some potential participants held misconceptions that were a barrier to participation. Misconceptions typically related to the study purpose and methodology, and the 'nature' of the study robot. A key recruitment strategy was to elicit these misconceptions and address them where possible. For example some residents believed that as they were "no good with computers", they would also be "no good" with the study robot. Such people were usually reassured by explaining that the robot's simple touch screen operation had been designed to be easily used by someone who had never used a computer before. Another common misconception was the time and effort required by participation. Consequently the costs and benefits of participation were outlined in detail to potential participants, along with a reminder that even if they agreed to participate they could still withdraw from the study at any time.

Since the initial requirement for robot acceptance is for people to choose to interact with the robot, it is important to maximise initial human-robot engagement. This may be achieved by encouraging positive attitudes and appropriate perceptions of robot mind among potential older users. While this is likely to be context dependent, it may be beneficial to design and promote robots as having balanced mind profiles of either high agency and high experience, or low agency and low experience, and avoiding the high agency:low experience mind profile.

The cognitions older people hold about robots influence their decisions to use robots and therefore have implications for (a) how robot designers and programmers design and integrate the robot components to present an overall interaction with the user, and (b) how robots are distributed and deployed to people. This includes the marketing and information about the robot's appearance and abilities. As the service robot market develops, it will be important for robot manufacturers and distributors to develop early generations of robots that people will engage with. These will need to be followed with new generations of robots that are sensitive to the changing trends in peoples' attitudes, and perceptions of robot mind experience and agency, that will likely arise from increased exposure to the robots.

Future longitudinal studies could both assess the effectiveness and efficiency of robotic eldercare, and assess it against non-robot eldercare such as human care or computers. Longer-term trials are required to assess continued usage of eldercare robots. While the RAS appears to both predict robot use and be sensitive to changes in robot attitudes, it is beyond the scope of the RAS to determine the causes of participants' robot attitudes. Future research could explore the origins of attitudes towards robots. Further research is also required on how to encourage positive attitudes prior to the introduction of robots to eldercare. Interventions could be developed in the distribution and marketing of robots to modify attitudes and mind perceptions to encourage use and promote acceptance of eldercare robots.

7.3. Study three segue – the *robot mind study*

There have been several other robot studies that have used the perceived mind dimensions measure. K. Gray and Wegner (2012) used the Mind Perception Questionnaire to examine associations between mind perception, humanlikeness, and the uncanny valley. The study methodology involved participants watching a brief video clip of either the humanlike front of the robot Kaspar, or the robot's machinelike back. Participants rated the robot's front aspect as more uncanny, or unnerving, than its mechanical back. K. Gray and Wegner suggest this result is a consequence of the ability to experience things (mind experience) being normally attributed to humans, not machines. Therefore, akin to an expectation-violation, the humanlike appearance of the front facing robot unnerved participants by triggering perceptions of mind experience in an agent that is not normally perceived to have this mind dimension.

K. Gray and Wegner's (2012) results in relation to perceived robot mind experience appear to contrast with those of the *robot mind study*. Although the *robot mind study* did not assess eeriness, participants did not appear to perceive robot mind experience as an aversive robot characteristic. Rather the variable was associated with robot acceptance (intentions to use), and, unlike agency, was *not* associated with non-use of the robot. However there are several methodological differences between the two studies that may explain these apparently opposing results. A key difference is that there was only one (machinelike) robot in the *robot mind study*, so any differences in perceptions of the robot's mind must have originated from the participants, not the robot. In contrast, in K. Gray and Wegner's study there were two different views of the robot Kaspar (front and back) in a between groups design. Therefore the results may have been due to the differing appearances of the robot triggering differing perceptions of robot mind in the participants.

Another robot study assessing perceived robot mind found a robot-participant gender interaction (Eyssel, Kuchenbrandt, Hegel, & de Ruiter, 2012). Participants rated the mind of the social robot Flobi after viewing a three second video of the robot speaking in either a male or female voice. Male participants rated the robot as having more mind when it spoke in the male voice, and vice versa, female participants rated the female-voiced robot as having the most mind. However, Eyssel et al. summed the mind perception measure, rather than assessing the two dimensions separately, and associations with perceptions of robot mind and robot acceptance were not assessed.

There are some method differences between the *robot mind study* and the two Eyssel et al. (2012) and K. Gray & Wegner (2012) studies, which may account for any differences in findings. Method differences include measures of mind perception being administered at one time point only in the latter two studies – after viewing the robots. Furthermore, this single administration was done after viewing a brief robot video rather than interacting with an actual robot. While different methodologies have different merits and limitations, a single post-HRI administration means that baseline perceptions of robot mind cannot be assessed, nor can any changes in mind perception as a result of the HRI, and nor can any influences of pre-factual perceptions of robot mind on acceptance be assessed.

The study described in segue two in which participants did a repeated measures blood pressure task with three different robot face displays (Broadbent et al. 2013), also involved the administration of the mind perception questionnaire. Also included were measures of uncanny valley effects, and participants' perceptions of the robot's personality.

To recap, the three robot face displays used in the Broadbent et al. (2013) study were a male humanlike face, a silver face (a 'silverised' version of the humanlike face), and a display without a face. In contrast to results from the *prior attitudes & drawings study*, where no preference was found between the different face displays, participants in Broadbent et al.'s study most preferred the humanlike robot face, followed by the no-face display, and least preferred was the silver face. However, similar to the *robot mind study*, all three versions of the robot in Broadbent et al.'s study received higher ratings for mind agency than they did for mind experience. Participants perceived the robot's humanlike and silver faces to have both more mind agency and experience, compared with the no-face robot display.

Results from the robot mind study indicate that different individuals can perceive different amounts of mind in the *same* robot and these differences predict use of the robot. Results from the other three studies described above (Broadbent et al., 2013; Eyssel et al., 2012; K. Gray & Wegner, 2012) - which also assessed perceptions of robot mind but used different robots from the Cafero robot used in the *prior attitudes & drawings study* - indicate that robot appearance and behaviour can also influence people's perceptions of robot mind.

Chapter 8. Specific reasons for unmet needs for more specific eldercare robot design [*unmet needs paper*]

8.1. Preamble to manuscript 4 - the *unmet needs paper*

The motivation for this paper arose from extensive conversations and interactions I had with older people, their families, and eldercare facility staff (participants and non-participants), over the course of these doctoral studies. These conversations suggested a number of barriers to developing acceptable eldercare robots.

The common combined barriers to participation in the HRI studies were the retirement village residents' perceptions that the robot was of no use to them and would be too difficult for them to use. A typical resident comment was that as they were no good with computers, they would also be "no good" with a robot. I explained to the independent-living residents that by participating in the robot study they would be helping *us* researchers by testing and providing feedback on the prototype healthcare robot. I assured them that we had designed the robot to be easily used by someone who had never used a computer before. In short, in accordance with the technology acceptance models, perceptions of robot usefulness and ease of use were important to many retirement village residents.

However, trying to determine what robot functions people *would* find useful was challenging. The approach of directly asking was limited in its effectiveness. Most people had very little idea of how robots could assist them in their daily lives.

Another approach for determining useful robot functions is to assess people's unmet needs - that could then be matched with robotic solutions. In keeping with the central thesis it is plausible that people's perceptions of their unmet needs will predict acceptance of a healthcare robot – mediated by their perceptions of robot usefulness.

However, assessing unmet needs met with other barriers. Some older people seemed unaware of, or unwilling to acknowledge their unmet needs. For example, it was not uncommon during preliminary conversation for residents to comment that they were lonely. Yet, when asked to rate their loneliness levels on a Likert scale, they would deny being at all lonely. While lack of company appeared to be a common problem for residents; readily apparent in casual conversation, there appeared to be a stigmatising barrier to consciously acknowledging that they were lonely.

After noting some barriers to determining robot functions that eldercare stakeholders would perceive as useful, I examined the literature on user centred technology and robot studies. Closer inspection showed that the term ‘user centred’ was often used to refer to usability needs rather than the user’s personal needs. Additionally, the research tended to be more product-driven than user centred.

While the field of HRI is becoming increasingly multi-disciplinary, it is still engineering dominated. In the same way that psychologists typically do not have training in engineering or other disciplines; typically engineers do not have training in psychology, gerontology, or human research methodologies. Consequently I wanted to provide robotocists with a psychology-informed paper on methodologies that would aid in the design of more acceptable robots and useful robot functionalities.

8.2. Manuscript four: Identifying specific reasons behind unmet needs may inform more specific eldercare robot design

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Abstract

Many countries are facing aging and aged populations and a shortage of eldercare resources. Eldercare robots have been proposed to help close this resource gap. Prevalence of eldercare robots may be enhanced by more acceptable robot design. Current assistive robot design guidelines are general and consequently difficult to translate into specific acceptable design. This paper proposes a method for developing more specific eldercare robot design guidelines. Technology acceptance models suggest acceptable robots need to be perceived as useful as well as easy to use. As older people often have high levels of unmet need, knowledge of the needs of older people and other eldercare stakeholders can suggest how robots could be usefully deployed. It is further proposed that determining the specific reasons why eldercare-needs are unmet may help lead to more specific design guidelines for eldercare robot form and function, as well as the design of robot marketing, distribution and deployment strategies.

Keywords: robots, older people, needs, HRI, technology acceptance, user centred design.

Introduction

Many countries are facing aging and aged populations (United Nations, 2012) combined with a shortage of healthcare professionals (Super, 2002). Eldercare robots may help mitigate this shortfall in eldercare resources (Beer et al., 2012). A key issue is ensuring that the robots are acceptable to users. While there are existing general guidelines for acceptable eldercare robot design, their very generality can make them difficult to translate into specific acceptable designs (Fisk, Rogers, Charness, & Sharit, 2009; Maciuszek, Aberg, & Shahmehri, 2005). This paper proposes that examining the underlying reasons for unmet eldercare needs may help refine the design problem and inform more specific robot design guidelines. This paper further examines some methodological limitations inherent in eldercare robot design research and suggests ways of circumventing them.

