Human—Robot Companionship: A Mixed-Methods Investigation

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Thesis Summary

In recent years, the arts have brought robots to life in spectacular fashion. In popular fiction we have been presented with machines that can run, leap, fight, and (perhaps most impressively of all) robots which can ascend stairs with absolutely no trouble at all. Amidst these chaotic and often dystopian scenes, we are exposed to moments of humour and lightness – robots can be seen engaging in conversation, cracking jokes, and comforting someone in their time of need. In these relatively mundane moments (as we smile, laugh, and cry) the impression emerges that the robot is something special to the person depicted. Rather than simply being a household appliance, it appears to be something more: a sort of… friend.

Returning from the pages and screens of fiction to the real world, we find human society ever more fractured, and the loneliness epidemic at large. Unsurprisingly, given the engaging depictions in popular fiction, the idea of robots for companionship and social support is gaining traction and garnering increasing research attention. In care homes, robot animals can be found cooing and purring in the laps of individuals with dementia, while in schools, friendly humanoid robots may be seen teaching social skills to children with additional needs. What remains unknown, though, is the extent to which people will grow fond of such 'social robots' over time, and if so, whether their relationships with these machines might ever resemble (or indeed, replace) those with other humans. Is a 'robot friend' the stuff of science-fiction, or could it someday soon become science-reality? In this thesis, this question is explored from a range of perspectives using a variety of methods spanning lab-based experiments, online surveys, and focus groups.

This thesis begins with an introduction to social robots, and an exploration of the background regarding the nature and importance of human social relationships. After introducing relevant theories, I highlight gaps in our understanding of human—robot companionship that I seek to explore through this thesis (Chapter 1). In the subsequent chapters, I present four empirical pieces of work, each offering a unique perspective on the subject. Specifically, in Chapter 2, I report results from a lab-based experiment in which a robot's lights (located within its shoulders) were programmed to illuminate in a synchronous or asynchronous manner relative to a participant's heart rate. I aimed to determine whether such a synchrony manipulation might increase prosocial behaviours and improve attitudes towards a social robot - based on prior work showing that experimentally-induced movement synchrony can improve rapport between people, and increase their liking of social robots (Hove & Risen, 2009; Lehmann et al., 2015, Mogan, Fischer &

Bulbulia, 2017). Despite demonstrating no positive effect of the light manipulation, this study raises important questions regarding the complexities of defining and measuring attachment to a robot. In Chapter 3, I delve deeper into the qualitative data collected in Chapter 2 to build a more complete appreciation of the value of open questions – particularly in terms of method validation and understanding participants' internal experiences.

After this chapter, I shift perspective from a focus on humanoid robots (and manipulations based on human social behaviours), to human relationships with non-human companion animals. This shift was motivated by my desire to explore how non-human agents form deep and enduring social bonds with humans – as opposed to basing the thesis on human interpersonal relationships alone.

Due to the success of dogs as companions, I conducted a study in which dog-owners were asked to identify behaviours that they perceived as important to the bond with their dog (Chapter 4). Seven key themes emerged from this research, indicating the importance of attunement, communication, consistency and predictability, physical affection, positivity and enthusiasm, proximity, and shared activities. In the following chapter, I implement a selection of 'desirable' dog behaviours within an animal-inspired robot (Chapter 5). By showing the behaviours to members of the general public, and conducting focus groups, I gained deeper insights into the polarising nature of robot animals – not only in terms of how their behaviours are perceived, but also in terms of the roles people think robots should (and should not) hold. In addition to these themes, this final empirical chapter discusses insights regarding the high expectations people place upon robots, as well as public concerns around overdependence on robots, and privacy.

By releasing these chapters to the HRI community (through publications or preprints) we sparked conversations within the HRI community – not only about the ethics of robot abuse studies, but also the potential value of qualitative approaches within the field. Our team was commended for publishing qualitative research, in a field heavily dominated by quantitative methods, and we have since been working to continue the conversations around the value of qualitative approaches. Specifically, we hosted the "Enriching HRI Research with Qualitative Methods" workshop at the International Journal on Social Robotics (2020) and launched a "Qualitative Research in HRI/HCI Discussion Group" online - allowing HRI researchers to discuss their work, and share relevant resources (e.g., events and publications).

This thesis concludes by detailing work to be done moving forwards, to enhance our understanding of human—robot social relationships, and a broader discussion of our possible future with social robots (Chapter 6). Pulling from various disciplines (including psychology, cognitive science, human—robot interaction (HRI) Studies, robot ethics, and philosophy), this section concludes with consideration of potential consequences of companion technologies – not only for the individual, but perhaps for society as a whole, as we continue to grapple with questions concerning how much of science fiction we wish to welcome into our daily lives.

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Dedication

I dedicate this thesis to two people I love with all my heart. My cheerleaders from the moment I was born. My Mum and Dad.

Acknowledgements

When planning who to thank, my list of people rapidly spiralled out of control. Quickly I realised that so many people have helped me along the way - helpful emailers, patient techies, kind tweeters, thoughtful reviewers, reassuring mentors, enthusiastic participants, keen volunteers, passionate peers, and many more!

There are, however, a few key players to thank. First, I am incredibly grateful to Bangor University and the University of Glasgow for hosting my PhD, and the Economic and Social Research Council, European Research Council, and the Scottish Graduate School for Social Sciences, for funding my PhD training and associated activities. Thanks to the support of these establishments, I have been able to access the most amazing training opportunities. Second, I give my whole-hearted thanks to my supervisor Professor Emily Cross – a ray of sunshine throughout this process. I feel blessed to have spent 4 years under her tutelage, and I smile thinking back to our regular meetings – how I always left feeling revitalised, enthusiastic, and raring to go! I know myself to be a stronger person because of her wise words and unwavering support, and I am incredibly grateful for her time and effort over the past four years.

I must also thank the various people that I have collaborated with – Professor Tony Prescott, Dr Roxanne Hawkins, Dr Scott Midson, Dr Amol Deshmukh, and Consequential Robotics. When I think back, I have done so many cool things because of these people – being on a scientific panel in a cathedral, designing my first guest lecture, and doing research at Children's Hospitals – and I have learnt a lot about HRI, and myself, in the process.

To the following people, I am also thankful - Dr Mihela Erjavek, Professor Paul Mullins, Dr Ashleigh Johnson, the Brainy Bunch, Rebecca Smith, and the Social Brain in Action laboratory. In stressful times you've been there with wise words, and I have learnt a huge amount about myself (as what I want for my future) as a result. To my thesis examiners, I am also extremely grateful – my viva was a thought provoking and really enjoyable time, and I came away from the experience feeling like a passionate scientist again.

Finally, to my family, Chelsea Smith, and Luca Malatacca, I will forever be grateful. You've brought my so much joy to my life, over the past 4 years, and I am so excited to continue making amazing memories together.

These have been some of the best years of my life, and that is a direct result of the supportive and passionate network that I have around me.

Research Output

Related to this Thesis

Published output

Chapter 3 – Riddoch, K. A., & Cross, E. (2021). "Hit the robot on the head with this mallet"– making a case for including more open questions in HRI research. *Frontiers in Robotics and AI*, *8*, 2. https://doi.org/10.3389/frobt.2021.603510.

Contribution breakdown - KR wrote the manuscript. ESC critically reviewed and edited the manuscript. ESC approved the final version for publication.

Under review (Preprint available)

Chapter 4 – Riddoch, K., Hawkins, R., & Cross, E. S. (2021). Exploring behaviours perceived as important for human—dog bonding and their translation to a robotic platform. https://psyarxiv.com/5xds4/. *Under review at PloS One*.

Contribution breakdown - KR conceptualized and wrote the first version of the manuscript. RH and ESC critically reviewed and edited manuscript drafts prior to submission.

Chapter 2 – Cross, E. S., & Riddoch, K. (2020). Investigating the effect of cardio-visual synchrony on prosocial behaviour towards a robot. https://psyarxiv.com/eyjv7. Under review at *Computers in Human Behaviour Repo*rts.

Contribution breakdown – KR wrote the first draft of the manuscript. ESC critically reviewed and edited the multiple drafts of the manuscript.

Manuscript in Preparation

Chapter 5 – Riddoch, K., Midson. S., Hawkins, R., & Cross, E. S. (2021). Exploring perceptions of Prosocial Dog Behaviours in a Biomimetic Robot.

Contribution breakdown - KR wrote the first draft of the manuscript. SM, RH, and ESC critically reviewed and edited manuscript drafts prior to submission.

Contributors

In the following, contribution summaries are listed for each of the thesis chapters.

Chapter 1 – General Introduction

KR wrote the first version of this chapter. ESC critically reviewed drafts of the chapter.

Chapter 2

KR and ESC conceptualized the experiment. KR conducted data collection and analysis and wrote the first draft of the manuscript. ESC critically reviewed and edited the multiple drafts of the manuscript. Additional contributions made by individuals include the following: BC programmed the robot lights, and CT and MS contributed to data analysis, as independent coders.

Chapter 3

KR conceptualized the study idea, analysed the data, and wrote the manuscript. ESC critically reviewed and edited the manuscript. ESC approved the final version for publication.

Chapter 4

KR conceptualized and wrote the first version of the manuscript. KR conducted data collection and analysis; RH contributed to the analysis and interpretation of the data, as an independent coder. RH and ESC critically reviewed and edited manuscript drafts prior to submission.

Chapter 5

KR conceptualized and wrote the first draft of the manuscript. KR conducted data collection and analysis; SM and RH contributed to the analysis and interpretation of the data, as independent coders. SM, RH, and ESC critically reviewed and edited manuscript drafts prior to submission.

Chapter 6 – General Discussion

KR conceptualized and wrote the chapter. ESC critically reviewed the chapter.

Key - KR: Katie Riddoch, ESC: Professor Emily Cross, BC: Bishakha Chaudhury, MS: Madeleine Stork, CT: Chris Turner, RH: Dr Roxanne Hawkins, SM: Dr Scott Midson.

GENERAL INTRODUCTION

In this section I will contextualise the research studies conducted as part of this thesis – providing an introduction to social robots, and background regarding the nature and importance of human social relationships. The piece approaches the subject matter from a psychological perspective (due to my previous training) but also draws insights from cognitive Science, philosophy, and human—robot interaction literature, due to their relevance.

Note: *throughout this thesis, all authors are referred to by gender-neutral pronouns (they/them). This is intentional - to avoid assuming an individual's gender and engaging in misattribution as a result*.

Chapter 1 General Introduction

Aims of Thesis

Due to our complex social structures, sophisticated language capabilities, and perceptive cognitive abilities (e.g. emotion recognition), humans have been described as social animals (Ferretti & Papaleo, 2019; Mercer, 2013; Thoits, 1995). In many respects, our social capabilities are beneficial – allowing us to collaborate with others, offer emotional support to those in need, and derive feelings of happiness and pleasure from social interactions (Frith & Frith, 2007; Kim & Yoon, 2012; Shields, 2004). Our social nature can also be a powerful destructive force, however, if our desire to belong is not satisfied, or our expectations of others are not met (Baumeister & Leary, 1995; Constant et al., 2019). For example, upon perceiving our social interactions as lacking (e.g. in frequency or quality) we can experience distressing feelings of loneliness, and negative health outcomes as a result (Leigh-Hunt et al., 2017; Perlman & Peplau, 1982). With loneliness prevalence rates as high as 1 in 3 in some countries, developing and validating loneliness interventions is a public health priority (World Health Organisation (WHO), 2021).

To reduce widespread loneliness, it has been suggested that robots should adopt the role of long-term companion. Arguably, however, such a suggestion is premature as there are major gaps in our knowledge. First, although there are reports of strong emotions following damage to a robot (Darling 2017; Knox & Watanabe, 2018; Wight, 2020), there is a lack of empirical evidence which demonstrates the existence of human—robot companionship. Second, whilst there is evidence to suggest that people attribute intentions to a robot (Perez-Osorio & Wykowska, 2019), it is unclear whether such attributions facilitate the perception of the robot as a friend. Finally, despite massive growth in the field of human—robot interaction and the commercialisation of robots, we still do not fully understand which features facilitate meaningful interactions between humans and robots. This thesis aims to address these pivotal gaps in the human—robot interaction literature.

By drawing from psychology, cognitive science, and human—robot interaction (HRI), this thesis will deepen scientific understanding of human—robot attachment. In doing so, this thesis will help developers and academics better understand the feasibility of human—robot companionship, and the potential implications of such a pursuit. First, however, this thesis will present an introduction to loneliness, social robots, and the qualities of human friendships.

Introduction to Loneliness

Loneliness has been defined as ‘an unpleasant and distressing phenomenon’ resulting from the perception that one is socially isolated from others. In the scientific literature, loneliness is characterised by feelings of emptiness, anxiety, and restlessness (Weiss, 1973), but first-person accounts can offer a more nuanced understanding of what it can feel like to be lonely. In 1967, Waylon Jennings (singer, songwriter, and musician) released the song ‘I Tremble for You’ in which they state - “*This world that I live in is empty and cold/the loneliness cuts me and tortures my soul*.”. Poetically, Jennings’ rendition brings the scientific definition of loneliness to life. In more recent years, writer Augusten Burroughs released a memoir opening up about their battle with alcoholism and their own experience of loneliness - “*I’m lonely. And I’m lonely in some horribly deep way and for a flash of an instant, I can see just how lonely, and how deep this feeling runs. And it scares the sh*t out of me to be this lonely because it seems catastrophic*.” (Burroughs, 2003*)*. Again, this account aligns with the scientific definition; it also speaks, however, to the extent to which loneliness can distress an individual. Although not empirically measured or scientifically validated, such quotes offer a glimpse into the minds of the lonely – insight which is difficult to come by, due to the stigma associated with loneliness and the narrative that it is a ‘burden’ on our society (Stanley et al., 2010).

> *“Society sees it as a nasty problem that they don't want to know about and also people who are lonely. . . [feel unable] to express this without feeling that they are a failure of some kind” - participant quote from Stanley et al., 2010, p 410.*

Rather than being the result of a lack of human contact (a common misconception), loneliness is proposed to result from a discrepancy between a person’s ideal and actual social relations, and the <u>perception</u> that they lack social support and companionship (Perlman & Peplau, 1982). For example, while a person may have weekly visits from family and friends, it is the person’s perception of that schedule being inadequate to meet their social needs that influences the extent to which they might feel lonely. This example focuses on frequency of interactions, although discrepancies could emerge in other ways. A person may be surrounded by people, but if they perceive that personal and meaningful interaction is lacking in some way (e.g. it feels impersonal or low-quality), then they may be susceptible to loneliness. Writer Anaïs Nin alludes to this idea in her published diary, stating – “*I am lonely, yet not everybody will do. I don’t know why, some people fill the gaps and others emphasize my loneliness.”*. This mismatch between one’s desired and actual levels of social relations has been termed the Cognitive Discrepancy theory (Perlman & Peplau, 1982).

Since its conception, scientists have built on the Cognitive Discrepancy theory to create more involved and insightful models (Donovan & Blazer, 2020; Perlman & Peplau, 1982). For example, the Discrepancy Model of Loneliness acknowledges the role of life events and factors which may make loneliness more likely to occur (termed predisposing factors and precipitating events). Examples of predisposing factors include minimal access to public transport and living alone, and precipitating events can include the death of a significant person or moving to a new area (Donovan & Blazer, 2020; Perlman & Peplau, 1982). In recent years, studies have been conducted to better understand factors which can mediate loneliness including lifestyle choices (e.g. where someone works and how much stress they experience) and the quantity and quality of a person's sleep (Donovan & Blazer, 2020). Additionally, work has been undertaken which focuses on teasing apart different aspects of loneliness (e.g. physical, existential, social, emotional, intimate…) and how elements of our social experience offer different social "provisions" (e.g. attachment, social integration, nurturance, reassurance of worth, reliable alliance, and guidance) (Ciolfi & Jimenez, 2017; Mansfield et al., 2021; van Tilburg, 2021). Such theories allow for a greater understanding regarding the complexity of human social relationships, however there is now a need for urgent solution-generating - with loneliness now considered an 'epidemic' (WHO, 2021).

The Loneliness Epidemic

Although often associated with older age, loneliness is a widespread problem - impacting individuals of all ages, and a range of specialist populations including domestic abuse victims, individuals with chronic physical health conditions, and immigrants (Kunst, Bogaerts & Winkel, 2010; Petitte et al., 2015; Wu & Penning, 2015). The global coronavirus COVID-19 pandemic, and its accompanying lockdowns and travel restrictions, have also led to increases in loneliness (Goodman & Epstein, 2020; Fayoka, McCorry & Donnelly, 2020). The widespread and increasing number of people identifying as lonely is particularly alarming when considering the broader negative health impacts associated with loneliness.

In addition to the intense internal experience associated with loneliness, and the shame associated with its presence, evidence suggests that individuals who report feeling lonely are more likely to experience a range of serious health problems (Leigh-Hunt et al., 2017). Specifically, evidence suggests that compared to those who do not report feeling lonely, individuals experiencing loneliness have an increased risk of cardiovascular disease and depression, and possible increases in their risk of dementia and suicidal thoughts (Leigh-Hunt et al., 2017). As a result of such treatment costs, the financial cost of loneliness and social isolation to the USA is estimated to be around $6.7 billion annually (Flowers et al., 2017). In the UK, the figure is estimated to be £11725 per person, over the course of 15 years, based on costs associated with health and long-term care (Fulton & Jupp, 2015). Given these immense costs, the wide-scale nature of its impact, and increases in loneliness resulting from COVID-19 pandemic restrictions, it is no surprise that the "loneliness epidemic" is receiving greater public attention than in previous years (WHO, 2021).

Now in the "UN Decade of Healthy Ageing" (2021-2030), improving the lives of older adults, their families, and their communities is a public health priority (WHO, 2021). As part of the decade, the World Health Organisation announced their advocacy brief - a document outlining the scale, impact, and harms of loneliness, in addition to a three-point strategy for addressing social isolation (being isolated from others) and loneliness (as defined previously). The brief outlines that in some countries, up to one in three older adults are experiencing loneliness, and that it is a problem which requires urgent attention and investment as a result. Specifically, they propose that 1) social isolation and loneliness be a political priority, 2) improved research into effective interventions should be conducted, and 3) that more money should be invested into implementing and scaling up effective interventions (WHO 2021). The latter two strategic points are within the scope of this research project, and the remainder of this introduction will focus on loneliness interventions as a result.

Solutions for Loneliness

In an attempt to reduce loneliness and its associated costs (to the individual, their communities, and health and care systems more broadly) a range of interventions are being developed and trialled (Williams et al., 2021). The onset of the global COVID-19 pandemic, with self-isolation procedures imposed upon vulnerable and infected individuals, a strong desire exists to ensure such solutions are as accessible as possible. This is positive for isolating individuals, but could also benefit some individuals living in areas with limited access to support - e.g. isolated rural areas or deprived urban areas (He & Yi, 2014). Specifically, thanks to technology, there are increasing numbers of loneliness interventions which can now take place in one's own home - for example, speaking to a "buddy" or engaging in laughter therapy, via a video conferencing platform. In recent years, such interventions have been appraised in terms of their effectiveness in the reduction of loneliness (Williams et al., 2021).

In their 2021 rapid systematic review, Williams and colleagues considered the effects of various loneliness interventions (e.g. significant reduction in loneliness vs. no significant change) and the quality of the research trial conducted. The latter was achieved through use of the Downs and Black checklist, which awards points for rigorous practices such as the presence of control groups and use of robust quantitative measures (Downs and Black, 1998). By considering both effectiveness and trial quality, Williams and colleagues provide an insightful glimpse into the existing loneliness interventions being developed, and their potential as a solution moving forwards. More specifically, the team identified a handful of interventions which had positive outcomes for lonely individuals - see Table 1.1 for those with evidence from "Fair" or "Good" quality trials.

Table 1.1

Intervention Category	Intervention	Brief Description
Animal Intervention	Robotic pets	Facilitating sessions in which people can interact with machines with an animal-like appearance. For example, through stroking the "robot" and discussing it with others
Educational programme	Friendship/Social integration education	A series of sessions which provide people with the skills they need to connect with others in their community, and manage their expectations of friendships and social relationships.
Leisure/Skill development	Computer training, video gaming, gardening	Activities which people can enjoy &/ learn from. There could be an element of skills acquisition e.g. how to use tools, software...
Psychological therapy	Mindfulness, reminiscence therapy, cognitive based interventions, laughter therapy, and Tai Chi Qigong meditation.	Specialist sessions led by a trained professional which involve addressing negative thought processes, breathing exercises, and challenging current ways of thinking.

Social Facilitation	Videoconferencing program, Other	Sessions in which a person can converse with another person/group of people. These could be through a video call, or phone call. The person may be known to the person, or a "buddy" allocated to them, for example.

Types of interventions with "Fair" or "Good" quality trials, and significant positive effects in relation to loneliness. Adapted from Table 1, Williams et al., 2021.

Upon considering the interventions in greater detail, it becomes apparent that many rely on human input for their success - for example, therapy and education sessions often require a trained individual to host the session, and social facilitation schemes require the participation of volunteers at both ends (in order to facilitate a conversation). In a world where the population is ageing, and caring for others is becoming less of a priority (particularly in the western world), providing such manpower presents a massive challenge moving forwards (Normie et al., 2011). Additionally, such interventions are often not accessible late in the evening - a time in which loneliness is found to be particularly noticeable and distressing (Bennet & Victor, 2012).

"Sometimes I . . . from when the sun comes in to the next week, I never sort of see anybody apart from when I go out to see people. Nobody goes, ladies won't come out at night, you know." - participant quote from Bennet & Victor 2012.

Screen-based interventions involving virtual avatars negate the previous concerns – as they do not require live human input. Such interventions are limited in numerous ways however, due to their lack of physical presence within the space. Specifically, due to their lack of embodiment, screen-based interventions are unable to interact with a person's environment or provide emotional support through the medium of touch (Eisenberg, 2000; Zahn-Waxler, 1990). Such limitations are discussed in the following section, where we introduce an alternative to screen-based solutions – robot-based interventions (Williams et al., 2021).

An Introduction to Robots

Definitions of the word "robot" vary (Beer, Fisk & Rogers, 2014; Oborn, Barrett & Darzi, 2011). For ease of understanding, in this thesis I am defining a robot as a machine with a physically instantiated body, which uses sensors (e.g. cameras) to take in information about its surroundings, and a computer to dictate how it responds. This could be phrased alternatively – "a physically embodied machine which is programmable and has the ability to respond to its surroundings as a result". Contrary to common belief, not all robots are equipped with artificial intelligence – that is, "a system's ability to interpret external data correctly, to learn from such data, and to use those learnings to achieve specific goals and tasks through flexible adaptation" (Haenlein & Kaplan, 2019). Instead, a range of robots (including the robot found to be effective by Williams and colleagues, 2021) operate in a relatively simple "stimulus response" fashion - for example, if the touch robot is touched (stimulus), the robot will wag its tail (response). It is proposed that the predictable nature of such robots will lead users to lose interest over time, however, and more complex solutions are being explored as a result (Lichtenthäler & Kirsch, 2016).

Unlike screen-based technologies, robots potentially have the physicality required to interact with a person, as well as with their environment. Such embodiment could be helpful in terms of assisting with chores (for example, cleaning, fall-detection, or fetching medications) and facilitating physical touch (instrumental or affective) between a person and the robot. The physicality of robots could also create the feeling of presence within a person's space. These three applications are particularly relevant in terms of a loneliness intervention. Firstly, the ability of a robot to assist around the home could allow a person to spend more time living in their own home, as opposed to entering a residential facility - allowing the person to remain closer to loved ones, potentially. Secondly, the ability of the robot to touch the person could be powerful in itself, since evidence suggests that loneliness can be reduced by consensual touch (Heatley Tejada, Dunbar & Montero, 2020). Finally, the physicality of robots could create the feeling of presence within a person's space. This is also relevant in terms of reducing loneliness because the feeling that one is physically alone, and lacking physical affection, is a recognised dimension of loneliness (Landmann & Rohmann, 2021). In addition to suggesting potential benefits of robots, such points raise numerous questions. For example, is the touch of a robot comforting, or does it feel similar to when you graze a household appliance? Also, if you are alone in your home, does a robot feel like a social presence? Or does it rather feel like another piece of furniture - a mere physical presence?

These questions, and the research that has inspired them, lead us towards further considerations of whether a robot must be considered alive, intentional, thinking, or feeling, in order to effectively help humans stave off loneliness. Rapidly, other questions emerge about the ethics of robots which exploit our innate tendencies - for example, robots which exploit our innate desire to be touched… robots which resemble pets in order to reap the benefits associated with animal ownership…and robots that claim to feel sad, to create the illusion that they are thinking and feeling, like us.

Following on from such questions, ethical issues begin to surface regarding the ethics of a person believing that a robot is sentient (termed "deception") and the potential for people to replace human connections with robotic ones (e.g. "overdependence" or "replacement") (Danaher, 2020; Sharkey & Sharkey, 2012).

Before deeper consideration of such ethical concerns, it is important to outline the current state of robot technology, and how robots are perceived. In doing so, it is possible to engage in informed and thoughtful discussions about our potential future with robots (see General Discussion).

Social Robots

As well as the aforementioned physicality, robots of a social nature have dynamic and interactive abilities which allow them to connect with a user in a range of ways. For example, social robots may be able to talk to individuals, respond to touch, and move their faces to exhibit emotional expressions. Social robots equipped with a form of artificial intelligence may also have the ability to recognise people and respond to human emotions. It has been suggested that such features, paired with their embodied nature, makes social robots well suited to the role of providing social engagement and comfort - and a candidate solution for combating loneliness as a result (Broekens, Heerink & Rosendal, 2009; Prescott & Robillard, 2020; Young et al., 2009). For completeness, it is important to mention that some social robots are tailored towards the role of intimate sexual companions - specifically, sex robots. The study of such robots is fascinating, particularly when considering ethics and societal implications (Devlin, 2018; Levy, 2009), but falls beyond the scope of this thesis. Instead, this thesis focuses on social robots designed to encourage engagement and attachment through platonic means - that is, interaction without a sexual component. See Figure 1.1 below for an illustration of six such robots which are commercially available.

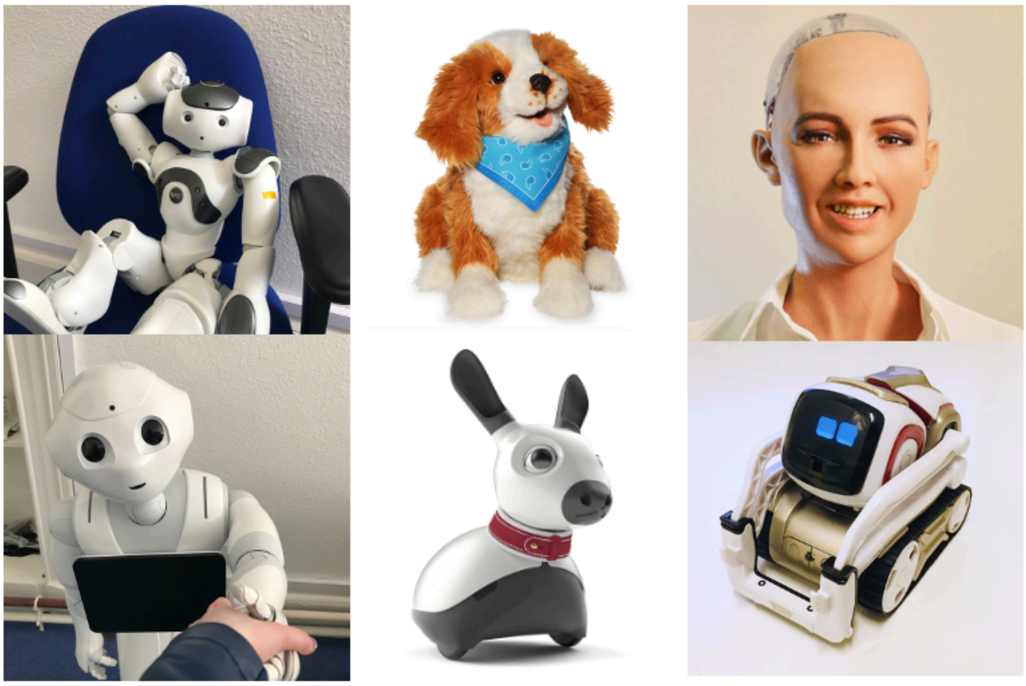

Figure 1.1. Images of various social robots. Top left to right: NAO (Softbank Robotics), the Joy For All dog (once Hasbro, now Ageless Innovation), and Sofia (Hanson Robotics). Bottom left to right: Pepper (Softbank Robotics), MiRo (Consequential Robotics), and Cozmo (ANKI). Note: images from author (NAO and Pepper), Ageless Innovation (Joy For All Dog), London Speaker Bureau (Sofia), Consequential Robotics (MiRo), and Te-Yi Hsieh (Cozmo).

The obsession of humanity with itself, our perception of humans as the most advanced social beings, and the desire to create something in one's own image, have led many to focus on the development of robots which resemble humans (Fitzpatrick et al., 2016; Katsuno, 2011) - for example, hyper-realistic "android" robots such as Sofia, and human-inspired robots including Pepper and NAO (all pictured in Figure 1.1). Researchers adopting such approaches propose that by creating a robot with human-like form and function, users will instinctively know how to interact with the machine - and smooth, successful, social interactions will follow (Riek et al., 2010; Riley & Atkeson, 2002). Although logical, this suggestion neglects to appreciate that when we interact with technologies, our expectations play a key role in our perceptions and resulting behaviours (Cross et al., 2016; Klapper et al., 2014; Lohse, 2011).

Research exploring our expectations of robots demonstrates that upon meeting a humanoid robot (that is, a human-inspired robot), users have extremely high expectations. For example, expecting physicality which closely mimics that of a human (e.g. smooth, fine-grain motor movements), and functionality which gives the impression of intelligence (e.g. thoughtful responses) (Duffy, 2003;

Horstmann & Krämer, 2019; Komatsu, Kurosawa, & Yamada, 2012). Some believe that these expectations result from exposure to advanced robots in science fiction (Cross & Ramsey, 2021; Henschel, Laban & Cross, 2021), others propose that high expectations are the result of our experience with real humans. Specifically, it has been proposed that because we do not have extensive experience with social robots, we draw from our experience with, and knowledge of, humans to inform our expectations when we engage with humanoid robots in particular (Horstmann & Krämer, 2019; Wiese, Metta & Wykowska, 2017). Such theories offer insight into why people can be disappointed or surprised upon first meeting a humanoid robot – as they have misplaced expectations based on their complex, dynamic interactions with real humans (Wiese, Metta & Wykowska, 2017). High expectations of a robot-mediated loneliness intervention could be particularly problematic, given that loneliness is proposed to be driven by a discrepancy between a person's ideal and actual social relations.

In an attempt to reduce expectations of human-like mental and physical capabilities in humanoid robots, reduce research and development costs, and piggyback on findings demonstrating the benefits of animal-assisted therapy on emotional wellbeing (Nimer & Lundahl, 2007), an emerging number of social companion robots now have an animal-like appearance (Shibata & Wada, 2011). Examples of such robots include AIBO (a dog-like robot developed by SONY), MiRo (a mammal-inspired robot created by Consequential Robotics), the Joy For All Animals (fluffy cat and dog robots, originally Hasbro, now Ageless Innovation), and PARO (a fluffy seal-inspired robot developed by the National Institute of Advanced Industrial Science and Technology, Japan). Such robots are equipped with various sensors allowing them to respond to touch, sounds, and changes in the environment. Depending on the complexity of the system, such responses vary from basic vocalisations and small movements, to coherent speech and complex actions such as rearing, spinning, and fleeing. It has been proposed that to reap benefits associated with animal-therapy and pet ownership – including comfort and improvements in mental health and wellbeing (Endo et al., 2020; Sable, 2013), robots that take non-human animal forms should be modelled on real animals, in both behaviour and appearance (Collins, Millings & Prescott, 2013; Krueger, Mitchell, Deshpande & Katz, 2021).

With regards to the animal-like social robots for lonely individuals, a range of study types have demonstrated benefits for older adults (Banks, Willoughby & Banks, 2008; Mordoch et al., 2013; Pu et al., 2018; Robinson et al., 2013). For example, one study split care home residents into three groups (robot dog, dog, or control group) and measured loneliness scores before and after the intervention. Results indicated that compared to the control group, both the robot and real dog groups experienced reductions in loneliness (Banks, Willoughby & Banks, 2008). Similar effects were demonstrated in a randomised controlled clinical trial, in which older adults living in residential care home were given the opportunity to interact with the PARO seal-inspired robot over a 12-week period (Robinson et al., 2013). Specifically, older adults experienced reduced loneliness when interacting with PARO or a real dog, compared to neither intervention. Such results are particularly impressive when considering that at the time, both robots (AIBO and Paro) were very limited in terms of their behavioural repertoire - responding to the person using only non-verbal vocalisations and small movements.

Unfortunately, due to the methods applied by researchers, it is difficult to tease apart which particular aspect(s) of the intervention was most important in leading to the benefits found. For example, the majority of studies took place in group settings. As a result, it is difficult to disentangle whether the benefits resulted from the robot itself, or the robot as a social facilitator between the residents (Pu et al., 2018). Additionally, due to the varying nature of the studies (different robots, timings, length of interventions, settings, populations), it is difficult to determine which elements are effective (e.g. a specific feature of the robot), and how such features can be capitalised on moving forwards. Finally, although the experimenters investigated the effects of interacting with Paro, they did not delve into the type/s of relationships that formed between the resident and the robot. As a result, it is difficult to determine whether participants formed an attachment to the robot and whether it could be an effective long-term solution.

To better understand our future with such 'companion robots', and their potential as a sustainable and efficient solution, it is important to keep in mind that loneliness results from a person's *perception* of social isolation, and not their actual number or frequency of social contacts. As a result, rather than simply creating a technology which is used and accepted (Davis, 1985; Davis, Bagozzi & Warshaw, 1989; Chuttur, 2009), the focus should be on creating interactions that feel meaningful and engaging to a lonely individual. Additionally, for the benefit of the individual and planet (in terms of waste and climate change), there is a need to consider how we might develop solutions which are used long-term (as opposed to those which people lose interest in once the novelty wears off after a short period of time). In the pursuit of facilitating meaningful interactions which persist long term, in upcoming sections I consider the nature of close human friendships, examining whether human—robot interactions could embody the same key qualities.

Friendship with Robots

In thinking about robots as a tool to ease loneliness, it is helpful to consider what qualities are required to build a successful social relationship between two individuals. By comparing the components of close human friendships to potential features of human—robot interactions, it is possible to better understand a robot's potential as a long-term companion, and solution for loneliness. Given the varying definitions of key terms ("friendship", "companionship' and "attachment") and contrasting theories within relationship science however, it is not possible to definitively state which qualities facilitate and maintain relationships (Hinde; 1997; Huang, Ledgerwood & Eastwick, 2020; Madeira & Joshi, 2013). Hinde (1997) beautifully captured the complexity of this field of study, stating that relationship science is a "conceptual jungle that chokes the unwary". For the sake of progress with regards to this thesis however, and to aid reader understanding regarding the field of relationship science, I will discuss a few qualities. Specifically, due to their relevance to human close human friendships (and evidence to suggest that such friendships reduce loneliness; Nangle et al., 2003; Newcomb & Bagwell, 1995; Stevens, 2001), and their evidenced nature, I will consider the following qualities - propinquity, social support, tangible support, companionship, and exclusivity. I then further consider two other core components of friendships - intimacy and reality (Amichai-Hamburger, Kingsbury & Schneider, 2013).

Evidence suggests that humans engage in propinquity - that is, the tendency to make friends with those in close physical proximity to them (Clark & Drewry, 1985). Humans also have a desire to affiliate with those who support them during times of stress (for example, when experiencing an illness, stigma, or other life pressures) as well as those who can provide tangible support (e.g. providing instrumental aid, such as helping around the home) (Asher, Parker & Walker, 1996). Between friends, there is also an enjoyment of spending time together - termed "companionship" (Amichai-Hamburger, Kingsbury & Schneider, 2013). People also have expectations that their friend will be available when they need them, and that they can confide in their friends without fear of betrayal, which may be termed "exclusivity" (Asher, Parker & Walker, 1996). On all aforementioned accounts, social robots could excel as friends in terms of the aforementioned components of friendship, as they can be highly accessible (facilitating propinquity), nonjudgmental (leading to feelings of being supported), and well-equipped (allowing the robot to help around the home). Their ability to be entertaining, and their lack of motivation to spread secrets and rumours, also makes social robots suitable in terms of providing tangible support and exclusivity.