The paper is divided into six sections. First, reasons why eldercare robots are not yet prevalent are explored, including low acceptance. Two dominant technology acceptance models are then described to see what factors are relevant to eldercare robot acceptance. The next section describes the range and methodology issues of robot design guidelines that have already been developed to promote eldercare robot acceptance, including matching user-needs to robot functionalities. Then related work in psychology and health are reviewed - focusing on assessment of elder-needs. Finally, to illustrate the concepts discussed, reasons for unmet eldercare-needs and their potential for translation into robot design are examined using the example of incontinence. Recommendations for developing more specific and acceptable robot designs are then made.

Why are eldercare robots not prevalent?

Eldercare robots can be described as assistive robots that aim to enhance the physical and/or mental health of an older person, such that their quality of life is maintained or enhanced. Acceptance of eldercare robots is defined as the robot being willingly incorporated into the person’s life (Broadbent, Stafford, et al., 2009). There are successful eldercare robots. The most notable arguably being the companion seal robot Paro (e.g. Robinson et al., 2013; Shibata et al., 2011). However while relatively few eldercare robots have been presented to the market, some have not met with commercial success (Mahoney, 1997; Robotics Today, 2007). Human-robot interaction (HRI) researchers have indicated reasons for the lack of eldercare robots. Reasons include: autonomous assistive robots must manage more uncertain environments compared with industrial robots (Breazeal, 1999), making them more difficult to build safely. People involved in the eldercare environment, such as caregivers or family, may not be accepting of robots (Broadbent, Tamagawa, et al., 2009). The cost of robots can be prohibitive to potential purchasers, especially when perceived benefits are inadequate (Mahoney, 1997). Older people can be less accepting of novel technologies than younger people (Czaja et al., 2006; Flandorfer, 2012). Sometimes potentially useful assistive devices are not accepted by older users as the product's design does not make the benefits of use clear to them (Forlizzi et al., 2004). In some instances, poor uptake and discontinued use of eldercare assistive devices (including robotics) may result from technology design being overly product-driven and insufficiently user-driven (Flandorfer, 2012; Gardner, Dukes, & Discenza, 1993; Keates, John Clarkson, & Robinson, 2002; Maciuszek et al., 2005; Mahoney, 1997). User-driven design may be more costly up front, but a review of user-centred IT design concluded any additional costs appear reasonable in terms of product success and user acceptance (Kujala, 2003).

In order to try to increase eldercare robot acceptance, it is useful to consider technology acceptance models.

Technology Acceptance Models

Technology acceptance models (TAM) specify variables that increase or decrease user acceptance of technology. The basic but seminal TAM proposed by Davis in 1989 provides two major determinants of technology acceptance; 'perceived ease of use' and 'perceived usefulness'. Davis's TAM was merged with eight other acceptance models to formulate the Unified Theory of Acceptance and Use of Technology model (UTAUT:Venkatesh et al., 2003). The four primary UTAUT predictors of intentions to use information technology are; perceived ease of use, perceived usefulness, social influence, and facilitating conditions. User variables, such as age and technology experience, were also included. 'Voluntariness of use' was also added in an attempt to redress self-selection confounds. While the UTAUT has been employed in an eldercare robot context (Heerink et al., 2010), current technology models may be limited in usefulness for robot design, due to inability to explain how particular variables predict technology acceptance (Bagozzi, 2007).

The next section provides examples of existing eldercare robot design guidelines that have been proposed in order to increase acceptance. Some limitations to the methods used to determine these guidelines are discussed.

Robot design guidelines issues

The concept of ‘eldercare robot design’ is not restricted to the design of robot hardware and software; rather it includes all aspects of robot design from early concept, the robot’s form and functionality, marketing, distribution, and deployment. HRI researchers have provided numerous assistive robot design guidelines. While providing valuable information for an emerging field, many guidelines are theoretical, general, untested (Maciuszek et al., 2005) and/or have not been shown to increase acceptance (Heerink, Krose, et al., 2006). Guideline examples include; assistive robots should be designed to be customizable (Forlizzi et al., 2004; Kuo, Broadbent, & MacDonald, 2008), manifest social abilities (Heerink, Krose, et al., 2006), have good error recovery (Fisk et al., 2009; Kuo et al., 2008), and match the users’ needs (Broadbent, Stafford, et al., 2009). Eldercare robots should be designed to be small (Scopelliti et al., 2005), slow-moving, and machinelike (Broadbent, Tamagawa, et al., 2009; Scopelliti et al., 2005). They should promote elder independence in balance with human connectedness, and avoid stigma (Forlizzi et al., 2004; Hirsch et al., 2000). Eldercare robots should look like familiar appliances to ‘afford’ ease of use (Forlizzi et al., 2004).

Preferred robot-tasks also suggest robot design guidelines. A focus group study showed independent-living older people most preferred a robot to clean, fetch and organize (Beer et al., 2012). In an assisted-living setting, a questionnaire of preferred robot tasks was designed based on focus groups conducted with older people, caregivers and managers (Broadbent, Tamagawa, et al., 2011). Administration of the resulting questionnaire showed the most preferred robot tasks included detecting falls, monitoring peoples’ locations, lifting people and heavy objects, and switching appliances on and off.

Some well-known examples of assistive robots with different design approaches are MOVAID and Care-O-bot. MOVAID (Dario et al., 1999) was based on the inclusive ‘design-for-all’ principles of Universal Design. Intended users were both disabled and older people. During initial design-scoping interviews, disabled people, their families and carers were asked about their needs for general technical assistance. Three key tasks identified for MOVAID were heating and serving food, cleaning kitchen surfaces, and removing dirty bed sheets. A dominant design rationale for Care-O-bot3 (Parlitz et al., 2008) was avoidance of an anthropomorphic appearance. Target users were derived from scenario-based design methods and were described as 'techies and soccer moms'. The minimum user criterion was familiarity with technologies such as digital cameras. Since conception Care-O-bot3 has been trialed in assistive-living facilities (Fraunhofer, 2011).

The robot design guidelines originate from a variety of methodologies. These include literature reviews, previous research, focus groups, ethnography, semi-structured interviews, and questionnaires. Possible methodological limitations include participants responding to closed questionnaires of possible robot tasks and appearances (e.g. Beer et al., 2012). A closed list may elicit valuable information, but may also reflect researcher bias as well as constraining peoples' reports of what tasks they would like robots to do (Wu, Fassert, et al., 2012). Focus groups obtain data relatively quickly, but participants may not disclose information through embarrassment or stigma. It may be difficult to access people's unconscious attitudes through direct questions (Sixsmith & Sixsmith, 2000).

In assessing generalisability of robot design guidelines it is useful to examine the methodology and questions the guidelines are derived from. Some studies provide this identifying information (e.g. Broadbent, Tamagawa, et al., 2011; Horrocks et al., 2004). Some studies do not (e.g. Beer et al., 2012). Some measures have been developed with younger participants (Ray et al., 2008), which may not generalise well to the design of robots for older people (W. A. Rogers & Fisk, 2010).

However older people are a heterogeneous population themselves. These differences can be generational, educational, gender, cultural, functional, individual and/or environmental. Therefore robot design measures may also have limited generalisability if developed with older participants that differ from the target older users. For example; older people who are living independently may have different technology and eldercare-needs from people in assisted-living. As seen in the CREATE Model of Technology and Aging (Fisk et al., 2009), older people tend to have a variety of eldercare support stakeholders.

These stakeholders can include the older person, caregivers, family, service providers, robot purchasers, and even robot research funding agencies. Therefore, acceptance of the robot by a range of eldercare stakeholders may be important to wider commercial acceptance. For example, caregivers can be fearful of losing their jobs to robots (Broadbent, Tamagawa, et al., 2009) and purchasers of eldercare robots are likely to be family or service providers rather than the older user (Mahoney, 1997). The opinions of older users are critical, but some robot design guidelines have been developed without consideration of the needs of other eldercare stakeholders (e.g. Beer et al., 2012). However some studies have considered the needs of multiple eldercare stakeholders (e.g. Broadbent, Tamagawa, et al., 2009).

Methodological issues aside, many robot design guidelines are difficult to convert into specific robot designs because they are too broad. Fisk et al. (2009) acknowledge this design problem and ascribe it to the difficulty of providing specific robot design guidelines that suit all contexts in the variable and complex eldercare environment. There may be ways to refine the design problem. In a series of eldercare robot acceptance studies, Heerink et al.(2010) found perceived usefulness was the strongest predictor of intention to use the robot. People may perceive a product as useful when they see it as meeting an interest or need (Maciuszek et al., 2005) and consequently be more likely to accept it. Therefore incorporating a greater understanding of user needs into the design process may aid development of more specific robot design guidelines (Beer et al., 2012; Hirsch et al., 2000).

However, despite calls for more user-needs assessment to facilitate robot design, HRI researchers are often referring to assessment of users' technology *usability* needs (i.e. how easy or difficult the technology is to use) e.g. Fisk et al. (2009), rather than assessing users' individual needs (i.e. companionship, hygiene, hydration, finance, accommodation etc.).

Similarly there are calls for user involvement early in the design process (Dario et al., 1999; W. A. Rogers & Fisk, 2010). Some HRI studies do employ potential users early at the conceptual stage of design (e.g. Beer et al., 2012; Broadbent, Tamagawa, et al., 2009; Sung et al., 2009). Yet, for other studies 'early' user involvement means at the usability testing stage, not the conceptual stage (e.g. Fisk et al., 2009; Fraunhofer, 2011). Usability is a critical but insufficient precursor to technology acceptance.

There are further issues with user-centred design as commonly deployed in eldercare robot research. Robot design studies often assess what tasks potential users would like an eldercare robot to do. Responses to that question have important implications for acceptance, but it is a different question from 'what are the individual needs of the potential user group?' The second question removes the robot from the equation so answers become less constrained by real or perceived technology capabilities or fears.

The difference between these research questions is described by the term ‘naïve consumer’. The term refers to the challenge of soliciting peoples’ opinions on products of which they have little or no experience: as has been noted in eldercare HRI studies (Beer et al., 2012; Broadbent, Tamagawa, et al., 2009).

There are several implications of the naïve consumer issue in robot design research. Through lack of experience of robots, robot-naïve participants may not think to request a potentially useful robot functionality that would meet some need. Conversely, they may reject the idea of robots performing particular tasks, but change their minds with actual experience. Older people reported improved attitudes towards a health robot after only a half hour interaction (Stafford et al., 2010) and improved attitudes to previously disliked assistive devices after actual use (Forlizzi et al., 2004). Consequently, robot design preferences expressed by robot-naïve participants should be interpreted in context. There is merit in each of these robot design approaches. Due to unique data captured by different methodologies, triangulation of varied research methods in HRI is advised for comprehensive data capture (Bethel & Murphy, 2010). However, assessment of the individual needs of potential eldercare robot stakeholders, independent of the product driven concept of an eldercare robot, should be included in the methodology mix. This may assist in circumventing the limitations inherent in the naïve consumer issue. Consideration of the literature from psychology and health about eldercare-needs helps to inform robotic designers about further potential design issues.

Eldercare-needs and needs assessment

Need is a psychological feature that arouses an organism to action toward a goal, giving purpose and direction to behaviour. Maslow’s seminal theory on human needs proposed a pyramid shaped model with survival needs on the bottom, such as food and shelter. These basic needs must be satisfied before a human can reach the more meaningful self-actualisation needs at the pyramid pinnacle (Maslow, 1943). Older people often have many unmet needs. Identifying the most important needs may help narrow the design process for acceptable eldercare robots (Maciuszek et al., 2005). Several HRI researchers have investigated how older people prioritise need. Giuliani et al. (2005a) found older people ranked theoretical elder-needs in accordance with Maslow’s hierarchical needs theory. However, an investigation of elder-needs priorities via a combination of literature reviews, focus groups, observation, and interviews found no clear ranking; rather older peoples' ranking of the importance of their own needs varied with their personal circumstances (Maciuszek et al., 2005). Two widely used elder-needs questionnaires are Activities of Daily Living (ADLs:Katz & Akpom, 1976) and Instrumental Activities of Daily Living (IADLs:Lawton & Brody, 1969). ADLs assess limitations in daily living such as bathing, transfer from bed, and toileting. IADLs assess limitations in routine activities such as shopping, housekeeping and using the telephone. Independently living older people tend to be high in IADL needs only. People in assisted-living facilities tend to be high in both IADLs and ADLs. Both these measures assess met and unmet elder needs, but not partially-met needs. Carer needs are not assessed.

A more recent and well-validated measure of elder-needs is the Camberwell Assessment of Need for the Elderly (CANE:Reynolds et al., 2000).The CANE contains the 24 elder-needs and two carer needs that research determined most important. The elder-needs items include accommodation, food, household skills, self-care, daytime activities, physical and mental health, information, deliberate and accidental self-harm, abuse/neglect, behaviour, alcohol, drugs, company, intimate relationships, caring for someone else, mobility/transport, money, memory, eyesight/hearing, and incontinence. The two carer items are information and psychological distress. The CANE assesses the three levels of 'need status'; whether the need is met, unmet or partially met. Clarifying need status – met, unmet or partially met, is typically undefined in the literature (K. Walters et al., 2000), and this is also true for HRI papers. For example, based on the premise that many people snack, M. K. Lee et al. (2009) designed a Snackbot for office workers in an office context. However, it was unclear whether office staff had snacking needs that were not already met by nearby vending machines or cafes, and no analysis showed how the robot could better meet their unmet or partially-met snacking needs.

K. Walters et al. (2000) assessed unmet eldercare needs and help-seeking amongst a UK sample. The CANE was combined with semi-structured interviews. The three highest levels of unmet needs were found to relate to incontinence, accommodation, and psychological distress. Differences were found in *which* needs people were more likely to disclose and seek help for. Both older people and carers were both more likely to seek and be offered help for mobility issues; compared with incontinence, psychological distress, eyesight, memory, accommodation problems, and loneliness.

Unfortunately determining unmet or partially-unmet needs is rarely straightforward (Sixsmith & Sixsmith, 2000). Needs assessment can be confounded by older people being unwilling or unable to express their needs. A UK elder-needs study (K. Walters et al., 2001) found help had been sought by older people in only 24% of cases of identified unmet needs. Reasons for not seeking help included people being resigned to their situation: while identifying a need they did not intend to do anything about it. Older people may not acknowledge needs such as loneliness or disability due to stoicism, pride and/or stigma (Hirsch et al., 2000). Fear of institutionalization is another reason older people may under-report need (Horrocks et al., 2004).

Some underreporting of need is less deliberate. Elder-needs can fluctuate rapidly alongside fluctuating mental and physical health. Consequently older peoples' perceptions of their capabilities (and therefore their ability to accurately report their needs) are often misaligned with their actual capabilities (Hirsch et al., 2000). Habituation to the inconvenience of both unmet and partially-met needs may also interfere with conscious recognition, and therefore reporting, of need (Hirsch et al., 2000; Horrocks et al., 2004).

Identification of eldercare-needs such as independence, incontinence, and assistance with chores provide indications for acceptable eldercare robot design (Fisk et al., 2009), as do insights into elder-needs barriers such as stigma. However, these elder-needs design guidelines are still insufficiently specific. For example, a study identified elder-loneliness as a high priority issue (Mast et al., 2010); however it is unclear whether the self-reported loneliness resulted from the death of a spouse or friends, insufficient contact with family, and/or being housebound. And if an older person is housebound….why? Is it lack of transport, or physical or mental disability? The specific reasons needs are unmet have implications for designing technology to match needs. Consequently a deeper understanding of the reasons for unmet elder-needs is recommended to further refine the design problem (Giuliani et al., 2005a).

As an example, the next subsection explores this concept with elder-incontinence needs.

Identification of Reasons for Unmet Specific Needs for More Specific Design

Incontinence is a common and potentially disabling issue for older people. Despite incontinence support being readily available through the UK public healthcare system many older people are not using these resources and unnecessarily suffering the physical and psychological consequences of incontinence.

Horrocks et al. (2004) identified many barriers to incontinence help in 20 older people aged 66-94 years through semi-structured interviews. Barriers included a generational reluctance to discuss personal and bodily functions. There were patient/doctor gender interactions. Older women preferred a female doctor; older men had no preference. Unlike women, older men actively disliked incontinence pads. Female-dominated incontinence product advertising meant both incontinence and incontinence products were perceived as 'women's problems' only.

Further findings include the association of incontinence stigma with distress. Distress often led to painstaking concealment of incontinence problems (however elders less distressed by their incontinence were also less likely to bother seeking help). There were also themes of 'not wanting to bother busy doctors' with 'trivial' incontinence complaints. House-bound participants were missing viewing incontinence information leaflets at health clinics. Self-management strategies for urinary leakage, such as restricting social activities, degraded the older person's quality of life. Some participants may have impaired their health by restricting fluid intake and altering medication regimes; especially reducing consumption of diuretics.

Opportunities for robots to overcome incontinence-needs barriers may be seen in this in-depth analysis. For example, older people may be more willing to seek information about embarrassing unmet needs from a robot than a human. People are also less likely to feel they are 'bothering' a machine (Mahani & Eklundh, 2009). A robot software programme could present solutions to common unmet elder-needs such as incontinence. Such a programme could combine understanding of incontinence needs and needs-barriers with input from psychogerontologists to reduce stigma and psychological distress.

There are further benefits of needs-technology matching. The ready availability of resources on a healthcare robot may be advantageous to housebound people. Understanding individual differences in eldercare stakeholder needs and need-barriers can guide customization. With regard to gender differences; incontinence information could be presented via a robot's monitor to older women in a female persona. Men (and women) could be offered a choice of robot persona gender. To raise male awareness of incontinence and solutions; information could be developed for robotic presentation using older male models. In marketing the robot to older people, the non-stigmatizing nature of intimate resources available via the robot could be discretely emphasized, as could the benefits of improved continence such as increased independence. In marketing the robot to family purchasers, the benefits of enhanced elder-independence and quality of life through improved continence could be emphasised, and any financial benefits of prophylactic healthcare emphasised to service provider purchasers.

The above suggestions for more specific robot guidelines for elder-incontinence are an example only. Beyond basic design principles, much eldercare robot design may be context dependent. Existing research on eldercare needs and need-barriers should be assessed for generalisability to the particular target robot stakeholder group. The above example is based on a 2004 British study of community-living people aged 66-94 which might not generalise well to, for example, a present day cohort of 80 + year old people in assisted-living facilities in a different country.

Recommendations for integrating these eldercare needs issues into more specific robot design guidelines are listed next.

Recommendations for More Specific Eldercare Robot Design

1. That stakeholder eldercare-needs and needs-barriers be incorporated early (at the conceptual stage rather than the user-testing stage) in the robot design process. Fewer costly design iterations may be required (Kujala, 2003).

2. One size will probably not fit all. Identify the specific context for the eldercare robot – independent-living, assisted-living, hospital etc. Identify key target stakeholders. Identify eldercare needs of different types of stakeholders.

3. Review the eldercare-needs literature. Assess specific reasons why specific needs of eldercare stakeholders are unmet, partially-unmet or met. Incorporate all key eldercare-needs into eldercare robot design, e.g. it is of limited use if an otherwise useful incontinence software programme is stigmatising.

4. Evaluate the methodology of relevant eldercare-needs literature for generalisability to the target stakeholders.

5. If relevant literature cannot be found, it may be advisable to conduct a separate study assessing stakeholders’ eldercare-needs and needs-barriers – using participants' matched to the target stakeholders.

6. Use data triangulation when assessing eldercare-needs and specific needs-barriers. As more ‘open’ methodologies, such as ethnography, observation, semi-structured interviews etc. may be effective for identifying latent elder-needs, these should be included in the methodology mix (Kujala, 2003). Feedback from carers, families etc. on their perceptions of elder-needs can help fill gaps in self-reports of need from elders.

7. Translate specific reasons for unmet needs into more specific robot design guidelines. HRI researchers can then better assess what robot aspects can be made available, designed, or modified to meet those needs and address need-barriers.

8. Integrate these guidelines into all aspects of eldercare robot design – including robot form and function, marketing, recruitment, distribution, and deployment.

Conclusion

Designing acceptable eldercare robots is a complex multifactorial and multidisciplinary task. This paper highlights the importance of research conducted into reasons for high rates of unmet eldercare-needs to increase awareness of these issues amongst roboticists. The individual issues are not new, but this paper combines an understanding of eldercare-needs and needs-barriers, with an understanding of associated methodological issues. This combined approach may aid roboticists in developing more specific and acceptable eldercare robot design guidelines.