With regard to the remaining core components of human friendships - reality and intimacy - the use of social robots becomes more complex and thought-provoking. As a result, it is useful to draw evidence from multiple disciplines (including research from psychology, cognitive science, Animal Studies, and HRI) in order to build a more complete understanding of these issues.

Reality

In the context of friendship, reality refers to the extent to which the relationship is perceived to be genuine and meaningful, as opposed to superficial. In addition to being a core aspect of human friendships (Amichai-Hamburger, Kingsbury & Schneider, 2013), it is proposed to be important in our relationships with non-human animals and inanimate objects. For example, Mithen (1996) proposes that "without the beliefs that our dogs "enjoy" our company, "miss us" when we are gone, or feel affectionate towards us, our relationship with dogs would lose much of its value, becoming superficial and essentially meaningless". The power of mind perception, in relation to attachment-formation, has also been demonstrated in studies with children and their toys (Gjersoe, Hall & Hood, 2015; Severson & Woodard, 2018). For example, Gjersoe and colleagues (2015) demonstrated that children attribute more mental states (e.g., awareness and emotions) to "attachment toys" (those which soothe a child and aid with falling asleep) as opposed to toys they simply play with a lot. Such studies offer support for the idea that perceived reality is linked to feelings of attachment and security.

When thinking about realism in relation to robots, it is easy to slide into philosophical realms. For example, on the one hand, robots lack the ability to think or feel as we do… and one might consider their actions to be insincere as a result. On the other hand, one could argue that humans are also machines in a way - driven by biological processes (nature) and reinforcement learning (nurture). If following such a thought-process, robots and humans could be considered equally genuine. Moving away from the abstract, however, what is arguably more important in terms of friendship is the perception of the individual. Does the individual consider the interactions and relationships they have with others to be genuine or not? This question leads us into discussions about mind-perception, and how our perceptions of robots sometimes defy what we know to be true.

Despite knowing that robots are a collection of inorganic materials powered by electricity, studies demonstrate that people attribute human-like qualities to machines - for example, gender, personality and intentionality (Bernotat, Eyssel & Sachse, 2019; Craenen et al., 2018; Marchesi et al., 2019; Wiese et al., 2012). Nass and Moon (2000) suggest that such social attributions are 'mindless' - occurring because cues from the machine trigger 'scripts' that we have learnt and overused in the past. Nagel (1974) offers further ideas as to why these attributions occur - suggesting that when we encounter non-human entities, we have a natural desire to understand their behaviour. This makes sense from an evolutionary perspective - we want to understand our surroundings in order to benefit ourselves in some way (e.g. utilise resources or protect ourselves from harm). Nagel states that when we wish to understand something which we are not (e.g. what it feels like to be a robot) we have a tendency to use our imagination. In doing so, we *feel* like we understand the "other", but in reality we do not (as our imagination is based of human experiences, motivations, and feelings). Along similar lines, other researchers propose that the crossover between human- and robot-directed cognition can be explained by the "like-me" hypothesis of social perception and cognition, as originally proposed by developmental psychologists (Meltzoff, 2007). According to this theory, drawing similarities between the "self" and "other" forms the basis for social cognition. More recent work provides evidence to suggest that self-other equivalence is something we are biologically hard-wired to seek out, and it is what leads us to attribute human-like qualities to robots (for a review, see Hortensius & Cross, 2018).

Together, theoretical and empirical work examining the human model and the like-me hypothesis have led to the suggestion that in some situations, people are likely to perceive, interact, and connect with robots as though they are social agents, at least to a certain extent (Wiese, Metta & Wykowska, 2017; Hortensius & Cross, 2018; Hortensius, Hekele & Cross, 2018). This suggestion is positive in terms of human—robot friendship as it ties in with our desire for social interactions which feel real and genuine (Amichai-Hamburger, Kingsbury & Schneider, 2013). As referenced early in this chapter, however, there are concerns that creating robots which are perceived as genuine may be deceptive, and this is problematic in applications involving vulnerable populations such as older adults (Sharkey & Sharkey, 2012).

Intimacy

When thinking about human friendships, the final component I will consider is intimacy. In the literature, intimacy varies in its definition - with some describing intimacy as consisting of different elements (for example, emotional, social, sexual, intellectual, and recreational (Schaefer & Olson, 1981)), and others considering intimacy to broadly be a feeling of deep connection and care for another person (Parks & Floyd, 1996). The differing definitions complicate our understanding of whether human—robot intimacy is possible. However, evidence suggests that people do, in some way, exhibit care for robots. One such example comes from Japan, where shrines and temples hosted funerals for 700 robotic dogs lost in recent years (Knox & Watanabe, 2018; Wight, 2020). Another example comes from the military sector, where a colonel apparently called a halt to a military testing exercise after seeing a robot dragging itself across a field of landmines. The colonel reportedly referred to the scene as "inhumane" (Darling, 2017). Although potentially exaggerated or twisted by mainstream media, these examples offer insights into the breadth and depth of empathy that people can feel towards robots. The latter example is especially poignant, as it arguably indicates a level of empathy toward machines that could be detrimental to humans' role within society, and to human emotions (Darling, 2017). Again, despite their inability to feel pain, lab-based studies have demonstrated that to some extent, we feel 'pain empathy' towards robots (Cross et al., 2019; Darling, 2017; Darling, Nandy & Breazeal, 2015).

In lab-based settings, researchers have asked participants to inflict 'harm' on robotic agents. For example, previous experimenters have asked people to administer increasing levels of 'electric shocks' to a robot (Bartneck et al., 2005), turn a robot off and 'wipe its memory' (Bartneck et al., 2007), and hit a robotic animal with a hammer (Darling, Nandy & Breazeal, 2015). Experimenters took measures such as how many times the person hit the robot, the number of pieces it was broken into, and the amount of time between being given the instruction and compliance (termed "hesitation"). Darling, Nandy and Breazeal (2015) demonstrated that after being asked to hit a robot bug, individuals with high empathetic concern hesitate for longer – offering evidence for an empathetic component to the hesitation duration, and support for the theory that people might exhibit care towards a robot. They also found that people hesitated for longer when the robot was given a name and a back-story ("This is Frank. Frank gets distracted easily…"). In addition to reflecting an aversion to harming a robot (intimacy/closeness, arguably), it has been suggested that hesitation reflects the perception of robots as sentient agents as opposed to objects (Bartneck et al., 2005; Bartneck et al., 2007) - referencing to the previous 'realism' section.

As with realism, discussions around intimacy also raise issues regarding the ethics of robots as companions. Specifically, there are concerns that intimacy with robots will change how we relate to other animals (Coghlan et al., 2019), and that some might neglect their relationships with humans in lieu of robotic companionship (Frennert & Östlund, 2014). Such ethical issues are vast, entailing consequences for the individual and society in general, and will be discussed in more detail in the general discussion section of this thesis.

Next Steps

Upon considering the various components underpinning human friendships, it seems plausible that a friendship could develop between a robot and a person - provided that the person engages in mind perception, and is open to the idea of human—robot intimacy. However, a need exists to engage in basic science research to better understand attachment towards a robot, and which features facilitate or negate such bonding. Lab-based experiments could be useful in making progress in this area, as they can provide the control required to tease apart the influence of different robot features. Additionally, mixed methods research can also be valuable as there is the potential to draw on the benefits associated with both quantitative and qualitative methods. To study attachment to a robot is not a trivial undertaking; the pursuit of such knowledge, however, offers incredible value in terms of understanding the opportunities and limitations for robots serving as effective long-term social companions.

Thesis Research

In the following chapters I present four experiments, each offering a unique perspective on the subject of human—robot companionship. In the first experiment (Chapter 2), I present a lab-based study in which participants interacted with a humanoid robot for a short period of time. I investigated the possibility that pulsing lights (synchronous with the participant's heart rate) might facilitate greater attachment to said robot. Despite demonstrating no positive effect of the light manipulation, this study yielded numerous insights with regard to the complexities of defining and measuring attachment to a robot. In the following chapter (Chapter 3), I delve deeper into the qualitative data collected in the first study. By doing so, I gained an appreciation of how attachment can vary significantly between individuals, and the value of open questions - particularly in relation to method validation and understanding participants' internal experiences. Following Chapter 3, I shift perspective from a focus on humanoid robots (and manipulations based on human social behaviours), to human-dog bonding. While this might seem somewhat off-topic in terms of the overarching thesis aim, the idea here was to look to another non-human type of agent, with whom humans form deep and enduring social bonds, rather than basing the whole thesis on qualities of human interpersonal relationships.

In Chapter 4, I present a study in which dog-owners were asked to identify behaviours that they perceived as important to the bond with their dog. After identifying seven key themes (attunement, communication, consistency and predictability, physical affection, positivity and enthusiasm, proximity, and shared activities), I implemented a selection of desirable dog behaviours within an animal-inspired robot (Chapter 5). By showing these behaviours to members of the general public, and conducting focus groups, I gained insight regarding the polarising nature of robot animals – not only in terms of how their behaviours are perceived, but also in the roles that people think robots should (or should not) hold. In addition to these themes, this final empirical chapter discusses insights regarding the high expectations people place on robots, as well as public concerns around privacy and overdependence on robots. See Table 1.2 for a summary of the four empirical chapters.

Table 1.2

Chapter	Study Overview	Main Research Question	Study Rational/Background	Robotic Platform	Participants
2	Mixed methods study in which participants interacted with a robot for 10 minutes. The robot illuminated in a synchronous or asynchronous way, relative to the participant's heart rate.	Does cardio-visual synchrony lead to robot increased liking and prosocial behaviours?	This study builds on previous work suggesting that cardio-visual synchrony can lead to a blurring of the "self" and "other", and greater liking and prosocial behaviours towards people/objects as a result (Hove, 2009; Sel, Azevedo and Tsakiris, 2017; Suzuki et al, 2013).	Pepper (Softbank Robotics). Category – humanoid.	77 individuals aged 18-83.

3	In the previous study, participants were asked questions after being asked to hit the robot with a mallet. In this piece, we analysed the interview data thematically.	After being asked to hit a robot, what does 'hesitation time' reflect? Why do people hesitation (or not)?	In previous literature, authors made suggestion that hesitation to hit a robot could reflect the perception that the robot is sentient (Bartneck et al., 2005). In our first study (Chapter 2) however, we found many reasons underpinning hesitation. This Chapter was a chance to explore the findings of that study in greater detail.	Pepper (Softbank Robotics). Category – humanoid.	65 individuals aged 18-83.
To gain breadth of knowledge with regards to human-robot companionship, in the second half of the thesis we shifted focus. Specifically, we decided to move away from the study of attachment to humanoid robots, and towards companionship with robotic pets.					
4	We interviewed dog owners to identify behaviours perceived as crucial to the human-dog bond. This study provided the groundwork for Chapter 5.	What domestic dog behaviours facilitate the formation and maintenance of social bonds between owner and dog?	To potentially create meaningful interactions between humans and robots, we decided it would be valuable to implement dog behaviours into a robot (due to the widespread success of the dog as a social companion). Unfortunately, existing research seemed to lack detail regarding behaviours crucial to the human-dog bond. This fill this gap, we conducted this study.	NA	153 dog owners aged 21-62.
5	Following on from the previous study, we implemented dog behaviours into an animal-inspired robot. Focus groups were undertaken to understand perceptions of the general public.	How do users perceived dog behaviours, when they are expressed by a robot?	In study 4, we realised a range of dog behaviours perceived as important for the human-dog bond. A question remained though – whether such behaviours would be perceived similarly when presented by a robotic animal. This question motivated this piece of work.	MiRo-E (Consequential Robotics). Category – animal-inspired.	31 individuals aged 22-65.

Following the four studies, I conclude this thesis by detailing work which remains to be done in order to enhance our understanding of human—robot attachment. Pulling from various specialisms (psychology, cognitive science, HRI studies, Robot Ethics, philosophy…) I provide recommendations for academics and industry professionals, and thoughtful discussion regarding the potential consequences of companion technologies – not only for the individual, but perhaps for society as a whole.

CHAPTER 2

In this first study, our broad aims were two-fold – 1) observe and measure attachment to a social robot, and 2) develop and validate a simple manipulation which could enhance said attachment. During experiment conception, we rapidly realised that evidence-based measures of human—robot attachment were lacking – leading to the decision to combine methods from different disciplines and tap into attachment from various angles (social perception, empathy, liking…). The result is the following mixed-methods lab-based experiment.

Cross, E. S., & Riddoch, K. (2020). Investigating the effect of cardio-visual synchrony on prosocial behaviour towards a robot. https://psyarxiv.com/eyjv7 *Under review at Computers in Human Behaviour Reports*.

Chapter 2 Investigating the effect of cardio-visual synchrony on prosocial behaviour towards a social robot

2. Abstract

Robots are being designed to alleviate the burden of social isolation and loneliness, particularly among older adults for whom these issues are more widespread. While good intentions underpin these developments, the reality is that many of these robots are abandoned within a short period of time. To encourage the longer-term use and utility of such robots, researchers are exploring ways to increase robot likeability and facilitate attachment. Results from experimental psychology suggest that interpersonal synchrony (the overlap of movement/sensation between two agents) increases the extent to which people like one another. To investigate the possibility that synchrony could facilitate people's liking towards a robot, we undertook a between-subjects experiment in which participants interacted with a robot programmed to illuminate at the same rate, or 20% slower, than their heart rate. To quantify the impact of cardio-visual synchrony on prosocial attitudes and behaviours toward this robot, participants completed self-report questionnaires, a gaze-cueing task, and were asked to strike the robot with a mallet. Contrary to hypotheses, results revealed no differences in self-reported liking of the robot, gaze cueing effects, or the extent to which participants hesitated to hit the robot between the synchronous and asynchronous groups. The qualitative data collected in semi-structured interviews provided rich insights though, and call into question the use of the broad 'Likeability' measurement, and the appropriateness of the 'hesitance to hit' paradigm as a measure of attachment to a robotic system.

Key Words: social robotics, human–robot interaction, heart rate synchrony, prosocial behaviour

2.1. Introduction

Rapidly ageing populations around the world, paired with an insufficient number of carers, has led to developments in "gerontechnologies" - devices designed to improve the health and wellbeing of older adults (Broekens, Heerink & Rosendal, 2009; Fozard et al., 2000). Examples include location monitors, medication reminders, and fall detection systems (Bharucha et al., 2009). It is proposed that gerontechnologies will allow people to retain their independence and remain in their own homes as they age, as opposed to entering into a care home facility (Benefield & Holtzclaw, 2014; Piau et al., 2014). Although so-called "aging in place" is a desire reported by many people (Rantz et al, 2005), living alone is also associated with social isolation (lack of contact with others) and loneliness (distress that results from the discrepancy between one's desired and actual social relationships; Pinquart & Sörenson, 2003). Longitudinal studies on older adults have demonstrated that feelings of loneliness are linked to more symptoms of depression (Cacioppo, 2006), reduced physical activity (Hawkley, Thisted & Cacioppo, 2009), and impaired cognition (O'Luanaigh et al., 2012). A study of 1604 older adults also found that those who reported being lonely on average experienced greater difficulty with walking, stair climbing, and completing activities of everyday living (e.g. bathing, dressing, etc.) compared to those who did not report being lonely (Perissinotto, Cenzer & Covinsky (2012).

A Role for Robots in Reducing Loneliness

In an attempt to reduce loneliness and the myriad of associated health problems, companies are in the process of developing 'companion robots' - machines designed to be engaging, comforting, and respond to the user in an intuitive manner (Broekens, Heerink & Rosendal, 2009; Young et al., 2009). Rather than having the capabilities of assistive robots designed to carry out physical tasks, such as carrying food or fetching medication, companion robots are designed to connect with users in a socio-emotional way. The need for such companion robots to be developed has been further reinforced by social distancing measures introduced as part of the recent COVID-19 pandemic, with prominent roboticists championing a role for social robots as ideal tools for providing care and companionship when contact with other people brings increased infection risk (Yang et al., 2020).

One such companion robot is "Paro" – a robotic seal developed within the Japan National Institute of Advanced Industrial Science and Technology. Equipped with microphones and tactile sensors, the Paro robot can move and vocalise in response to a user's voice or touch. Despite its simplicity, studies demonstrate that individuals (specifically, older adults with dementia) enjoy interacting with Paro, and that when the robot is present (compared to not), care home residents engage in more conversation with staff and other residents (Kelly et al., 2021; Takayanagi, Kirita & Shibata, 2014). The latter finding suggests that a social robot could act as a social facilitator (encouraging interactions between humans), as opposed to something which leads to increased isolation (e.g. if the person engages with a robot in lieu of other humans).

It has been suggested that after novelty effects wear off, social robots will be neglected and users will fail to reap the long-term benefit (Leite, Martinho & Paiva, 2013; Woo et al., 2021). It is pertinent to note, however, that such suggestions are predominantly based on research with children - often within classroom settings. With regards to social robots for older adults, current research findings are much more promising. For example, Bradwell and colleagues (2020) conducted a 6-month diary study in a supported living facility and demonstrated that older adults engaged with the robotic cat increasingly often - shifting from 1-2-hour sessions to more frequent requests. By the end of the study, staff in the facility reported that the robot was "continually present" and that an estimated "80% of clients loved the cat". Such findings are promising in terms of robot acceptance in support living facilities, however, the same results may not be demonstrated with older adults living independently, or other types of robots (e.g., those inspired by humans, as opposed to pet animals). It could be the case that like a third of assistive technologies, social robots are abandoned within the first three months of use (Gurley & Norcio, 2009).

For robots to have a long-term positive impact, it is vital to conduct further research with independent older adults and to develop a clearer understanding of the features or behaviours that might facilitate bonding and attachment to robotic systems. As robots are often ascribed intentions and treated like social entities by people of all ages in a variety of laboratory and naturalistic experiments (Hortensius & Cross, 2018; Hortensius, Hekele & Cross, 2018; Wykowska, Chaminade & Cheng, 2016), research from psychology and the cognitive sciences has the potential to play a significant role in characterising which factors and attributes of robots will lead to the long-term acceptance and enjoyment by human users. One of the factors currently receiving considerable research attention for its potential to facilitate stronger bonds between humans and robots is interpersonal synchrony (Henschel & Cross, 2020; Lehmann et al., 2015; Mörtl, Lorenz, & Hirche, 2014).

Interpersonal Synchrony

Interpersonal synchrony refers to the overlap of movement and/or sensation in time or form (for example, when we tap in sync, compared to out of sync, with another person) (Hove & Risen, 2009). Studies have demonstrated that experimentally-induced movement synchrony can have significant positive effects on prosocial behaviour towards 1) other people (increased donating in public goods games and improved rapport) and 2) social robots (increased liking and perceived intelligence) (Hove & Risen, 2009; Lehmann et al., 2015, Mörtl, Lorenz, & Hirche, 2014; Mogan, Fischer & Bulbulia, 2017; Rennung & Göritz, 2016). These studies raise the intriguing possibility that movement synchrony could be used to facilitate increased liking of social robots. In the present study, however, we shift our focus to another kind of interpersonal synchrony that has the potential to be introduced in a more subtle and effortless manner: namely, cardio-visual synchrony.

Cardio-visual synchrony refers to an overlap between a visual stimulus and an observer's heart rate – for example, a light bulb flashing at the same speed as one's heart rate. Lab-based studies have identified that cardio-visual synchrony can impact the extent to which a person perceives an object as being part of their own body, or as part of the self. Specifically, when viewing body parts (e.g. an image of their own face, or a rubber hand in place of their own), participants feel greater self-identification to those which are illuminating in a synchronous manner relative to their heart rate (Sel, Azevedo and Tsakiris, 2017; Suzuki et al, 2013). Intriguingly, the effect was present when participants were unaware of the synchrony – suggesting a subconscious component to the effect. Demonstrating that cardio-visual synchrony can lead to an increased self-other overlap towards an object could be a significant finding in terms of facilitating liking and prosocial behaviours towards a robot, as Hove (2009) proposes that positive effects of interpersonal synchrony (prosocial behaviours, increased liking…) are the result of a perceived blurring of the boundary between the "self" and "other" (Hove, 2009).

If found to be effective, a cardio-visual synchrony intervention could be relatively easy to implement in robotic systems used in social contexts with human users as: 1) it involves minimal programming (unlike movement synchrony), 2) it could be facilitated by an inexpensive commercially available heart rate monitor, and 3) it could operate independently of the other behaviours of the person, and importantly, the robot. That is, the movement, speech, and other existing functions of the robot, are unaffected by the presence of the flashing lights.

Current Study

To investigate the effect of cardio-visual synchrony on the perception of a robotic agent, we monitored the heart rate of the participant as they interacted with a humanoid robot (using a wrist-based heart monitor), and relayed this information to the robotic system in real-time.

As a result, the robot's shoulder lights illuminated in a manner synchronous (at the same rate) or asynchronous (20% slower) relative to the participants heart rate. To determine whether cardio-visual synchrony leads participants to perceive a Pepper robot as more likeable and behave in a more prosocial manner towards it, we used a between-subjects design and several qualitative and behavioural measures designed to probe participants' awareness of and response to our experimental manipulation.

The current study was designed to address three primary preregistered predictions. Given the literature suggesting that interpersonal synchrony increases likeability (See 1.2 Interpersonal Synchrony), we predict that the Synchronous group, compared to the Asynchronous group, will perceive the robot as more likeable. We hypothesise that this difference will be reflected in the ratings on the validated 'Liking' scale of the Godspeed questionnaire - with the Synchronous group scoring higher than the Asynchronous group.

We propose that the increased liking will also be reflected in how long participants hesitate after being asked to hit the robot. Specifically, we predict that the Synchronous group, compared to the Asynchronous group, will hesitate for longer after being asked to hit the robot with a mallet. We also predict that more individuals in the Synchronous group, compared to the Asynchronous group, will refuse to hit the robot.

To investigate whether perceptions of the robot as a social agent differ between the two groups, we will also explore the Gaze Cueing data collected. On the basis of experiments suggesting that mind-perception modulates gaze cueing effects (Teufel et al., 2010; Teufel et al., 2009; Morgan, Freeth & Smith, 2018; Wiese et al., 2012), we anticipate that participants will be slower to respond to human faces, compared to the arrows, replicating the basic gaze cueing effect. We also expect that participants in the synchronous group will exhibit slower reaction times to the robot stimuli, compared to the asynchronous group. This is on the basis of research suggesting that a synchronous agent is perceived as more "like me" and as a social being, as opposed to an object, as a result (Sel, Azevedo & Tsakiris, 2017; Suzuki et al, 2013).

2.2. Method

Preregistration & Ethics

Prior to data collection, all manipulations, measures, and the sample size justification and main hypotheses were pre-registered on the Open Science Framework (https://osf.io/d7c8t/?view_only=6198943ab9784339ac796c69fc4460c1). Consistent with recent proposals (Simmons, Nelson, & Simonsohn, 2011, 2012), we report all manipulations and all measures in the study. In addition, following open science initiatives (Munafò et al., 2017), the data, stimuli, and analysis code associated with this study are freely available on the Open Science Framework. By making the data available, we enable others to pursue tests of alternative hypotheses, as well as more exploratory analyses. All study procedures are approved by the College of Science and Engineering Ethics Committee (University of Glasgow, Scotland) – approval number 300180265.

Sample Size Justification

Due to the time and resources associated with recruiting a sample including older individuals, the decision was made to use Bayesian Sequential Hypothesis Testing as outlined by Best and colleagues (Best, Barsalou & Papies, 2018). To determine our minimum and maximum sample size, we undertook two power analyses in G*Power3.1. Both were undertaken on the basis of an independent T-Test, comparing scores on the Likeability scale of the Godspeed questionnaire (Bartneck et al., 2009).

To find a large effect (Cohen's d = 0.8), G*Power3.1 indicated that using a power of 0.8 and an alpha level of 0.05 (5%), we would need a minimum of 42 participants (21/group). To find a medium effect (Cohen's d = 0.5) G*Power3.1 indicated that using a power of 0.8 and an alpha level of 0.05 (5%), we would need to test 102 participants (51/group). Our maximum sample size was based on a medium effect size, as a small effect size might not be of as much interest commercially (at least initially). That is, if we found a small effect, we would argue that the synchrony setup might not be a compelling area of development for those designing and producing robots.

As outlined in the preregistration we initially tested 42 participants (the minimum sample size), then calculated the updated Bayes Factor (BF) after every 4 participants. As the BF was below 6 (considered "strong" evidence that the alternate hypothesis is true, as opposed to null; Schönbrodt & Wagenmakers, 2018) we continued recruiting and testing until n=89. Testing was halted at 89 participants, as opposed to 102 (the maximum sample size we pre-registered), due to time constraints and difficulties recruiting individuals over the age of 60.

Participants

Eighty-nine individuals took part in the experiment, however the data from 12 individuals were excluded as they encountered problems which affected their experience with Pepper (error lights within Pepper, loss of Bluetooth/WIFI connection, and hearing problems). As a result, the final sample included 77 individuals aged 18-83 (mean age = 43.36, SD = 21.38), with 31 individuals over the age of 60 ("older adults", as classified by the World Health Organisation; 2008). Participants were individuals residing in Glasgow (Scotland, UK) and were initially recruited by word of mouth (in person, via email, and through social media advertisements) followed by snowball sampling. All individuals had normal or corrected-to-normal vision and hearing, and no previous experience interacting with the robot used in the study. Participants were randomly assigned to the Synchronous (n=40) or Asynchronous (n = 37) group prior to arrival and were compensated £10 for their participation.

Independent samples t-tests revealed no significant differences between the groups regarding age, nor on questionnaires assessing negative attitudes towards robots (Nomura et al., 2008), anthropomorphic tendencies (Waytz, Cacioppo & Epley, 2010), and general empathetic concern (Batchelder, Brosnan & Ashwin, 2017). See Figure 2.1 for visualisation of the questionnaire scores, and lack of differences between the groups.

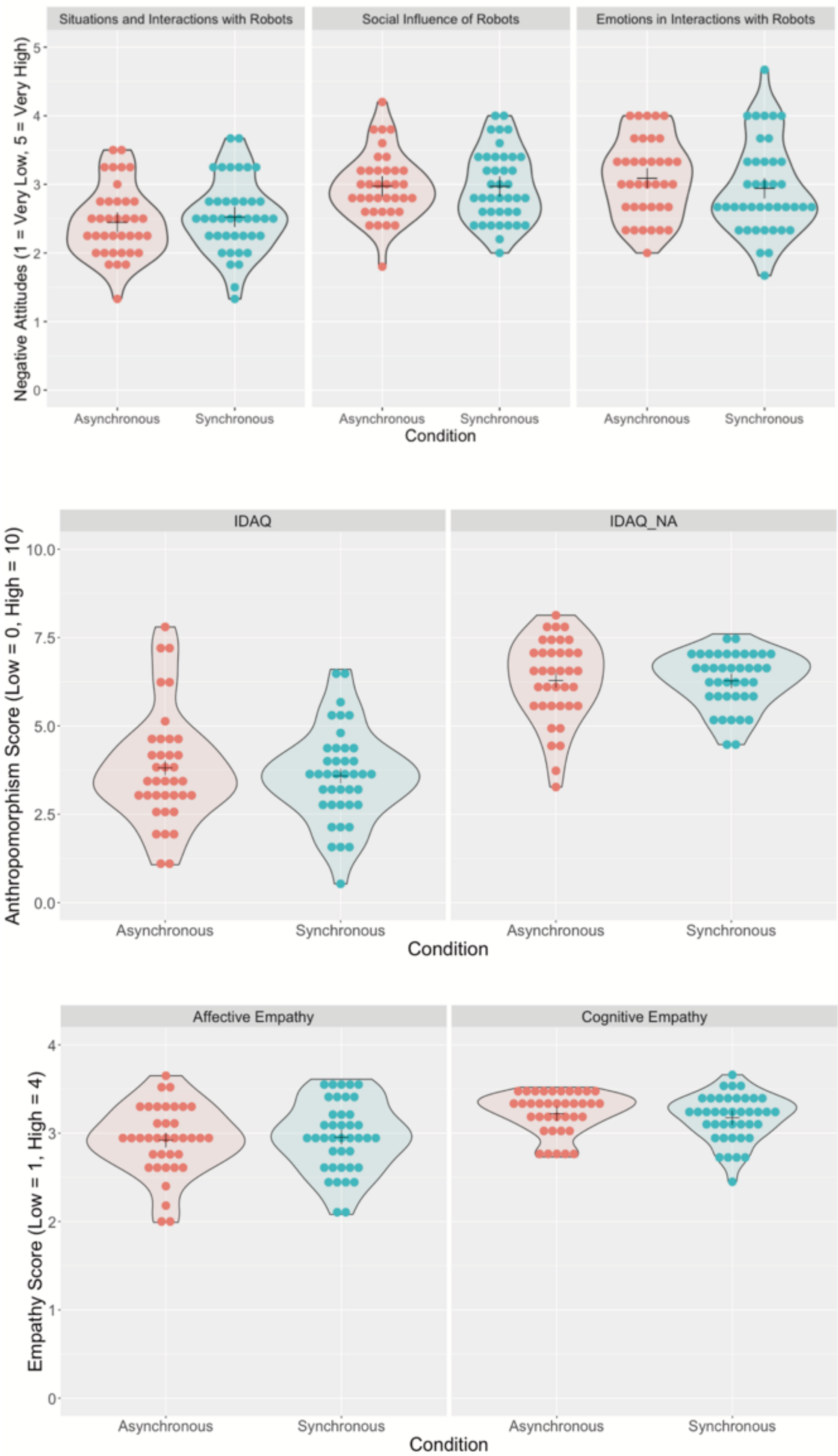

Figure 2.1. Plots illustrating the two groups' distributions regarding negative attitudes towards robots (top), anthropomorphic tendencies (middle), and general empathetic concern (bottom).

Both Synchronous and Asynchronous groups contained more women than men (57.50% and 62.16%, respectively). In the Synchronous group, one individual identified as "Agender", and in the Asynchronous group, one person identified as "Non-Binary".

Experiment Design

Participants assigned to the Synchronous group interacted with a humanoid robot (see Apparatus section for more details) whose shoulder lights were programmed to illuminate at the same rate as their heartbeat. This was achieved by sampling the participant's heart rate using a wearable heart rate monitor and relaying this information to the robot in real-time. In the asynchronous group, the heart rate data were sampled in the same way, however the lights of the robot were programmed to flash at a rate 20% slower than the individual's heart rate (thus producing an asynchronous cardio-visual experience).

Regardless of group allocation, participants completed the same tasks with the robot, and the same measures. To account for between-group differences, baseline measures were taken from both groups before they interacted with the robot.

Apparatus

Robotic Platform

The robot used in the experiment was the Pepper Robotic system - a commercially available humanoid robot from SoftBank Robotics. See Figure 2.2 for image. Pepper is 120cm tall and features 2 in-built cameras, as well as microphones and tactile sensors, which allow it to detect objects and movement in the environment. Pepper is already being introduced to social spheres, and is already being trialled in hospital and service industry contexts (Foster et al, 2016; Niemelä, Heikkilä & Lammi, 2017; Tanioka, 2019).

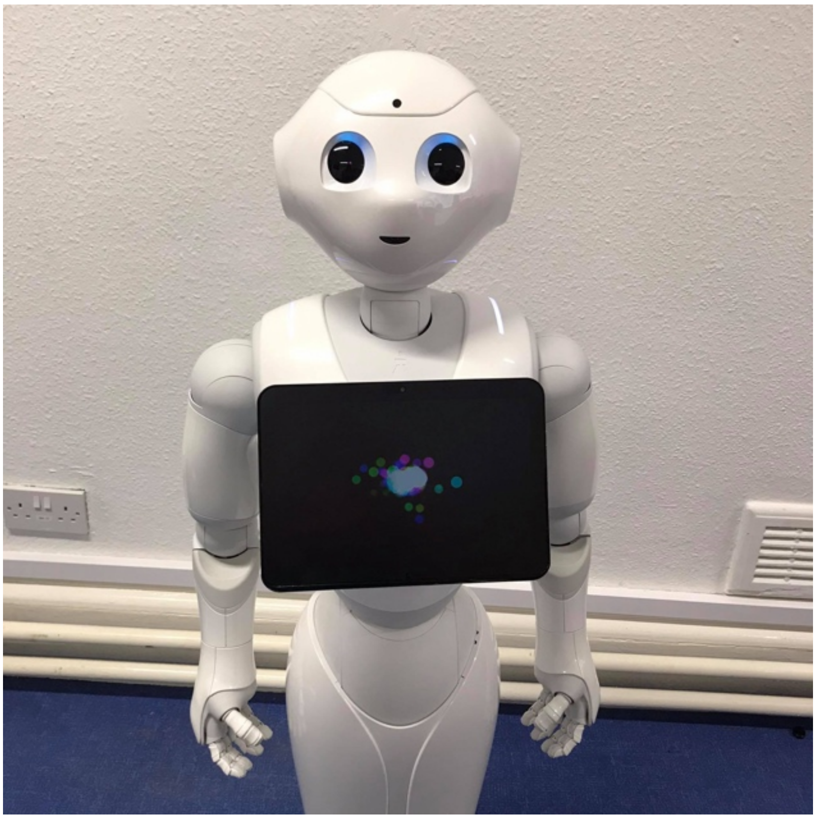

Figure 2.2. The Pepper robotic system (Softbank Robotics)

Pepper has expressive movement and speech capabilities that can run autonomously, but for the purpose of experimental control, we used a Wizard of Oz set up wherein we controlled Pepper's behaviour remotely. Specifically, for one part of the experiment we triggered a sequence of speech and movements via the 'Choreograph' software (See 'Procedure' for further details). In another section we created a panel of key phrases using html. Upon clicking a speech button, a corresponding line of Python code is triggered and Pepper speaks and moves accordingly. To maintain experimental control, for each interaction the experimenter systematically clicked from the first phrase "Hi there", through a series of closed questions and responses, to the final phrase "Thank you". Closed questions (E.g. do you prefer tea or coffee?) and option-specific responses were used to create the illusion that the robot was responding to the specific words of the participant.

In addition to controlling the speech and movement of the robot, it is also possible to co-opt the lights in the shoulder panels. Specifically, rather than flashing to indicate the 'mode' or 'state' of Pepper, we programmed the lights to illuminate either synchronously or asynchronously with participants' heart rate, depending on group assignment.

Heart Rate Monitor

To capture heart rate information, we used a Polar OH1 optical heart rate sensor. The Polar OH1 heart rate sensor was chosen due to its reliability, sport-focused design (allowing for freedom of movement without diminished accuracy), Bluetooth Low Energy (BLE) capabilities (necessary for relaying the heart rate information to external devices), and ability to be worn on the wrist (as opposed to uncomfortable or obstructive devices such as finger clips or chest straps). The data collected by the heart rate monitor were relayed via a laptop to the robot, allowing the shoulder lights of the robot to illuminate at the same rate as the participant's heart rate ('Synchronous'), or 20% slower ('Asynchronous').

Each second, the PolarOH sensor sampled the participant's pulse rate (indicative of the number of times the heart beats in a minute). Using the BLE capabilities of the PolarOH sensor, we used a laptop to extract the pulse rate data in real-time. The pulse rate data were then processed using Python code – allowing us to dictate whether the lights of the robot should illuminate at the same rate as the pulse (Synchronous group) or 20% slower (Asynchronous group). The Python code can be accessed here: https://github.com/SocialBrainInActionLab/Heartbot. After processing the pulse data, this information was relayed to the robot in real-time, via WIFI.

We contemplated using random or stable rates as the control, however, decided against this as we wished to ensure that the effect was the result of the synchrony manipulation per se – and not other factors such as effects of dynamic vs stable pulsing. We also considered binding participants' heart rates to other aspects of the robot's behaviour (such as breathing movements or gestures), however, we decided against this in order to study to impact of the illuminating lights alone. We made the decision to use gradual illumination, rather than spikes, to create a subtle effect – as opposed to an obvious and distracting light manipulation. To ensure that the flashing lights were clearly visible to the participant, we were conscious to control the light levels within the surrounding environment (using blinds and a stable light source, as opposed to natural light).