Chapter 9. Discussion

This thesis contains four peer-reviewed published[21] scientific papers on the theme of understanding psychological variables associated with acceptance and non-acceptance of eldercare robots. Three of the papers are based on HRI studies and one is a discussion paper.

Key thesis findings

There are five key findings of this thesis. The first key finding is the replication of earlier research that the attitudes that people hold about robots prior to an HRI can predict their robot acceptance across a range of study methods. These study methods include the conduction of trials in eldercare facilities, and evaluation of people's acceptance of robots with both subjective and objective measures. Subjective measures include people's intentions to use the robot again. Objective measures include whether they use a robot or not.

The second key thesis finding is that that people's perceptions of a robot's mind can predict whether they will use a robot or not. The third is that people's use of a robot can influence their robot attitudes and perceptions of a robot's mind. The fourth is that, not only can people's attitudes towards robots change rapidly; from before to after a single 30 minute interaction, but that these attitude changes predict robot acceptance. The fifth key finding is that people's pre-interaction robot drawings are correlated with both their robot evaluations and physiological responses after a robot interaction. The implications of these key thesis findings and other contributions to the field of HRI, are discussed in this chapter.

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[21] As of 24/09/2013 the status of the manuscript for the *prior attitudes & drawings study* is *in submission – accepted with minor revisions.*

Chapter outline

Section 9.1 discusses the thesis findings in relation to robot attitudes. This includes the associations with robot acceptance, and consideration of the merits of the RAS as a questionnaire measure of robot attitudes. Section 9.2 outlines contributions in relation to perceptions of robot mind and associations with robot acceptance. In section 9.3, robot drawings, as a more implicit measure of robot attitudes are discussed. Next, in section 9.4, the contributions of the discussion paper on reasons for unmet needs to the field of eldercare HRI are summarised. Thesis strengths are described in section 9.5. A proposal for a new model of robot acceptance is presented in section 9.6. Sections 9.7, 9.8, and 9.9 contain, respectively, limitations of this thesis, suggestions for future research, and the thesis conclusion.

9.1. Robot attitudes

The association of prefactual robot attitudes with robot acceptance

Unusually for HRI studies, in addition to two of the three studies administering measures *after* participants had interacted with a robot, all three thesis studies administered psychological measures at baseline - before participants had interacted with the robots. Results from all three studies showed participant's baseline, or prefactual, robot attitudes were significantly associated with their acceptance of the robot. Specifically, in the *prior attitudes & drawings study* participant's baseline robot attitudes predicted both overall rating and intentions to use (averaged into 'robot evaluation'). In the *robot mind study* they predicted who would and would not use the robot. In the *improved attitudes study*, they predicted overall rating of the HRI.

This association between participant's baseline robot attitudes and robot acceptance was particularly notable in the *improved attitudes study*. In that study, participants completed the baseline measures before they even saw the robot. This result supports earlier research (Broadbent et al., 2010) that people's generic, pre-factual, robot attitudes, can predict acceptance of specific robots. In comparison with other HRI studies that have administered psychological measures before and after the HRI; Lohse et al. 2011 did not assess robot acceptance. It is also unclear whether Lohse et al. administered the baseline measures before or after participants viewed BIRON, the Bieleford Robot Companion. In Paepcke and Takayama's (2010) expectation manipulation study, participants viewed the robot pets *before* the baseline measures were completed.

The strong evidence that baseline, pre-interaction, robot attitudes not only exist, but predict robot acceptance, concurs with the opinions of some researchers and disagrees with others. Bartneck et al. (2009) advise researchers not to administer psychological measures prior to an HRI on the grounds that people could not hold opinions about a robot they had not yet experienced. Conversely, Bagozzi (2007) and Bhattacherjee (2001) have criticised technology acceptance models for lack of consideration of 'pre-factual' attitudes. In his 1989 and 1993 papers, Davis allows for the existence of pre-interaction attitudes (and for their influence on acceptance), but proposes they are completely derived from the physical appearance of the technology.

However this explanation for the origins of pre-factual technology attitudes appears insufficient on two counts. As participants in the *improved attitudes study* were found to hold pre-factual robot attitudes that predicted acceptance of a robot they had not even seen, their baseline robot attitudes could not have been informed by the physical appearance of the robot. Furthermore, while the physical appearance or behaviour of a technical device or robot *does* influence people's responses (DiSalvo et al., 2002; Syrdal, Dautenhahn, Woods, Walters, & Koay, 2007); that people respond differently to identical robots (Forlizzi & DiSalvo, 2006; Paepcke & Takayama, 2010) argues that the physical appearance and behaviour of robots is not the only influence on people's technology (and robot) attitudes.

Overall, the thesis study finding that people can hold baseline robot attitudes that predict robot acceptance across a range of HRI contexts and methods, is an important contribution to the HRI field. Implications include the possibility of optimising robot acceptance in potential users by promoting adaptive robot attitudes. The emphasis, however, needs to be on *adaptive* robot attitudes. The *robot mind study* results show that people are less likely to use a robot if they have negative robot attitudes.

However Paepcke and Takayama (2010) showed that, compared with people who were manipulated to have low expectations of a robot's abilities, people who were manipulated to have high expectations were more disappointed in the robot. Consequently 'adaptive robot attitudes' may mean robot attitudes that are sufficiently positive so that people are willing to interact with the robot, but not so high that they are disappointed with the robot when they do interact with it.

People's baseline robot attitudes appear important for robot acceptance, but their very first interaction with a robot also appears important for robot acceptance. When people transition from a 'never robot user' to someone who has used a robot, their attitudes about robots transition from being completely informed by sources *other* than personal experience of robots, to *being* informed by personal experience of robots (Bhattacherjee, 2001).

Results from the *improved attitudes study* show that while people's baseline robot attitudes predicted a large amount of variance in robot acceptance, *change* in robot attitudes as a result of the interaction predicted approximately an equal amount. This result implies that the experience of the HRI is at least as important to robot acceptance as baseline robot attitudes.

People's robot attitudes can change rapidly

The method of both before and after administration of psychological measures in two of the three thesis studies showed not only the existence of influential baseline robot attitudes, but also that people's attitudes towards robots can change rapidly. Sometimes positive changes in participant responses can be attributed to the confound of researcher, observer, or Hawthorne effects. In an HRI context, the Hawthorne effect describes a situation where people are responding to the presence of the researchers rather than the presence of the robot. However, in the *robot mind study*, while robot attitudes did improve significantly in retirement village residents who used the robot during the two week trial, robot attitudes did not change in people who did not use the robot. Because the researcher had contact with all participants, this suggests researcher presence was not a confound in this study.

People's robot attitudes may change more rapidly than indicated in the HRI literature. Even more dramatically than in the two week *robot mind study*, the participants' robot attitudes in the *improved attitudes study* improved from before to after interacting with the robot for only 30 minutes. The combined findings of the *improved attitudes study* and the *robot mind study* provide further support for the malleability of robot attitudes, and the potential for interventions to foster adaptive robot attitudes in potential robot users.

Other HRI research and opinion on attitude change

There is little discussion in the HRI literature on change in robot attitudes. Nomura, Suzuki, et al. (2006) propose that robot attitudes are unlikely to change in the short term, and instead offer a generational perspective. They think it is likely that society's attitudes towards robot will become more positive as the younger generations, more familiar with novel technologies such as robots, become the older generation. Several other HRI studies have been located that assessed change in people's perceptions of a robot's abilities from before to after an interaction (Lohse, 2011; Paepcke & Takayama, 2010).

In a comparable study, Kuo et al. (2009) administered the RAS to older and younger people before and after interacting with a healthcare robot. No differences were found in participants' robot attitudes from before to after the HRI, or between the younger and older participants. As the focus of the Kuo et al. study was on age and gender, the RAS items were not assessed against an outcome measure – attitudes towards healthcare robots. However, baseline robot attitudes did predict how enjoyable the HRI was, and the quality of the experience (Broadbent et al., 2010).

However, no other studies have been located that have used the before and after methodology in a real-world context: with older people and eldercare facility staff interacting with a healthcare robot, with a hard behavioural acceptance measure – whether people choose to use a robot or not.

Relative advantages of the RAS as a questionnaire measure of robot attitudes

The association between robot attitudes (as assessed by the RAS) and robot acceptance has been replicated across all three thesis studies. However the RAS is not the only questionnaire measure of robot attitudes. The most commonly used other robot attitudes measures are the NARS (Nomura, Kanda, et al., 2006) and attitude items derived from technology acceptance models. The latter includes the Almere Model attitude items (Heerink et al., 2010). However, the RAS has some characteristics that may give it a competitive advantage as a measure of robot attitudes.

As discussed in Chapter 3, the NARS has some limitations which may impair its effectiveness as a measure of robot attitudes (Tsui et al., 2011). These include concerns about the measure's cross-cultural validity (Syrdal et al., 2011). The double-barrelled nature of some NARS items may confuse participants and compromise the validity of their responses. As several studies have demonstrated the effectiveness of framing or priming effects on people's responses to computers and robots (Hinds, Roberts, & Jones, 2004; Paepcke & Takayama, 2010; Rutjes, 2013), the negatively worded robot attitude items, combined with the assumptions of robot speech and emotions, may mean administration of the NARS may influence the very construct it is trying to assess. Despite these possible limitations, NARS responses have been associated with some HRI outcomes (Nomura et al., 2008; Syrdal et al., 2011). However, the lack of direct real-world outcomes makes it difficult to assess the existence or extent of associations between the NARS and robot acceptance.

The other commonly used measure of robot attitudes come from the Almere model. There is evidence for an association of the Almere robot attitudes measure with robot acceptance (Heerink et al., 2010). (as the Almere model is based on technology acceptance models, studies that use the Almere model also tend to incorporate measures of robot acceptance). However the operationalization of attitudes in these models casts doubt on the completeness of the construct. These detected associations may result, at least partially, from overlap with other variables that are predictive of robot acceptance - such as perceived robot usefulness and intentions to use the robot - rather than from attitudes towards robots as such.

Apparent construct overlap was the rationale Venkatesh et al. (2003) gave for the removal of the technology attitudes variable from the Almere's parent model - the UTAUT. Inspection of both the UTAUT and Almere attitudes measures suggest the items are more representative of attitudes towards *using* the technology or robot, rather than assessing attitudes towards the robot itself.