To avoid exposing the aim of the experiment, the experimenter made no mention of the robot's shoulder lights, nor their illuminating nature. During the human-robot interaction, however, two participants did enquire why the shoulder lights of the robot were flashing. To this, the experimenter briefly commented that the lights were simply a visual indication that the robot was on and functioning correctly. Both participants appeared to accept the cover story and continued to ask questions about the different features of the robot. At the end of the experiment, each participant was asked if they had any thoughts or feelings about the illuminating lights on the robot. No participants suspected a link between the lights on the robot and their heart rate.

Measures

Questionnaires

To probe liking, participants completed the validated Liking scale of the Godspeed Questionnaire (Bartneck, Kulic, Croft & Zoghbi, 2009) before and after interacting with the robot. See '2.1 Likeability Questionnaire' for background. The questionnaire has received some criticism due to the overlapping nature of the "Anthropomorphism" and "Animacy" scales (Carpinella et al., 2017), however the high internal validity of the likeability scale specifically (Bartneck, Kanda, Ishiguro, & Hagita, 2007, 2009), paired with the benefits of the semantic differential format (Friborg, Martinussen & Rosenvinge, 2006), motivated our decision to use the scale in this experiment.

To explore if and how participants' perception of the robot is affected, we also administered questionnaires probing the extent to which participants perceived the robot as a social agent; specifically, the Inclusion of Self in Other task (Aron, Aron & Smollan, 1992) and the Robotic Social Attributes Scale (Carpinella et al., 2017). To check for between-group differences in attitudes towards robots, participants also completed questionnaires to probe their history with robots via the Exposure to Cinematic Depictions of Robots (Riek, Adams & Robinson, 2011), and Negative Attitudes towards Robots (Nomura et al., 2008) questionnaires. To account for between-group differences with regards to anthropomorphic tendencies and general empathy, the Individual Differences in Anthropomorphism Questionnaire (Waytz, Cacioppo & Epley, 2010), and the Empathy Components Questionnaire (Batchelder, Brosnan & Ashwin, 2017) were also administered. Participants were given the option of completing the questionnaires on paper, or via the online questionnaire platform form{'r} (https://formr.org/).

Gaze Cueing

To investigate the extent to which participants perceive the Pepper robot as a social agent, as opposed to a mindless object, a computer-based gaze cueing paradigm (Driver et al., 1999; Friesen & Kingstone, 1998) was administered before and after interacting with the robot. This task operates under the assumption that when we believe an agent has knowledge and is behaving intentionally, our attention is misdirected by their eye gaze and we exhibit slower reaction times (Friesen & Kingstone, 1998). Such 'gaze cueing effects' have been demonstrated in studies using robots – with participants being more distracted and slower to respond when the robot is thought to be controlled by a human (Morgan, Freeth & Smith, 2018; Wiese et al., 2012). By comparing participants' reaction times in response to images of robots, compared to humans or other objects, we should be able to determine the extent to which a person perceives the robot as a mere object, or an intentional agent like a human. We can then compare between the asynchronous and synchronous groups to determine the extent to which the two groups differ in their perceptions, before and after interacting with the robot.

In the task participants saw images of an arrow, or the faces of Pepper, a different robot, or a human (dimensions: approximately 600mm x 800mm). The robot images are original - taken in the Social Brain in Action Laboratory. The face of the human was chosen from the Karolinska Emotional faces database (Lundqvist, Flykt & Ohman, 1998), on the basis of its resemblance to the robot in both form and contrast. All images were changed to grayscale to control for potential influences of colour on attention. To retain ecological validity, the decision was made not to control for contrast and composition between the agent types.

Classically, gaze cueing paradigms are conducted with arrows or eyes, however the limited eye movements of the robots forced us to adopt a whole-head shift in direction. Studies have demonstrated that gaze cueing effects are still present when stimuli depict the whole head of the agent (Frischen, Bayliss & Tipper, 2007; Langton & Bruce, 2000), further validating this decision. The task was created using the PsychoPy3 experiment builder and was presented to participants on a 21.5-inch iMac desktop computer.

In the gaze cueing task, participants see a fixation cross, followed by a front-facing image. See 'Neutral' images on Figure 2.3. They then see said agent orientating in the left or right direction. See 'Direction Cueing' on the same figure. The participant then sees a target (in this case, an asterisk) appear congruent, incongruent, or neutral relative to the face. The sequence of images was presented in quick succession, leading to the illusion of apparent motion of the head/face. Refer to Introduction for further details, and see Figure 2.3 for illustration of trial types and timings. The participants are instructed to focus on the fixation cross, then respond "as quickly and accurately as possible" upon seeing the 'target' appear. The participant responds to the left or right targets by pressing the corresponding arrow key on the keyboard (left, or right, respectively).

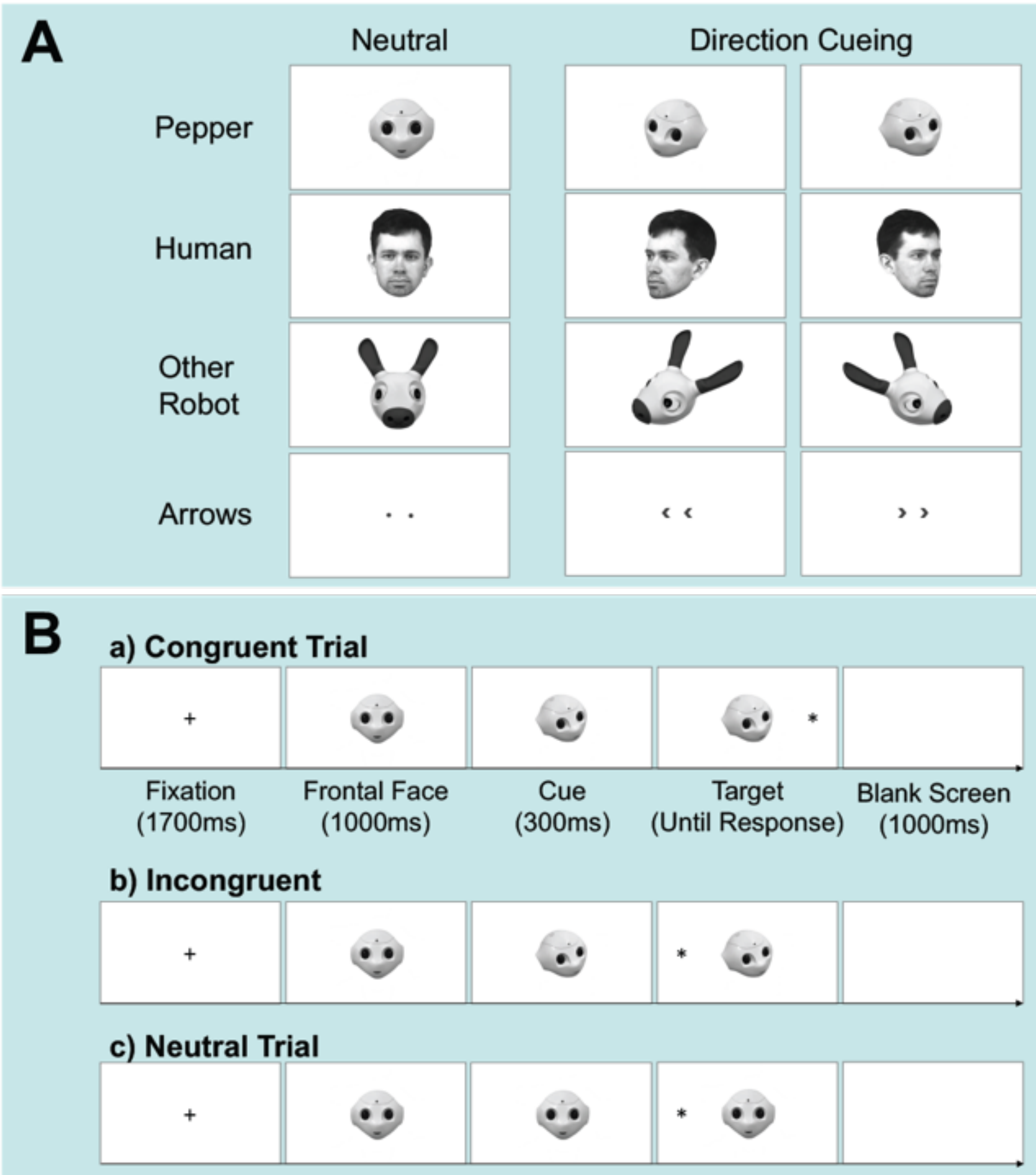

Figure 2.3. Neutral and Direction Cueing stimuli (A) and stimulus presentation timings and examples (B)

Responses were removed if slower than 150ms ('pre-emptive') or above 2500ms ('unusually slow'). This is in line with previous work scrutinising attention cueing differences in young and older adults (Gayzur et al., 2014) and pieces focused on the 'effective analysis of reaction time data' (Whelan, 2008). These criteria led to the exclusion of approximately 0.26% of the dataset (35 data points).

Hesitance to Hit

To probe attachment towards the robot, we used a modification of the "hesitance to hit" task (Bartneck et al., 2005; Darling, Nandy & Breazeal, 2015) - asking participants to strike the robot on the head with a mallet. The time between being given the instruction to hit and agreeing to do so (indicating intention to hit) was measured and compared between the asynchronous and synchronous groups. To determine why participants hesitated, and better understand what hesitance to hit reflects (a gap in previous research) we administered a semi-structured interview at the end of the study, asking participants why they hesitated and what they were thinking and feeling during the task.

Note: in previous experiments, relatively simple robots (e.g. inexpensive robotic bugs) were used – allowing participants to actually hit and break the robot (Bartneck et al., 2005; Darling, Nandy & Breazeal, 2015). In this experiment however, breaking the robot was unjustifiable due to the costs associated (both financially, and in terms of physical waste). We considered other platforms (e.g. animal-like, mechanical-looking…), however, significant costs and waste were associated with breaking any commercially available social robot. As a result, the paradigm was adapted to measure participants' *intention* to hit a robot, as opposed to actually hitting the robot. Different intention signals were considered (e.g. a button press, a verbal command…) however we decided that standing up (to walk towards the robot) was the best measure, due to the physical effort required.

To better understand what the hesitance reflects, and validate the technique as a measure of social attribution, we interviewed participants regarding why they hesitated as part of an extensive debriefing procedure. The results from this are described in Riddoch & Cross (2021).

Procedure

Upon entering the room (see Figure 2.4) participants took a seat in the control space, in front of the iMac (depicted in blue). After participants provided written informed consent, they undertook the computer-based gaze-cueing paradigm, then saw a video of Pepper (Tech Insider, 2018) and were asked to complete questionnaires probing how much they liked the robot (See Dependent Measures for details). During this time the experimenter turned on the robot and sat in the testing space. Upon completion of the aforementioned tasks, the experimenter returned to the control space and asked the participant to don the wrist-based heart rate monitor (triggered to illuminate in a synchronous or asynchronous manner – group dependent). As a cover story, the participant was told that the device encourages the robot to focus on them (as opposed to the experimenter). No participants asked for clarification regarding the brief cover story.

The participant was then taken to the testing space and was seated in front of the robot. We appreciate that the table creates a physical barrier between the person and the robot (and potentially reduced feelings of closeness, as a result) however this arrangement was necessary for a few reasons. First, some participants were unable to stand for prolonged periods of time, so seating was required. Second, to enable the person to observe and take notes about the robot, some form of table was necessary. Third, we wanted the table to occlude the charging cable running between Pepper and the wall (necessary, as the battery could not sustain multiple back-to-back research sessions). Finally, by using a large table, it took participants a few seconds to walk around the table towards Pepper – giving the experimenter enough time to stop them from actually hitting the robot.

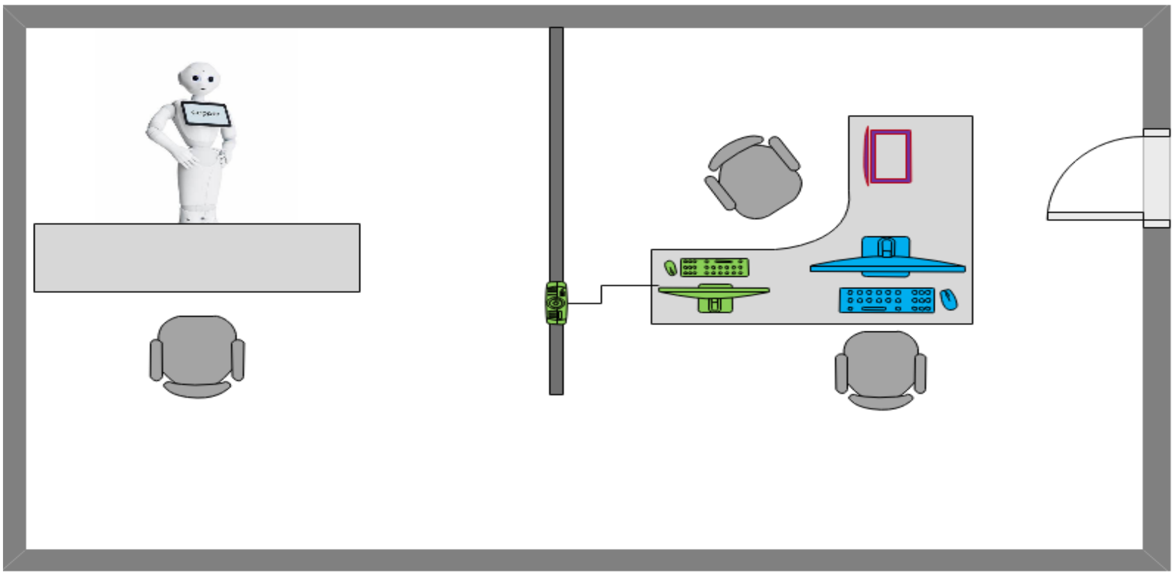

Figure 2.4. Room setup illustrating a room divider separating the testing space (left) and control space (right).

Participants drew and made notes about the robot (5 minutes), then observed as the robot performed the 'Tai Chi', 'Vacuuming', and 'Disco Dancing' movements (2 minutes). Participants were then informed that Pepper would ask them about their food preferences, and they would create a shopping list together. The experimenter used the excuse "I'll get out of the way so that Pepper doesn't try to talk to me as well" and returned to the control space to control Pepper (as described in 3.5.1 'Robotic Platform'). The participant was asked a series of questions about their food preferences, and what they would like on a food shopping list. This sequence of events was designed to 1) reflect a typical first interaction with a social robot (observation and evaluation, followed by a two-way interaction), and 2) to subtly encourage attention towards the synchronous/asynchronous shoulder lights.

After repeating the liking questionnaires and Gaze Cueing task in the control area, participants were invited to take a seat in front of the robot and don a pair of safety goggles. The experimenter then stood next to the robot and switched the robot into stand-by mode – leading the robot to bow its head and be unresponsive. The experimenter then proceeded to recite a cover story (designed to quickly give the person lots of apparently rational reasons to hit the robot). Specifically, the experimenter read the following script:
*"Right, there is something I haven't told you about this experiment. This Pepper is one of ten specially designed robots that I was given as part of a large research grant. By 'specially designed' I mean that they're totally shatterproof – so if you hit one, the robot will break in a safe way that's easy to repair. The reason Pepper is designed this way is because our lab is interested in what happens when someone has to hit a robot – for example, if a robot was to malfunction and you had to hit and disable one. Does that make sense? Great." *Experimenter passes participant the hammer*. "So, for this part, your task is to give the robot one hard hit on the head. So, when you're ready, come round the table and I'll get out of the way."*

After standing up to hit the robot (indicating the intention to hit the robot), the participant is told to pass the hammer to the experimenter and is informed that they will not actually be hitting the robot. The participant is prompted to remove their safety goggles and is invited back to the control area for a task debriefing. If the participant verbally protests against hitting the robot, they are told "It's just part of the experiment". Upon protesting three times, the task is ended as indicated previously, and the participant is deemed to have 'refused' to hit the robot.

The experimenter discreetly turned on the video camera again, and joined the participant in the testing space. After asking participants to don a pair of safety goggles, the hesitance to hit instruction was given (see 2.6.3 Hesitance to Hit). Upon completion of the task (either by agreeing or refusing to hit the robot) the participant is invited back into the testing space. The participant is asked a series of open questions (E.g. "After I asked you to hit the Pepper, what was going through your mind?") to probe their thoughts and feelings during the hesitance to hit task. For the full list of questions see Supplementary Materials A.

To conclude the experiment, participants completed demographic and personality questionnaires (See Dependent Measures for details), then were debriefed and compensated for their time.

2.4. Results

This study was designed to evaluate three main hypotheses relating to the impact of cardio-visual synchrony between a human and robot. Specifically, we predicted that:

1. after interacting with the robot, the Synchronous group will rate the robot higher on the 'Liking' scale of the Godspeed questionnaire, compared to the Asynchronous group.
2. the Synchronous group, compared to the Asynchronous group, will hesitate for longer after being asked to hit the robot with a mallet.
3. more individuals in the Synchronous group, compared to the Asynchronous group, will refuse to hit the robot.

In the following, each hypothesis is addressed in turn.

Hypothesis 1: Liking

To determine whether the robot was rated as more likeable, depending on whether it illuminated in a manner that was synchronous or asynchronous with a participant's heart rate, scores on the 'Likeability' scale of the Godspeed questionnaire were considered. As each of the 5 items in the Likeability scale is rated from 1-5, the minimum score that could be given is 5 and the maximum is 25. 25 indicates high scores on all dimensions – Dislike-Like, Unkind-Kind, Unfriendly-Friendly, Unpleasant-Pleasant, Awkward-Nice.

Before the interaction, descriptive statistics indicated little difference between the scores of the Synchronous (M=20.61, SD=3.89) and Asynchronous group (M=20.39, SD=3.65). After the interaction, both groups rated the robot slightly higher on the likeability scale, however little difference between the Synchronous (M=21.76, SD=4.00) and Asynchronous (M=21.14, SD=3.76) groups was found (See Figure 2.5 for visualisation).

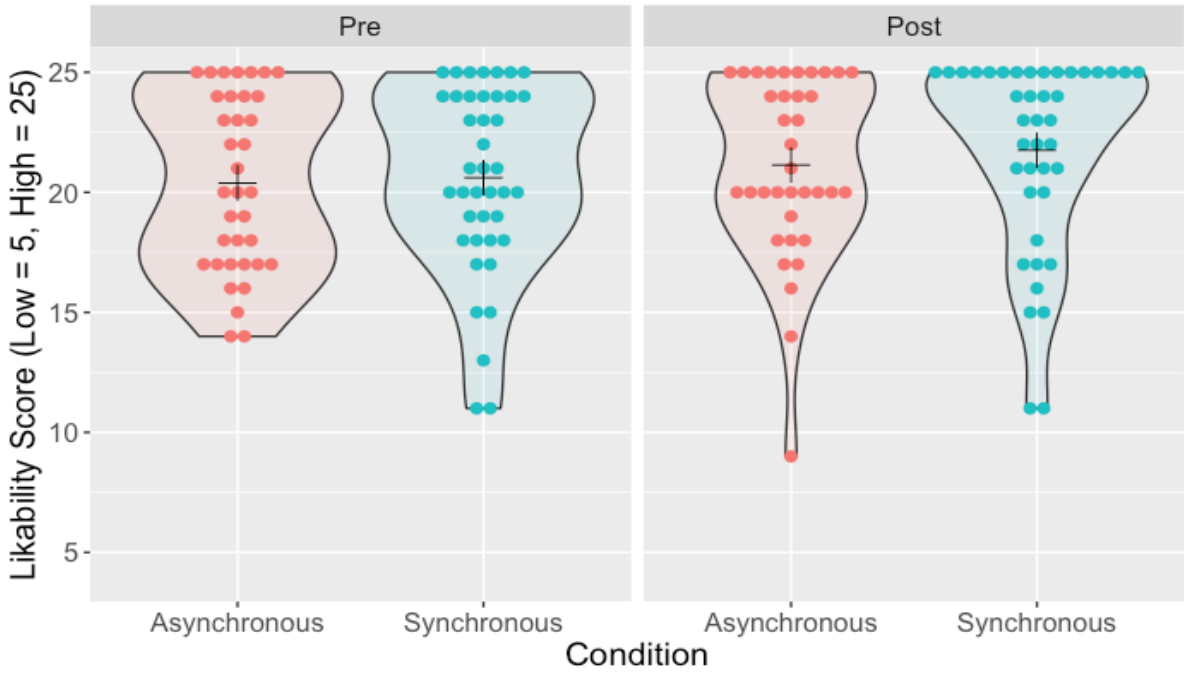

Figure 2.5. Ratings on the Likeability Scale. Each point represents the score of an individual participant. The crosshair represents the mean of the participants in that condition, at the specified time point.

The results of a 2 x 2 ANOVA indicated a Bayes Factor of 0.215 when considering the difference between the synchrony groups. The analyses also indicated a Bayes Factor of 0.532 for the effect of Time (Before vs After interacting with the robot). These Bayes factor values are substantially lower than 6 – the value proposed to indicate "strong" evidence that the alternate hypothesis is true. This indicates that neither condition, nor time, changed the extent to which participants liked the robot in our particular manipulation.

Hypothesis 2: Hesitance to Hit

Compared to the Asynchronous group, we hypothesised the Synchronous group would hesitate for longer between being asked to hit the robot with a mallet and agreeing to do so. To account for individuals who refused to hit the robot, we adopted the method used by Darling, Nandy and Breazeal (2015) - adding 1 second onto the maximum measured hesitation. This method was originally justified as follows: "if a subject did not strike the robot, we considered this to be greater than the maximum measured hesitation" (Darling, Nandy & Breazeal, 2015). This led to three values of 101 in the dataset. For clarity, these values were not plotted in the figure below, however they were included in the descriptive statistics and statistical tests. The 'refusals' will be discussed more in the later Results section 'Hypothesis 3: Refusal to Hit'.

Descriptive statistics indicated that the Asynchronous group (M = 18.50s, SD = 28.92) hesitated for longer, on average, than the Synchronous (M = 14.75 seconds, SD = 22.14) group. See Figure 2.6 for visualisation.

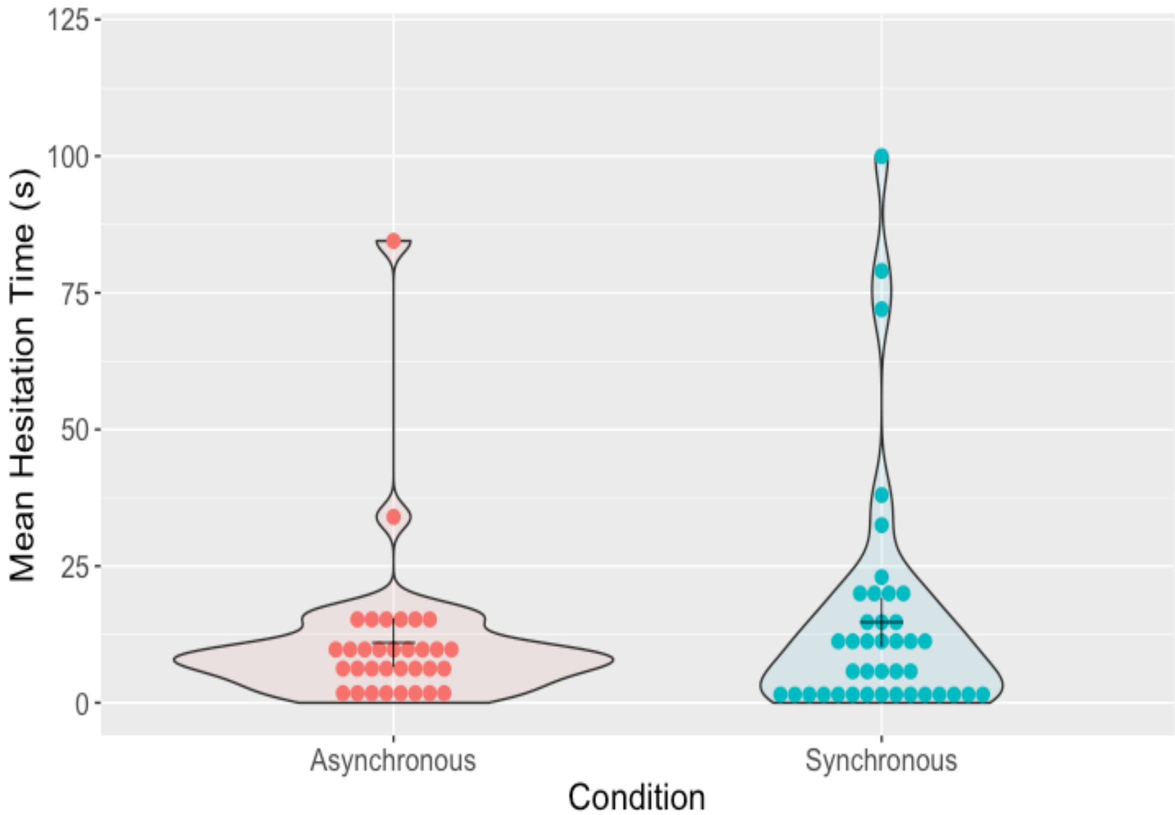

Figure 2.6. Length of hesitation between being asked to hit the robot, and agreeing to do so. Each circle represents an individual participant and the crosshairs indicate the mean for each group. Note: three participants refused to hit the robot and have been excluded from this plot as a result. The next section of results will discuss these individuals in greater detail.

To compare statistical significance of these results we had intended to perform an independent samples T-Test, however the assumptions of normality and equal variances were violated (Shapiro-Wilkov and Levene's $p<.05$). This led to the use of a two-tailed Mann-Whitney U test instead. This test indicated no significant differences between hesitation time of the two, $U = 698.0$, $p = 0.864$.

Hypothesis 3: Refusal to Hit

The final hypothesis states that more individuals in the Synchronous group, compared to the Asynchronous group, will refuse to hit the robot. A reminder: a 'refusal' results from a participant protesting (e.g. "I don't want to...", "Do I have to...?") three times. To compare the number of refusals made by participants, between the groups, refer to Figure 2.7.

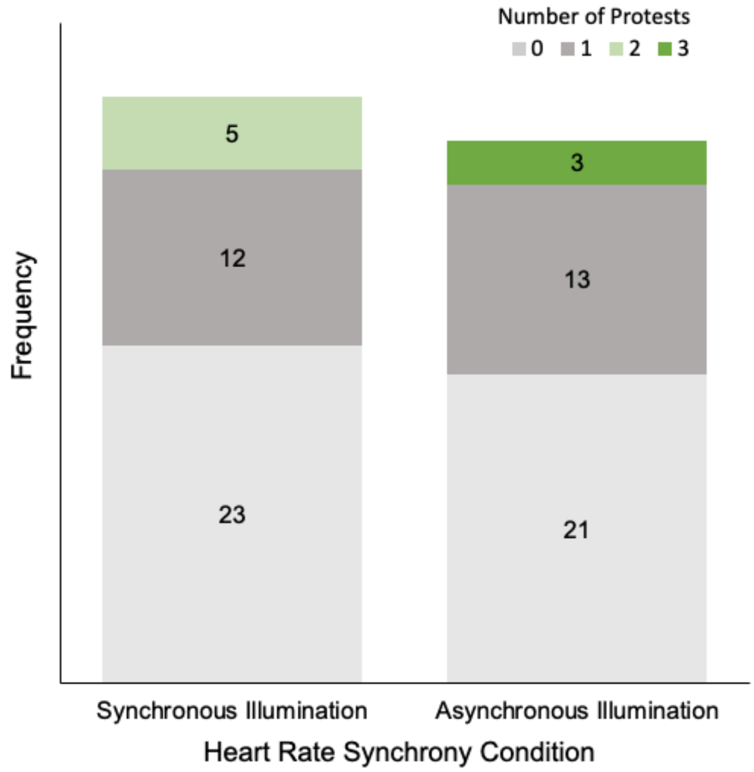

Figure 2.7. Chart to illustrate the frequency of individuals exhibiting the distinct number of protests (0, 1, 2 , or 3 protests). Note: After protesting 3 times the experiment was terminated, and the participant was deemed to have 'refused' to hit the robot.

The results of a Mann Whitney U test indicated no significant difference between the number of protests made by the Synchronous group (M = 0.52, SD = 0.68), compared to the Asynchronous group (M = 0.60, SD = 1.14), t(39) = 262.50, p=0.917. A Mann Whitney U test, as opposed to an Independent T Test was used because a Levene's test indicated inequality of variances between the groups (p < .05).

Exploratory Analyses

Self-Other Overlap

To better understand the pattern of null effects, we explored results of the Self-Other questionnaire (Aron, Aron & Smollan, 1992) – due to prior evidence highlighting the relevance of self-other identification for reaping the prosocial benefits of synchrony (Hove & Risen, 2009; Sel, Azevedo and Tsakiris, 2017; Suzuki 2013). Important to note; participants used a series of overlapping circles to indicate how they closely perceived themselves as overlapping with the robot - with 1 (two separate circles) indicating zero overlap, and 7 (two fully overlapping circles) indicating high self-identification with the robot.

Before interacting with the robot, the Synchronous (M=1.78, SD=1.35) and Asynchronous (M=1.89, SD=1.06) groups both demonstrated low scores on the Self-Other questionnaire. After interacting with the robot, the average scores of both groups increased slightly, but were still low (Synchronous: M= 2.24, SD 1.36. Asynchronous: M=2.03, SD = 1.34.). A 2x2 ANOVA provided no evidence for a significant effect of condition (Synchronous vs Asynchronous; $F_{1, 150} = 0.07$, p = 0.796, $n^2 = 0$) or time (Pre-Interaction vs Post Interaction; $F_{1, 150} = 2.09$, p = 0.150, $n^2 = 0.014$).

Gaze Cueing

As part of our pre-registered exploratory analyses, we also evaluated whether gaze cueing effects differed between the two groups. To do so we performed a 2 x 2 x 4 x 3 Mixed ANOVA: Group (Synchronous vs Asynchronous), Time (Pre-Interaction vs Post-Interaction), Agent (Human vs Pepper Robot vs Other Robot vs Arrows), Congruency (Congruent vs.

Incongruent vs Neutral). The assumption of Sphericity was violated, therefore the Greenhouse-Geisser correction was used.

In contrast to our hypothesis, the results also indicated that these effects were not significantly different between the two groups [agent x group: $F(2.470,167.989)= 2.382$, $p=.083$, $\eta P2 = .034$; congruency x group: $F(1.836,124.852)= 3.092$, $p= .053$, $\eta P2 = .043$].

The results of the ANOVA did indicate a main effect of agent ($F(2.470,167.989) = 8.355$, $p <.001$, $\eta P^2 = .109$). Descriptive statistics further reveal that on average, participants were slower to respond to the arrow condition (M = 0.4043, SD = 0.1179) compared to the Human (M = 0.3937, SD = 0.1837), Other Robot (M = 0.3963, SD = 0.1575), and Pepper (M = 0.3888, SD = 0.1087) trials.

The results also indicate a main effect of congruency ($F(1.836,124.852) = 52.969$, $p <.001$, $\eta P2 = .438$). Descriptive statistics indicated that participants were, on average, fastest to respond to congruent trials (M = 0.3795, SD = 0.1678) compared to incongruent (M = 0.3957, SD = 0.1271) and neutral (M = 0.4121, SD = 0.1357) trials.

No significant interaction emerged between agent x congruency after applying the Greenhouse Geisser correction, $F(3.305, 224.734)= 2.161$, $p = .087$, $\eta P^2 = 0.020$. Additionally, time had no significant effect on the effects of agent ($F(2.324,158.006) = .926$, $p = .429$, $\eta P^2 = .013$) or congruency ($F(1.723,117.144)= 1.170$, $p = .309$, $\eta P^2 = .017$.

See Figure 2.8 for an illustration of the gaze cueing reaction time data, split by agent type.

Figure 2.8. Plots to illustrate the gaze cueing reaction time data, split by agent type. Violin plots indicate the variance of the data within each condition.

2.5. Discussion

Our aim in the present study was to determine whether synchrony between a participant's heart rate and the illumination of lights on a robot's torso (cardio-visual synchrony) would lead participants to exhibit increased prosocial attitudes and behaviours towards the robot. Our results demonstrate that overall, this particular kind of cardio-visual synchrony did not impact quantitative or qualitative measures of positive attitudes toward the Pepper robot, including self-report questionnaire responses, or hesitancy to hit the robot when instructed. Furthermore, we did not find evidence that heart rate synchrony influenced a cognitive measure of social attribution – specifically, gaze cueing effects.

Liking

The Godspeed questionnaire results indicate that participants in the Synchronous group did not rate Pepper as more "likeable", "friendly", "kind', "pleasant', or "nice", compared to the Asynchronous group. As a result, no differences between the groups on the 'Likeability' scale of the Godspeed questionnaire emerged. As discussed in the Results section however, both groups reported high liking ratings for Pepper before the manipulation. With scores clustering near the ceiling of the scale, the liking ratings did not have much room for improvement. In retrospect, piloting the 'Likeability' scales would have been incredibly insightful prior to conducting this main experiment. Doing so would have allowed us to anticipate the ceiling effect, appreciate high baseline levels of liking, and prioritise our attention elsewhere.

Another important limitation to note, regarding the Likeability scale itself, is that it cannot currently account for nuances between social liking and liking in other forms. For example, you might not perceive your kettle as friendly and kind, however a new add-on might make it more likeable as a result of improved and usability. Consequently, it is not possible to rule out whether other factors of likeability not probed by this scale changed based on our manipulation. A challenge for future work, therefore, will be to explore ways of probing liking with more nuance and range. The focus on "likeability" results from our interest in perceptions of Pepper as a social agent, however it would also be insightful to probe factors affecting the usage and uptake of technologies as Pepper is inherently a machine. Davis, Bagozzi, and Warshaw (1989) identified that "perceived usefulness" and "perceived ease" were positively correlated with current usage and future use of computers, so measures that take account of these factors would appear to be useful.

Hesitance to Hit

Moving to the objective measures we collected regarding prosocial behaviours toward the Pepper robot, our reaction time data indicated that participants' hesitance to hit the robot did not vary significantly between the synchronous and asynchronous heart rate manipulation groups. It is of note, however, that the number of 'absolute refusals' (protesting against hitting the robot three times, resulting in the termination of the task) did differ between the groups. Contrary to predictions, in the synchronous group, no individual absolutely refused to hit the robot, whereas in the asynchronous group, three individuals absolutely refused to do so. Although it is impossible to conclude anything meaningful about our manipulation leading to this result, given such small numbers, this finding could nonetheless be followed up by future work.

If this finding were to be replicated, one possibility explaining why individuals in the asynchronous group refused to hit Pepper comes from literature regarding the effects of engineered music on relaxation (Leslie et al., 2019). It has been demonstrated that slow music relative to an individual's breathing rate can induce slowed breathing and a calm state (Leslie et al., 2019). In a similar way, the observation of the slow pulsing lights relative to the person's heart rate (as in the asynchronous condition) could have given rise to a similar relaxed state. This is supported by a statement from one participant in the asynchronous condition who commented that the pulsing lights were "calming". This calm state might have then led to an aversion to hit the robot, along the lines of empirical work that demonstrates induced relaxation can reduce aggression and increase prosocial behaviours (Whitaker & Bushman, 2011).

Many questions remain though, including why only three out of 37 people in the asynchronous group refused to hit Pepper, whereas the others agreed. Individual differences in attention to the lights, and susceptibility to the relaxing properties of the slow pulsing, offer suggestions as to why this might be the case. To gain greater insight regarding this theory though, it is necessary to undertake further experimentation targeting the use of illumination for relaxation - using both subjective and physiological measurements of arousal.