This might not be an issue, except that the Almere attitudes measure only consists of a few items and they all appear to reflect attitudes towards use of the robot, and not address other aspects of people's mental models of robots. In recognition of this, Heerink et al. (2010) suggest that other types of robot attitudes should be investigated. However, arguably a more serious reason for the redundancy of the attitudes variable, is that when operationalised as 'attitudes towards use of the technology' is that it actually overlaps with the dependent outcome "intentions to use the technology'.

Possible RAS advantages over other measures of robot attitudes include that it assesses attitudes *towards* robots, not just attitudes towards *use* of robots. The RAS measure does include two items on perceived usefulness and perceived ease of use of the robot. It also includes the items friendly, trustworthy, reliable, safe, helpful, and interesting[22]. The high Cronbach's alpha scores from HRI studies that have used the RAS indicate the items are measuring the same construct (Kuo et al., 2009; Stafford et al., 2010; Stafford et al., 2013; Stafford et al., 2014).

9.2. Perceptions of robot mind

Thesis findings in relation to perceptions of robot mind

Results from the *robot mind study* showed people's baseline perceptions of robot mind predicted who used the robot. However, robot users and non-robot users only differed in their perceptions on one of the two robot mind dimensions. There was no difference in baseline perceptions of the robot mind dimension of *experience* (capacity for 'feeling') between robot users and non-robot users. However, compared with people who did use the robot, non-robot users perceived significantly more robot mind *agency* (capacity for 'doing') at baseline.

[22] the RAS humanlike-machinelike item is a separate subscale

Furthermore, from the beginning to the end of the two week HRI trial, robot users' perceptions of robot mind agency decreased. In contrast, non-robot users did not change in their perceptions of robot mind agency. This suggests that people perceived the robot as having more capabilities than it actually did, and when people actually used the robot and experienced its actual capabilities, these perceptions were revised downwards.

Immediate implications of these findings suggest that perceptions of robot mind, like robot attitudes, appear to both predict robot acceptance and be modifiable. This also suggests (again like robot attitudes), that the variable of perceived robot mind may be a candidate for interventions to promote robot acceptance.

There are several studies that provide evidence for the effectiveness (and efficiency) of such interventions. K. Gray and Wegner (2012) were successful in manipulating people's perceptions of how much mind agency and experience a computer possessed. Using an adapted version of the Mind Perception Questionnaire, Eyssel and Kuchenbrandt (2012) were also successful in manipulating people's perceptions of a robot's mind and levels of anthropomorphism. In both studies (similar to the method used by Paepcke and Takayama, 2010, and Hinds et al., 2004), the manipulation consisted of simple framing effects embedded in the wording of instructions.

Support for a two dimensional model of robot mind: and are people predisposed to perceive robot minds as high agency:low experience?

The associations detected between perceived robot mind and robot acceptance in the *robot mind study* were correlational only, and it is unclear from the results whether one or two dimensions of perceived robot mind influenced acceptance of the robot. The Mind Perception Questionnaire, unlike more established uni-dimensional concepts of mind, such as agency (Takayama, 2012) or intentionality

(Dennett, 1987), has the two dimensions of mind agency and mind experience. In the *robot mind study*, considered in isolation, only participants' baseline perceptions of the robots mind agency, and not mind experience, predicted use of the robot. This could suggest that robot mind is only perceived on one dimension of agency; that the mind dimension of experience is redundant; and that a uni-dimensional measure of robot mind would suffice just as well as a two dimensional one.

However, in addition to the model's psychometric validation (H. M. Gray et al., 2007), there is other support for a two dimensional model of perceived mind. One source of support comes from further, and apparently conflicting, data from the *robot mind study*. While participants with higher perceptions of robot mind agency at baseline were less likely to use the robot (this suggests higher perceived mind agency was a negative robot attribute for non-robot users); in participants who actually used the robot, higher perceptions of *both* robot mind experience and agency at baseline were positively (and separately) correlated with intention to use the robot again[23].

This latter finding suggests that, for robot-users, higher perceived robot mind agency was a positive attribute, as well as suggesting that the two mind dimensions are valued independently. This concurs with findings from Gray, Gray, and Wegner's (2007) original work, that both mind dimensions are associated with liking a character, wanting it to be happy, wanting to protect it from harm, and believing it has a soul. In fact, Gray et al. suggest this commonality between mind agency and mind experience is why perceived mind is traditionally viewed as a uni-dimensional construct. However, as the robot mind dimension of agency is valued by robot-users in the *robot mind study* (as well as being valued by

[23] Participants who did not use the robot over the two week trial were not asked to rate the HRI, or how much they would like to use it again.

participants in Grey et al.s study), it does not follow that *robot mind study* participants who perceived *higher* amounts of robot mind agency at baseline were less likely to use it.

There are several possible explanations for this apparent contradiction. Although perceived mind agency appeared to be a negative attribute for non-robot users and a positive one for robot users, it should be recalled that non-robot users perceived significantly higher levels of robot mind agency at baseline than robot users. It could be that higher amounts of robot mind agency are aversive, but lower amounts are not.

Another explanation for this apparent anomaly is that robot mind *is* perceived on two dimensions *and* that they act in concert. The two dimensions may combine to form mind profiles, which may vary in acceptability, depending on the HRI context. A robot with a high agency:low experience mind profile may be aversively perceived as agentic and unfeeling. A robot with a low agency:low experience mind profile may be perceived as having the mind of a useful ‘robot-as-tool’ machine. Yet another explanation is that there is something inherently different about people who are predisposed to use robots and those who are not.

A one dimensional model of perceived mind can explain why people are inclined to perceive humanlikeness in robots, or anthropomorphise them. The HRI context contains many triggers for anthropomorphism. But a one dimensional model of mind struggles to explain why perceived robot humanlikeness is associated with negative responses in some instances and positive responses in others. Part of the conundrum may be that HRI research has been somewhat preoccupied with the one dimensional question of whether a robot should be machinelike or humanlike. In contrast, a better question might be; what *type* of machine or human should a robot be like? After all, not all humans nor human behaviour is desirable.

Media representations of robots - and their minds

Other support for the concept of robot minds being perceived on two dimensions, rather than one, comes from studies of the origins and manifestations of people's mental models of robots. It is clear from robot survey results that lack of personal experience with robots is not a barrier to people holding opinions about robots (e.g. Arras & Cerqui, 2005; A. J. Moon, Danielson, & Van der Loos, 2012). So, if not from personal experience, from where do people acquire their mental models of robots? There is evidence that these are acquired from popular media, including films and literature (Broadbent et al., 2010; Khan, 1998). Kriz et al. (2010) ascertained robots are typically portrayed in popular film as being high in cognitive capabilities and low in social capabilities. Congruently, in a related study Kriz et al. found participants rated a Peoplebot as being most likely to have cognitive capabilities and least likely to have social capabilities. These abilities appear, respectively, similar to the dimensions of mind agency and mind experience.

Several robot surveys have found similar proportions of perceived robot capabilities. At a robot show, people were asked which of ten characteristics they thought applied to robots. The characteristics most commonly ascribed to robots were precision, reliability, rationality, and perfection. The characteristics *least* commonly ascribed to robots were life, humanity, and feelings (Arras & Cerqui, 2005). In a different study, 117 mixed-aged participants were surveyed on the possible characteristics of an imaginary domestic robot (Ezer et al., 2009). Participants rated robots as being significantly more likely to have performance-oriented traits than socially-oriented traits.

These combined findings raise the possibility that people are predisposed, or 'primed' by media representations, to perceive robots as having minds that are high in agency and low in experience. The notion that this high mind agency:low mind experience mental model of robots is common is endorsed by the popular dictionary definitions of robots listed at the beginning of this thesis: a machine programmed to perform specific tasks in a human manner, esp. one with a human shape; a person of machine-like efficiency (Collins Paperback Dictionary, 2003, p. 713); a machine that looks like a human being and performs various complex acts (as walking or talking) of a human being; a similar but fictional machine whose lack of capacity for human emotions is often emphasized; an efficient insensitive person who functions automatically (Merriam Webster Dictionary, 2013, online); an intelligent mechanical being designed to look like a human or other creature, and usually made from metal (chiefly science fiction); (figuratively) a person who does not seem to have any emotions (Wicktionary, 2013, online).

While there appears to be a media-driven predisposition for people to perceive robots as having a high agency:low experience mind, not everyone perceives robots as having this particular mind profile. Results from the *robot mind study* show that while perceptions of a high agency:low experience robot mind predict *non*-acceptance of the robot (possibly because such robots are perceived to be like their media representatives: intelligent agents that are indifferent to people's needs), the study also shows that not all people perceive robot mind dimensions as high agency:low experience.

Rather, people who *did* use the robot in the *robot mind study* perceived the robot's mind to be low in both agency and experience. This difference may be explained by people's perceptions of robot minds being influenced by their personal experiences, as well as by the media. Not only did robot-users decrease in the (already low) amount of mind agency they perceived in the robot from before to after the two week trial, but, to begin with, they had significantly more computer experience than non-robot users. Both of these results suggest that more computer and robot experience may moderate media representations of high agency:low experience robot minds. Personal experience of technology and robots may promote more realistic and adaptive ideas of a robot's capabilities and mind.

There are a number of characteristics of the complex HRI which may trigger perceptions of anthropomorphism, and/or moderate perceptions of robot mind. Robot characteristics that appear to influence perceptions of robot mind include appearance (Broadbent et al., 2013; K. Gray & Wegner, 2012), and apparently agentic behaviour (Levin, Killingsworth, Saylor, Gordon, & Kawamura, 2013). Human variables that may influence perceptions of robots include motivation. For example, people who are lonelier are more likely to anthropomorphise robots (Eyssel & Reich, 2013).

There is some evidence that these human and robot variables interact to influence perceptions of robot mind. People are more likely to anthropomorphise an unpredictable robot compared with a predictable one, *but* only if they are expecting to interact with it (Eyssel et al., 2011). Syrdal et al. (2009) found people who scored higher on the neuroticism scale, were more likely to have both more negative robot attitudes and to find a 'socially responsive robot' more autonomous and unacceptable.

Evidence of HRI variables interacting to influence people's perceptions of the desirability of robot humanlikeness may be seen in the *improved attitudes study*. In that study, retirement village staff and residents appeared to respond differently to perceptions of robot humanlikeness in the same robot. Overall, participants' perceptions of robot humanlikeness were not significantly correlated with their robot attitudes. However staff who found the robot more humanlike *after* interacting with it, also reported more post-interaction positive emotions. This suggests that staff perceived robot humanlikeness as a positive attribute. In contrast, residents who had elevated heart rate *prior* to the interaction found the robot more humanlike *after* interacting with it. This suggests residents perceived robot humanlikeness as a negative attribute. It is possible these differences in response to perceived robot humanlikeness reflect the moderating effects of human and interaction variables on perceptions of robot mind.

9.3. Robot drawings

As a more implicit measure of robot attitudes, robot drawings may be a useful contribution to the HRI toolkit. There are two main categories of robot drawing results from the *prior attitudes & drawings study*. One is the provision of the type and number of facial features that people expect a robot therapist to have. Analysis of the drawing contents show that the presence of human-typical features, such as ears and hair, were associated with more positive robot evaluations and less physiological reactivity. The other main category of drawing results related to size of the drawings. Larger drawings were associated with elevated systolic blood pressure after interacting with the robot.

A few other robot studies have used robot drawings. An early robot survey asked participants to draw their idea of a domestic robot (Khan, 1998). However, aside from Khan noting that the drawings appeared influenced by robots from science fiction, the drawing content was not assessed against any outcomes. A more recent healthcare robot study did combine robot drawings with outcome measures. Similar to the *prior attitudes & drawings study* described in this thesis, results from the Broadbent, Lee, et al. (2011) study included larger robot drawings being associated with elevated physiology measures. These results concur with findings from *non*-robot healthcare drawing studies, where larger drawings are associated with worse outcomes (Broadbent et al., 2006; Broadbent et al., 2004).

However, while results from Broadbent, Lee, et al.'s (2011) study and the *prior attitudes & drawings study* concur in that both studies found an association between drawing size and outcomes, some drawing results from the two studies appear contradictory. The evidence is mixed as to whether humanlike characteristics in the robot drawings are perceived as a negative attribute or a positive attribute. In Broadbent, Lee, et al.'s study, participants who drew robots that were humanlike, rather than boxlike, were more likely to have an increase in both blood pressure and negative emotions from before to after interacting with the robot – indicating that perceived humanlikeness in robots made people more anxious. In contrast, in the *prior attitudes & drawings study*, participants who drew human-typical features of hair and a neck on their picture of a robot therapist's face, were more likely to evaluate the robot positively. Furthermore, people who drew the human-typical feature of ears had lower heart rate at both baseline and post-HRI. This indicates that for the *prior attitudes & drawings study* participants, perceived humanlikeness in robots predicted less physiological reactivity.

The differences in results between the two studies may arise from the different methods used. One difference is the robots had different functions (healthcare vs. conversational/therapist), and accordingly, participants were given different drawing instructions. In Broadbent, Lee, et al.'s (2011) study, participants were asked to draw their idea of a healthcare robot: in the *prior attitudes & drawings study* participants were asked to draw their idea of a robot therapist's face. These different instructions resulted in different types of robot drawings that were consequently assessed differently. The drawings in Broadbent, Lee, et al.'s study were either machinelike or humanlike. In the *prior attitudes & drawings study*, all drawings had faces (as per drawing instructions) and hence were more humanlike.

Other method differences between the two robot drawing studies include that the faces on the robots' display screens were different. The single robot face displayed on the Peoplebot's monitor in Broadbent, Lee, et al.'s (2011) study was a very basic human face (it had hair but not ears) and many people did not like it. Broadbent, Lee, et al.'s study also had younger participants (vs. older), and was a between groups design (vs. repeated measures). Consequently, any combination of the many method differences between the drawing studies may affect people's mental models of robots, and explain why in Broadbent, Lee, et al.'s (2011) perceived robot humanlikeness appeared to be an undesirable quality, yet in the *prior attitudes & drawings study* robot humanlikeness appeared to be a desirable quality. In future the use of the Mind Perception questionnaire may help explain this type of finding.

Overall, the combined findings of the two robot drawing studies indicate that drawing *size* is a useful, more implicit, measure of robot attitudes across a range of methodologies. In contrast, specific features of the robot drawings, particularly in relation to humanlikeness, may depend on the selection of study methods; such as type of participants, robots, and drawing instructions. It is unknown if the content or size of robot drawings might change in response to an intervention and/or and HRI (i.e. if drawings were administered twice: before and after the HRI). Generally, the use of more implicit psychological measures can usefully complement more explicit psychological measures such as self-report.

9.4. Specific reasons for unmet needs

A goal of this thesis is to increase awareness of the importance of understanding reasons for the unmet needs of eldercare stakeholders. While perceptions of robot mind and robot attitudes appear important additions to a model of eldercare robot acceptance, two key predicators of acceptance form the TAM and UTAUT models, perceived usefulness and perceived ease of use, still appear relevant and important in an eldercare robot context. Understanding the reasons for the unmet needs of older people and other eldercare stakeholders may help in the design of more useful robots, and consequently more acceptable robots, in several ways.

Overall, it may be beneficial to think of ‘acceptable robot design’ holistically, rather than just limited to the physical design of a robot. Understanding the reasons for the unmet needs of older people could be considered one aspect of holistic acceptance robot design. This knowledge may assist robot designers in designing robotic solutions to meet those needs. However, for useful robots to be accepted, they must be *perceived* as useful by potential users. Knowledge of the reasons for older people's unmet needs may assist in designing interventions that convey an understanding of robot usefulness, in meaningful terms, to potential users. However, for robots to be perceived as useful, they must first be perceived to be meeting a need. For a number of reasons, as outlined in the *unmet needs paper*, people can be unable or unwilling to acknowledge that they have unmet needs. Therefore, in some cases, in order for eldercare robots to be perceived as useful, sensitive interventions may be required to raise awareness in potential users of their unmet needs. This could perhaps be done prior to offering robotic solutions. Again, understanding the reasons for unmet needs may assist in the design of such interventions.

9.5. Thesis strengths

The studies reported in this thesis have a number of strengths, many of which contribute to the likelihood of the results generalising to other real-world eldercare contexts.

The closer a robot study can approximate a real-world eldercare HRI environment, the greater the likelihood the results will be able to contribute to the development of acceptable eldercare robots (Bethel & Murphy, 2010). There are a number of ways the studies reported in this thesis approximate a real-world eldercare robot environment. All three studies used actual robots, with all the attendant real-world challenges. Robot studies conducted in the absence of robots, using methodologies such as video or surveys, can provide valuable information. Moreover, there are likely to be unique aspects to interacting with an embodied robot, such as ease of use, which cannot be assessed by other methods.

A further strength of this doctoral thesis is that all study robots were autonomous robots, rather than the commonly used Wizard of Oz method. The latter method can be useful for assessing human responses to robots without the technical challenges of autonomous robots. But the Wizard of Oz HRI is limited in the contributions it can make to the technical development of commercially viable robots that must operate in a socially and technically complex real-world environment.

The inclusion of a hard measure of robot acceptance in the *robot mind study* – actual use of the robot – is a significant strength of this thesis. For real-world eldercare deployment, it is important to know what variables are associated with older people actually using a robot or not (unlike employees, it is unlikely that older people can be mandated to use a robot). Compared to actual use of a robot, people's intentions to use a robot are a useful, but inferior predictor of robot acceptance.

The thesis has contributed to the HRI field by furthering understanding of how people's emotions towards robots, and changes in those emotions as a result of an HRI, can influence robot acceptance. In the *improved attitudes study*, eldercare facility staff and residents' baseline negative emotions towards the robots decreased from before to after interacting with the robot. Their positive emotions towards the robot did not change. Both baseline negative emotions, and changes in negative emotions, predicted acceptance of the robot. This is the first time the emotions of eldercare stakeholders towards a robot have been assessed both before and after an HRI, in a real-world eldercare context, with a validated measure of affect (PANAS: Watson, Clark & Tellegen,1988), and with the inclusion of measures of robot acceptance.

Two of the three HRI studies reported in this thesis were conducted in a real-world eldercare environment. Real-world trials are extremely challenging (Weiss et al., 2009), requiring extensive financial, personnel, equipment, and time resources. There are two key benefits to the real-world HRI methodology. One is the greater ecological validity of the results. A second benefit is the opportunity to resolve technical issues required for commercial robot deployment. While laboratory trials are necessary for preliminary robot developmental work, they cannot fully anticipate the issues inherent in deploying robots in real-world eldercare environments – the ultimate goal of eldercare robots. Without awareness of these issues, it is not possible to design solutions to overcome them. In contrast to these thesis studies, the majority of eldercare robot studies either do not involve an actual robot, and/or are not conducted in a real-world eldercare environment. (A notable exception is the work of Marcel Heerink's research group. E.g. Heerink, Krose, et al, 2006; Heerink et al., 2010.)

Another approximation to the eldercare HRI environment is that all the three thesis HRI studies have recruited older people as participants. Recruiting older people for robot trials can be more costly in time and resources compared with convenience samples of younger university students or university staff. However there are differences between older and younger people, as well as between more and less well educated people (Czaja et al., 2006; Milne et al., 2005; More, personal communication, April 16, 2013; Sanchez, Fisk, & Rogers, 2004), which may be important considerations when developing robots intended for eldercare.

To the best of the PhD candidate's knowledge the recruitment method used in the *robot mind study* is both novel and makes several important contributions to the eldercare HRI field. The method involved approaching all residents in the retirement village building where the two week robot trial was taking place and inviting them to participate. Residents were told that use of the robot was optional, and not a requirement of participation. Benefits of this approach included the assessment of psychological differences between people who did and did not use the robot after the two week trial. This recruitment method, in combination with the before and after administration of psychological measures, meant that baseline psychological differences between robot-users and non-robot users could be assessed, as well as changes in these variables as a result of interacting (or not) with the robot.

One of the methodological limitations of many eldercare robot studies is small sample sizes. Recruiting sufficient numbers of older people for HRI studies can be challenging. At a practical level, the recruitment methodology in the *robot mind study* had the advantage of substantially boosting participation rates. A number of participants were happy to complete questionnaires, but only agreed to participate because using the robot was optional. While clearly this recruitment method is not suitable for all eldercare HRI studies, researchers may want to bear it in mind when considering how to increase participation rates, and actual robot use or not is a study outcome.