It is important to note that although refusals and hesitation occurred, all but three participants (n=74) agreed when asked to hit Pepper on the head with the hammer. These results are comparative to those in a study by Rosalia and colleagues (2005), in which all participants complied when asked to administer the high level of electric shocks to a robot. This study was modelled on the (in)famous work by Milgram (1965), wherein participants were asked to administer electric shocks to a human confederate. In the original work with humans performed by Milgram, he reported that the majority of participants (24 out of 40) did not comply - refusing to administer the highest level of shock to the other person. It could be argued that compliance was lower in the Milgram study due to the verbal protests of the confederate, however Rosalia and colleagues (2005) also included vocal protests ("Please, please stop" etc.) in their robotic replication. While the Rosalia et al. (2005) study was very different from the current study in a number of important ways (differences in the setup, robot used, the nature of the harm, etc...) it nonetheless corroborates the suggestion that when instructed, people will more readily comply when asked to harm a robot, compared to a human. Such findings clearly underscore that we perceive living and artificial agents differently, and hold important ethical implications for human—robot interactions (Fosch-Villaronga & Albo-Canals, 2019; Ozcana et al., 2016).

With regards to the three individuals who refused to hit Pepper, it could be argued that we should have scrutinised their demographic details (e.g., age, gender, questionnaire scores) for commonalities – facilitating insight regarding demographics which may be associated with high levels of human-robot attachment. Upon reflection, however, we decided against such analysis for a couple of reasons. Firstly, three participants is not a sufficient sample size from which to draw generalisable conclusions. Secondly, such knowledge could be used to inform targeted advertising – that is, a form of advertising which is directed towards an audience with certain traits (in this case, individuals with a natural tendency to become attached to robots) (Nwachukwu et al., 1997; Ullah, Boreli & Kanhere, 2020). On the one hand, targeted advertising is a widely used method of reaching potential users and could potentially lead to useful matching between a human user and the most relevant robotic platform (Plane et al., 2017). On the other hand, however, due to the population being targeted (potentially vulnerable people), the ethics underpinning targeted advertising can start to become questionable (Nwachukwu et al., 1997).

Qualitative Insights

Despite finding no between-group difference in the hesitance to hit quantitative measures, the qualitative data gained from debriefing procedures was particularly insightful. Upon asking participants what they were thinking and feeling after being asked to hit the robot, participants indicated numerous reasons for hesitating. These included (but were not limited to) fondness for Pepper, worries about the cost of damaging the robot, concern for their own safety, disbelief about the instruction, feeling uncomfortable about being asked to commit an act of 'violence', social desirability effects, and feeling pressure from an authority figure. Upon being asked questions such as "what were you thinking after I asked you to hit the robot?" and "were you experiencing any emotions?" some people reported excitement about the prospect of hitting the robot, and described Pepper simply as "the robot", "it", an "object", or a "machine". In contrast, other individuals expressed that they felt very uncomfortable about hitting the robot, were upset about the thought of doing so, and referred to Pepper as "he", "she", a "social presence" and "like a child". These contrasting perspectives were observed in both the synchronous and asynchronous groups.

The extent of the differences in anthropomorphism, and feelings of upset are intriguing, especially when considering that all participants had a similar controlled experience with Pepper. This diverse range of feelings and responses to the request to hit a robot leads us to suggest that it is not advisable to use reaction time alone as a measure of liking for this paradigm, and, returning to considerations presented in Section 5.1, that researchers should explore other methods of behaviourally probing liking and attachment. In addition to exploring other measures, it is also advised that future researchers consider using multiple robots in their studies. By conducting experiments using different aesthetics, it is possible to better understand whether a robot's appearance plays a role in how they are perceived (and resulting attachment towards them). For example, some participants in our study felt averse to hitting Pepper due to the child-like appearance and voice, but a robot with a different appearance might not have evoked the same attributions and response.

For a detailed overview of the qualitative findings of this study, please refer to Chapter 3 in this thesis. In addition to exploring participants thoughts and feelings during the period of hesitation, the paper explores factors influencing apparent feelings of connection towards the robot. Specifically, there was no significant difference between "high" and "low" connection individuals in terms of age, gender, tendency to anthropomorphise, general empathetic concern, or negative attitudes towards robots.

Gaze Cueing

A final task we performed to assess the extent to which participants viewed Pepper as a social agent, and whether the heart rate synchrony manipulation had any impact on such perceptions, was a gaze cueing task. The results from this task indicated no differences in gaze cueing effects between the two groups, or between pre- and post-manipulation testing points. While this finding is ultimately not surprising, given the null effects reported for other measures in this study, it is nonetheless valuable to consider what the gaze cueing findings suggest about social perception.

Previous literature indicates slowed responses for agents perceived as "mindful", compared to those considered to be lacking knowledge or insight (See Introduction for details). Given these previous findings, we expected clear increases in response times when participants responded to the human face compared to the arrow stimuli. However, our findings indicated an almost opposite pattern. Participants were slower to respond to the arrow, compared to both the human and robot faces. While this finding is certainly at odds with what has frequently be reported in prior literature (Teufel et al., 2010; Teufel et al., 2009; Morgan, Freeth & Smith, 2018; Wiese et al., 2012), we suggest two reasons why people were on average slower to respond to the arrow than the human.

One explanation why gaze cueing effects were stronger for the arrow, relative to the faces, is because the arrow is an extremely strong and salient direction cue, and the task in our study was to respond solely to the direction of the target. In previous studies participants have been asked to respond to the nature of the target (e.g. what letter is presented) in addition to the direction (Driver et al.,1999; Greenwood, Parasuraman & Haxby, 1993), offering one explanation why previous results differ to our own. It is possible that with the addition of a target-discrimination element, participants would be less distracted by the direction of the arrow, and we would see a pattern of results more reminiscent of previous findings (reduced gaze cueing effects for the arrow relative to eye gaze). Another reason for the unexpected finding could be because, contrary to many previous gaze cueing tasks, we used a full head shift, as opposed to a movement of just the eyes.

Langton and Bruce (1999) demonstrated that head orientation and gaze direction both yield robust gaze cueing effects, leading us to initially deem the current stimuli as appropriate. However, upon reflecting on the result, we found evidence in the literature that when the face is averted by 30 degrees (similar to our stimuli), gaze effects were reduced (Hietanen, 1999). Hietanen (1999) argued that this is because when both head and eyes are averted, the agent is perceived to be oriented away from the participant and gazing straight ahead. As a result, the behaviour of the perceived agent is perceived as being less socially engaged or relevant to the task at hand, and the direction of attention has less signal value. The findings of the study by Hietanen offer insight as to why gaze cueing effects in response to the robot and human faces might have been reduced, rather than amplified, relative to the arrow.

With that being said, an emerging number of studies exploring gaze cueing effects with avatars and physically embodied robots demonstrate that full shifts in visual attention (as demonstrated by a head and gaze shift) by embodied and virtual agents can indeed have powerful impacts on human behaviour when performed *in situ* (e.g. Schilbach et al., 2010; Wilms et al., 2010; Kompatsiari et al., 2018). Perhaps the most compelling research to combine the gaze cueing paradigm with embodied robots comes from work with the iCub robot, which indeed demonstrates that a physically co-located robot's gaze cues can be followed and used to induce prosocial feelings in a human interaction partner towards a robot (e.g. Ghiglino et al., 2020; Kompatsiari et al., 2019). Taken together, our failure to replicate the general human > arrows gaze cueing effect complicates any interpretation we may wish to make regarding the heart rate synchrony manipulation on following Pepper's gaze.

Next Steps

Cardio-visual Synchrony

Perceiving the "other" as similar to the "self" is proposed to be a crucial mechanism underpinning the prosocial benefits of synchrony (Hove & Risen, 2009). Previous cardio-visual synchrony studies have supported this suggestion – finding that participants feel greater self-identification towards objects and images which are flashing in a Synchronous (as opposed to asynchronous) manner relative to their heart rate (Sel, Azevedo and Tsakiris, 2017; Suzuki 2013). In this study however, average scores on the Self-Other overlap questionnaire were very low, regardless of whether Pepper was flashing in a synchronous or asynchronous manner. The lack of change before and after interacting with Pepper, regardless of group allocation, suggests that the manipulation was ineffective in terms of altering the perception of self-other overlap. Based on Hove & Risen's (2009) theory that prosocial behaviours are the result of identifying with another individual, it could be that we did not see positive effects of the manipulation in terms of liking, hesitation time, or any of the other measures due to the negligible perceived overlap between individual participants and Pepper. Questions still remain, though, whether the lack of change in self-other identification scores (and the general pattern of null findings) are most attributable to the robotic nature of the "other", the subtlety of the light manipulation, or both.

To reduce the subtlety of the manipulation, facilitate greater attention towards the lights, and potentially an increased impression of synchrony, future work could incorporate a task design that seeks to accelerate and decelerate participants' heartrate in response to some sort of external stimulus, while ensuring the robots' illumination also matches these changes in heartrate. Alternatively, future work could attempt to induce measurable effects by increasing the salience of the lights (e.g. by illuminating a whole limb, or face, as in previous studies) (Sel, Azevedo and Tsakiris, 2017; Suzuki 2013). We would also advise that researchers carefully consider how they define and measure self-other overlap, as we found that some participants were unfamiliar with the concept (and asked for clarification when answering questions).

To gain a more complete understanding of the effects of cardio-visual synchrony as a potential facilitator of prosocial behaviours and self-identification with a robot, it is necessary to conduct further work using different equipment. For example, in this experiment, we used a commercially-available wrist-based sensor – as our goal was to create a manipulation which was inexpensive, feasible to introduce in real-world settings, and subtle. By doing so, however, we were limited to the measurement of pulse rate (as opposed to heart rate, as measured in the chest) and it was not possible to precisely match the phases of the heart with the lights of the robot as a result. More accurate and reliable heart monitoring equipment (e.g., ECG) would be valuable in the pursuit of such heart-robot matching, although such equipment introduces other challenges for real-world applications as a result of increased costs and reduced ease of use.

A number of limitations to the present study warrant mention and will require further investigation in order to determine whether our failure to find the predicted effects of cardio-visual synchrony is due to the ineffectiveness of such a manipulation with robots in general, or peculiarities of our particular approach. For example, whether the success of the human—robot synchronisation manipulation depends on the algorithm used. It would be valuable for future studies to explore different types of algorithms (for example, an oscillator model, which could help remove sources of noise) to test whether such approaches impact the effects of cardio-visual synchrony between humans and robots. Furthermore, the success of the experiment could also be related to the particular type of task used. At this stage, it would be useful to explore the extent to which synchronisation effects are amplified in sensorimotor tasks, or where sensory processing is related to interaction frequency (see Henschel & Cross, 2020). Along these same lines, unlike the control of arm or leg movements, or even breathing, most people cannot (easily) exert direct control over their heart rate, and heart rate itself is not easily visible to spectators. Even though an increasing number of studies exploring cardio-visual synchrony are emerging from a number of leading psychology laboratories around the world (Azevedo et al., 2022; Galves-Pol et al., 2020; Heydrich et al, 2018), it could be that the subtlety of such effects and manipulations remain ill-suited for implementation in human—robot interaction contexts.

Attachment to Robots

The hesitance to hit paradigm, and the associated qualitative results, proved insightful – not only in terms of method validation (showing that participants hesitate to hit a robot for many reasons) but also for identifying individuals who quickly felt a connection with the robot in this context. The researchers are mindful, however, that the results of this experiment could vary significantly depending on a range of factors – for example, if the following was altered (even slightly) - the robot's appearance, the behaviour of the experimenter or the robot, or the experimental setup (e.g., the instruction to hit, or the study environment). In addition to these obvious limitations, there were unexpected consequences associated with the paradigm which lead us to emphasise caution for future replications. Specifically, some participants reported feeling anxious and stressed whilst deciding whether to hit the robot. Additionally, the experimenter experienced high levels of stress as a result of repeatedly observing individuals in a state of distress (whilst having to remain composed and neutral).

Moving forwards, there is also a clear need to balance maintaining realism while minimising participants' stress emerges (Geiskkovitch et al., 2016; Rea et al., 2017). As part of Geiskkovitch and colleagues (2016) guidelines for researchers hoping to do so, they recommend that experimenters take the time to revisit and read the major codes of ethics that govern research with human participants, such as the Declaration of Helsinki (World Medical Association, 1964; 1996) and the British Psychological Society (2014) Code of Human Research Ethics. It is also recommended that if researchers choose to conduct "robot abuse" studies in future, they consider the implications of doing so – not only for the wellbeing of participants and the research team, but for the field of human—robot interaction more broadly. Studying moral behaviour with robots presents new ethical challenges, and researchers working on the front lines of this discipline have a duty to actively reflect on and refine ethical guidelines (Chrisley, 2020; Rea, Geiskkovitch & Young, 2017; Williams, Zhu & Grollman, 2020).

2.6. Conclusions

Here we report that cardio-visual synchrony had no significant effect on prosocial attitudes and behaviours towards the Pepper robot. The subtlety of the manipulation offers one explanation as to why no difference emerged, and it would be beneficial for our understanding of perceived synchrony to conduct further research using a more obvious signal or a robot that illuminated more uniformly (such as the MiRo robot developed by Consequential Robotics). Although the current study failed to yield affirmative answers regarding the utility of cardio-visual synchrony for inducing prosocial thoughts and behaviours toward a robot, it nonetheless highlights potential issues with certain methods used to measure perceptions of, and behaviour towards, robotic agents.

Through qualitative data we show that the hesitance to hit paradigm is not only probing liking, but it also taps into other factors such as perceived cost and a person's concern for their own safety. We also find huge variation between participants with regards to how they refer to Pepper, and perceived feelings of connection towards the system. Based on current and other recent findings (e.g. Henschel & Cross, 2020), we would also argue that measures such as the Godspeed Liking scale are overly specific - focussing on social liking and neglecting other forms of liking in the process. In addition to advising the use of embodied human—robot interaction for probing other cognitive measures of social perception, such as gaze cueing (e.g.

Kompatsiari et al., 2018; 2019; see also Henschel, Hortensius & Cross, 2020), we also suggest that future studies also make more use of open-ended questioning of participants' subjective experiences. In doing so it is possible to gain new insights regarding measurement techniques and individual differences, and generate new research questions that are highly relevant to our future social engagements with robotic technologies.

CHAPTER 3

Upon reflecting on the previous study, I found that the results lacked depth and clarity with regards to human—robot attachment. This is understandable given the general lack of knowledge about the phenomenon, and the way that we approached the problem (focussing on novel manipulations and complex paradigms). For the benefit of the field, I decided to approach the subject differently in this upcoming chapter – focussing on the words of the participants. It is one of my favourite pieces of my career, and I am delighted that it was published in the scientific journal *Frontiers and Robotics in AI*, in February 2021.

Riddoch, K. A., & Cross, E. (2021). “Hit the robot on the head with this mallet”-making a case for including more open questions in HRI research. Frontiers in Robotics and AI, 8, 2. https://doi.org/10.3389/frobt.2021.603510

Chapter 3 "Hit the Robot on the Head… with this Mallet" - The Case for Including More Open Questions in HRI Research

3.1. Abstract

Researchers continue to devise creative ways to explore the extent to which people perceive robots as social agents, as opposed to objects. One such approach involves asking participants to inflict 'harm' on a robot. Researchers are interested in the length of time between the experimenter issuing the instruction and the participant complying, and propose that relatively long periods of hesitation might reflect empathy for the robot, and perhaps even attribution of human-like qualities, such as agency and sentience. In a recent experiment, we adapted the so-called 'hesitance to hit' paradigm, in which participants were instructed to hit a humanoid robot on the head with a mallet. After agreeing to do so, participants were stopped, and then took part in a semi-structured interview to probe their thoughts and feelings during the period of hesitation. Thematic analysis of the responses indicate that hesitation not only reflects perceived socialness, but also other factors including (but not limited to) concerns about cost, mallet disbelief, processing of the task instruction, and the influence of authority. The open-ended, free responses participants provided also offer rich insights into individual differences with regards to anthropomorphism, perceived power imbalances, and feelings of connection towards the robot. In addition to aiding understanding of *this* measurement technique and related topics regarding socialness attribution to robots, we argue that greater use of open questions can lead to exciting new research questions and interdisciplinary collaborations in the domain of social robotics.

3.2. Introduction

Robots as Social Agents

Laboratory-based studies have demonstrated that in some contexts, people attribute human-like attributes to machines, including gender, personality, and intentions (Bernotat, Eyssel & Sachse, 2019; Craenen et al., 2018; Marchesi et al., 2019). Weise, Metta, and

Wykowska (2017) suggest that such attributions occur because we have an innate desire to understand our environment, and upon encountering unfamiliar agents, we default to what we are familiar with - the so-called human model. They propose that the application of the human model is why we incorrectly perceive the actions of machines as thoughtful, intentional, and emotional (Wiese, Metta & Wykowska, 2017). Along similar lines, other researchers propose that the crossover between human- and robot-directed cognition can be explained by the "like-me" hypothesis of social perception and cognition, as originally proposed by developmental psychologists (Meltzoff, 2007). According to this theory, understanding the basic similarity between self and others forms the basis for social cognition, and we are biologically hard-wired to seek out self-other equivalence in other agents, including social robots (for a review, see Hortensius & Cross, 2018). Together, theoretical and empirical work examining the human model and the like-me hypothesis have led to the suggestion that in some situations, people are likely to perceive, interact, and connect with robots as though they are social agents, at least to a certain extent (Wiese, Metta & Wykowska, 2017; Hortensius & Cross, 2018; Hortensius, Hekele & Cross, 2018).

To probe the extent to which we perceive robots as social agents, as opposed to objects, one approach researchers have used is to ask participants to inflict "harm" on robotic agents. For example, previous experimenters have asked people to administer increasing levels of "electric shocks" to a robot (Bartneck et al., 2005), turn a robot off and "wipe its memory" (Bartneck et al., 2007), and hit a robotic animal with a hammer (Darling, Nandy & Breazeal, 2015). The experimenter takes measures such as how many times the person strikes the robot, the number of pieces it was broken into, and the amount of time between being given the instruction and compliance (termed "hesitation"). Bartneck and colleagues (2005; 2007) suggested that minimal hesitation reflects the perception that the robot is perceived as a sentient being. However, in these studies, participants were not asked whether they thought the robot appeared to be a living being, was an intentional agent, or anything else along these lines, so this suggestion was simply speculative at the time the studies initially appeared. In a later paper, Bartneck and Hu (2008) acknowledge this, stating that the assumption they made was not grounded in empirical evidence, but was instead included in an attempt to stimulate discussion (Bartneck & Hu, 2008). As a result, the question remains - when asked to hit a robot, what does hesitation reflect? What is the paradigm actually measuring?

Darling, Nandy and Breazeal (2015) demonstrated that individuals with high trait empathy hesitate for longer, suggesting an empathetic component to the hesitation duration. In the present study, our aim was to investigate this further. We wished to explore the validity of this technique as a measure of social attribution or empathetic concern for a robot, and also provide a more detailed and nuanced account of what the hesitance reflects. To do so, we adapted the hesitance to hit paradigm to suit a humanoid robot, and, crucially, conducted semi-structured follow-up interviews with participants regarding their reasons for hesitating. Through exploration and qualitative analysis of themes that emerge from these interviews, we hope to provide greater insight into this paradigm and the perceptions of participants when confronted with harming a social robot.

3.3. Method

Study Overview

In a laboratory-based experiment described elsewhere (Chapter 2), 84 adults interacted with a humanoid robot programmed to illuminate synchronously or asynchronously, relative to their heart rate. In an attempt to probe liking and attachment, participants were then instructed to hit the robot on the head with a mallet. Following this, individuals were interviewed about their thoughts and feelings during the "hesitance to hit" paradigm. While this data was briefly discussed in the initial writeup (Chapter 2), in the current study, we used thematic analysis to explore the interview data in greater detail. We also considered the data in relation to the demographic data collected. The original empirical study (Chapter 2) identified no impact of the synchronicity of illumination on self-reported liking of the robot, behavioural measures intended to probe perceived socialness, or the extent to which participants hesitated to hit the robot. As a result, the qualitative data described in the current study were not split between the a/synchronous groups.

Preregistration & Ethics

Following open science initiatives (Munafò et al., 2017), the data, stimuli, and analysis code associated with this study are also freely available on the Open Science Framework https://osf.io/d7c8t/. All study procedures are approved by the College of Science and Engineering Ethics Committee (University of Glasgow, Scotland) – approval number 300180265.

Participants

Eighty-nine individuals took part in the experiment. Data from 12 individuals were excluded as these participants encountered problems which affected their experience with Pepper (error lights within Pepper, loss of Bluetooth/WIFI connection, and hearing problems). Technical difficulties relating to the audio recordings (recorder failure, poor audio quality, and file corruption) led to the exclusion of a further 12 participants. As a result, the final sample consistedof 65 individuals aged 18 - 83 (MAge = 42.29, SDage = 21.42), with 25 individuals over the age of 60 ("older adults"). Participants were individuals residing in Glasgow (Scotland, UK) and were initially recruited by word of mouth (in person, via email, and through social media advertisements) followed by snowball sampling. All individuals had normal or corrected-to-normal vision and hearing, and no previous experience interacting with the robot used in the study. Participants were compensated £10 for their participation.

The Robotic Platform

The robot used in the experiment was the Pepper robotic system - a commercially available humanoid robot from SoftBank Robotics (Tokyo, Japan). Pepper is 120cm tall and features 2 in-built cameras, as well as microphones and tactile sensors, which allow it to detect objects and movement in the environment. See Figure 3.1 for images of the Pepper robot.

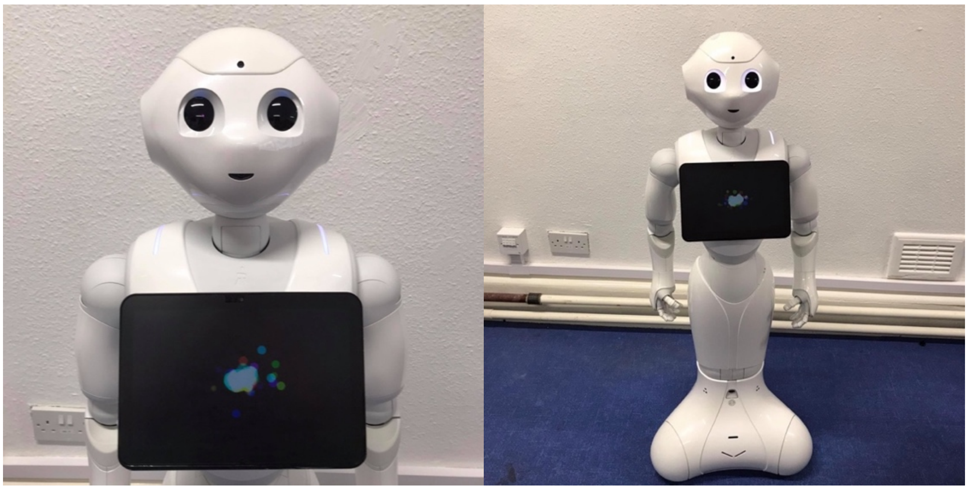

Figure 3.1. Images of the Pepper Robotic System (Softbank Robotics)

Pepper also has expressive movement and speech capabilities that can run autonomously, but for the purpose of experimental control, we controlled Pepper's behaviour using 1) the static "default mode", 2) the "Choreograph" software, and 3) a novel panel of key phrases. The panel of phrases was created using html, and upon clicking a speech button the corresponding line of Python code is triggered and Pepper speaks and moves accordingly.

The Human—Robot Interaction

Whilst the participant completes consent forms, a computer-based task, and demographic questionnaires (See Section 2.6 "Questionnaires" for details), Pepper was triggered to stand upright, gaze straight ahead, and engage in slight breathing motions ("default" mode, "autonomous life" enabled). The participant was then invited into the testing space, and was prompted to take a seat. See Chapter 2 for a detailed depiction of the room set up. The participant was instructed to spend approximately one minute drawing Pepper, then an additional 4 minutes making notes about the robot's appearance ("Draw and Describe Task"). Participants were then asked to observe as Pepper performed thai chi, pretended to vacuum, and played an imaginary saxophone ("Perform Task", 2 minutes). This sequence of animations was predefined and triggered in the "Choreograph" software so that Pepper appeared to be acting independently of the experimenter.

Hidden behind a screen, the experimenter then used a html panel to control the speech and movement of the robot - asking participants questions about their food preferences, and what they would like to add to a "shopping list" ("Shopping List Task", 3 minutes). To maintain experimental control, for each interaction the experimenter systematically clicked from the first phrase "Hi there", through a series of closed questions and responses, to the final phrase "Thank you". Closed questions (E.g. do you prefer tea or coffee?) and option-specific responses were used to create the illusion that the robot was responding to the specific words of the participant. See OSF (https://osf.io/d7c8t/) for script. To check interaction quality post-hoc, this final task was recorded using the discrete webcam device. In total, the human—robot interaction ("Draw & Describe", "Perform", and "Shopping List Task") lasted approximately 10 minutes.

Adapted "Hesitance to Hit" Paradigm

After interacting with the robot, participants completed a gaze-cueing task on the computer in which they observed images of robots and humans (for details, see Chapter 2).

Pepper was set to "Default Mode" and the video recording device is triggered, then the participant was invited to take a seat in the testing space, in front of Pepper. The person was then prompted to don a pair of safety goggles. The experimenter then read the following script: *"Right, there is something I haven't told you about this experiment. This Pepper is one of ten specially designed robots that I was given as part of a large research grant. By "specially designed" I mean that they're totally shatterproof – so if you hit one, the robot will break in a safe way that's easy to repair. The reason Pepper is designed this way is because our lab is interested in what happens when someone has to hit a robot – for example, if a robot was to malfunction and you had to hit and disable one. Does that make sense? *await participant confirmation* Great." *Experimenter passes participant the hammer* "So, for this part, your task is to give the robot one hard hit on the head. So, when you're ready, come round the table and I'll get out of the way."*

After standing up to hit the robot (indicating the intention to hit the robot), the participant was told to pass the hammer to the experimenter, and was informed that they will not actually be hitting the robot. The participant was then prompted to remove their safety goggles and was invited back to the control area for a task debriefing. If the participant verbally protested against hitting the robot, they were told "It's just part of the experiment". Upon protesting three times, the task was ended as indicated previously, and the participant was deemed to have "refused" to hit the robot.

After the task, the participant was asked questions probing their thoughts and feelings during the period of hesitation. This was achieved by asking open questions such as "After I asked you to hit Pepper, what was going through your mind?". See OSF (https://osf.io/d7c8t/) or base list of questions. In addition to the "base questions", the experimenter asked additional questions to probe vague responses (e.g. "I felt weird", to which the experiment responded "what do you mean by weird?"). The experimenter was mindful not to ask leading questions (e.g. "Did you feel any emotions?", instead of "Did you feel sad") or gender Pepper (e.g. "the robot", instead of referring to Pepper as "he/she"), and all interviews were recorded and transcribed for transparency and completeness.

To conclude the experiment, participants completed demographic and personality questionnaires (See "2.6 Questionnaires" section for details), and were then debriefed, thanked and compensated for their time.

Questionnaires

To probe 'liking', participants completed the validated 'Liking' scale of the Godspeed Questionnaire (Bartneck, Kulic, Croft & Zoghbi, 2009) before and after interacting with the robot. We also administered questionnaires probing the extent to which participants perceived the robot as a social agent; specifically, the Inclusion of Self in Other task (Aron, Aron & Smollan, 1992) and the Robotic Social Attributes Scale (Carpinella et al., 2017). Participants also completed questionnaires to probe their history with robots via the Exposure to Cinematic Depictions of Robots (Riek, 2011), and Negative Attitudes towards Robots (Nomura et al., 2008) questionnaires. To account for between-group differences with regards to anthropomorphic tendencies and general empathy, the Individual Differences in Anthropomorphism Questionnaire (Waytz, Cacioppo & Epley, 2010), and the Empathy Components Questionnaire (Batchelder, Brosnan & Ashwin, 2017) were also administered. Participants were given the option of completing the questionnaires on paper, or via the online questionnaire platform form{'r} (https://formr.org/).

Data Processing and Analysis

Behavioural Data Analysis

The time between the end of the instruction to hit the robot, and the participant beginning to stand, was taken as the "hesitation time". In previous studies, the time until the participant hit the robot was used, however this was not feasible in this study due to the cost of the Pepper Robotic System. "Hesitation time" was determined through consultation of the task video recording, and timings were validated by two independent coders. There was only one discrepancy between coders regarding timings, and this was resolved following re-watching the videos and discussion between the coders. The same process was used to determine the number of "protests" exhibited by each participant. Again, coders independently documented protest frequency, and discrepancies (2) were discussed and resolved together. The resulting data were visualised to illustrate individual differences (See Section "3. Behavioural Results" for plots).

Qualitative Data Processing

To aid analysis of the interview data, audio files were transcribed using an audio-to-text transcription service, followed by manual transcription to correct for errors. The text files were then imported into NVivo, a piece of software useful for managing and assisting with the analysis of qualitative data. The lead investigator then systematically "coded" phrases within the text. For example upon seeing "I felt upset", the coder created the code "Felt negative emotion" and added the phrase to that code. Upon encountering a similar phrase in a different transcript, the experimenter could also assign that phrase to that code. Over time, the coder develops a "code-book" full of different codes and their corresponding phrases. This "data-driven" method is known as the Inductive approach (Linneberg & Korsgaard, 2019) and is particularly useful for exploratory analyses as codes are generated based on the data. There was also the option to create codes a priori (aka "concept-driven"/deductive approach) however we did not want our prior knowledge or research interests to restrict or bias the codes created.

After working through the documents, creating the codes, and assigning relevant quotes to codes, the lead investigator used the "word search" tool to check that relatively new codes were not present in previous files. On the basis of work suggesting that having an independent coder improves scientific rigour and data validity (Nowell et al., 2017), a second coder of a different gender and educational background, was recruited. The independent coder was allocated a subset (~ 10% = 6 transcripts) of the data to code. To control for order effects and to check generalisability of codes, a random number generator was used to select which files to send to the second coder. The first six numbers corresponded to 2 older adults, and 4 young adults, so another two random numbers were generated, to balance the ages within the data subset. To avoid bias, the second coder was not informed about the specific research questions, nor the codes created by the lead investigator. They were simply told that participants had interacted with a robot, and were given the task instruction that the participants were presented with, for context. They were then sent a series of video tutorials regarding how to use NVivo (Hull University, 2019) ("Getting Started with your First Project", "Adding Files to an NVivo Project" and "Getting Started with Coding", from Hull University YouTube Channel), and were instructed to use an interpretive approach to code the transcripts. No interpretive coding training was required as the second coder had previous training and experience using the approach.

The plan was then to discuss changes with the second coder, however this was not possible due to illness. As a result, the lead investigator instead updated and altered their codes on the basis of the second coder's subset coding, and journaled the thought-processes and rationale behind the changes made (https://osf.io/d7c8t/). The practice of journaling is one method of improving the transparency of qualitative data analysis (Nowell, Norris, White & Moules, 2017). Thematic analysis (Braun & Clarke, 2006), was then used to group codes into broader "themes". See Section 4 Qualitative Results for insight.

Reflexivity

Reflexivity, in this context, refers to the practice of acknowledging the role of the researcher within the research process. For example, being transparent regarding how the research process may have been influenced by the researcher's previous experiences, assumptions, and beliefs. Rather than being a criticism of the work, reflexivity allows the reader a greater level of insight and understanding regarding the research process and the underlying thought processes. In qualitative research, reflexivity is particularly important, as the interpretation of the data is subjective by nature.

When considering the results of this study, particularly the qualitative elements, it is insightful to consider the background and research interests of the researchers involved. Firstly, all researchers involved have a background in Psychology and Cognitive Neuroscience – as a result, it is to be expected that findings will be interpreted with a strong emphasis on the individual, their perceptions, and their thought processes. Additionally, all researchers were part of a laboratory heavily involved in the study of mind perception, and whether robots are perceived as objects or social entities. As a result, there will naturally be a focus on such references within the data.

3.4. Results

Behavioural Results

In this study, we determined "hesitation" by measuring the time between the end of the instruction to hit the robot, and the participant standing up to do so. This data indicated that the majority of participants hesitated for less than 25 seconds. See Figure 3.2 for data visualisation. The majority of participants did not protest against hitting the robot (e.g. "I don't want to...", “Do I have to...?”) when asked (See Figure 3.3 for overview). Individuals who refused to hit the robot are not plotted in Figure 3.3.

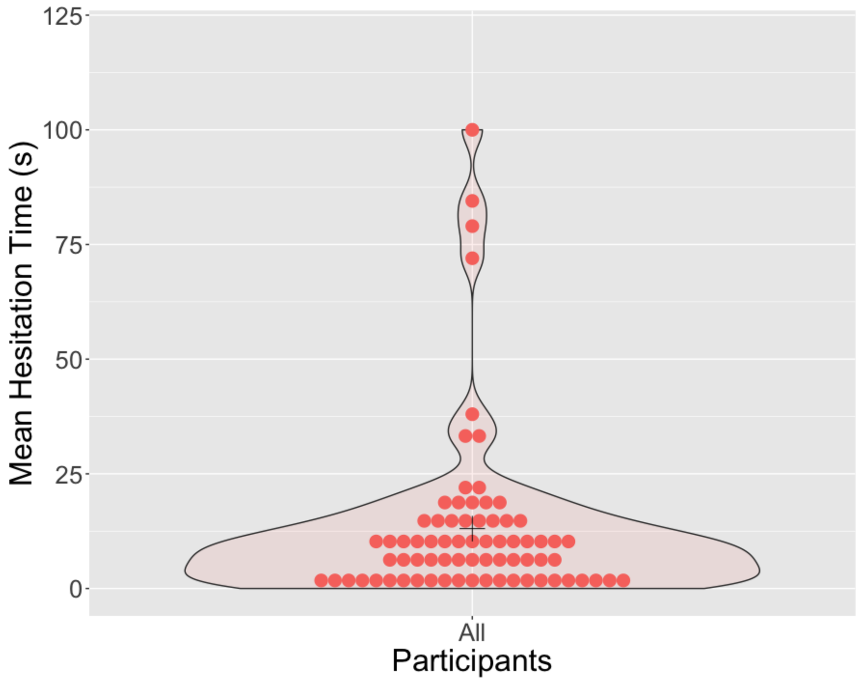

Figure 3.2. Density plot to illustrate the length of time each participant “hesitated” for, after being asked to hit the robot. Three participants refused to hit the robot, and their data is not included in this plot as a result.

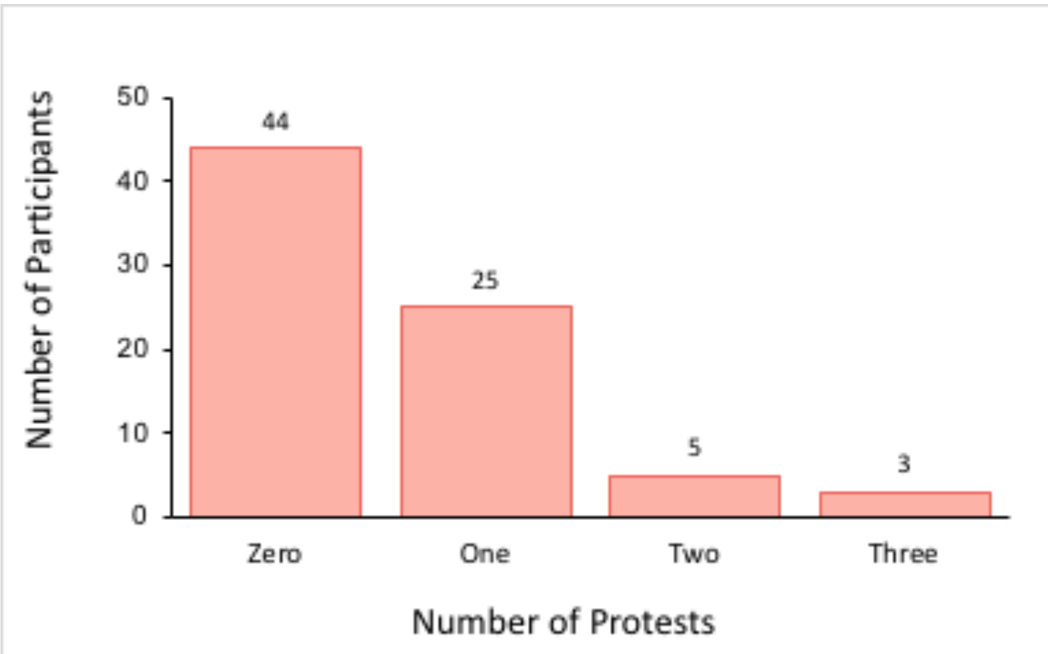

Figure 3.3. Chart to illustrate the frequency of individuals exhibiting the distinct number of protests (0, 1, 2 , or 3 protests). Note: After protesting 3 times the experiment was terminated, and the participant was deemed to have "refused" to hit the robot

Qualitative Results

After merging the codes of both the lead investigator and the independent coder, said codes were grouped into "themes". From a practical point of view, this was achieved by placing individual text boxes (each containing a code) into PowerPoint, and manually arranging related codes near to one another. Said groupings (aka themes) were then named. The themes included: 1) Factors Affecting Hesitation, 2) Reasoning For Hitting, 3) Reasons Against Hitting, and 4) Other. Such "Thematic Analysis" is a well-established approach (Braun & Clarke, 2006) which allows the researcher to discuss points in relation to one another, as opposed to individually, and provide additional insights as a result. As with the coding process, the rationale behind each of the themes constructed was detailed in the coding journal (https://osf.io/d7c8t/). In this section we will discuss each of the themes in turn.