The *robot mind study* recruitment method also raises awareness of the self-selection bias in eldercare robot studies (i.e. people who volunteer for HRI studies may be more favourably inclined towards robots than those who do not volunteer). As described in the previous paragraph, people who did not wish to use the robot were *not* excluded from the study. This resulted in a more representative sample of retirement village residents. That more than half of participants chose not to use the robot over the two week trial period, does however suggest that self-selection bias may be a substantial confound in eldercare HRI studies. The results obtained in the *robot mind study* are likely to be relatively free of this confound.

The eldercare social environment is often complex (Hirsch et al., 2000). One of the thesis studies, the *improved attitudes study*, recruited multiple eldercare stakeholders (retirement village residents and staff). The staff included caregivers, nurses, and management. As older people are unlikely to be the only eldercare stakeholder group involved in the purchase and operation of eldercare robots, including multiple groups in eldercare robot studies also contributes to the ecological validity of the findings.

Further ecological validity for the thesis results was provided by the real-world robot functionalities used in two of the three thesis studies. These robot functions, which had been stated as desirable by eldercare user groups, included vital signs measures, medication management, cognitive stimulation, human to human communication, and entertainment. Evidence for the real-world application of these functions is provided by the purchase by a healthcare company of four robots that use these functionalities (3-News online staff, 2013). In contrast, while exploratory research is important, many HRI studies use robots with less real-world applications (Bemelmans et al., 2012).

Replication of the RAS results is a strength and contribution of this thesis. Review authors have indicated more validation of HRI measures is required (e.g. Bethel & Murphy, 2010). The finding that robot attitudes (as measured by the RAS), are associated with robot acceptance was replicated across the three thesis studies. While replication does not address construct validity, it helps establish the reliability and generalisability of measures. Replication of results across a range of study methods indicates that results are not restricted to a narrow research context, or arise from statistical anomalies.

The greater the variety of methods results are replicated across, the stronger the evidence for their reliability. While the three thesis studies had the same underlying theme of eldercare robotics, there was variation of context and method. Variations included different robots (Cafero vs. Peoplebot) with different functionalities (healthcare modules vs. conversational), different populations (eldercare facility staff and residents vs. community living older people). Other variations included participants' baseline robot attitudes being assessed in different contexts (*improved attitudes study* – RAS completed before participants saw the Cafero robot vs. *prior attitudes & drawings study* – RAS completed while participants seated in front of the Peoplebot), and in different HRI study environments (eldercare facility vs. university office). Overall the combined thesis studies provide strong evidence that the RAS is predictive of acceptance, sensitive to changes in robot attitudes, and can be used by robotocists in a variety of HRI contexts.

A strength of the experimental study reported in this thesis (the *prior attitudes & drawings study*) is the inclusion of manipulation checks. While manipulation checks can be done at any stage, pre-trial pilot checks were conducted for the *prior attitudes & drawings study* to ensure that the four different faces displayed on the robot's monitor did not vary on perceived emotional expression. These checks increase the chance that participants were actually rating the robot's faces on the variables of interest - humanlikeness/machinelikeness and gender – and not the pleasantness or unpleasantness of their facial expression.

The inclusion of pilot tests for all three thesis studies also contributes to the robustness of the results. The pilot tests helped identify and resolve technical and method problems prior to the start of the main study. For example, pilot testing of measures for the *improved attitudes study* revealed that the intended computer experience item was overly subjective. Pilot results showed people tended to rate their computer experience as 'average' on a generic Likert scale, regardless of their level of skill. Consequently, a computer experience Likert scale with more objective semantic anchors was devised and used in these thesis studies.

The use of data triangulation is a further strength of the thesis studies. As different measures have different merits and limitations, the use of multiple measures helps address limitation 'gaps'. The three thesis HRI studies not only used multiple measures, but also a range of measure *types*. These included physiological (heart rate and blood pressure), drawings, behavioural (use or not of the robot), and self-report.

The studies in this thesis have both measured and reported comprehensive participant sociodemographics. This is important for two reasons. Many of these sociodemographic variables such as age and technology/computer experience are associated with computer acceptance. Secondly, the reporting of comprehensive participant sociodemographics enables other HRI researchers to better assess the generalisability of our findings.

Also helping ensure validity of the results, the potential confound of socially desirable responding was minimised during the studies. While completing measures older participants frequently indicated they were inclined to respond politely, rather than honestly, in evaluating the robot and its functions. Consequently it was part of the measure administration protocol for the researcher to assure participants that their honest opinion was the most helpful one, as we needed this information to best improve the robot.

The validation of 'overall rating of the [HR]interaction' against 'intention to use [the robot again]', is a strength of this study. At this early stage of eldercare robot development, it is common to test robots that are either not fully developed and/or are only present in an eldercare facility for a brief time. In these eldercare HRI scenarios, the acceptance outcome of 'intention to use the robot again' may not be appropriate. Items, such as intention to use, from the TAM and UTAUT may need to be adapted to fit specific contexts (Venkatesh et al., 2003). As described in the segues for the *improved attitudes study* and the *prior attitudes & drawings study*, the combined findings of these studies show that correlations between the two outcome variables of 'overall rating' and 'intention to use' reached multicollinearity levels. This result suggests the two items represent the same construct, and supports the use of the 'overall rating of the HRI' item as a measure of robot acceptance in settings where the 'intention to use' outcome variable is not appropriate.

It is important that two particular limitations of subjective measures of robot acceptance, such as overall rating and intention to use, are borne in mind. One of these is that, even if overall rating of the robot interaction is comparable to intentions to use the robot; intentions can be poor predictors of actual behaviours (Davis, 1989; Sheeran, 2002; Sutton, 1998). The second caveat is that subjective ratings of robot preferences provide little evidence for the *effectiveness* of a robot. This was demonstrated in Goetz et al.'s (2003) exercise robot study. People preferred the fun robot but did more exercise with the serious robot. With the possible exception of companion robots, people liking a robot does not necessarily mean a robot will be effective at what it is designed to do.

9.6. Implications for robot acceptance models

Technology acceptance models have much to offer for understanding the acceptance of eldercare robots. However, as Heerink et al. (2010) observes, the TAM and UTAUT were designed with and for younger workers in an organisational context with non-embodied technologies such as computer systems. There may be differences between that context, and the eldercare HRI context which the UTAUT does not address.

The studies presented in this thesis add to our knowledge of the variables that predict acceptance of eldercare robots. The results have implications for models of robot acceptance. A proposed model of eldercare robot acceptance is pictured in Figure 22. This model is speculative only and needs to be evaluated. The model is described next, in tandem with the thesis study results that have informed aspects of the model.

Model features

The proposed model is an iterative one. The model shows how a person's first use of a robot is completely informed by physical and psychological variables *other* than actual robot experience, but that all subsequent interactions will be at least partially informed by the experience of the HRI. Results from all three thesis studies showed that pre-interaction attitudes and emotions towards robots, and perceptions of robot mind, predicted robot acceptance. Results from the *improved attitudes study* showed that, similar to the Expectation-Confirmation Model of IT acceptance, changes in participants' robot attitudes as a result of the interaction predicted their acceptance of the robot. It is also proposed that actual use of the robot is the primary outcome acceptance measure, not intentions to use.

It is proposed that the 'attitudes' variable be included in a model of robot acceptance. Despite being removed from the UTAUT, attitudes towards robots appear important in understanding robot acceptance. Attitudes towards robots have been shown to predict intentions to use in the *improved attitudes study* and *prior attitudes & drawings study*, and actual use of a robot in the *robot mind study*. However, when selecting measures of robot attitudes, care should be taken as to their reliability, and construct and cross-cultural validity.

Perceptions of robot mind also appear important to robot acceptance. Perceived robot mind predicted actual use of a robot in the *robot mind study*. A two dimensional model of perceived mind may explain some distinctive characteristics of the eldercare robot context. These characteristics may be less relevant in the organisational contexts that the TAM and UTAUT were developed for: where younger people tend to be interacting with more familiar and less embodied technologies.