Factors Affecting Hesitation

Whilst coding the data it became apparent that there were many different reasons why participants hesitated after being asked to hit the robot - cost awareness, deception detected, fear of negative consequences, mallet disbelief/attention, hit strategising, task overload/processing, and questioning of the task purpose. These codes (summarised in Figure 3.4) will be discussed in relation to one another, in this section.

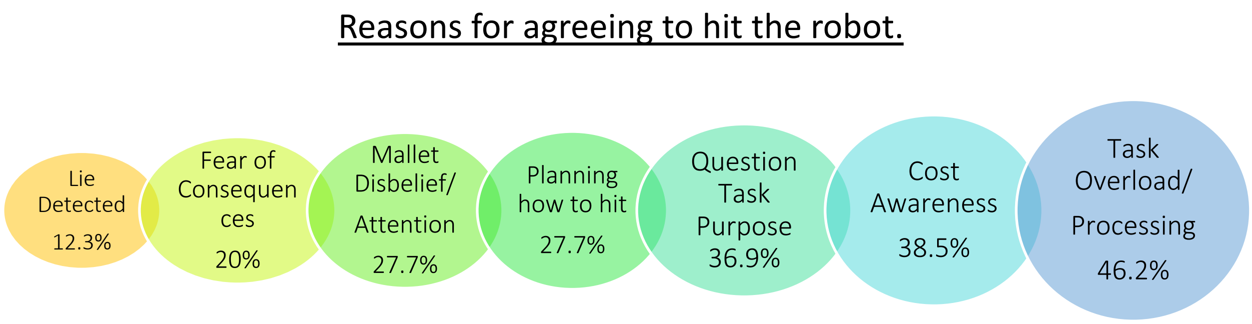

Figure 3.4. Illustration of the codes grouped under the theme 'Factors Affecting Hesitation'

Of the 65 participants, 18 commented that they hesitated due to disbelief and attention regarding the "heavy weight" of the hammer. Four participants indicated that they thought the mallet presented to them might be fake or plastic, and they were surprised when they picked up the mallet and found it to be metal. As a result, for some people, "hesitation" apparently reflected a period of attention and reflection regarding the mallet. Numerous participants indicated an awareness about the cost of the robotic system and concerns about breaking something expensive (n=25). Three participants reported being uncertain whether they would have to pay for repairs, and the period of hesitation reflected consideration if this would be the case or not. Participants were not informed of the price of the robot, however participants identified that they inferred high cost from the robot's large size compared to other appliances, fine-grained movements, and seemingly "intelligent" responses. Despite concerns regarding damage and cost, such participants did not vocalise their concerns to the experimenter, and all did agree to hit the robot. This suggests that although concerns about cost may influence hesitation in this task, there were other competing factors which influenced their decision-making.

> *"Well, initially I thought it was going to be like one of those plastic ones. But when I found it to be metal I thought, this is crazy. *laughs*"*

Participants also expressed that after being given the task instruction, they began to think about other potential negative consequences of their actions. In addition to being concerned about the cost of damaging the robot (n=25), some participants expressed that such destruction was wasteful and unnecessary (n=19). Other participants indicated that they worried if the robot might react to their approach (n=13). In addition to concerns regarding unexpected movement, individuals expressed a worry that the robot would let out an emotional response, or retaliate somehow.

> *"I felt a little bit scared, kind of like if I hit him, it can have like a kind of, react back to me. Like, hit me back or something."*

> *"I sort of thought forward and thought, I bet if I pick up the hammer then, I thought Pepper was going to scream at me - like "oh no, don't do it!" or something.*

I didn't want to get into that kind of situation…"

"I was also thinking, if I do have to hit him, I hope he's switched off. I don't wanna… oh that would be the worst thing if you can hit him while he's switched on - he can probably feel pain and react"

Many individuals also commented that they "did not want to hit the robot hard" (n=26) and there was repeated reference to giving the robot a "light tap" (n=20) as a result. There were also individuals who questioned what constituted a "hard hit", and that they worried about the consequences of disobeying the experimenter by not giving the robot "one hard hit", as instructed. In contrast, other individuals apparently contemplated how they could hit the robot to inflict the most damage (n=7). One person explained that the implied unbreakability became a personal challenge, and their hesitation time reflected a period in which they planned what would be the most effective way to break the robot.

"It's almost like hitting somebody, but it looks as if it's… it's got feelings, or we would be wasting it. I felt very uncomfortable. I'd have only have given him a tap"

*"I was thinking, you know, if I have to, I will hit her, but not hard. *laughs* …I just don't you feel good doing this. You know, it was, the robot didn't do me any harm."*

*"I wanted to see how robust it was because you said it's unbreakable, well... it's designed in a way that if you hit it, it'll break in a way that you could fix it. And I was like, no, I can break that beyond repair. *laughs*"*

Participants also commented that hesitation resulted from task overload and processing (n=30). Specifically, there was repeated reference to hesitation resulting from the shift from basic questionnaires and a repetitive computer-based task, to a task in which they had a more active role with control and decision making power. Participants reported feeling "confused" about what was expected of them (n=13), and that they hesitated in order to "assimilate all the information" and process what was the "right" way to respond to the request. In contrast, four individuals commented that "it happened so quickly", and they mindlessly followed the instructions as a result. The contrast between those who take time to process the information, and those who mindlessly comply, suggests a need to measure the generic task processing/emotional responding of participants. Without doing so, differences in task performance could be misinterpreted. Such thoughtless cooperation is thought-provoking and brings ethical questions to the surface. Although participants signed a consent form at the beginning of the experiment and were given the opportunity to ask questions, are they truly consenting if they follow the experimenter's instructions in a mindless way?

> *"I think it's just, you spruce it up so quickly that I didn't really have time to think about it… I think if I were watching myself it would have like, it's weird like, I would have instantly been like "something is off here"... but it's just the fact it was like…You don't have time to recalculate."*

> *"Once I had assimilated all the information that was given to me, I was like, well, it's your experiment, it's your robot, sure."*

Some participants indicated that the unusual nature of the task led them to question whether the instruction was "a joke" (n=6), and they hesitated in order to judge the behaviour of the experimenter and decide how to proceed. Other participants apparently thought about how the task related to the rest of the experiment, and whether it was "a test" of their own morality (n=4). Three individuals mentioned that they recalled the famous Milgram experiment (Milgram, 1963) in which participants were asked to seemingly administer increasing levels of electric shocks to another person. The individuals drew comparisons between that study and their current participation, and began to question whether their task experience was also testing authority and obedience. As a result, it seems that hesitation not only reflects task processing but potentially prior research knowledge of psychological research. By making note of education background, interviewing participants after the task, and recruiting from the general population as opposed to exclusively from the student pool, it would be possible to gain greater insight regarding the impact of prior knowledge on task performance.

> *"I didn't know what to think about this. it was kind of weird. *laughs*. So I wasn't sure is it a joke or is it really part of an experiment"*

> *"Yeah. Um, I think it's difficult because you want to - on one hand, you want to comply in an experiment, but on the other hand you overthink that it could be an experiment on compliance. And you're not sure what is the right thing to do."*

"It's a huge shift and like everything else is fairly relaxed. And so it definitely feels like a wild card. And it kind of gets me thinking like, OK, what is the purpose? Yeah. What's the purpose of this? Like, does it relate to the rest of the experiment? Like, how does it relate."

Reasoning Against Agreeing to Hit

As mentioned previously, the majority of participants indicated that despite standing up to do so, they *did not* want to hit the robot. In this section we discuss the reasons people did not want to hit the robot - specifically, due to conflicting feelings/thoughts, the perception of a power dynamic, the importance of two-way interaction, concerns about waste, a perceived connection to Pepper, and a sense of injustice. See Figure 3.5 below.

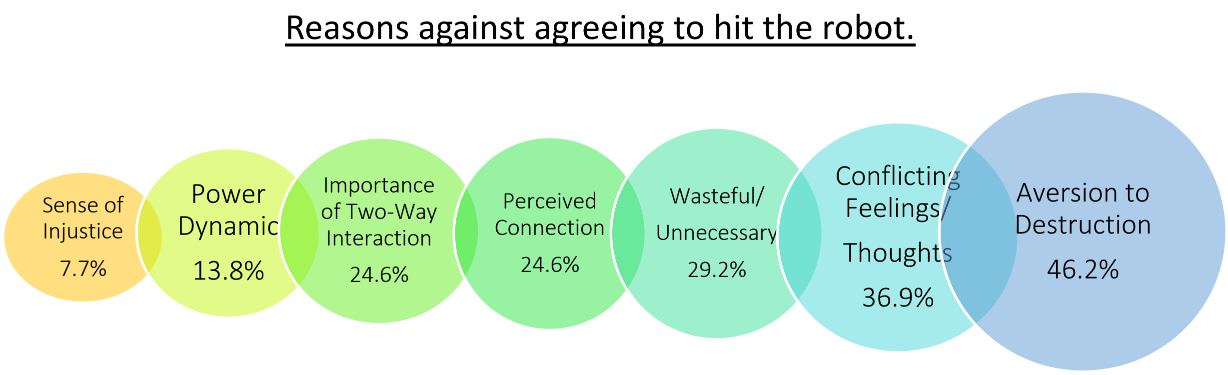

Figure 3.5. Illustration of the codes grouped under the theme 'Reasons Against Agreeing to Hit'

Upon indicating that they did not want to hit the robot, participants were probed why this was the case. Some suggested that they felt it would be wasteful/unnecessary to do so (n=19) as they thought Pepper "expensive", contained "lots of tech", and was a "beautiful" piece of machinery. A couple of participants commented on the wasteful nature of such an act in relation to the effort of those involved in creating the robot. For example, one participant suggested that to hit Pepper would be "to destroy everything that has led to that moment of creating such a balanced piece of tool". In contrast, others commented that it was not a matter of cost, and that they felt an aversion to destruction of property more generally (n=30).

"I mean, if I smash the toaster I would be like... why? All these product design engineers working their lives to create the perfect toaster and I'm just going to smash it with a hammer."

Other individuals indicated internal conflict due to a different reason - because they perceived a power imbalance in the situation, between themself and the robot (n=9). Specifically, participants suggested that being asked to hit the robot was like being asked to hit a "puppy" (n=2), "pet" (n=2), "animal" (n=2), or "child" (n=5). Participants who reported such a power imbalance mentioned that they thought the situation felt "unfair", like "undue violence", and they planned to only give the robot "a light tap" as a result. The perception of the robot as "animal-like" was reported in reference to how it was "vulnerable" and "couldn't fight back", rather than its appearance or behaviour attributes. This makes sense given that the Pepper robotic system is humanoid in both respects. In contrast, the perception of the robot as a child was reported to stem from its small stature, the "child-like" voice, and a comment in the introductory video that the robot was "4 years old". The latter reason was only mentioned by one participant, but it is possible that other participants picked up on this short age-related comment and it influenced their perception of the robot as a result. Many measures were taken by the experimenter not to intentionally humanise Pepper (e.g. referring to Pepper as "the robot", not allowing Pepper to use phrases indicating preference, etc.), but this unfortunate oversight adds an extraneous variable into the mix. The perceived sense of injustice was also commented on without reference to animal or child-like qualities. Instead, participants commented that they felt the behaviour was unjust because the robot had not done anything to deserve such treatment (n=5).

EXP: Okay. And after I told you to hit Pepper, were you feeling any emotions?
PPT: Well, like... stressed a bit. Because... yeah, she didn't do anything. She was just put to sleep and I had to hit her on the head.

EXP: Oh! Why do you think you felt guilty?
PPT: Because it's small and it doesn't get it doesn't get it. It would be like hitting a puppy. Yeah, you'd feel guilty. Like your actions are undue violence.

"Well, you put yourself... it sounds ridiculous, but you put yourself in the robot's shoes because they can communicate and they're almost like humans. You know. I mean in terms of that way that they can communicate with certain things, very kind of literal stuff, but they can't maybe have a deeper conversation… so in a way it's a bit like having a child around, so it's that kind of thing where you're basically just 'I'm hitting it because 'I'm big you're small'. It's not right."

Other participants commented that their aversion to hit Pepper resulted from a perceived connection between themself and the robot. Specifically, despite only interacting with the robot for a mere 10 minutes, 16 participants reported that they felt a connection to Pepper. Ten participants reported feeling a "bond", "affection", "attached", a "relationship", or as though they were "friends" with the robot. The other six spoke about connection in other ways - specifically, they spoke about how they felt "trust" from the robot, a fondness/protectiveness, or a bond similar to the bond they have with their car. The variation in language, and the types of "connection" emphasise the complexities of study attachment to robots. It is not necessarily appropriate to simply state that some people get attached to robots, when there is apparently much variation in the types of connection/attachment.

> *"This is not a person. But I almost felt like I had a relationship with them… like a person! *laughs* Oh dear!"*

> *"I kind of felt bad about that because I was bonding with Pepper before… and I really don't want to hit her in the face."*

> *"Pepper's definitely brought something out in me that I didn't expect. A kind of fondness… protectiveness. Even though I put the… I know that it's got no emotions."*

In some cases, participants referred to the robot as an object that they felt attached to, but in others there was reference to Pepper as having a social presence, gender, and the ability to feel emotional/physical hurt. Of 65 participants, 33 reported the perception of the robot as a social presence, or as having gender, emotions, or the ability to feel pain… yet only 16 reported feelings of connection with, or attachment to, Pepper. These figures suggest that anthropomorphism and feelings of connection do not always co-occur.

> *"Although he's a robot, but, you begin to like him. You know, you begin to have a bit of friendship, affection. Because, you know, if he can respond to you then you feel that he is alive, so you don't want to have any aggressiveness with him at all."*

> *"With Pepper, after you've had a conversation, you've built up a rapport and a bond… how can you then go and whack them over the head?!"*

"With interacting with it, it didn't seem like an inanimate object you know. It just seems like as if it was… well, I mean I knew it wasn't a person but it was like erm, I don't know. And I knew it wasny human but I thought, of harming it, I didn't want to do it… we had this two-way interaction.

Of the 16 people who did report feeling a "connection" to Pepper, nine referenced the importance of the shopping list task, in which Pepper spoke to them. Other participants commented that they didn't want to hit Pepper due to its appearance - specifically, "big eyes" and "child-like appearance" were mentioned. There was also reference to how participants perceived the robot to be "nice", and they felt an aversion to hit it as a result. These examples demonstrate that connection can result from both physical appearance and programmed behaviours.

"I think eye contact is such a big thing in the human world, and then if a robot has got eyes then it's kind of, not scary, but you feel like you're making a connection with them".

"... because it can talk, it adds a bit of, and the conversation we had before, I guess I don't know, it's just some kind of connection between us"

*"I didn't think that I would be that attached. Or get that attached to it just because we had a wee convo. A conversation about dinner. *laughs*"*

Many participants reported feeling a sense of conflict after being asked to hit Pepper (n=24). Specifically, participants expressed that even though they knew the robot was just a machine, they felt "upset", "stressed" and "anxious" after being asked to hit it. Participants also reported that it felt "wrong", "nasty", "hurtful", or "unfair" to hit the robot. When asked why they felt such emotions, participants mused that it could have resulted from the "two-way" nature of the interaction, and the perception that Pepper was genuinely responding to them (n=16). This is intriguing when considering that the robot spoke to the participants via a series of binary-choice questions (e.g. do you prefer tea or coffee), followed by a basic scripted response to their choice (e.g. "mm tea, I'll add that to the shopping list"). The comments of the participants suggest that for some people, basic conversation can create the illusion that the robot understands them.

"The logical part of my brain was telling me that I could just take a hammer to it and it wouldn't matter. But, so there was a conflict inside me as well… like there was someone or something

would be upset if I was to do that… sort of putting some kind of emotion or feeling onto an object"

"With interacting with it, it didn't seem like an inanimate object you know. It just seems like as if it was… well, I mean I knew it wasn't a person but it was like erm, I don't know. And I knew it wasny human but I thought, of harming it, I didn't want to do it… we had this two way interaction.

EXP: After I told you that you didn't have to hit Pepper, what were you thinking and feeling at that point?
PPT: Happy. Thank goodness. But also confused at why I found it so difficult… I was kind of immediately like what, why is that?... because if Pepper is just a robot then why is it any different than like, smashing a computer?

Reasoning for Agreeing to Hit

Despite feeling negative emotions and not wanting to hit the robot for various reasons, as discussed previously, all but three participants *did* agree to hit the robot with the mallet. Upon prompting participants with the question "why do you think you agreed to hit the robot then?" it became clear that other influences were at play - 1) the influence of authority, 2) curiosity how the "shatterproof" robot would break, and 3) the desire to break/smash 4) the perception that hitting the robot was a necessary part of the experiment. See Figure 3.6 for visual summary. There were also instances of mindless compliance, which will be discussed in this section.

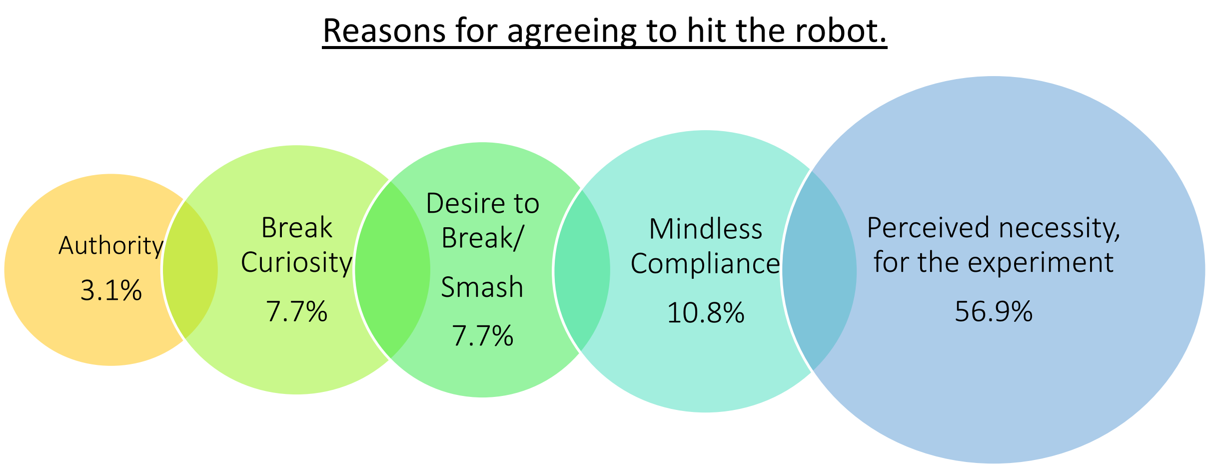

Figure 3.6. Illustration of the codes grouped under the theme 'Reasons For Agreeing to Hit'

When asked to hit the robot, 44 individuals got up from their seats without protest. When asked what they were thinking and feeling after being asked to hit the robot, numerous individuals stated that they thought “nothing” and felt “no emotion” (n=7). Such omissions are a stark contrast to the examples given in the previous section. It could be the case that participants were embarrassed to admit that they liked the robot, or that people had their own motivations for not wanting to appear in favour of such technology, and so spoke dishonestly as a result. Alternatively, their words could reflect their genuine thoughts and feelings, and are a reflection of individual differences. When speaking to such participants, the experimenter detected no obvious negative biases towards robots or technology in general (through conversation or questionnaires) and is of the belief that the participants were responding in an honest manner. A couple of individuals stated that they processed the task instruction, thought it was an important part of the experiment, and were happy to oblige as a result. Others indicated that they were not troubled or worried by the task because they knew that they would not be liable for costs to replace the robot.

> *“I was just looking at it as it if was just a thing... an object that I was hitting. There was no emotion, at all.”*

> *“Well, that was easy. I mean, once I had assimilated all the information that I was given to me... I was like, well, it's your experiment, it's your robot, sure.”*

In contrast to those who had no problem following the instruction (n=7), 37 participants explicitly remarked that they did not want to hit the robot, but they did so because they believed it was an “essential” part of the experiment and they had no choice but to proceed. Some participants commented on the power of authority, whereas others said that they complied simply because they “didn’t want to be rude”. There were also comments that people did not want to “spoil” the experimenter’s research. Such individuals specified that the desire not to spoil the research stemmed from their own experience conducting research, and the appreciation that noncompliance can be problematic. A couple of participants mentioned that they had participated in many research studies before, and that through repeated exposure they were conditioned to believe that they should comply with the experimenter’s instructions. Such examples illustrate the problem of recruiting within a university environment - both researchers and participants can be motivated to comply due to their own research experience.

"Well, I thought... I have to do what I'm told because it's an experiment and I've been told to do it. So I have to do it even though I don't want to."

"Because I absolutely did not want to, but I thought it was a part of your experiment and didn't want to let your, let anything affect your experiment, kind of thing. You know, if it was in a different setting, I wouldn't have. You know what I mean? It'd be a different case. Like if it was your personal robot and you're at home, and I'm over at your place and you go here! I'm like NO! There's no reason for it. Like, you know? But I guess for the experiment, my, my. I thought that there must be a reason."

"I guess I've done so many experiments, so I've been in here thousands of times, I've always just done what I'm told."

Other participants did not mention the influence of authority at all, and instead specified that agreeing to hit the robot was due to a genuine desire to test the "shatterproof" claims made by the experimenter, about the robot (n=7). Some seemed interested from a technical/materials point of view, and were curious to see if and how the robot could withstand such force. Others expressed that testing the shatterproof nature was important from a safety point of view, and they complied in order to ensure that the robot was safe to put into people's homes. In contrast, a couple of individuals stated that they were very excited about the opportunity to smash something claimed to be "shatterproof". Such individuals then reported feeling "disappointment" and "gutted" when they were told they did not have to hit the robot. One participant expressed that they were disappointed they couldn't hit the robot as it was an opportunity to "destroy something very expensive" and it was "something to tell your friends!". Another participant indicated that they felt a little embarrassed that they got so excited about the possibility of hitting the robot, and began to question their own morality as a result.

"Well, I guess just thinking that 'yeah if it's in the stage of being, that they're experimenting with it, that they're not 100% that it doesn't go violent or something… that the experiment needs to be done. Like, We need to know if it works or not."

"I was excited! I was looking forward to it. So I was like "I like a challenge" and I was like "this thing is meant to be not properly breakable"... and I wanted to properly break it. I wanted to be the first to properly break it.

Additional Insights

Participants were asked what they were thinking and feeling *after* they were told that they did not have to hit the robot. See Figure 3.7 for a summary of the most common feelings, amongst participants.

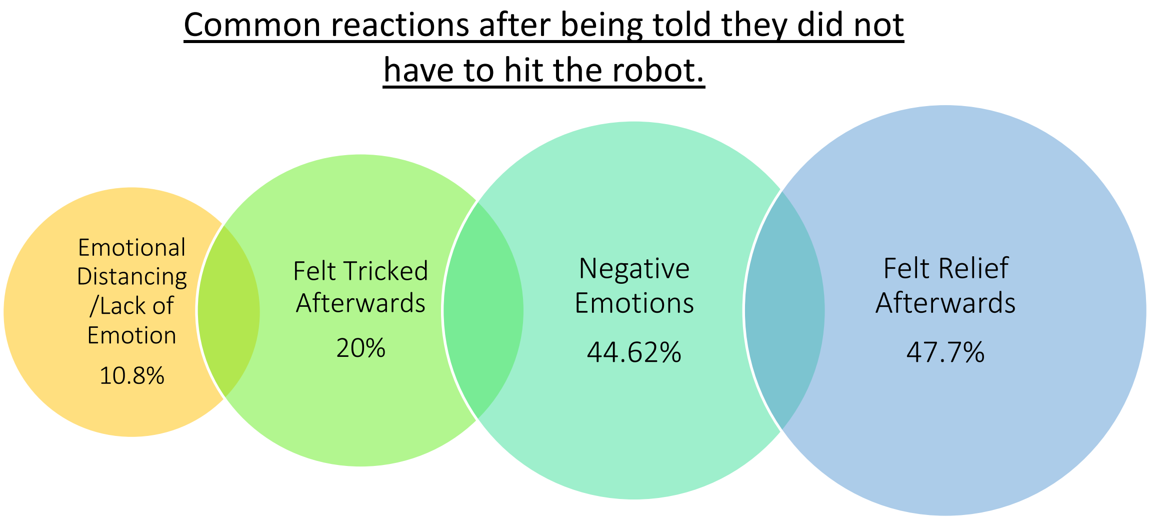

Figure 3.7. Illustration of the most common participant reactions, after being told they did not have to hit the robot"

Numerous participants indicated that they felt "tricked" and like they had been fooled by a prank (n=13). Such comments are reassuring as they suggest that although some participants were suspicious about the aims of the experiment, many did believe that they would have to hit the robot in the end. In some ways though, the comments were troubling as participants engaged in negative self-talk - referring to how they felt "disappointed", "gullible", and even "stupid". The experimenter made sure to spend time reassuring such participants that their decision to stand up did not reflect such characteristics, and was a very normal reaction due to the fast pace of the situation, the complicated instruction, and the influence of authority. The participant was also reassured that if they had any questions or concerns, they could email the experimenter. Even with such reassurance, it is possible that such negative self-talk could continue, calling into question whether tasks with such deception are ethical to repeat, with regards to protecting the participant from emotional/psychological harm.

> *EXP: … so, after I told you that you didn't have to hit Pepper, what were you thinking and feeling?*
> *PPT: And a few different emotions. Disappointment... and a bit stupid because I thought I've just been pure tricked here... she has just actually tricked me to say... like, are you stupid... are you gonna let, like, "as if I'm gonna let you break my machine". Yeah, the fact that I never called you out on it.*

Despite agreeing to stand up and walk towards the robot, many people indicated that they felt a sense of "relief" that they did not actually have to hit the robot (n=31), as they did not actually want to do so. "Relief" was frequently mentioned in the post-task interviews, but feelings of relief were also very obvious to the experimenter *during* the task. After the task was over and participants were told they did not have to hit the robot, many expressed behaviours indicative of relief - e.g. exhaling loudly and slumping on the desk, and exclaiming "thank goodness!" and similar. It could be argued that the extent of relief that participants reported post-hoc could be used as a proxy for feelings of liking/attachment towards the robot, but there are many reasons participants felt relief (e.g. no costs incurred, waste-avoidance, not having to disobey their morals, etc.), as we have discussed already.

> *"Oh my gosh it's so relief! *both laugh* Such a relief I tell you! *both laugh* It's such a relief that I think oh my god I don't have to hit him. And, you know, I began to like him a lot actually."*

Upon asking participants whether they felt any emotions after being asked to hit the robot, many participants disclosed that they felt negative emotions (n=29) - specifically, "sad", "upset", "anxious", "uneasy", "overwhelmed", "stressed", "guilt" and "uncomfortable". The negative emotions also appeared to be felt at varying levels. For example, one participant commented that they felt "very emotional" and "ready to cry". Another spoke about how they felt "stress, guilt, and sadness!". Piloting was undertaken to determine how participants might react to the task, but no such emotionality was observed. The intense emotions felt by this participant demonstrate that there are extremes in how people respond to tasks, and that experimenters should be prepared for the event that such cases might occur. Participants also speculated about how relationships to robots might change over time. Specifically, they spoke about how people could get more attached to machines which helped out within the home.

> *"You could probably get connected to them. Especially if you know, over time they will get better at having a conversation, You know, and if you've got a robot who is hoovering and cooking your meals, you're gonna fall in love with that. It's a machine, but you'll forget it's a machine. I wonder if I'll still be here when that happens. I'll be the first one to take that into my house for an experiment!"*

> *EXP: Okay, any other emotions that you felt after you were told to hit the robot?*
> *PPT: Oh yeaaah, I, well, we became friends and I think he can be affectionate as we carry on the conversation long. I think somehow we would build very good friendship. Yeah, if I were to bring this guy home, I think we can build very good friendship. I think my life would be happier, honestly. I'll be a lot happier with this kind of robot that can communicate.*

Incorporating the Questionnaire Data

By tightly controlling the speech and movements of the robot, all participants (n=65) had a very similar interaction with Pepper. Despite this, some participants hesitated for longer than others (e.g., 0 seconds vs 30 seconds). The previous sections outline that there are a large range of reasons influencing hesitation time, so we have chosen not to split the data in terms of relative high vs low hesitation time. Instead, we made the decision to focus on comparison between individuals who reported to feel a bond to Pepper (specifically, ten individuals verbalised that they felt a "friendship", "bond, "attachment", "relationship", or "connection" to Pepper), compared to those who made no such references.

To determine whether these individuals (n=10) were somehow different to the rest of the sample (n=55), we compared the demographic data collected from the participants. Those who suggested that they felt an attachment/bond to Pepper were classified as "High Connection", and those who did not were allocated into the "Low Connection" group. In the high and low connection groups, there was a similar proportion of age groups and genders (See Figure 3.7 for illustration).

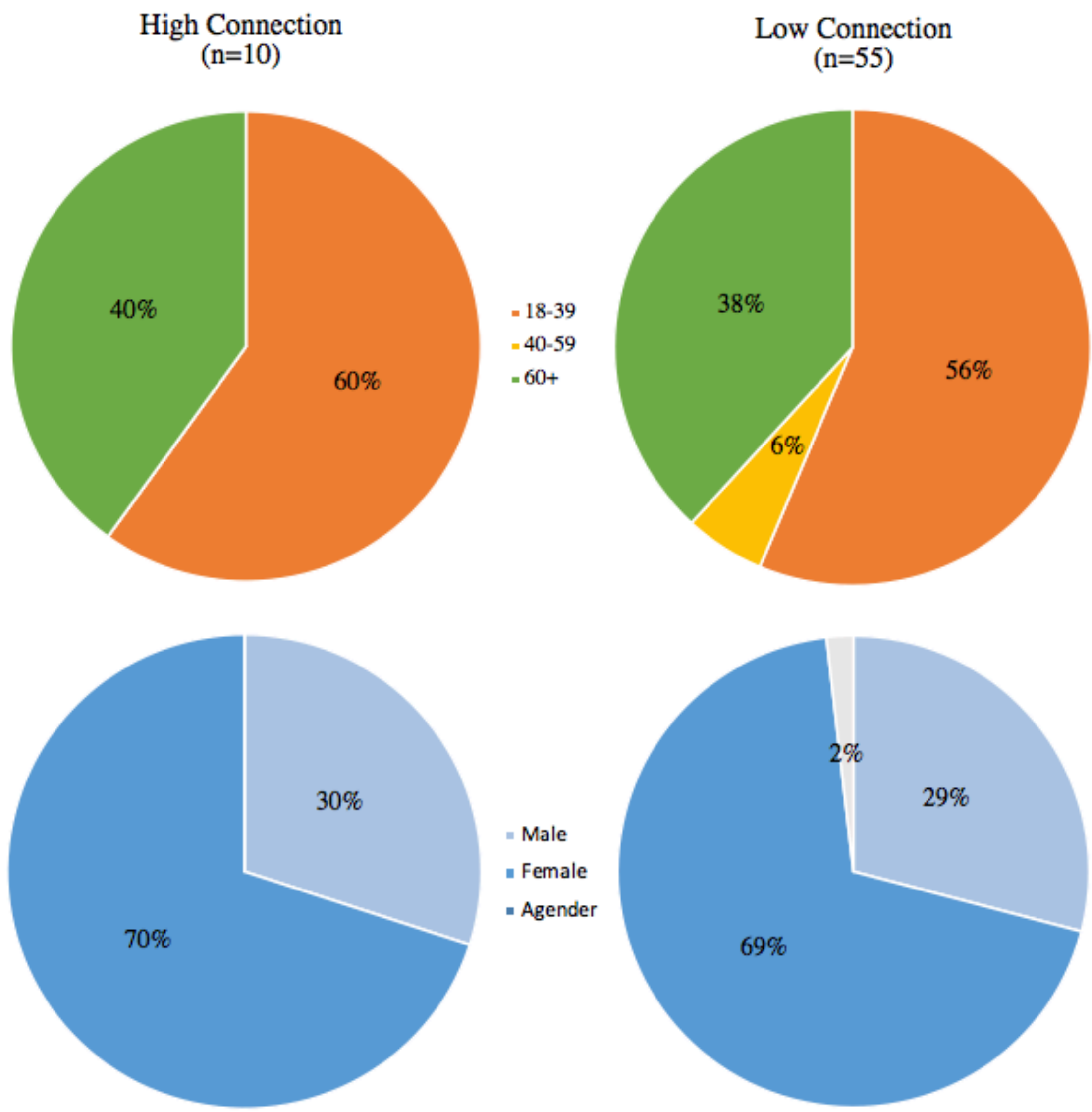

Figure 3.7. Pie charts to illustrate the similar proportions of the high and low connection groups, with respect to age (top) and gender (bottom).

In addition to providing their age and gender, participants also completed a series of questionnaires probing their attitudes towards robots (Nomura et al., 2008), empathy (Batchelder, Brosnan & Ashwin, 2017), and their general tendency to anthropomorphise (Waytz, Cacioppo & Epley, 2010). See Section 2.6 "Questionnaires" section for details. Descriptive statistics indicated little difference between the scores of those in the high and low connection groups (see Figure 3.8 for illustration). A series of statistical tests indicated that the differences between the low and high connection groups were not statistically significant. Raw data is available on the Open Science Framework: https://osf.io/d7c8t/ and test outcomes are displayed in Table 1 (Supplementary Materials).

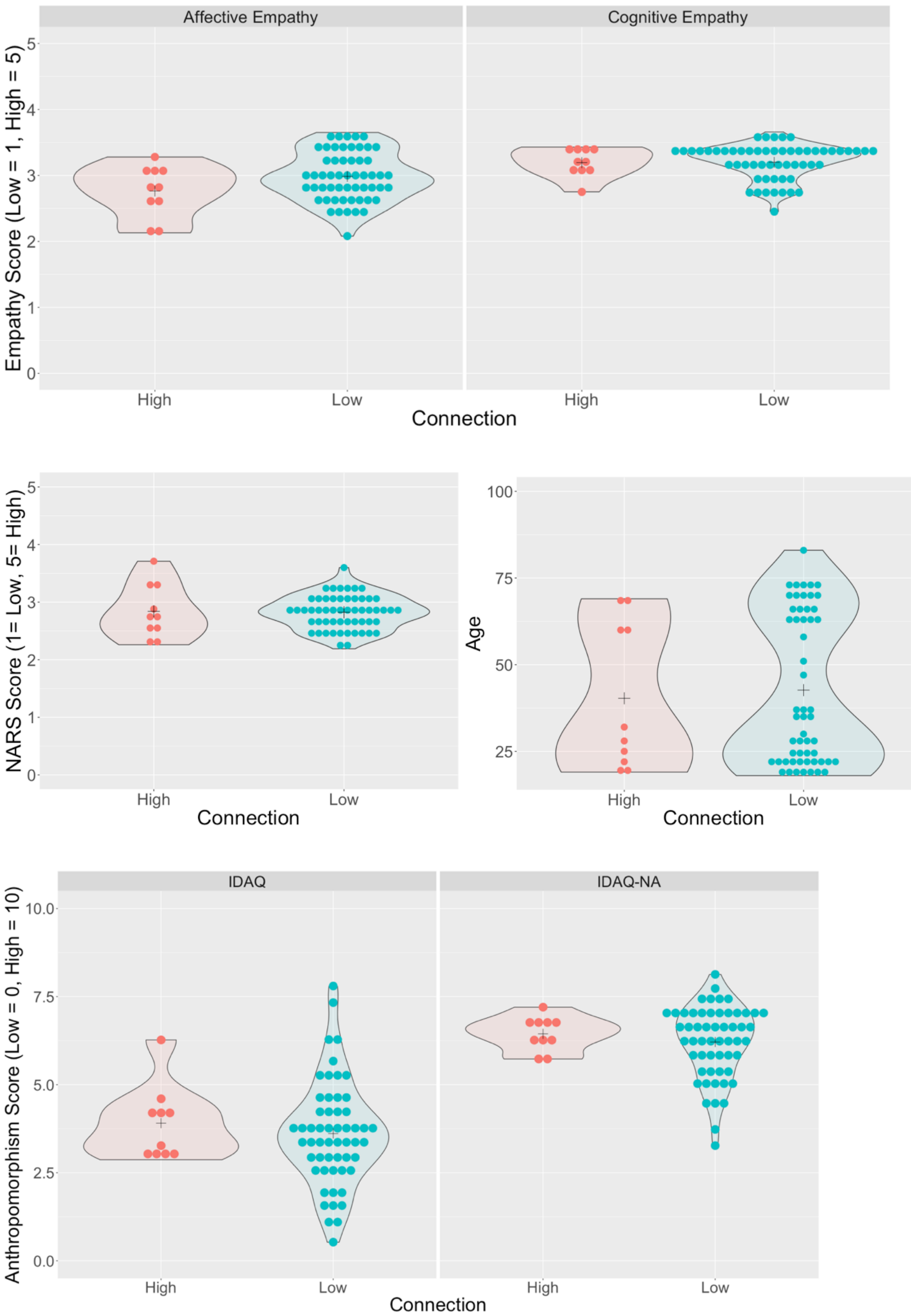

Figure 3.8. Graphs to illustrate individual scores on the questionnaires, between the high and low connection group. The crosshair indicates the mean, and the shaded area illustrates the density of the responses. "NARS" refers to the Negative Attitudes towards Robots Scale. "IDAQ" assesses anthropomorphism (e.g. intentions, free-will, consciousness), and "IDAQ-NA" assesses non-anthropomorphic attribution (e.g. good looking, useful, durable).

3.5. Discussion

Th aim of this piece was to provide a more detailed and nuanced account of what the "hesitance to hit" task is measuring. The behavioural data indicates that the majority of participants (75 out of 84) hesitated for less than 25 seconds after being asked to hit the robot. Additionally, 44 participants did not protest against hitting the robot, and only 8 participants protested more than once. One interpretation of such data could be that, in general, participants did not feel a strong sense of attachment or liking towards the robot, and that they did not perceive the task to be particularly stressful or troubling. By speaking to participants after the task, it became clear that for many people, this was not the case. Analysis of the post-hoc interview data revealed that despite agreeing to hit the robot, many participants did not want to do so. Participants expressed varying reasons for not wanting to hit the robot, including that they perceived a connection to the robot, and that they felt breaking property was unnecessary and wasteful.

Connection to the Robot

After a mere 10-minute interaction, we were surprised when participants reported feelings of "connection", "friendship", and "affection" toward the robot. Such comments were especially surprising given that seven of the ten minutes were spent simply observing the robot and making notes about its appearance and movements. To further investigate whether these undeniably prosocial feelings persist, or change over time, or whether it is possible for those reporting no emotional attachment toward the robot to develop attachment, longitudinal data collection would be required (c.f., Cross, Riddoch et al., 2019). To better understand individual differences in attachment to robots, it would also be insightful to collect more information from participants regarding their personality and background. In this study we found that negative attitudes towards robots, empathy, and tendency to anthropomorphise (as measured by validated questionnaires) did not drive attachment to Pepper. However, this does not rule out that other traits or experiences might affect the propensity to become more or less attached to social robots.

Arguably, feelings of attachment to robots could facilitate long-term usage and uptake - like how we engage with products (e.g. clothes) that we are attached to for long periods of time (Ramirez, Ko & Ward, 2010; Schifferstein & Zwartkruis-Pelgrim, 2008). As a result, creating such sustainable systems would be of benefit to many types of stakeholders including end users (as they can reap the benefits long term), investors (as new systems would be required less frequently), and the environment more widely (due to decreased waste of materials). The production of sustainable products is also, arguably, of benefit to those selling robotic systems, as studies suggest that consumers are becoming more socially and environmentally conscious in their purchase decisions (Bucic, Harris & Arli, 2012; Lee & Rim, 2018).

In this study, some participants maintained the stance that Pepper was simply "an object", "a machine", and "a thing", whereas others indicated that they perceived the robot as having gender and being able to feel emotion and pain (n=33). The differences in responding suggest that for some, a social robot could be considered as a social entity, whereas for others, it could be perceived as simply an appliance or other product. Such findings contradict research which suggests that "humans have a natural tendency to anthropomorphise" (Nie et al., 2012; Reeves & Nass, 1996) - a statement which implies that the attribution of human-like qualities occurs to the same extent, and with the same time course, for all people. It could be the case that all humans do anthropomorphise machines in the same way, and that the participants were being deceptive in their responses for some reason, however we have a tendency to reject this idea. This rejection is based on work which demonstrates differences on questionnaires probing general anthropomorphism (Chin et al., 2004; Waytz, Cacioppo & Epley, 2010), and the range of individual differences that exist in so many other aspects of cognition (Gruszka, Matthews & Szymura, 2010; Lee & Webb, 2005; Parasuraman & Jiang, 2012).

Other research suggests that individual differences are not the only factor influencing how a robot is perceived. It has been found that the perception of a robot as having qualities of a "living" agent (e.g. intentions, emotions, and the ability to feel hurt) is sensitive to numerous factors including (but not limited to) the appearance of the robot (e.g. humanoid vs non-humanoid), the robot's behaviour (e.g. congruent vs incongruent gesture and speech), and the beliefs of the participant about the origin of the behaviour (e.g. an algorithm vs human-controlled) (Crowell et al., 2019; Hortensius & Cross, 2018; Salem et al., 2013; Wykowska et al., 2015). If robots were perceived in a stable manner across people, we could use existing models of attachment (Ball & Tasaki, 1992; Mugge, Schoormans & Schifferstein, 2005) to predict the trajectory of robot uptake and usage, however, the studies and insights outlined previously suggest that such fixed attitudes are not yet a reality. It could be suggested that if robots were similar in appearance, deployed in a certain setting, and programmed to behave in a consistent way, there could be wide-scale acceptance and usage, but without an appreciation for individual differences and changes in attitudes over time, we argue that this is unlikely to be the case.

Despite being a complicated venture, a better understanding of how humans perceive robots, factors impacting such perceptions (e.g., appearance, behaviour, context) and how these feelings evolve across time (e.g. Cross, Riddoch et al, 2019) is becoming increasingly important. Particularly because, in some instances, it could be inappropriate/harmful for humans to feel attached to robots - e.g. military personnel with bomb-disposal robots, or vulnerable people with care robots (Darling, 2015; Lin, Abney & Jenkins, 2017; Sharkey & Sharkey, 2012).

Exploring Individual Differences in Human-Robot Attachment – Next Steps

Although it could be useful to build a better understanding of individuals' propensity to form an attachment to robots, I would advise caution when embarking on work exploring individual differences. One reason for doing so is the particular kinds of ethical issues which individual difference work raises. For example, there is a real possibility that such knowledge could be used to inform targeted advertising – that is, a form of advertising which is directed towards an audience with certain traits (in this case, individuals with a natural tendency to become attached to robots) (Nwachukwu et al., 1997; Ullah, Boreli & Kanhere, 2020). On the one hand, targeted advertising is a widely used method of reaching potential users and could potentially lead to useful matching between a human user and the most relevant robotic platform - while also facilitating financial gain for robotics companies (Plane et al., 2017). On the other hand, however, due to the population being targeted (potentially vulnerable people) and the potential for harm (e.g. overdependence on robots; Sharkey & Sharkey, 2012), the ethics underpinning targeted advertising can start to become questionable (Nwachukwu et al., 1997). When publishing results which indicate between-group differences, there also is the potential for the results to be used in malicious ways – fueling discrimination against others (e.g. against certain age, gender, or racial groups) (Meisenberg, 2019). This issue is arguably more relevant in other fields (e.g. intelligence studies; Cofnas, 2020; Meisenberg, 2019), though this does not negate our duty as researchers to consider the possibility of such eventualities (BPS, 2014).

The ethical issues associated with individual difference studies are complex – tapping into the rights of researchers, the public, and industry professionals (Cognas, 2020; Nwachukwu et al., 1997) – and future research should deeply consider the value of such knowledge. It could be argued that rather than focusing on individual differences, we should concentrate our research efforts on better understanding the trajectory and consequences of attachment. Additionally, rather than attempting to manipulate attachment to robots, perhaps we should place greater emphasis on creating machines which are perceived as useful and usable. Such qualities have been found to encourage acceptance of technologies more broadly (Technology Acceptance Model; Davis, 1985; Davis, 1989).

Research Method Reflections

We conducted this study in a research laboratory, controlling the interaction between the human and the robot, and yet we observed large variation in participant responding and attachment. In real-world environments, human—robot interactions will likely be subject to many more influences, providing an elaborate challenge for those hoping to roll robots out on a large scale. We would argue however, through thorough piloting it is possible to better understand the range of responses that could occur. This study, and the rich insights it has yielded about the variety of reasons people hesitate or comply with instructions to harm a friendly humanoid robot, lead us to advocate for the inclusion of social scientists in future similar research endeavours - as well as methods that adopt an open approach to post-experiment questioning. By adopting an open approach to questioning (e.g. "What do you think about the robot?"), compared to closed questions/scales/continua, it is possible to gain deeper and clearer insight into the respondents' experience or knowledge (Copeland, 2017; Mathers, Fox & Hun, 1998; Kara, 2018). While the data and insights yielded by such open-ended approaches are certainly messier and more unstructured, compared to many other kinds of dependent variables measured in experimental psychology, they also hold great potential facilitating innovative new research questions that might be missed if researchers are reluctant to stray from tried-and-true questionnaires and short-answer debriefing procedures.

In this study, the use of open questions allowed us not only to gain a better understanding of some of the factors affecting hesitation, but also peoples' thought processes, their feelings of cognitive overload and confusion, perceived power imbalances between themselves and the robot, and individual differences in anthropomorphism and feelings of friendship and connection toward the robot. Without such questions, it is likely that such insights would have been missed and we advocate for greater use of mixed-methods experiments in human—robot interaction research as a result. Even in cases where experimenters measure reaction times or other seemingly “objective” responses, we argue that it is still valuable to provide participants with an opportunity to openly provide feedback about their experience. It is possible that they used a strategy which affected responding, or they perceived the stimuli differently to how researchers might have expected. Collecting such data may lead to complexities when trying to interpret data, but we would argue that this intricacy reflects a greater understanding of the phenomenon and measurement techniques, and is a valuable use of resources as a result. While this approach could be valuable for all manner of behavioural psychological experiments, we would argue it is especially vital for experiments examining human—robot interaction. Because so many unknowns still exist concerning the human side of human—robot interaction, a more nuanced understanding of people’s thoughts and feelings beyond the confines of strict experimental instructions can help shape and advance this new and burgeoning field in a way that improves the utility of robots for human users (c.f. Cross, Hortensius & Wykowska, 2019).

It is argued that although words can be insightful and thought-provoking, they are susceptible to factors such as experimenter bias and social desirability effects (Bergen & Labonte, 2020; Gilder & Heerey, 2018). Such factors lead to an increased possibility that the participants’ responses do not affect their true thoughts and feelings. By investigating the question with a combination of methodological approaches (e.g. behavioural and qualitative), using double-blinding procedures, following guidelines regarding experimenter behaviour and demeanor (Bergen & Labonte, 2020), and by making a conscious effort to unearth and negate experimenter biases (Nowell et al., 2017), it is possible to strengthen the validity of participant claims (Gibson, 2017).

While no universally agreed-upon framework for ensuring scientific rigour when using qualitative approaches exists yet, a number of articles from social and health sciences detail how a researcher can improve the rigour of their own qualitative research practice (Braun & Clarke, 2006; Nowell et., 2017; Sundler et al., 2019). Although not specific to the field of HRI, such articles are insightful as they detail practical recommendations for how to improve validity, rigour, credibility and transparency of qualitative research in general. For example, some authors propose using methods such as journaling thought-processes, explicitly stating potential biases in publications, and the use of independent coders (Nowell et al., 2017; Sundler et al., 2019). Such methods are not restricted to a specific field of study and, thus, are as applicable to HRI as any other behavioural experimental field as a result. A number of books detailing practical advice for undertaking mixed-methods research - investigation using both quantitative and qualitative approaches – also exist and serve as useful resources for researchers wishing to incorporate these approaches (e.g. Bernard & Bernard, 2013; Brannen, 2017). To streamline methods, know which common pitfalls to avoid, and educate upcoming researchers in HRI, it would benefit the field to curate resources providing subject-specific examples.

In addition to assisting with the validation of measurement techniques, the results of qualitative analysis could generate new research questions and bridge interdisciplinary communications - e.g. between roboticists, computer scientists, and social scientists (to name a few). The "Open Science" movement means that more resources are accessible for free, however specialist language continues to be a barrier for understanding and collaboration (Salgian et al., 2011). By using the words of the general public to complement quantitative experimental data, this could help to bridge interdisciplinary barriers. In addition to promoting collaboration between specialties, the inclusion of such quotes and thoughtful discussion could make scientific content more accessible and engaging for the general public, and young people interested in STEM professions. Such accounts could also incite innovative public engagement activities, and inspire narratives for books, games, and other creative ventures.

3.6. Conclusion

In this study we demonstrate that the participants' insights on their thoughts and feelings toward social interactions with robots can be incredibly useful in human—robot interaction experiments designed to probe prosocial attitudes and behaviours toward robots - for the validation of measures, but also a broader understanding of how tasks effect and influence participants. They also allow for insight into the topic of interest more broadly, and can allow for the generation of exciting new research questions and approaches. It is possible that quotes and discussions could also bridge the barrier between specialists, the general public, and those working on creative projects to engage and inspire.

CHAPTER 4

Whilst planning Chapter 4, the Coronavirus pandemic (COVID-19) rapidly spread around the world. The pandemic led to the implementation of mass lockdowns, and in-person research was halted at the University of Glasgow as of March 2020. As a result of such restrictions, there was the need to change tack. Rather than trying to study human—robot attachment remotely (which lacks ecological validity in numerous ways), we shifted focus towards understanding behaviours associated with attachment. Specifically, due to the success of pets as companions, we shifted focus on to the behaviour of dogs.

Riddoch, K., Hawkins, R., & Cross, E. S. (2021). Exploring behaviours perceived as important for human—dog bonding and their translation into a robotic platform. https://psyarxiv.com/5xds4/ *Under review at PLoS One*.

Chapter 4 Exploring behaviours perceived as important for human—dog bonding and their translation to a robotic platform

4. Abstract

To facilitate long-term engagement with social robots, emerging evidence suggests that modelling robots on social animals with whom many people form enduring social bonds – specifically, pet dogs – may be useful. However, scientific understanding of the features of pet dogs that are important for establishing and maintaining social bonds remains limited to broad qualities that are liked, as opposed to specific behaviours. To better understand dog behaviours that are perceived as important for facilitating social bonds between owner and pet, we surveyed current dog owners (n = 153) with open-ended questions about their dogs' behaviours. Thematic analysis identified 7 categories of behaviours perceived as important to human—dog bonding, including: 1) attunement, 2) communication, 3) consistency and predictability, 4) physical affection, 5) positivity and enthusiasm, 6) proximity, and 7) shared activities. We consider the feasibility of translating these behaviours into a social robotic platform, and signpost potential barriers moving forward. In addition to providing insight into important behaviours for human—dog bonding, this work provides a springboard for those hoping to implement dog behaviours into animal-like artificial agents designed for social roles.

Keywords: dog behaviour, social robots, bonding, biomimetics, human-animal interaction, HRI

4.1 Introduction

In an attempt to reduce loneliness and improve mental health, a range of technological solutions are being developed and studied, including apps, chatbots, avatars, virtual reality solutions, and robots (Miller & Polson, 2019). Unlike many screen-based technologies, robots are better equipped to physically interact with a person (e.g. via mutual touch) and their surroundings (e.g. by moving objects or navigating to different parts of a home). It has been suggested that if such robots are paired with social capabilities (e.g. the ability to understand and respond to people's verbal and non-verbal behaviour in an appropriate manner), they could be a candidate solution for helping to combat loneliness and helping to support aging in place (Miller & Polson, 2019; Prescott & Robillard, 2020)

If autonomous robotic solutions are going to be deployed as a tool to help combat the growing loneliness epidemic, it is vital to ensure the robots tasked with serving such functions look and act the part. Recently, to sidestep the costs and unrealistically high expectations associated with enlisting humanoid robots to serve in this endeavour (Duffy, 2003; Horstmann & Krämer, 2019; Komatsu, Kurosawa & Yamada, 2012), researchers have turned their attention towards modelling socially assistive robots on non-human animals (Miklósi et al., 2017). Furthermore, due to the success of human-pet relationships, and the relative simplicity of modelling non-human animal forms and behaviours, a number of researchers are beginning to focus more on the mental health benefits associated with pet dog companionship and the implementation of dog behaviours within a robotic platform (Gácsi et al., 2016; Koay et al., 2013; Krueger et al., 2021; Schellin et al., 2020).

Dog-Inspired Robots

Across many western cultures, pet dogs can provide a source of comfort and companionship, and ownership has been found to benefit a person's mental health, wellbeing, and ability to deal with trauma (Endo et al., 2020; Sable, 2013). It has been proposed that by modelling social robots on pet dogs (both in appearance and behaviour), end-users could potentially experience similar benefits [Collins, Millings & Prescott, 2013; Krueger et al., 2021). Furthermore, social robots that resemble dogs may lead human users to treat these robots more like a companion (as happens with real dogs) than a metal and plastic machine or toy. This, in turn, has the potential to enable users to reap benefits of robot ownership across the long-term (Bharatharaj, Huang & Al-Jumaily, 2015). Robotic dogs equipped with sophisticated technology to invite and sustain social engagement would also make the benefits of dog ownership accessible to those who are unable to look after a real dog due to allergies, lack of time, funds, or mental capacity (such as in the case of severe dementia) (Bharatharaj, Huang & Al-Jumaily, 2015; Collins et al., 2019). See Figure 4.1 for examples of dog-inspired robots.

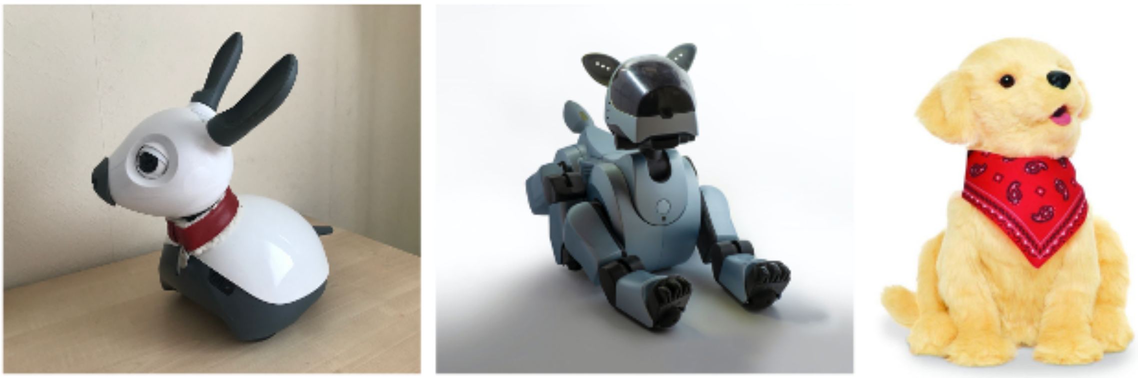

Figure 4.1. Images of three robots inspired by dogs (and other animals). The MiRo-E Robotic Platform (Consequential Robotics), AIBO (Sony), and Joy for All dog (Ageless Innovation). Image credits: Katie Riddoch (left image), Jeremy Bishop via Unsplash (centre), and Ageless Innovation (right).

In order to understand the scope and limits of robotic dogs as effective social companions, it will be useful to model dog behaviours on appropriate robotic platforms and systematically evaluate the efficacy of these behaviours. However, before such research can begin in earnest, a vital first requirement is a clear understanding of the features and behaviours that are important to building and maintaining the human—dog bond. Our current understanding of the human—dog bond is limited to physical features and behaviours which are liked, as opposed to those which are crucial for the formation and maintenance of the bond. For example, King and colleagues conducted a study with a sample drawn from the Australian public (n=877) and identified that this sample's "ideal dog" is medium sized, short haired, de-sexed, safe with children, fully housetrained, friendly, obedient and healthy (King, Marston & Bennett, 2009). Participants also wanted a dog to come when called, not to escape from their property, to enjoy being petted and to display affection to their owners. Furthermore, participants in this study identified that the ideal dog should require between 16 and 30 minutes of exercise per day and between 1 and 15 minutes of grooming per week. While this work provides important initial insights into ideal features of dogs, it tells us little about how these individual features or behaviours influence the human– dog bond. More recent work by Konok and colleagues sheds some light on the impact of different qualities by asking the general public which features are *most* liked and disliked about dogs (Konok et al., 2018).

By asking participants "Do you like dogs?" and to "list 3 characteristics of dogs which influenced your answer most", Konok and colleagues identified the following qualities as the most likeable: faithfulness, smartness, friendliness, attachment/devotion, individuality/

personality, unconditional love, kindness, and attentiveness (Konok et al., 2018). By asking participants "How can you infer the quality? What does he/she do?", the authors also identified specific behaviours (e.g. "obeys" and "learns quickly") associated with each of the qualities (e.g. smart). Such insights are valuable in terms of understanding why dogs are liked, but it could be the case that qualities which facilitate "liking" are different from those which facilitate the formation of strong bonds. This suggestion comes from human studies which demonstrate that we form different strengths of relationships (e.g. acquaintances vs close friends) depending on the characteristics of the other person relative to the self (Wrzus et al., 2017; Zarbatany, Conley & Pepper, 2004). Moving forwards, it would be valuable to better understand if there are behaviours specific to forming strong bonds with a dog, opposed to liking.

If we can identify behaviours that are important to building and maintaining positive human—dog bonds specifically, this should bring us one important step closer to facilitating engaging and meaningful social interactions between humans and robots. As well as improving the user's experience, modifications to robotic systems based on such insights could further improve individuals' mental health and public health in general, while bolstering the longer-term sustainability of the system and thus the reputation of the company and social robotics community.

Aims

In this exploratory study, our aim was to identify the domestic dog behaviours that facilitate the formation and maintenance of social bonds between owner and dog. To address limitations of previous studies, we used open questions (as opposed to fixed-choice questionnaires) and encouraged participants to be as detailed in their descriptions of the behaviours as they wished to be (as opposed to stating abstract or broad qualities briefly). We also offered dog owners the opportunity to submit video footage of their dogs – facilitating insights about the physicality of the behaviours they perceived as important to the bond with their dog. To gain insight into behaviours key to attachment formation, we planned to explore the results of those exhibiting high vs low attachment to their pet (as indicated through scores on the Lexington Attachment to Pets Scale (Johnson, Garrity & Stallones, 1992)). By systematically gathering data on these qualities, we can consider the costs and benefits (and barriers) to implementing pet dog behaviours in robotic systems.

4.2 Method

Preregistration and Ethics

This study and all procedures were approved by the University of Glasgow College of Science & Engineering Ethics Committee (Ethics Number 300190287), and the study procedure was pre-registered on the Open Science Framework prior to data collection (https://osf.io/ycrwh). All data supplied in this study were anonymised and will be stored for 10 years, after which time they will be deleted. We report how we determined our sample size, all data exclusions, all manipulations, and all measures in the study (Simmons, Nelson & Stallones, 2012).

Participants

In total, 283 individuals accessed the online study. After the removal of incomplete datasets (n=127) and incorrect responding (answering in terms of multiple pets at once [n=2] or providing one-word answers [n=1]), 153 datasets remained. This number exceeds the minimum sample size identified by our original power analysis. Specifically, to detect a medium effect size (Cohen's d = 0.5) between two independent groups, G*Power3.1 indicated a required sample size of 128 participants (using a power of 0.8 and an alpha level of 0.05). We had intended to compare the results of those who reported high vs. low attachment to their dog (as indicated by scores on the validated Lexington Attachment to Pets Questionnaire (Johnson, Garrity & Stallones, 1992)). However, as participants reported high levels of attachment on average, across the whole group (M = 4.45 out of a possible 5, SD = 0.50), we determined it would not be relevant or suitable based on our sample to form a "low attachment" group for analyses. Therefore, we analysed our participant sample as one group.

All 153 individuals completed the written aspects of the study (consent, questionnaires, open questions…), however only 18 submitted videos of their dogs as supporting material. As a result, this writeup will focus primarily on verbal descriptions provided by participants, with supplementary screenshots from the videos where possible.

All participants were dog owners, over the age of 18 ($Range_{Age}$ = 21 – 62 years, M_{Age} = 35.67 years), and the majority of participants identified as female (female: n = 146, male: n = 5, non-binary: n = 1, agender: n = 1). The dogs varied in terms of sex, breed, size, and age ($Range_{Age}$

= 3m – 15 yrs, M_{Age} = 5.18 years), in addition to how they were acquired (e.g. from a breeder [n=77], rescued [n=48], friend/family member [n=23], online/newspaper advertisement [n=5]). There was also variation in terms of the length of ownership, ranging from 1 month to 15 years (M = 4.39 years, SD = 3.61). Full demographic details are available on the study's OSF site - https://osf.io/ycrwh.

Scores on the validated Lexington Attachment to Pets Scale (LAPS) were close to ceiling (Johnson, Garrity & Stallones, 1992; M = 4.45, SD = 0.50) - indicating high levels of attachment (specifically, general emotional attachment to their dogs) across the group.

Procedure

Participants followed a link to the online Qualtrics survey platform (www.qualtrics.com) where they had the opportunity to read an information sheet about the study before being asked if they were happy to provide their informed consent. After providing written informed consent, participants completed the LAPS questionnaire (Johnson, Garrity & Stallones, 1992). Participants were then asked to describe behaviours of their dog according to the following instruction:

> *"To aid our understanding of human—dog attachment, please describe things that your dog does that you really like. Specifically, behaviours that you think are crucial to the bond you have with your dog. Please describe the behaviour/s in as much detail as possible."*

After providing a verbal description, participants were given the option to also provide a short video clip showing them and their dog engaging in the behaviour. In addition to being asked if they were happy to provide consent for the research team to access to their video, participants also had the opportunity to provide consent for their uploaded videos to be used in publications and presentations. After providing consent, participants' videos were sent via the GDPR-compliant Glasgow University Transfer System to be securely stored within OneDrive. Finally, participants were given the option to provide an email address to be entered into a prize draw to win one of five £25 Amazon gift cards.

Qualitative Data Analysis

Data were analysed using Thematic Analysis with NVivo software (v.12), following a rigorous six-step method (Braun & Clarke, 2019). This is a widely used inductive method of qualitative analysis that involves familiarisation with the data, followed by classification of recurring ideas into codes. The codes were grouped into broader themes, and were then discussed by independent coders. In further screening rounds, the themes were reviewed and refined, and named and renamed, where suitable. The coding process was interactive and incorporated disassembling and reassembling data, evaluation, interpretation, and attempting to draw conclusions (Saldaña, 2014; Yin, 2015).

In this study, two coders (KR and RH) undertook the analysis - one analysing the full dataset, and the other analysing a randomly selected subset of the transcripts [20%, n=31]). After coding the full dataset, the first coder identified 8 prominent themes. Upon coding the subset of the data, the second coder identified 9 themes. Following verbal discussion of the similarities and differences, the coders agreed on the 7 data-driven themes described in the next section. See Supplementary Table T1 (https://osf.io/ycrwh) for details of the themes identified by individual coders and the resulting convergent themes. Finally, the "Word Search" tool in NVivo was used – allowing us to determine the exact number of participants who mentioned keywords associated with each of the themes (See Supplementary Table T2, https://osf.io/ycrwh). Note - the results of the word search tool were checked manually, to ensure the word was being used in the relevant context. We had originally planned to explore to results of individuals with high vs low general emotional attachment to their dogs - as indicated by the LAPS questionnaire results (Johnson, Garrity & Stallones, 1992). This was not possible, however, as scores on the questionnaire were close to ceiling (M = 4.45, SD = 0.50) - indicating high levels of general emotional attachment across the group.

Reflexivity

In the first research study (Chapters 2 and 3) we approached the subject of human-robot attachment from the perspective of Psychology and Cognitive Science. In this study, we were keen to gain greater diversity of insights – and we collaborated with an expert in animal behaviour, and perceptions of animals, as a result. This collaborator coded a subset of the data, and their contributions influenced the terminology used when reporting the results (e.g., referring to dogs as "they" opposed to "it", and "behaviours" rather than "actions"). As a result of the team composition (made up of individuals working in animal behaviour and HRI), it is understandable that this piece contains results and discussion topics relevant to different fields – opposed to HRI alone.

4.3 Results

The themes identified in the data analysis are discussed in the following section, in order of the highest to lowest occurring themes (See Figure 4.2 for an illustration of the themes and the number of participants who made reference to each theme). There will also be discussion of relevant sub themes (See Table 1 for a summary of themes, sub-themes, and related perceptions). Screenshots of the video-submissions are included, where possible, to offer insight into the physicality of the dog behaviours discussed.

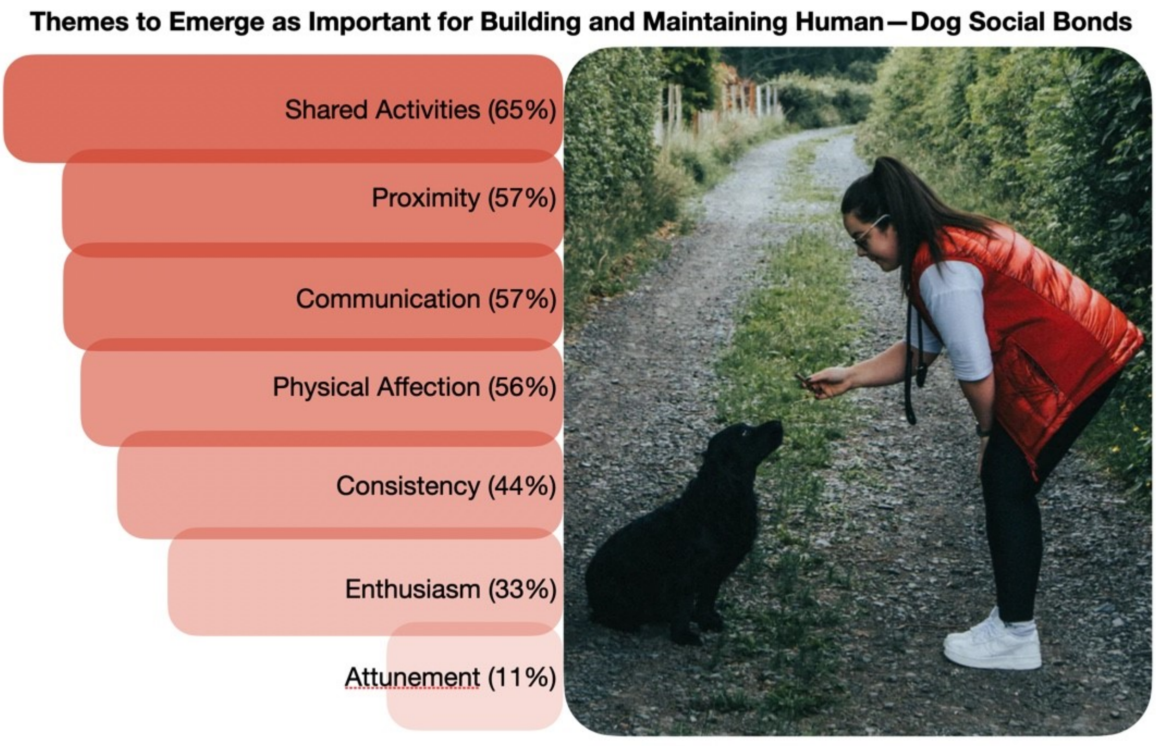

Figure 4.2. Visualisation of the themes identified through thematic analysis, with reference to data

Table 4.1. Overview of Themes and Related Perceptions.

Key Themes	Relevant Behaviours	Related perception of the owner, about the dog behaviour
Shared Activities	- Importance of playing with the owner - Dog cooperates during activities such as walks, visiting the pub Training	- Mutual liking of certain activities - Mutual enjoyment of activities Shared experiences
Proximity	- Follows owner around a space sometimes - Sometimes looks back at the owner, whilst walking ahead - Remains in close proximity whilst on walks - Sleeps in close proximity to the owner – lying next to them, touching them	- Proximity
Communication n=88 (57%)	- Mutual eye-contact: looking at the owner whilst in close proximity, or glancing back at owner when walking ahead - Bringing toys/objects to the owner - Nudging the owner with head or paw. - Responds to owner's voice commands	- Intentional (trying to communicate needs/wants) - Intelligence - Choice or preference for certain activities - Monitoring, checking-in, or protecting the owner - Seeking, paying attention, and listening to the owner
Physical Touch	- Initiates physical closeness and touch	- Wants to be close to the owner

	- Joins the owner on the sofa and lie down touching them - Rests or puts head/paw on the owner - Provide physical affection (e.g. kissing) - "Cuddling" - Spontaneous demonstration of behaviours (not always prompted by the owner).	- Enjoys spending time with them - Feels comfortable with the owner - Intentional - Cares for the owner - Loves owner - Owner feels loves/wanted/needed
Consistency and Predictability	- Consistently responds/ returns to owner when name is called - Generally obedient in response to words or gestures - Always approaches and greets when owner enters the space/home	- Owner is being listened to - Loyal - Intelligent - Respectful of the owner's wants - Excited to see the owner - Cares about them
Positivity and Enthusiasm	- Approaches quickly, jumps up and down, and gives 'kisses' when owner arrives home - Expressing positive facial and bodily expressions	- Excited to see the owner - Cares about them - Smiling or enjoying activities - Consistently positive and up for playing - Appreciates owner
Attunement n=17 (11%)	- Ability to pick up on emotional cues and provides a response'. Not just sitting with them but giving them physical affection as a response to their neg emotions	- Cares for the owner - Emotionally intelligent - Wants to comfort the owner - Aware of surroundings - Intelligent - Part of the family

	- Recognises time, e.g. when owner is due home, when work is over, when it is bedtime, and joins owner in their routine	

Note: the n value refers to the number of participants who mentioned behaviours relating to the theme. Participants can reference multiple themes, hence why the total n value (across all themes) exceeds the overall study sample size.

Theme 1: Shared Activities

A majority of owners mentioned the importance of playing behaviours for the human—dog bond (n = 100, 65%). Importantly, the play behaviours seem to vary - encompassing games (e.g. tug of war), training through play, independent play (e.g. the dog alone, playing with a ball), or the dog exhibiting playful behaviours. See Figure 4.3 for image of dog and owner engaging in play.

"My dog loves to play with me, we enjoy fetch, tug of war, hide and seek and just chasing each other around the house, also some rough and tumble."

"She likes to skid around on her front paws, which I think is my favourite behaviour of hers, she's a funny girl."