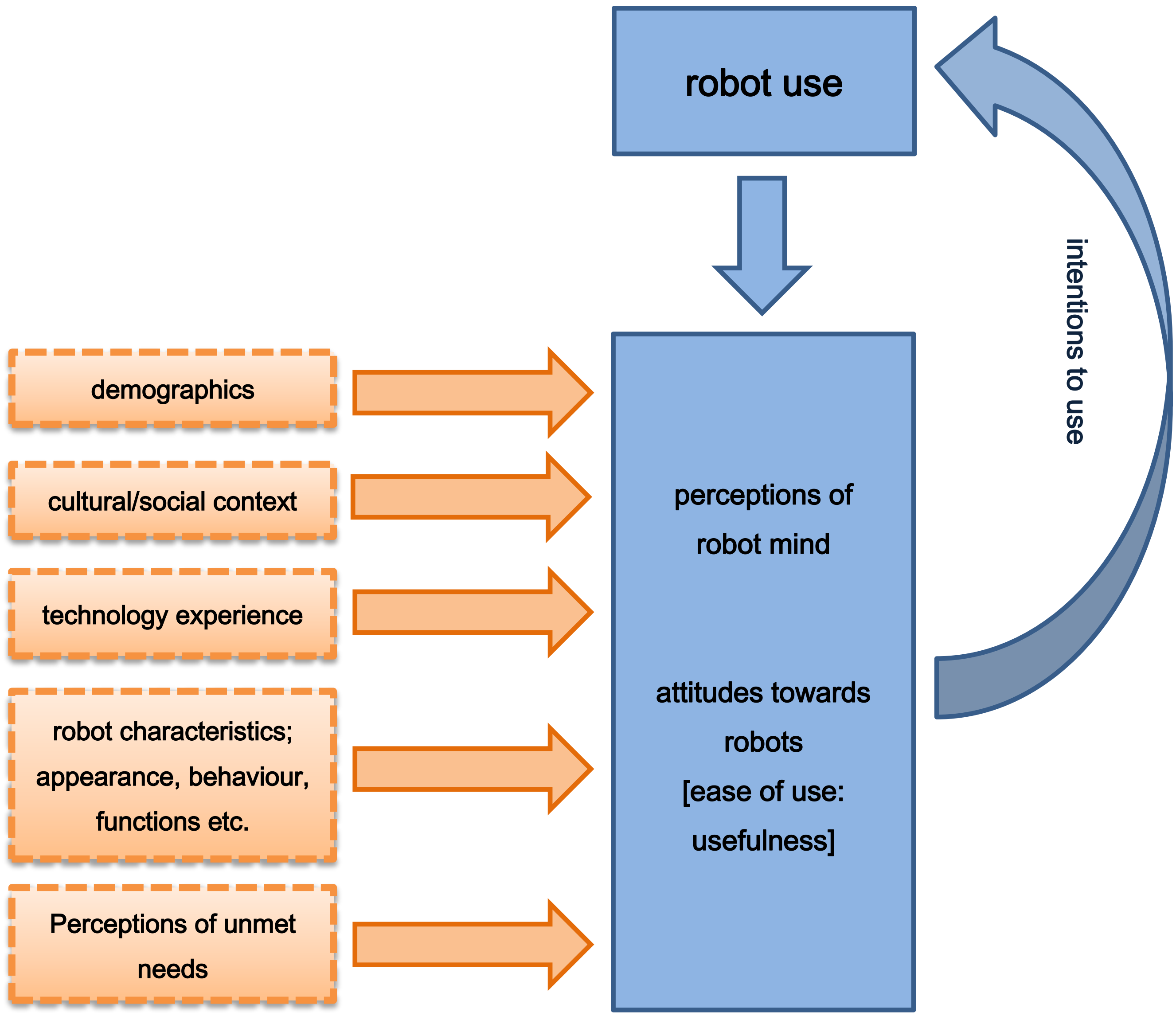

Figure 22. Suggestion for a model of eldercare robot acceptance

Perceived usefulness is important for robot acceptance. However for people to perceive something as useful they must first perceive they have unmet needs. Hence, perceptions of unmet needs is shown as an influence on people's robot attitudes. In all three thesis studies perceived usefulness was included in the RAS, which was shown to predict robot acceptance. In the *prior attitudes & drawings study* the RAS items were also inspected separately. Participants' baseline perceptions of the robot as useful and helpful were correlated with robot acceptance. It appears that measurement of people's attitudes towards robot usefulness may either be embedded in a more general measure of robot attitudes, like the RAS, and/or measured separately.

9.7. Thesis limitations

The thesis results should be considered in light of possible limitations of the thesis studies.

The HRI studies reported in this thesis were not controlled, in the sense that none of the robots were compared with alternatives. Appropriate alternatives for an eldercare robot might include humans or the equivalent functionalities installed on a computer or a tablet. Therefore it was not possible to assess if robotic delivery of eldercare was perceived as superior or inferior to alternatives. However randomised controlled trials of these robots would have been difficult at the stage of robot development. The robots required further technological development. The trials described in this thesis helped inform that development.

The sample sizes used in these thesis studies, while reasonable for the HRI field, may have impaired the detection of significant results. In the *prior attitudes & drawings study*, the study was sufficiently powered to detect of medium effect sizes in people's differential responses to the robot's different face display screens. However, the study was underpowered to detect differences of small effect sizes. A further possible limitation of this study is the number of conditions combined with the relatively short interaction time. The method involved participants interacting with six different robot face conditions for five minutes each. It may have been too many conditions with too brief an interaction time, for differences in participants' responses to the different faces to be detected. Participants may also have been fatigued by the number of conditions

There were omissions of some items and measures from the thesis studies; the inclusion of which may have added to understanding of robot acceptance. One omission was the variable 'intention to use the robot' was not inserted in the baseline measures for the *robot mind study*. Inclusion of this variable would have meant the strength of the association between intentions to use and actual use of the robot could have been assessed. We chose not to re-administer the RAS during the *prior attitudes & drawings study* after each of the six interactions, or at the conclusion of the study. This was to minimise participant burden, and, due to the number of interactions, the results would be difficult to interpret. However this omission may have limited understanding of associations between changes in robot attitudes and robot acceptance in this study.

A possible limitation is that participants in the *improved attitudes study* and *prior attitudes & drawings study* may have had more positive views of robots than the general population. Due to the *robot mind study*'s recruitment method of inviting all residents to participate, regardless of whether they were willing to interact with a robot or not, a self-selection bias would likely have been minimal in that study.

9.8. Future research for enhanced understanding of acceptable eldercare robots

The findings of this thesis suggest future research areas in order to further understanding of the components of an acceptable eldercare robot.

In addition to development and validation of an eldercare robot acceptance model, future research could further develop and validate evaluation methods and measures for the eldercare robot context. More research could be conducted on possible associations between perceptions of robot mind, robot attitudes, and acceptance. The use of larger sample sizes, while difficult to obtain in eldercare HRI, will allow the use of statistical techniques such as regression and structural equation modelling. In turn this will allow the relative contribution of variables predictive of robot acceptance to be assessed, and clarify the relationships between variables. The RAS could be further validated by comparison with other measures of robot attitudes.

Further understanding of what an adaptive perception of robot mind is for different robots may help optimise robot acceptance. In the *robot mind study*, a low agency:low experience mind profile appeared most acceptable to participants. However different perceived mind profiles might be more acceptable for different types of robots. It is possible a low agency:high experience mind profile may be more acceptable for companion robots. More research into perception of robot mind includes further understanding of what features of a robot portray particular mind dimensions, and how they are associated with acceptance. Robotocists have already begun designing robots that appear to display theory of mind (Scassellati, 2002). Future work may focus on ensuring eldercare robots portray a mind that is acceptable to eldercare stakeholders.

While the three thesis studies provide some validation of the RAS, further validation is required. The studies provide evidence of predictive validity (people with more positive RAS scores were more likely to be more accepting of the robot), and concurrent validity (the RAS could distinguish between people who would use the robot and those who would not). Additionally, factor analyses results and high Cronbach's alpha scores for the RAS (when the 'humanlike/machinelike' item is removed) also indicate the RAS has high internal consistency. However further validity testing could include test-retest reliability. The RAS could also be used in conjunction with Nomura et al.'s (2006) Negative Attitudes towards Robots Scale (NARS) to assess convergent or divergent validity.

The word 'robot' appears to predispose people to perceive robots as having minds that are high in agency and low in experience. This robot mind profile was associated with lack of use of the robot in the *robot mind study*. It is possible that eldercare robot acceptance may be enhanced by referring to robots as something *other* than robots. Future research could assess the impact of the word robot on acceptance, and determine alternative acceptable robot descriptions that are not associated with high agency:low experience mind profiles.

More research on the use of drawings to assess attitudes towards robots may help develop more implicit measures of robot attitudes. In particular, future research could assess if drawing size and content change from before to after an HRI, and if those changes are associated with robot acceptance. If people's drawings of robots do prove sensitive to peoples changes in robot attitudes, then drawings may be suitable to administer before and after interventions designed to promote adaptive robot attitudes and perceptions of robot mind. Results may indicate the effectiveness of the interventions. To date, in robot drawing studies, each person has only been asked to draw one robot picture of a specific HRI context.

There is some limited evidence that perceived humanlikeness in robots appears to be a positive attribute in some contexts and not in others. Therefore another robot drawing research question is – do the same people draw different robot drawings for different HRI tasks? A subsequent question is – how are humanlike characteristics in those robot drawings associated with outcomes, such as robot evaluations, robot use, and physiological reactivity? Combining drawings of robots with the Dimensions of Mind Perception Scale (Gray, Gray, & Wegner, 2007) may also help future researchers further understand how perceptions of robot 'humanlikeness' are associated with robot acceptance.

More research is recommended into the unmet needs of eldercare stakeholders; and the specific reasons why they are unmet. Subsequent research could develop robotic solutions (if a robotic solution appears the optimal solution) to meet these unmet eldercare needs.

9.9. Conclusion

This thesis makes a number of contributions to furthering understanding of the psychological variables that predict acceptance of eldercare robots. These contributions may assist in the development of acceptable eldercare robots.

Expanding on earlier research, people's initial, or baseline, attitudes towards robots have been shown to be important for their acceptance of robots. Furthermore, the RAS assesses attitudes *towards* robots rather than just attitudes towards use of robots, as in TAM- or UTAUT-derived attitudes measures. The RAS also does not contain assumptions of humanlike characteristics in robots, as does the NARS.

This association between people's robot attitudes and robot acceptance has been replicated in these thesis studies across a variety of eldercare robot study methods: different eldercare populations, different robots, different robot functions, and different study environments. A notable example of the latter is the inclusion of real-world eldercare environments. An important feature of these thesis studies is the assessment of baseline robot attitudes. While the method allows assessment of influential baseline robot attitudes, when combined with post-HRI measures, it also allows detection of any changes in peoples robot attitudes, which also appear important for robot acceptance.

This thesis provides HRI researchers with some measures of robot attitudes that have been validated against robot acceptance outcomes, including actual use of a robot. The measures include robot drawings as a measure of more implicit robot attitudes in the *prior attitudes & drawings study*. The RAS questionnaire has been used in all three thesis studies. In all three studies the RAS has had good Cronbach's alpha scores, indicating good internal validity of the measure. Replication of the RAS findings across a variety of study methods, suggests both good generalisability of the thesis results, and that the RAS is a useful measure for researchers across a variety of HRI study contexts.

Older people's perceptions of robot minds appear important to actual use of the robot. In particular, *perceptions* of a robot's mind as being high in agency (capacity for doing) and low in experience (capacity for feeling) predicted non-use of the robot. Consequently, along with robot attitudes, perceptions of robot mind may be an important addition to models of robot acceptance. The variable of perceived usefulness, from generic technology models, also appears relevant for robot acceptance. Understanding the underlying reasons for eldercare stakeholders unmet needs, may assist in designing robotic solutions that are perceived as more useful, and therefore more acceptable.

The results of this thesis support the foundation premise of the TAM and UTAUT, that people's perceptions of technology characteristics are at least as important as more objective technology parameters. However there appear to be important differences between the organisational, computer system context these technology acceptance models were derived from, and the eldercare robot context. These differences may impair the ability of traditional technology acceptance models to effectively explain the acceptance, and non-acceptance, of eldercare robots. It appears that the addition of perceptions of robot mind and attitudes towards robots to acceptance models may improve understanding of eldercare robot acceptance. That these psychological variables appear to be both predictive of robot acceptance *and* readily modifiable bodes well for their potential in optimising people's acceptance of eldercare robots.

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