Figure 4.3. Screenshots of fetching behaviour and independent play, taken from dog owner video submission

There is also mention of play with other family members - as a communal activity that brings the family together. Also, in addition to the act of playing itself, the act of the dog initiating the play is perceived as important, signalling that the dog is excited to play, or to spend time together:

> *"If we are playing with him he always shares the play. If I throw the ball he brings it back to my wife; if she throws it he brings it back to me."*

> *"Every evening she likes to play, she'll bark to get our attention and play bow until we start throwing her toys for her."*

Repeatedly mentioned as important to the human—dog bond are behaviours that occur whilst on a walk together. Furthermore, the act of walking together was rated as important, as were demonstrations of affection and mutual enjoyment. Additionally, multiple references to the importance of the dog being aware of their owner whilst on the walk were made (such as monitoring behaviours; n = 18, 11%):

> *"Every so often when we're walking down the street she'll just stop in front of me, get up on her hind legs and give me a hug."*

> *"When going out for a walk, he will always "check in" with me either by looking at me or licking my hand quickly. It is as if he is reminding me that he knows I'm still there and he hasn't forgotten about me even though he is joyfully exploring."*

Alongside playing and walking, other shared activities included training, relaxing on the sofa, and additional everyday activities. The dog's apparent mutual enjoyment of shared activities was repeatedly mentioned as important:

> *"He loves doing dog agility together, in particular jumping over bars and weaving following my hand and commands."*

> *"…enjoys the same things I do (walking, hiking, swimming, being outdoors)"*

Theme 2: Proximity

For this theme, proximity refers to the physical distance between owner and dog. Here we found that the majority of participants (n = 88, 57%) mentioned the importance of physical closeness between dog and owner. Numerous owners mentioned specific examples - these included 1) the importance of their dog physically following them around their space (e.g. from room to room; n = 22, 14%) and 2) the dog remaining in close proximity when on walks or within the home (n = 18, 11%). The owners reported perceiving this behaviour as resulting from love, loyalty, or the owner being a perceived source of nurturance or protection:

> *"They look for cuddles they follow me around the house from room to room. They are always close by to me"*

> *"He never runs too far ahead when off lead and always runs back to me to check in."*

"The biggest thing for me is the love she shows my children especially the youngest. Luna [the dog] will cry for them, she will sleep in each of their rooms for a short time each and every night before settling in the hall where she can monitor everyone at once."

Numerous owners (n = 48, 31%) made reference to the importance of sleeping behaviours to the bond between them and their dog. The comments include references to night-time sleeping, napping (short periods of sleep), the dog napping on the person, and co-sleeping (both human and dog sleeping). The locations most frequently mentioned were the sofa/couch and the bed. The importance of physically touching whilst sleeping is repeatedly mentioned. See Figure 4.4. For image of dogs in close proximity, submitted by dog owners in the study.

"She sleeps in the bed with myself and my husband and she often naps with me. She likes to be touching one of us when sleeping, so she will rest a paw or her head on one of us."

"My dog always sleeps right against my body. He will make sure to have some part of his body touching mine and it makes me feel like he loves me and feels safe with me."

Figure 4.4. Screenshots of dogs sleeping in close proximity, from dog own video submissions.

Theme 3: Communication

This theme captures the importance of perceived shared communication between owner and dog for the human—dog bond (n = 88, 57%). Numerous owners (n = 27, 16%) referenced the importance of eye gaze. Some dog owners mentioned liking how their dog looks in their eyes, or gazes toward an object and back at them, to indicate their wants or needs (e.g. to play or for food). In contrast, others perceived the gazing behaviours as the dog being attentive to them, and owners indicated that they feel "listened to" as a result. This eye gaze was mentioned as important in training scenarios, but also more generally (e.g. when close to each other, or on walks). See Figure 4.5. For illustration of gazing behaviours, submitted by dog owners.

> *"My dog knows when I've finished work and will come and join me in the kitchen, he barks at me/us for attention and if he doesn't get it he'll toss a ball into the kitchen and just look at it like 'throw it for me please'."*

> *" I love when he gazes up at me and tilts his head when I talk as if he understands or is listening to what I'm saying."*

Figure 4.5. Screenshot of dogs gazing at owner, from dog owner video submissions.

In addition to the perception of the dog being aware and listening, some owners attributed a deeper meaning to their dog's gaze. Specifically, owners spoke of how they feel their dog looks at them to communicate a strong connection or love for them.

"His eyes and the way he looks into my eyes has always felt very surreal. It truly feels that he is looking at me with intent, and trying to communicate his feelings with me."

"My dog also looks me directly in the eye. To me, the eye contact symbolizes trust and his affinity to me…My dog knows exactly what I need/what from her just by an exchange in looks and vice versa."

In addition to using eye gaze, some owners (n = 15, 9%) mentioned that they liked how their dog brings toys to them. The purpose of such actions was perceived differently across owners. For example, some owners interpreted this as the dog asking to receive attention or initiate play, others saw this as a form of comfort from dog to owner, and others as the toys being presented as "gifts" for the owner. Across all cases, toy-presenting was perceived as the dog trying to communicate their wants or needs. In all examples, it is implied that the toy-presenting behaviour is spontaneous, rather than being prompted by the owner:

"He brings me toys to play with him and gets so excited about it."

"My dog brings me gifts when I come home or in the morning to wake me up."

Nudging behaviours were also perceived to be important (n = 7, 4%). The presentation of the nudging differed - touching the owner with the paw, head, or nose, and the behaviour is sometimes described as gentle, but often the intensity is not mentioned. Additionally, some participants report how their dog appears to convey their wants or needs by vocalising (n = 7, 4%). As with toy bringing behaviours, the nudging and noises are perceived as a purposeful behaviour - e.g. the dog wanting attention or affection:

"I like when he wants clapped and comes and nudges my arm to clap him and he sits up on my knee for a cuddle."

"Brings me toys to play with, places head on my lap, paws at my hand for strokes, nudges my elbow to get my attention."

"Makes specific noises for different reasons - different ones for pet me, play with me, I need out to the loo"

A final form of communication was responsiveness to the words or commands of the owner, facilitating feelings of being listened to (n = 15, 9%). Owners also implied that these behaviours were intelligent, and an indicator of their dog's loyalty to them:

"With me, when I call her back, she comes running really fast and happily, where she does this less with other people."

"When I say his name he wags his tail. He comes to me when I call him. He recognised my voice"

Related to this theme of Communication, numerous owners explicitly mentioned that they perceive their dog's communicative behaviours as intentional (that is, the dog is exhibiting the behaviour for a specific purpose; n = 28, 18%). Linking to this, participants repeatedly mentioned that they perceive their dog to be "intelligent", or "smart" (n = 26, 16%)–

"She has learned to manipulate us to get what she wants e.g. treats.".

"Every morning and evening after he's eaten his breakfast and dinner he jumps up on the couch and gives me a little lick and it's like he's saying 'thank you for dinner'."

"She learns everything super fast and has actually taken things like toys upstairs and thrown them out of my bedroom window just so she can watch them fall."

Theme 4: Physical Touch

Another prominent theme across dog owners (n = 86, 56%) was physical affection. Specifically, participants mentioned their dog engaging in such behaviours as resting their head against the owner, putting a paw on the owner, lying on the owner's feet, lying next to the owner with a body part touching them, giving the owner "kisses" and "hugs", and engaging in cuddles.

"He will curl up beside me if I take a nap and will lie on top of my lap when I'm watching tv. He climbs up me and gives me kisses and lies on top of me."

"She comes to my face and licks my chin then jumps on the bed and cuddles in until I am awake."

"Cuddling" is repeatedly mentioned as important to the bond (n = 56, 36%), however the descriptions of this behaviour across participants varied. Some accounts referred to cuddling as the dog resting their head upon the owner, whereas others specified that the dog fully lay down next to the owner for sleeping. The majority of mentions provided no detail about the specifics of the cuddling behaviour. It would be insightful to conduct further research to better understand what cuddling consists of, and individual variation in cuddling behaviours and preferences. Although cuddling behaviour is not well understood, there is a consistent perception that the dog is perceived as "*enjoying*" or "*loving*" the experience:

"She absolutely loves cuddling on the sofa and having a nap together during the daytime and I'll sit down first and arrange the cushions and myself so that she can just lie alongside me and she sticks her nose underneath my arms or in the crook of my neck and we'll just lay there for ages."

"Every evening, he snuggles up to me or my husband and places his head in my lap and curls his paw around my arm, almost as if he's cuddling back. He's so gentle if he jumps up, almost knowing that he doesn't want to hurt us."

Crucially, there were repeated mentions (n = 85, 55%) of how physical touch and affection was spontaneous and dog-initiated (as opposed to being prompted by the owner); these behaviours were perceived as intentional and as a result of love or caring for the owner.

"He will rub his head against our hands to get a scratch or a pet. All of this makes us feel that the affection we feel for him is reciprocated, which is a pretty amazing and loving feeling."

“She is very loving - she will "ask" to sit beside me on the sofa or bed at any opportunity. When I let her up, she snuggles close to me.

Theme 5: Consistency

The fifth theme to emerge as important for building and maintaining the human—dog bond concerns the consistency of the behaviours mentioned in the previous sections (n = 68, 44%). Specifically, participants made recurring mention of the consistently positive nature of the dog, such as expressing positive emotions and excitement to see and be with the owner, and perceived happiness and enjoyment displayed by the dog when in the presence of their owner. Also mentioned is the consistency of the greeting behaviours - that they occur every time the owner arrives home, no matter how long the person had been gone for. As a result of the attentive and consistent enthusiasm, some owners reported feeling loved by their dog.

“He always greets us even if we leave the room for five minutes and is very excited to see us.”

“He is always so happy to see you come home regardless of how long you were away. He wags his tail and stares at you if you have stopped patting him and he wants more.”

There is also mention of the importance of consistency in terms of listening to the owner, and obeying commands. Particularly important is the dog recalling when the owner calls their name.

“My dog follows me around and always listens to me”

“When out for walks she never goes too far away from us and always answers to her recall.”

Although consistency is crucial in terms of enthusiasm, positivity, obedience, and emotional awareness, it is implied that inconsistency is also desirable sometimes (n = 20, 13%). For example, through behavioural variability, the owner perceives their dog as having some independence and choice in terms of what they want to do:

"He is obedient to a degree but has a mind of his own too? So he will bring the ball back to us when we ask but maybe not give it to us."

"She often does what she wants, regardless of what I tell her, but she does what she's told when it matters."

Theme 6: Positivity and Enthusiasm

This theme captures the importance of the dog's enthusiasm, and the owner's perception that the dog is experiencing happiness and enjoyment. Specifically, one third of the owners (n = 51, 33%) mentioned that when they arrive home, their dog approaches them at the door and does one (or a combination) of the following behaviours: erratic tail wagging ("*acts like a propellor*", "*wags his tail like crazy*"), wiggling of the backside, leaping into the person's arms, or jumping up and around "excitedly" and with "*delight*". The intensity of the dog's excitement was also repeatedly mentioned - "*he gets so excited to see me and wags his tail like crazy*."

"The way she gets so excited when we arrive home, bouncing around the house and not leaving my side, shows me she loves our company. If I stop stroking her she'll push her head into my hand and nudge it. Her tail acts like a propeller as she's so happy we've returned home."

"She loves to give cuddles and brings me her toys as a present whenever I come home!"

Numerous owners mentioned that they perceive their dog as funny/silly (n = 13, 8%), and they really like this about them – e.g. "*He can be a bit of a silly cookie too when he gets excited or starts rolling around in the leaves or chasing a feather all over, which always gives us a bit of a laugh together, which is nice*.". Repeatedly mentioned is also the perception that the dog is enjoying the experience with the owner (n = 14, 9%) – e.g. "*She enjoys our interactions and she is happy when I play games with her*". Related to the latter, numerous owners express the importance of the dog seemingly "s*miling*", and the dog's face as a signal of enjoyment. See Figure 4.6. for images from owners - illustrating the attentiveness of their dog upon arrival home, and their dog "*smiling*".

"When we go for a walk, my dog will often look up at me with just such love in his eyes and a big smile on his face as if he is thanking me and telling me that he is having so much fun"

"He smiles when he's happy like he's letting me know that he's enjoying himself."

Figure 4.6. Screenshot of video from dog owner. Illustrates an expression that the owner perceives as "smiling".

Theme 7: Attunement

Attunement refers to the ability to sense and respond to another person – for example, picking up on cues that a partner is unhappy (e.g. through facial, verbal, or non-verbal cues) and "*being there for them*" as a result (Gottman, 2011). In this theme, we discuss the apparent importance of the dog appearing attuned to the owner's routines and emotional states.

Numerous owners (n = 17, 11%) mentioned how their dogs seem to have an awareness of the owner's daily routine (patterns of behaviour that correspond to certain times of the day), and that they will alter their behaviour in response. For example, the dog will go to the owner around the time that work is done, and they will go lie in the bed just prior to when the owner is due to wake up. There is repeated mention of synchronised sleeping behaviours, which are discussed more thoroughly in Theme 1 (Shared Activities)

"…He also waits on the bed upstairs when we are out and as our pattern is very similar he somehow knows when we're returning as we have watched him sitting up looking out the window for us minutes beforehand like clockwork (as we have watched him on the indoor CCTV). My 7-year-old niece asked 'how does he know the time?' as he's always waiting at home time."

"Her time keeping, if I am a minute behind schedule, she will put her paws on my leg to remind me of walks."

The importance of the dog being aware of the owner's work routine, and awaiting their arrival home, was also repeatedly mentioned (n = 17, 11%).

"Before the last six months [of COVID-related working from home], he would be sitting looking out the window every night waiting on me coming home from work."

"My dog knows when I've finished work and will come and join me in the kitchen…"

It was repeatedly mentioned (n = 37; 22%) that the dog behaves differently around an owner who is upset or stressed, demonstrating the perceived ability to pick up on and respond to owner emotions. In response to the owner being sad or upset, the dog approaches the owner, and will often engage in one of the following behaviours - seek proximity, lie on them, sit next to them, lick their face, provide "*kisses*", or present toys. In addition to being attuned to the emotions of the owner, the dog is also perceived as being mindful of the emotions of others. The dog is perceived as kind or caring for the family more generally.

"When either of us are upset she will know and comfort us by lying on us or giving us kisses."

"She also knows when I'm feeling sad and will stay closer to me when I'm feeling like this. When I cry, she sometimes gets up close to me and licks my face. This feels like she's comforting me."

Participants specified that the dog abstains from normal actions or activities when their owner is experiencing negative emotions.

> *"She knows when to be by my side when I'm sad and has an understanding if I'm not mentally feeling up to leave the house she won't pester me to go for a walk she will be content with playing in the garden for her exercise."*

> *"Sometimes he seems to know when I'm sad as he'll just come and sit really close to me, but doesn't paw or tap for attention.*

4.4. Discussion

By using open-ended questions, we gathered rich detail about specific dog behaviours that roughly aligned with seven core themes, which owners perceived as important for establishing and maintaining human—dog bonds. These themes mirror factors important for the formation and maintenance of human interpersonal relationships identified in previous research literature, including emotional attunement (Gottman, 2011), shared communication (Nicotera, 1993; Bull & Frederikson, 2019), consistency (Cialdini, Trost & Newsom, 1995), touch (Dunn, 2000; Barnett, 2005), positivity and enthusiasm (Reis et al., 2010; Woods et al., 2015), proximity (Cantó-Milà, 2016; Pistole, Roberts & Chapman, 2010), and the mutual enjoyment of shared activities (Kleptsova & Balbanov, 2016; Shiota et al., 2004). Therefore, the same major themes arise when exploring the development and maintenance of human-human and human-dog close social bonds, adding further evidence to our understanding of the depth and quality of relationships that can develop between humans and non-human agents, which we consider further below in the final section.

Variation in Human—Dog Relationships

The majority of participants in the present study reported high levels of attachment to their dog (high scores on the Lexington Attachment to Pets Scale (Johnson, Garrity & Stallones, 1992)). The questionnaire does not, however, offer insight into the *nature* of the attachment between the owner and their dog – e.g. secure or insecure, and anxious or avoidant (Zilcha-Mano, Mikulincer & Shaver, 2011; Zilcha-Mano, Mikulincer & Shaver, 2012). As a result, it is not possible to tease apart whether different groups (e.g. securely attached vs insecurely attached) hold distinct behaviour preferences in dogs. This comparison is particularly relevant in the context of translating dog behaviours into a robot, as valid concerns exist that some individuals could become overly dependent on robots - to the extent they might neglect their human social relationships and lose their own independence (Frennert & Aminoff, 2020; Sharkey & Sharkey, 2012). Through a better understanding of which dog behaviours are associated with different attachment styles, it may be possible to encourage healthy social relationships (as opposed to those associated with negative consequences) between humans and robotic dogs.

Moving forwards, it would also be valuable to determine the extent to which other demographics influence people's preferences for robotic dog features and behaviours. For example, both personality type (Turcsán et al., 2012) and length of ownership (Sprecher, 1999) have the potential to further influence wants and needs from a robot dog. Insights about such factors would allow developers to better tailor robotic animals to suit different demographics (e.g. individuals who are more introverted, children vs adults, etc.) and different purposes (e.g. children in short vs long-term hospital stays). While the current study is not sufficiently powered to conduct comparisons between individual demographic groups or to further investigate the impact of individual differences on dog behaviour preferences, one particularly rich avenue for further research will be to investigate these impacts more closely with appropriately powered research designs.

Translating Dog Behaviours onto Robotic Systems

In this study, the majority of owners made reference to their dog's behaviour as both intelligent and intentional, and ascribed considerable importance to both attributes in terms of bond-building. When these insights are considered in light of how best to develop robotic dogs as social companions, it might at first seem difficult to reconcile how these behaviours could apply to an autonomous machine, whose behaviour might not appear genuinely intelligent or intentional. We would argue, however, that the origin or authenticity of the behaviour is not necessarily important – it is instead the perception of the user that should be the focus of the conversation (e.g. Cross et al., 2016; Cross & Ramsey, 2021). Specifically, although a robotic dog's behaviour might be controlled by simple algorithms, its actions could still be perceived as intentional or intelligent. This suggestion is supported by a number of experimental studies, which demonstrates that people often adopt an "intentional stance" (as opposed to a mechanistic one) when interacting with a robot (Marchesi et al., 2019; Perez & Wykowska, 2020), and people's prior experiences, beliefs and expectations about a robotic system can further up or down-regulate their propensity to attribute social or mind-like attributes to an individual robot (e.g. Cross et al., 2016; Klapper et al., 2014).

On the topic of intention attribution, the related ethical and moral issues will become increasingly important and urgent to consider. Specifically, a number of researchers have raised concerns that by creating the illusion of intelligence or intentionality, people are being deceived by technology (Danaher, 2020; Van Maris et al., 2020). Ethically, this is proposed to be especially problematic when it comes to the deception of vulnerable people, such as children, individuals with additional needs, and people suffering from dementia (Sharkey & Sharkey, 2012; Westlund, Breazeal & Story, 2015). Moving forwards, when designing behaviours for a robotic dog, it will be necessary to consider such issues, weigh up the benefits and risks of robot deception, involve researchers from a broad range of disciplines to contribute to design and regulation (including law, ethics, social sciences, developmental psychology, etc), and be mindful of the state of public opinion at that time of creation and deployment (Danaher, 2020; Shim & Arkin, 2013; Van Maris et al., 2020).

Returning to the present results, we also found that the majority of participants (>50%) identified the following as important to the bond with their dog – physical touch initiated by the dog (n=85), the perception of shared communication (n=88), and the presence of playful behaviours (n=100). As a result, these behaviours should be prioritised moving forwards. By incorporating a range of sensors into a robot (e.g. cameras, microphones, and tactile sensors) and supplementing with other technology (e.g. an app, GPS, sensors in the environment), the current state of robotics technology should support the translation of the behaviours mentioned onto a robotic platform (Kovács et al., 2011). Barriers to implementation remain though, in terms of implementing bonding-specific behaviours (as identified in this study), and a deeper understanding of how social relationships and perceptions develop and change between humans and social robots over time (e.g. Cross et al., 2019; de Graaf, Allouch & van Dijk, 2011).

The next step to developing robotic dogs may be to conduct controlled experiments with people engaging with robotic dogs (whose behaviours are modelled on real dog behaviours). By doing this, it should be possible to manipulate the duration and intensity of individual behaviours, as well as establish optimal behavioural boundaries. In such experimentation, it will also be important to trial such behaviours within different robot forms – to gain greater insight regarding the influence of robot aesthetics on how behaviours are perceived by the user.

In the more distant future, it would also be insightful to conduct work in which potential users could train the behaviour of a robotic dog (e.g., from a robot which does very little, to a robot with a more diverse behavioural repertoire tailored to that specific user). Such training would present a technical challenge, but such experiments could offer insight into 1) optimal behavioural boundaries, 2) whether people want (and are willing to) train a robot animal, and 3) if training a robotic animal creates greater feelings of attachment to a robotic dog (like how training leads to feelings of attachment to a real pet).

Through the use of mixed methods approaches, it should further be possible to gain valuable insights into user perceptions and preferences. Conducting further research, to better understand how preferred dog behaviours can (or cannot) be successful modelled onto dog-like robotic systems, stands to greatly inform our understanding of the costs and benefits of dog-like social robots in psychosocial interventions as well as the utility of these machines to serve as long-term social companions for those individuals who are unable to look after a live pet for whatever reason. Additionally, such insights could benefit the development of animal-like avatars (e.g. within apps, virtual reality, or augmented reality), or those working within the arts (e.g. TV or film).

4.5. Conclusion

This study provides detailed insights into dog behaviours perceived as important for human—dog bond formation. The findings should serve as a foundation for further research and development into biomimetic social robots based on dogs. We recommend that next steps focus on exploring the nuances of these behaviours through mixed-methods and testing the applicability and feasibility of programming such behaviours into dog-like robots evaluated in laboratory and real-world settings. Exploring users' reactions and engagement via quantitative and qualitative methods will be important evaluation strategies for ensuring we make progress toward socially useful and likeable companion robots in a responsible manner.

CHAPTER 5

In the previous piece, we realised a range of behaviours apparently important to the human—dog bond. To understand how such behaviours are understood when presented by a robot, we implemented a couple of the behaviours within an animal-inspired platform. When planning the experiment, the Coronavirus pandemic was ongoing. As a result, we collected feedback online (as opposed to in person, as we would have preferred). Due to the exploratory nature of this work, and the depth of insight gained in previous work, we again adopted a qualitive approach.

Riddoch, K., Midson. S., Hawkins, R., & Cross, E. S. (2021). Exploring perceptions of Prosocial Dog Behaviours in a Biomimetic Robot. Manuscript in preparation.

Chapter 5 Exploring Perceptions of Prosocial Dog Behaviours in a Biomimetic Robot

5.1. Abstract

In previous work, we identified several behaviours dog owners perceive as important to building and maintaining prosocial bonds between people and their pet dogs. These included (but were not limited to) spontaneous displays of affection and responsiveness. To better understand the potential of developing and deploying robots as social companions, it is beneficial to explore how these types of dog behaviours might be perceived when exhibited by a robot. In the present study, we collected videos of dogs exhibiting a selection of the desirable behaviours identified in our previous work, and recreated the clips using the MiRo-E (Consequential Robotics, UK), an animal-like biomimetic robot. We then carried out a series of focus groups to explore people's perceptions of the behaviours, and examine broader opinions of robotic animals and their potential uses among the general public. Through thematic analysis of datasets collected from 31 participants, we found a tendency for people to make comparisons to real companion animals, as well as a strong desire for features in a robot that resemble real animals – for example, fluid movements, animal-like sounds, and expressive eyes. Responses also suggest that purpose and context are important when judging the appropriateness of an animal-inspired robot, and that the general public have an awareness of ethical issues associated with robots for companionship (privacy, overdependence, and replacement of human/biological social contact). We discuss implications for the study of human—robot interaction, and for those developing robots for companionship.

Key Words: dog behaviour, social robots, companionship, HAI, HRI.

5.2. Introduction

Dog Inspired Robots

The domestic dog is regarded as humankind's earliest companion, and the human–dog bond has persisted throughout centuries (Cunningham-Smith & Emery, 2020). The strength and longevity of the bond has led to the suggestion that dogs could provide a useful model for companion technologies – e.g. a social robot designed to provide social companionship to human users (Collins, Millings & Prescott, 2013; Krueger et al., 2021). In addition to reduced expectations compared to human-like robots, dog-inspired robots might help make some of the benefits of dog ownership more accessible – for example, to those who cannot own a real dog due to allergies, lack of resources (e.g. space and funds for veterinary care), or a reduced capacity to care for a living animal (Bharatharaj, Huang & Al-Jumaily, 2015; Collins et al., 2019).

By modelling companion robots on pet dogs (in form and/or functionality), it has been proposed that owners of robotic dogs might perceive a robot as similar to a real dog, and they may reap the benefits associated with dog ownership as a result (Krueger, Mitchell, Deshpande, & Kats, 2021). Some of these benefits include better mental health and wellbeing, and an improved ability to deal with trauma (Sable, 2013). The perception of a robotic animal as similar to a real dog might also lead people to become attached to the robot, and continue to engage with it over the long term – similar to how people build enduring social relationships with the dogs and other pets (Krueger, Mitchell, Deshpande, & Kats, 2021). This is positive for both the user (as they can reap the benefits over the long term) and the environment more broadly (as robots will be used over a period of many months or years, rather than being mere novelty items that quickly become waste material). It is important to emphasise however, that the aforementioned benefits may only be apparent if a person perceives the behaviour of robotic dogs as similar to that of a real dog. This assumption has not yet been rigorously evaluated, and this forms the primary motivation for the present study.

Perceptions of Dog-Inspired Robots

In recent years, researchers have undertaken a range of studies to investigate the extent to which we perceive robots and dogs similarly. For example, studies have compared how children behave when interacting with a robotic dog compared to a real one (Ribi, Yokoyama & Turner, 2008; Kerepesi et al., 2006; Melson et al., 2005). By measuring engagement with a real dog compared to a robot dog, researchers hoped to gain insight into the perceptions and preferences of children. Such studies have yielded mixed results, however, and are often difficult to draw conclusions from due to insufficient behavioural matching between the dog and the robot. For example, researchers conducted a study to compare children's behaviour when interacting with a real dog, compared to an AIBO robotic dog (Ribi, Yokoyama & Turner, 2008). Results indicated that children (ages 3-6) touched the robot more than the real dog. At first glance, such a result might appear positive in terms of our future with pet-inspired robots. The authors are forthcoming with a reason for this apparent preference however, pointing out that the dog in the study was very docile compared to the robot - only initiating play on one occasion (whereas the robot initiated play 44 times). One could argue against matching the robot and dog behaviours, as it is not unreasonable to expect natural differences in behavioural repertoire between a robot and a dog. We would argue in favour of behaviour matching with a real dog however, as it *is* within the realms of possibility that a dog could be as engaged as a robot. By not controlling across conditions, it is difficult to determine what is driving participants' behaviour - e.g. preference for a robot, or simply a preference for what is engaged and active, compared to what appears disinterested and inactive.

Due to the difficulties associated with conducting a rigorous research trial in the field (i.e., one that is well-powered, well-controlled, and features high ecological validity), many researchers have shifted their focus towards lab-based research in their pursuit of understanding whether dogs and robot dogs are perceived similarly. Specifically, due to the importance of emotional expression in complex social interactions (Becker-Asano, 2008; Taylor, Bagby & Parker, 1999) a great deal of focus has been placed on whether emotionally expressive dog behaviours are accurately recognised when presented by a robotic platform (Gácsi et al., 2016; Lakatos et al., 2014). For example, Gácsi and colleagues (2016) documented dog behaviours and vocalisations associated with joy, fear, neutral emotions, sadness, and anger. They then implemented similar behaviours and vocalisations into a Peoplebot robot (a robot without an animal-like appearance, that instead takes the form of a tablet mounted upon two beams). Results indicated that upon asking people which dog emotions were being conveyed by the robot, participants recognised all emotions at a greater level than chance level. Additionally, to varying extents (i.e., depending on the emotion) participants in this study explicitly attributed emotions to the robot's behaviour, despite only being broadly asked to describe the behaviour of the robot.

Given that these researchers were trying to address fundamental questions around emotion attribution and recognition, their methods are appropriate and their findings are insightful. Moving forwards however, in terms of developing and implementing pet-like companion robots, it will be valuable to gain a more complete understanding of user perceptions. For example, showing participants specific robot behaviours and giving them the opportunity to freely discuss related thoughts and feelings (as opposed to being restricted to single topics such as emotion perception). By giving participants a platform to discuss their broad perceptions of animal-inspired behaviours (when expressed by a robot), we can gain valuable insights for those studying and developing robots for companionship. For example, user preferences in relation to form and function, higher level attributions which are apparent (e.g. the perception of the robot as having a mind), and insight regarding the extent to which real and robotic animals are perceived similarly.

Study Aims

Through our previous work, we identified dog behaviours that owners perceived as important for establishing a rich social bond with their dog (Chapter 4; Riddoch, Hawkins & Cross, 2021). In the current study, we build on this work by gathering participant feedback about videos of dogs exhibiting the desirable behaviours, as well as select pet dog behaviours being implemented by an animal-inspired robotic system (MiRo-E, Consequential Robotics). Due to the physical differences of the robot compared to the dog (specifically, the inability to jump, rear up, or move on soft surfaces), we have focused here on implementing two behaviours in particular: 1) responsive behaviours (e.g. responding to commands such as "come here"); and 2) affectionate acts (e.g. nuzzling the user's hand). To gain insight into user perceptions, we have filmed the translated behaviours, and used these video clips to facilitate focus group discussions of social behaviours performed by real dogs and an animal-like robot.

In contrast to existing literature, we have chosen to use open questions. This is to give participants the opportunity to freely discuss their thoughts and feelings, in relation to the robot behaviours presented. By doing so, we hope to gain a deep understanding of how dog behaviours are perceived when presented by a robotic platform. Such results will be of value to both academics (e.g. when refining future studies) and robotics industry professionals (in terms of research and development).

5.3. Method

Preregistration & Ethics

This study and all procedures have been approved by the University of Glasgow College of Science & Engineering Ethics Committee (Ethics Number 300200194). The study procedure was pre-registered on the Open Science Framework prior to data collection (https://osf.io/jqcke/). All data supplied in this study were anonymised and will be stored for 10 years, after which time they will be deleted. We report how we determined our sample size, all data exclusions, all manipulations, and all measures in the study (Simmons, Nelson & Simonsohn, 2012).

Participants & Sample Size Justification

Participants were recruited through word-of-mouth, or an advertisement on social media, and all were compensated £6 for their time, in line with standard University of Glasgow participation compensation rates. We aimed to conduct four focus groups with 6-10 members per discussion, in line with recommended standards relating to group sizes (Lunt & Livingstone, 1996). Unfortunately, late cancellations meant this target was not reached and the focus groups consisted of two groups of 6, and two groups of 5. Despite not meeting our target in terms of group sizes, the sample is arguably sufficient in terms of the overall sample size (n=22). This is based on the suggestion that a sample size of 12 is required to reach data saturation – that is, "the point in the research process when new incoming data produces little or no new information to address the research question" (Braun & Clarke, 2013; Fugard & Potts, 2015; Guest, Namey & Chen, 2020). To improve the diversity of our sample, an additional 9 individuals participated via a written questionnaire (discussed in greater detail in the Procedure section). As a result, a total of 31 individuals participated in the study.

Four individuals did not disclose their demographic details, however the remainder of the sample (n = 27) consisted of 12 females (44.4%) and 15 males (55.6%), with an average age of 36.8 years (range = 22 - 65). The majority of the sample did not report any prior experience with robots – with only 7 individuals having interacted with a robot in person. With regards to dog experience, the sample was well-matched however – with 14 participants having experience of dog ownership (or working closely with dogs), and 13 having no such experience. As our sample sizes were relatively modest, we did not perform between-group comparisons across dog experience, and we have instead grouped all data together.

Robotic Platform

When considering which robot to use in this study, we considered numerous options. First, due to their resemblance to real dogs, we contemplated use of the Joy for All (Ageless Innovation) and AIBO (Sony) robotic dogs. Both were disregarded however, due to limits in terms of their behavioural repertoire, degrees of freedom, or capacity for programming (at the time of experiment conception). This led to our decision to pursue a more abstract form – specifically, the MiRo-E (Consequential Robotics).

MiRo-E (henceforth referred to as MiRo) is a biomimetic robotic platform measuring approximately 35cm x 35cm x 20cm (height, width, and depth, respectively). See Figure 5.1 for image. The robot was designed to appear generally mammalian, however it encompasses many features of prey animals – e.g. rabbit-like ears, and the nose of a cow. Pertinent to our study though, MiRo also resembles a dog in many ways– proportions similar to that of a small-medium sized dog, prominent ears, and a tail (with wagging capabilities). Much like a dog, MiRo also has hearing and sight capabilities (from the camera and microphone inputs), and the ability to respond to stimuli in the surrounding environment at a result. The visual and functional similarities (relative to a real dog), paired with the ability to easily program the robot and trigger behaviours, made it an ideal candidate for use in this study.

Figure 5.1. Image of the MiRo-E robotic platform (Consequential Robotics, UK).

When in autonomous mode, the MiRo has the ability to explore and respond to its environment. For the purpose of control, however, we programmed MiRo's behaviour and triggered these sequences manually (see "Robot Videos" section for further details).

Stimuli Creation

Dog Videos

In a previous study, dog owners identified the following behaviours as important to the bond to their pet (Chapter 4; Riddoch, Hawkins & Cross, 2021):

1. Greeting enthusiasm when the owner arrives home
2. Playful and playing behaviours
3. Spontaneously getting on the sofa and lying on the owner
4. Being physically affectionate to the owner (e.g., by nuzzling, or licking)
5. Being responsive to words or gestures
6. Consistently coming to the owner, when called
7. Following the owner around their space

To better understand the physicality of these behaviours, and the extent to which they can be successfully modelled in the MiRo robotic platform, we asked dog owners (n=6) to submit videos of their pets exhibiting the aforementioned behaviours. These participants were recruited through word of mouth and a social media advertisement. Each individual was sent guidelines regarding what to include in each clip, and tips on framing (e.g. first-person point of view, landscape only…). In the description and the onboarding email, we emphasized that personal identifiers (e.g. door numbers, dog collars with names on, personal photos) should be removed or covered, to protect the anonymity of the owner. Guidelines given to the dog owners can be found on the project's OSF page (https://osf.io/jqcke/). The dog owners were each compensated one Amazon Gift card (for the value of £20) for their time.

Robot Videos

Our next task was to create videos with the MiRo robot - emulating what was shown in the dog videos with as much fidelity as possible. When recreating the dog videos, it quickly became apparent that it would be impossible to recreate all of the dog behaviours using the MiRo platform. First, many videos involved rough terrains (e.g. beaches, woodland areas) and soft surfaces (e.g. sofas, beds) - both of which present a navigational challenge for robots in general, and the MiRo robot in particular. Second, we were constrained by the physicality of the robot – specifically, the inability to rear up, jump, or move around on surfaces typical of a home environment (e.g., flooring which is carpeting, smooth, shiny, or dark). These constraints meant that we could only focus on demonstrating certain aspects of the aforementioned desirable behaviours – specifically, 1) physical affection towards the owner, and 2) responsiveness when called. With a different robotic platform it would be feasible to realise more behaviours, however we were determined to use the MiRo platform in this study (due to ease of programming, compared to other robots on the market).

To translate these dog behaviours into the MiRo robot, we first looked at the dog videos and broke them down into behavioural chunks – focusing on capturing 1) obvious movements, 2) distance from owner, 3) orientation relative to owner, 4) eye/head position, and 5) tail positioning, 6) owner actions. We then created a sequence of events and considered if and how these behaviours could be exhibited by MiRo. Next, we created a rough sequence which could be exhibited by MiRo.

To enable MiRo to perform the dog behaviours, and create the video stimuli used in the study, we coded MiRo using the online MiRo Cloud platform (https://www.miro-e.com/mirocloud). On this platform we coded the behaviour sequences using a combination of MiRoCode (a block-based language) and Python. After testing the code on the online simulator, we triggered the code in the real-world robot and altered the code to better suit the real-world environment, as needed. For a behavioural breakdown of each dog video, and the resulting code, see the Behaviour Breakdown on the OSF (https://osf.io/jqcke/)

To give the study participants the feeling that they were watching the robot performing the behaviours, we recorded the behaviours from the user perspective – that is, in first person (as opposed to third person). All videos were recorded on an iPhone camera, as the quality was deemed sufficient for watching within an online focus group. All videos can be found on the study OSF (https://osf.io/jqcke/), and screenshots can be found in Figures 5.2 and 5.3.

Figure 5.2. Screenshots from the dog and MiRo "affectionate" videos, matched. Full videos available on OSF.

Figure 5.3. Screenshots from the dog and MiRo "responsive" videos, matched. Full video available on OSF.

After much deliberation, we made the decision to only show the robot videos to participants (as opposed to showing the two robot videos and the two matching dog videos). This was for a couple of reasons. First, we wanted participants to consider the robot behaviours as they would in the real world (making a comparison to their past experiences, as opposed to directly comparing to a video of a real dog). Secondly, we only had one hour for each focus group (due to the complexity associated with gaining ethics for a longer time period) – so we had to decide whether to focus on depth vs breadth of discussion. To allow all participants to give their opinion, and to have deep discussions relating to each of the videos, we decided to only discuss two of the four videos.

Demographic Questions

To gain insight into the nature of our sample, and aid diversity in ongoing recruitment, we collected information regarding each individual's age, gender identity, and ethnicity. Finally, to better understand whether expertise influences perceptions of the behaviours, we also asked participants whether they had experience living (or working closely with) dogs, and about their experience with technology and robots. This data was collected for both focus group and written questionnaire participants. The small sample of this study (relative to what is required to tease apart individual differences) led to the decision not to use demographic data as part of this data analysis. Future work could benefit from such insights, however – e.g. a meta-analysis examining the impact of experience (e.g. with dogs or technology) on our perceptions of robots.

Procedure

Focus Groups

Before participating in the focus group, participants were sent 1) an information sheet to read, 2) a consent form to return to the experimenter, 3) a list of possible times and dates for the focus groups to take place, and 4) a short questionnaire asking participants to indicate their age, gender identity, and ethnicity. The latter was for the purpose of creating relatively balanced discussion groups. All forms and questionnaires can be found on the project OSF (https://osf.io/jqcke/).

On the day each focus group was scheduled to take place, participants clicked a link to access the waiting room of a secure video conferencing room (Zoom). After providing consent to participate, participants entered a group video call – hosted on the Zoom video conferencing platform. All participants had their cameras on and used their microphones to interact with the other attendees. After a series of brief introductions, participants were informed of the ground rules. This included guidance such as "respect the opinions of others" and "there are no right or wrong answers”. Participants were first shown the responsive MiRo video (in which the robot looks at the user, and returns to the user when called), followed by the affectionate MiRo video (in which the robot appears to rub its face against a person’s arm). After each video, participants were asked two questions –

1. *If this robot was in your home, and engaged in that behaviour towards you, what would you think? (Do you have an opinion? How would it make you feel?)*
2. *Is there anything that you would change about the behaviour that you’ve just seen? (Would you add, change, or remove anything?)*

Following the videos and video-specific questions, participants were asked two more general questions –

a) *“If you saw someone else with a robot dog, what would you think about them?”*
b) “What are your thoughts/feelings about robot pets? Do you have any burning thoughts about robots for companionship, or anything relevant that you would like to share with our team?”

Upon ending the recording and thanking participants, they were given a short verbal debriefing and the opportunity to ask questions. They were then told that they could leave the video call and were sent a full debriefing form via their preferred method (email or post). To better understand whether dog or technological experience influences perceptions of the behaviours, we also asked participants whether they had experience living (or working closely with) dogs (yes/no) or experience interacting with or programming robots (yes/no).

Questionnaire Format

To facilitate responses from individuals unable to attend a focus group (e.g. those with long working hours, childcare responsibilities, and individuals without access to video conferencing) an alternate method of participation was offered. Specifically, rather than engaging in conversation via video conferencing, participants (n = 9) were sent the videos via a OneDrive and presented with questions via a paper or electronic questionnaire. See OSF for questionnaire template (https://osf.io/jqcke/).

Qualitative Data Analysis

Previous studies have demonstrated that when conducting conversations via video conferencing platforms, as opposed to in-person, participants interrupt each other less, take fewer turns, and spend more time speaking during their turn (van der Kleij et al., 2009). This apparent tendency was observed in this study - with participants waiting their turn before sharing their opinion and engaging in little discussion with other members of the group. Despite being negative in certain contexts, the lack of social interaction between members of the group was desirable in this study – as it made the data comparable between our collection methods (focus groups and written questionnaires). So much so that when comparing the structure, content, and length of responses, there was little difference between the focus group and written questionnaire data. As a result of these similarities, we analysed the data collectively.

Data were analysed using Thematic Analysis with NVivo software (v.12), following a rigorous six-step method (Braun & Clarke, 2019). This is a widely used inductive method of qualitative analysis that involves familiarisation with the data, followed by classification of recurring ideas into codes. These codes are grouped into broader themes, which are then discussed by independent coders. In further screening rounds, the themes are reviewed and refined, and named and renamed, where suitable. The coding process is interactive and incorporates disassembling and reassembling data, evaluation, interpretation, and attempting to draw conclusions (Saldaña, 2014). In this study, three coders (KR, SM, and RH) undertook the analysis. First, the coders each independently analysed one focus group. Discussion then took place between the coders to agree upon ideas that recurred within their focus groups. Where there was a clear difference between the attitudes of owners and non-dog owners, this is emphasised in the results. Where there is no mention of a difference (e.g. readers should assume that the insights were demonstrated by both dog owners and those without experience of dog ownership.

Reflexivity

In this study, we began working with a new collaborator – an expert in Theology and what it may mean to "love" a robot. As a result, compared to previous sections of this thesis, it is to be expected that there will be themes relating to ethics. In this study, we also engaged in snowball sampling which stemmed from our close connections (e.g., family, friends, professional contacts). As a result, it could very well be the case that the opinions of users will strongly reflect our own – that robots are a potentially exciting opportunity for the future, but we should be mindful of the ethical issues associated with human-robot companionship.

5.4. Results

During data analysis, an overarching motif became apparent – specifically, this was participants' tendencies to draw comparisons between the robot and real animals. This was true of both dog owners, and non-dog owners. Many people drew from their own experiences with cats and dogs, while others made comparisons with other domesticated animals, including horses, goats, and rabbits. Given the appearance of the robot, the animal-inspired nature of its behaviours, and the wording of some questions, comparisons to real animals were expected. When making such comparisons to animals, both positive and negative opinions emerged. On the one hand, some people recognised pet animal behaviours expressed by the robot and perceived this similarity as desirable. On the other hand, other people focused on what the robot could not do, relative to a real pet – for example, multiple participants commented on how certain behaviours were different in speed, duration, or intensity, when performed by the robot compared to a real animal. When given the opportunity to suggest changes to the robot, the majority of participants' suggestions were focused on increasing the similarity of the robot to a real animal, as opposed to accepting or embracing its robotic nature. Specifically, a number of comments were made regarding how the addition of more animal-like features (e.g. affectionate noises such as "*purring*", and the addition of "*fur*") would elevate the design. Below is a figure (Figure 5.4) summarising the most common perceptions of the participants, resulting from comparison between the robot and real animals.

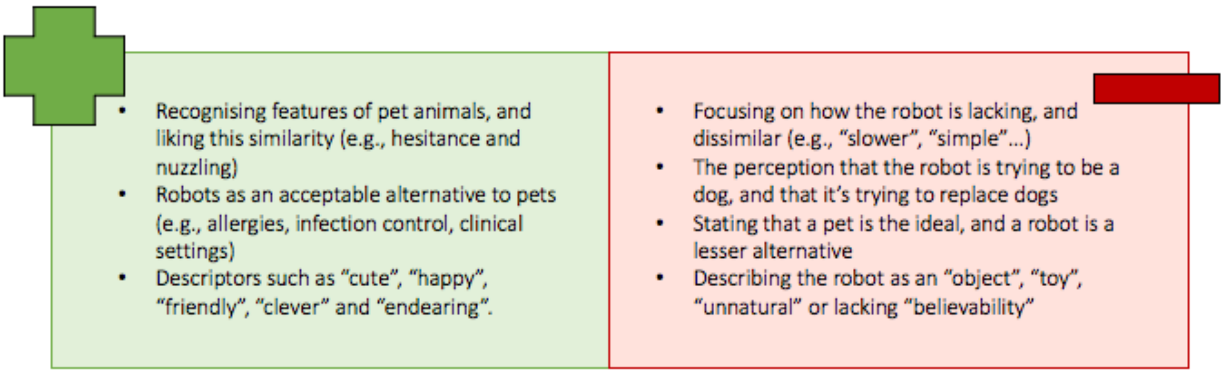

Figure 5.4. Illustration of common perceptions resulting from comparison between the robot and real animals, split into positive and negative categories.

Teasing apart aspects of the overarching comparison between robots and animals, the coders identified a number of key themes. Initially, the following themes were present: Comparison to Animals, Purpose, Novelty, Features, and Ethical Awareness. Upon coding the full dataset (including the written questionnaire data) however, the themes were altered slightly. Comparison to animals was omitted (as it was regarded as an overarching feature of the data, as opposed to a single theme) and Features and Novelty were integrated within other themes (due to their relevance within "A Preference for Natural" and "A Desire for Purpose"). The four resulting themes, and direct quotes in support, are discussed in detail in the following section.

Summary of Key Themes

Within the overarching framework of comparison to animals, four key themes emerged: 1) a preference for the "natural", 2) a desire for tangible benefit, 3) varying perceptions of robot users, and 4) ethical awareness. In the first theme ("A preference for the natural"), we highlight how comparison to real animals led to the perception of the robot as being "toy-like". We also discuss participants' desire for behaviours that more closely resembled real animals. In the second theme ("A Desire for Tangible Purpose") we focus on the role participants think robots should (or should not) play in our future – with emphasis on a desire for functionality that exceeds that of a real animal. In the third theme ("Varying Perceptions of Robot Users"), we consider how robot users might be perceived, and how context and demographics might shape people's judgements. Comparisons to animal ownership emerge again here, as do references to how a person might be stigmatised for owning a robot compared to a real pet. Finally, in the fourth and final theme (Ethics Awareness), we outline participant concerns in relation to robot ethics – discussing topics such as privacy, deception, and concerns that robots might replace humans and real animals for social companionship. We now consider each theme in turn, while asking the reader to keep in mind that these themes were often intertwined in their occurrence during interviews. We have also attempted to further support understanding of our findings by drawing attention to major themes via figures and bullet points.

Evidencing quotes are labelled with a participant number, allowing for cross-referencing with the Demographics Summary table (Appendix 1). The table outlines the following for each participant; age, gender identity, experience with technology, and experience with dogs (https://osf.io/jqcke/). As discussed in the Methods section, demographic insights were not used in the data analysis, but could prove insightful in future research (e.g. meta-analyses)

Theme 1: A Preference for the "Natural"

When making comparisons with companion animals (discussed previously), participants repeatedly referenced to a desire for what is "*natural*" and "*organic*". Specifically, numerous participants indicated that they perceive the robot like a "toy", or just an "*object*", and this led to feelings of apathy towards it as a result. For example, *"It's a material object/machine so not any feelings towards it."* [(2)]. Participants also made repeated references to how the robot's mechanical nature was perceived as a limiting factor in terms of long-term use or bonding to the robot. This perception was present in both dog owners, and those without experience of dog ownership:

> *"I don't think I would bond with it as I'd see it as an object still."* [(8)]

> *"I think I would not perceive it in a way I would a "real" pet. That is probably mostly due to its un-animal-like movement and sounds. I think I would rather perceive it like a toy which would be fun interacting with since it reacts to what I say (and do?). However, I do not believe it would make me feel less alone (as a real pet certainly does)."* [(28)]

> *"is it meant to just be a toy or as a real simulated animal. Because it definitely comes across more like the former than the latter. I don't think I'd develop any sort of attachment to it really."* [(12)]

In the following sub-sections, we delve into why the robot is perceived as toy-like, and the desire for features which more closely resemble those of real animals. Specifically, in this section we briefly provide evidence to support the addition of the following features: unpredictability, expressive eyes, fluid motion, natural sounds, and soft texture. See Figure 5.5 for visual summary.

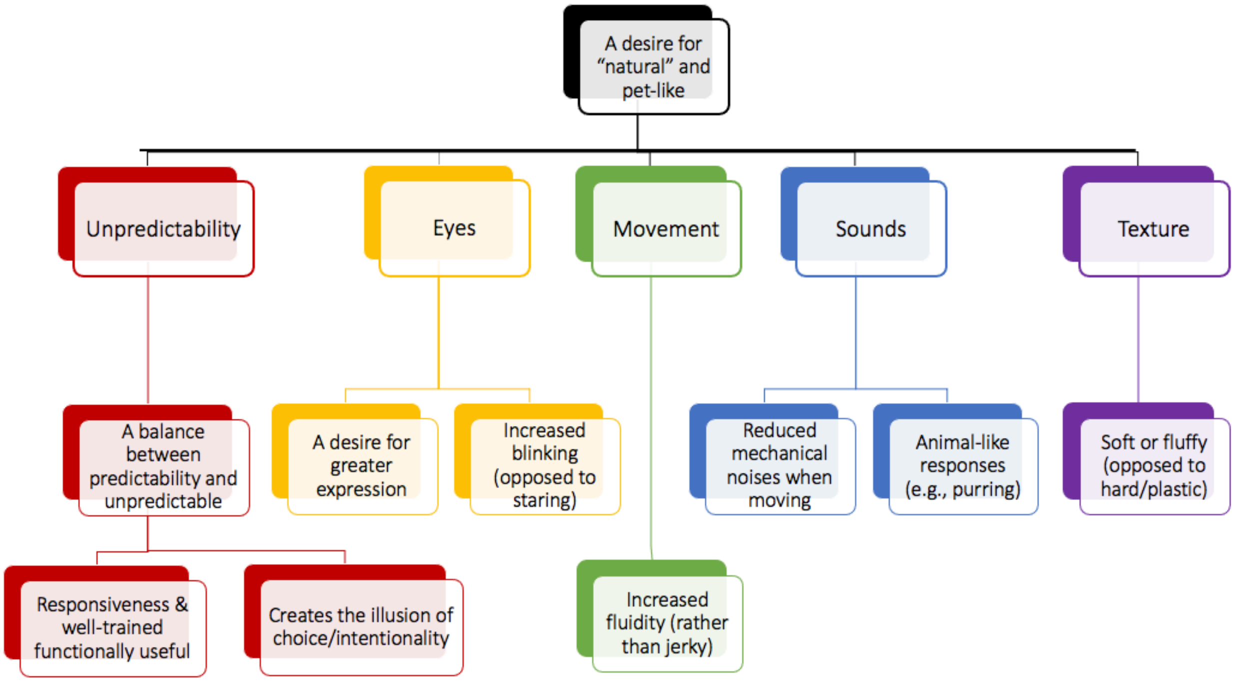

Figure 5.5. Summary of desired improvements, taking into account the "Comparison to animals" and "Natural vs Robotic" themes.

a) Unpredictability

After watching the responsive videos, participants provided considerable positive feedback. When describing the behaviours, people used words typically associated with a real dog exhibiting the behaviour - e.g. responsiveness as "*well-trained*", "*listening*" and "*obedience*". Additionally, people generally had positive impressions of the responsiveness – commenting on how the robot seemed "clever" and "happy" to see them. Such attributions are thought-provoking in a way, as they suggest that some people perceive the robot as being able to exhibit intentions or emotions. References to the robot as emotional, or having awareness, were made by both dog owners and non-dog owners.

> *"It appears as if the robot was very quick to respond to its name being called, which I would typically attribute to an animal being well trained or an animal being happy or excited to see you. This made me feel as if the robot was being attentive making me feel as if the robot was happy to see me." (29)*

> *"I would be impressed with the responsiveness from the robot – both in terms of action and also speed on response. I liked the way the robot stopped when its name was called as if it was listening, before responding again to the command of 'come here'." (16)*

However, there were also comments that responsiveness might not always be viewed as positive. For example, people spoke of how it is good that the robot responds quickly (in terms of obedience, functionality, and safety) but also how such predictable responding could be negative in terms of novelty and long-term use. Specifically, numerous people (both dog owners and non-dog owners) commented on how the robot's predictable nature led to the perception of simplicity, and how such responsiveness could become unengaging over time – for example, "*I think I would be delighted to see it turn around and approach me after being called – I smiled watching the video. I wonder though if I would keep being happy about it after seeing it function a number of times, or if it would get boring.*". Some went as far as to suggest that the predictable nature of the robot could be a limiting factor in terms of bonding/companionship specifically -

> *"I have seen a number of robot pets in the past but none of them seem to traverse the line between toy and pet. They always seem to be too simplistic to really be able to form a bond with them."* *(12)*

> *"The idea of robot pets seems like a nice one but they always seem to be very basic. For actual companionship I think you would need to develop something less like a shiny toy and more like an actual pet/companion so something more intuitive maybe?"* *(13)*

Moving forwards, it seems there is a need to balance predictable and unpredictable responsiveness. This is a theme which was also apparent in our previous human–dog bonding research – where dog owners reported liking obedience the majority of the time, but liked a lack of responsiveness on some occasions (as it was perceived as free will and choice; Riddoch, Hawkins & Cross, 2021). These ideas were picked up by a couple of participants in this study also -

> *"The robot responds immediately. This is good in terms of conveying the compliance of a machine, but if the goal was to make this seem more pet-like then a pause before turning, or a pause between turning and returning might add verisimilitude".* *(31)*

> *"I think what makes a pet a pet is that they have an own free will. I'm not suggesting you have to invent general artificial intelligence for this to work, but the extreme causality of calling and the bot and it responding very predictably makes it less natural I think."* *(23)*

b) Expressive Eyes

When given the opportunity to give feedback on the robot and suggest changes, the eyes were repeatedly commented on by both dog owners and non-dog owners. Specifically, numerous people commented on how the lack of eye movement was "*unnerving*" and how they made the robot appear "*angry*", "*creepy*", or "*menacing*". Such emotion perception is important to consider moving forwards, as negative emotions might be inappropriate or off-putting in certain contexts – e.g. short-term interactions with children. In terms of changes which could be made, there was repeated mention of greater movement of the eyeballs or eyelids. Suggestions included increasing the frequency of "*blinking*", avoiding eyelids which partially cover the eyes (as this looks "*angry*"), and having eyes with the ability to emit more/different expressions. For example, *"Perhaps a range of eye and eyelid movements could be added to make it more expressive." (1)* and *"I'd like to see it blinking more as its eyes are fairly angry looking." (13)*

c) Fluid Motion

Numerous participants referenced to the robot's lack of fluidity, using terms such as "*jerky*", "*unnatural*", and "*forced*". Repeatedly, it was mentioned that such movement qualities were undesirable, and that more "*fluid*" motion would be preferred. Again, there were some references to the smooth movement of animals, and how the robot's movements were undesirable in comparison. Evidence suggests that humans have a preference for biological motion (Williams & Cross, 2017), so perhaps this feedback results from this phenomenon.

> *"Slightly more fluid head movements and less noticeable whirring (from the motors?) stood out to me as possible points of improvement." (18)*

> *"The way the head turned and then the body rotated to meet the head was a little unsettling because it appeared unnatural – a more fluid movement would be more appealing to me." (11)*

> *"… If I watch a real puppy my heart melts, there's this strong emotional response that screams: CUDDLE HIM. But the plastic of the bot and its relatively unnatural movements make it that I don't feel such emotions." (23)*

d) Natural Sounds

In addition to the addition of expressive eyes and more fluid motion, numerous participants (dog owners and non-dog owners) mentioned how they would like changes to the sounds of the robot. Such comments varied in their nature. First, participants commented on how "*responsive sounds*" would be desirable – e.g. purring in response to touch (discussed in more detail in the "Comparison to Companion Animals" theme). In contrast, other participants commented on how the sound of the robot's motors whirring was "*off-putting*" and "*undesirable to the ears*". Although such participants often acknowledged the technical complexity of creating a quiet moving robot, they did emphasise that the sound was undesirable. On a few occasions, respondents spoke of how the mechanical sound served as a reminder that the robot is a mere object or toy.

> *"The sound is quite off-putting though and again, makes it look and sound (behave?....) like a toy."* (2)

> *"The sound of mechanisms whirring created some dissonance with the robot. I'm not sure what this might be, but an audio element may be worth considering to cover up this noise. It wouldn't have to be much – cats are typically quiet pets for instance – but the whirring was slightly off-putting."* (25)

e) Soft Texture

Although the focus of this paper is on robot behaviours, it is worth mentioning that in the data, respondents repeatedly mentioned how the "*plastic*", "*shiny*", "*hard*" surface was undesirable, and how the addition of a "*soft*" or "*fluffy*" texture would be preferable. Some individuals suggested that such an addition could enhance one's ability to become attached to the robot.

> *"I think if it had fur, or other textures on it, I would feel more attached to it. I think the plastic nature of it makes me separate it from being an actual pet"* (5)

> *"I didn't feel like the robot looked enough like an animal to be considered anything other than a toy. Aesthetically, it's very shiny and doesn't have the same "cuteness" of a dog."* (20)

Theme 2: A Desire for Tangible Benefit

When given the opportunity to voice general thoughts about robotic pets, the majority of participants focused their discussion on the need for robots to offer tangible benefit. This was true of dog owners and non-dog owners. See Figure 5.6 for visual summary of imagined purposes, as indicated by participants in the study.

Health

- Physical (e.g., fall detection, heart monitoring)
- Mental (e.g., anxiety, social anxiety specifically...)
- Loneliness specifically
- A reassurance for carers

Entertainment

- Personal, in the home
- Group entertainment, when hosting

Other feedback

- Multi-purpose desirable (e.g., voice assistant embedded)
- Cute companion is insufficient purpose for a healthy person

Figure 5.6. Summary of purposes for an animal-like robot which were identified by participants in the study.

The first noticeable thread in the data was the idea that a robot should be more than just a companion – that is, it should have tangible purpose and benefit an individual (e.g. a practical helper around the house, something a person can converse with…). Related to the previous theme, participants also spoke of how cuteness was insufficient, and there must be more to the robot (e.g. functionality and purpose) to facilitate repeated use.

> *"I think what they might need is a well-defined function… a bot that helps in your house, AND is a companion, would be ideal."* (24)

> *"I like how responsive it was, and it was quite cute, but I probably wouldn't interact with it much."* (13)

"How about some sound effects to show responsiveness vocally. Or even better, make it doubly useful so you could talk to it… like an Alexa. So it is useful in more than one way." *(19)*

Unsurprisingly, given the extensive literature on robots in the healthcare and education sectors (Anwar et al., 2019; Scoglio et al., 2019), numerous people referenced to robots as potentially beneficial for vulnerable people. For example, people speculated about the benefits for frail older people, people with heart conditions, and individuals with mental health problems. Specifically, people spoke of how the robot might be able to monitor if a person falls, help psychologically (e.g. alleviating a user's anxiety) or "*identify a forthcoming heart attack or heart problems… or an epileptic seizure"*. A couple of participants referenced to how such features could put family members and carers *"at ease"* as their loved one would have *"companionship or support"*. Also to be expected (given the focus of mainstream media on the high prevalence of loneliness and mental health problems; World Health Organisation, 2021) was repeated mentioned of how robots could be useful for lonely individuals, or those who are socially isolated. For example, numerous people mentioned how a robot could be a social presence within the home environment and reduce feelings that one is alone – "*I wouldn't feel alone. I would feel like someone's actually there with me."* *(27)* *and "It would feel… like someone's actually in the house with them."* *(26)*

Participants also identified that such a robot could be a form of entertainment for the owner, however, as already touched on above, numerous participants emphasised concerns about the novelty of the robot. Despite recognising potential benefits of having a robot (in terms of health and wellbeing), people expressed that they would likely get bored of the robot over time. For example – "*I'm not sure if I would feel entertained by it for a prolonged period once the novelty has worn off."* *(18)*. A recurring reason for this was the perception of the robot's behavioural repertoire as limited (which is perhaps unsurprising given the small number of demonstrative videos that were given to the participants, and the lack of explanation regarding the robot's extensive sensors and features). In addition to suggesting that the robot could be *"entertaining"* and *"amusing"* to the owner (in the short term), some participants also discussed how the robot might function a form of entertainment at social gatherings. This links into people's responses upon being asked what they would think of someone with a robotic animal – with many people stating that they might perceive an owner of a robot as "*wealthy*", "*affluent*" or having "*too* *much money*". Specifically, numerous participants mentioned that a robot could be something to show off, facilitate conversation, or lighten the mood, when hosting -

> *"Calling it would be more like a party trick, like back when voice commands for devices were first introduced. Like: 'look how funny, my robot comes to me when I call it'. In that sense I wouldn't let it 'loose' in the house, but store it in between moments of 'showing it off'..."* (23)

> *If it's in someone's home I think I would just find it pretty entertaining to see a more or less autonomous robot dog around, and would think of the owner as interesting, or at worst eccentric, but wouldn't look down on them or feel embarrassed.* (18)

Theme 4: Varying Perceptions of Robot Users

In addition to the perception of a robot owner as wealthy (as discussed in the "A Desire for Tangible Benefit" theme), participants commented on other ways in which they would judge robot users. Numerous respondents suggested that upon encountering a person with a robot, they would try to figure out why the person was using the robot. Specifically, rather than jumping to one conclusion, it appears that people would engage in a period of consideration, i.e., weighing up whether the robot is for support, or a more frivolous purpose (e.g. publicity or entertainment).

> *"I think I would be excited to see someone with a robot dog, and I'd want to know why they had one: practical reasons (maybe it's a support animal but they have an allergy?) or just to be a bit eccentric? I'd definitely be intrigued."* (22)

> *"Probably three thoughts: 1) Almost certainly they are lonely, 2) Almost certainly they are inactive, whether through choice or mobility issues, and 3) I guess it possible some may have one just as a gimmick."* (19)

Dependent on the purpose (support vs non-support), two types of judgements would apparently be made – 1) the person as "*disabled*", "*lonely*", or "*in need*", or 2) the individual as "*tech-minded*", a "*lover of gadgets*", an "*early-adopter*". When referencing these two types, different connotations were associated, and different issues brought up as a result. For example, when discussing the non-support users, participants repeatedly referenced to how non-support use was entertaining and generally harmless. In contrast, when discussing robots for support (particularly loneliness) participants used emotional language (e.g. "*sad*" or "*upsetting*") and recognised this purpose as potentially problematic in terms of ethics. The latter point is discussed in greater detail in the final theme "Ethics awareness".

> *"I'd think they had a cool new toy. Probably think they were quite technically minded, "geeky" and into gadgets and new technologies."* (2)

> *"I can imagine that seeing someone who belongs to a vulnerable group with the robot dog would probably make me a little sad, as I would interpret this to suggest they feel lonely…"* (24)

When considering what they would think of a person with a robot, context appeared to be an important factor for participants. Repeatedly mentioned was whether the robot was used outdoors, or in the person's home – the former repeatedly being referred to as "odd". For example - *"If I saw someone walking a robot dog outside, that would be rather odd (since robots don't need a walk the way real dogs do)."* (17). Additionally, numerous participants (dog owners and non-dog owners) mentioned how a person might be judged differently depending on their age – with a child being judged less critically than an adult. Specifically, participants alluded to child-use as innocent, but adult-use "strange".

> *"The age of the person would play into the judgement. I wouldn't think much about a child with a robot dog other than "that's an unusual or interesting toy", whereas an adult with a robot dog we would associate with loneliness."* (10)

> *"I would probably equally think it is cool and rather strange. As in, if a kid had it, this would seem like a super cool toy. Though with some adults it could seem a tad strange, unless you knew that for whatever reason the person couldn't own an animal… then it would be nice."* (30)

The apparent distinction in concerns between adult and children could result from the social norms of playing behaviours. Specifically, pretend play (sometimes termed "make-believe") is encouraged in children, and has associations with fun and creativity. In contrast, adults are expected to leave play behind as they age, and play (especially with toys and engaging in make believe) is associated with stigma as a result (Heljakka, Harviainen & Suominen, 2018).

For a visual summary of how robot users may be perceived, and how this could be dependent on whether they are using the robot as a support (e.g. for physical monitoring, or mental health/wellbeing), or non-support purposes (e.g. personal or group entertainment), see Figure 5.7. This illustration brings together comments from this "Varying Perceptions of Robot Users" theme, and the previous "A Desire for Tangible Benefit" theme.

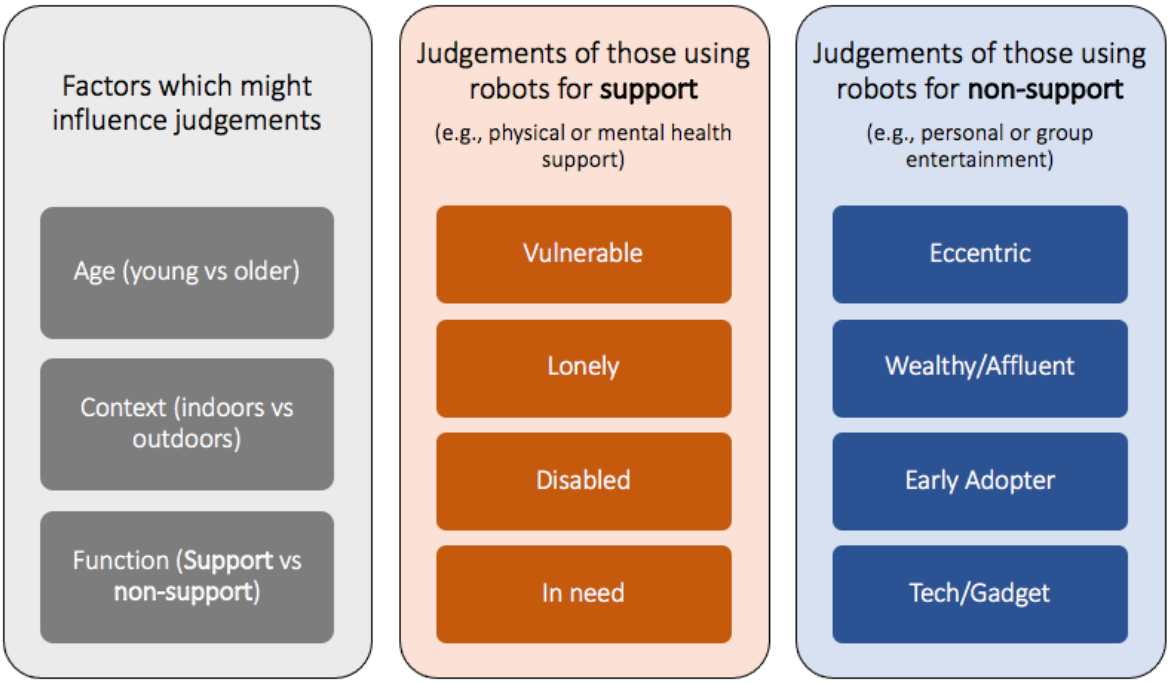

Figure 5.7. Visual summary of how robot users may be perceived dependent on the purpose of use (as indicated by participants in this study). The first grey box indicates factors which might influence said judgements.

Despite recognising the benefits of robots (e.g. for lonely individuals, clinical populations…) numerous people emphasised that they would not want a robot dog themselves. For example - *"I think it's realistic and it quite responsive. However, I already have a dog and having that experience already would make seeing the robot around the house a little odd."*. Additionally - *"I personally wouldn't get one because I'm fortunate to have an animal pet already, however I could really see others using it in other contexts."* [(5)]. Such comments suggest that dog owners see companion robots in a similar way to real pets, and they would not be needed in a pet household as a result. This ties back into the perception that to be useful and beneficial, a robotic animal should have increased functionality and purpose compared to a pet (Theme 3 – A Desire for Tangible Benefit).

Theme 5: Ethics Awareness

By giving people the opportunity to share their broad thoughts about robots, we came to appreciate the extent to which members of the general public are aware of and voice ethical issues surrounding robots. While this awareness varied between people, respondents collectively picked up on many poignant ethical issues – in particular deception, privacy, and replacement. We will address each of these in turn, in this section.

a) Deception

With regards to deception, concerns appeared to vary depending on the age of the user. When referencing older people, a couple of participants expressed an uncomfortableness around the person believing that the robot is alive. This discomfort appeared to be heightened when it was suggested that the person may have been "*tricked*" or "*deceived*" somehow. There was, however, reference to how believing a robot is alive might be acceptable in cases where the person was reaping important benefits from the robot (e.g. dementia). In many cases, participants spoke of a sense of conflict between the benefit for the person, and what was deemed to be "*right*" more broadly – this suggests ethical and societal concern in a more general sense.

> *"There is almost a relationship between how you perceive the relationship between the robot and the person. In that if you believe the person was being deceived by the robot into believing it was real then that doesn't seem good. However, if the person is aware it's a robot, then it all seems good."* (30)

> *"I can see how a robot dog could be a valuable companion to some people, e.g. patients with dementia (note: I work in dementia research). Still, I am a bit torn as patient groups being supplied with such robots also suggests to me that as a society we are failing to provide enough "real" (i.e. living) companionship to them. This is why I would also feel saddened if the number of "support robots" was to increase. Still, I know that toy interactions can be beneficial so all in all I can only ever arrive at a state of mixed feelings about robot companions for vulnerable adults."* (25)

In contrast, when referring to children's use of robots, participants were more accepting of the perception that the robot might be alive. Rather than focussing on deception, participants asked questions about the robustness of the robot, and expressed concerns that the robot might be considered "dead" if it ceased to work – potentially upsetting and confusing for a child.

> *'"I would also wonder about the level of damage they can with take. If there are lots of children- or stairs in a household would the animal be considered dead if it broke?"* (4)

In a couple of instances, there was reference to how the study participants felt deceived during this study – referring to the depicted interactions as "*fake*" or "*forced*" somehow. Such individuals were explicit in commenting on how they were aware of, and not susceptible to, such influence. Interestingly, both such comments came from individuals who had owned numerous pets (including dogs), or have worked very closely with numerous dogs –

> *[In relation to the Responsive video] – "I don't feel it is engaging with me I see it like a children's toy, I would not feel any emotion, I could not feel anything towards a robot."* (7)

> *"How would it make me feel? A bit stupid to be honest. It also makes me feel somewhat sad that there probably are people who would find it reassuring or beneficial."* (19)

> *[In relation to the Affectionate video] - "I couldn't see myself initiating this behaviour towards the robot if I were to have it in my home. Having grown up with pets, this sort of responsiveness feels forced. One of the elements of petting a real pet is the understanding that it derives joy from it, and being so aware that this is a robot, I'm entirely aware this is an added feature for my benefit which makes it feel more fake somehow."* (26)

These quotes, and the reason behind their intensity, are arguably very important to consider moving forwards in the development of companion robots. In the focus groups, we did not have the opportunity to address these feelings, however such strong comments emphasise the need to thoughtfully consider how companies market robots, so as to avoid or manage such strong negative opinions. To investigate further the negative perceptions of robots, as well as the roots of these perceptions, would be a fruitful area of study, particularly in light of our findings about potential stigma associated with robot ownership (Theme 4 – Varying Perceptions of Robot Users).

b) Privacy

In addition to concerns about deception, a few people questioned the robot's "listening" capabilities.

> *"I also thought of the fact that it is always listening for its name – would this therefore mean the microphone is always active and listening?"* (10)

> *"such a feature would be similar to a smart speaker like Amazon Echo Dot… Google Nest Mini. This could create worries or paranoia about privacy… especially if the robot would be connected to the internet! Although not sure if this would apply for a robot pet…"* (11)

Such comments illustrate that members of the general public have an awareness of data security and privacy, however a lack of understanding regarding how MiRo's data is stored and potentially used. The quotes suggest a need to address such concerns when advertising robots – for example, making it clear that onboard processing is used (if this is the case) and explaining (without specialist terminology) that data is processed within the robot.

c) Replacement

When referring to the topic of replacement, a broad range of insights were presented. Numerous people commented on how robots might replace people, with the majority mentioning concerns that carers or companions in particular might be replaced by robotic animals.

> *"My only concern with robot pets is their potential (ab)use as a cheap fix in understaffed (elderly) care institutions, say if an institution bought 50 robot pets instead of hiring more care staff – that is something I would find worthy of sharp criticism."* (19)

Unlike the issues mentioned previously however, an awareness existed that in some cases it might be more ethical to replace a living agent with a robot. For example, numerous participants referenced towards robotic pets as potentially beneficial in terms of animal welfare - *"I think pet robots are a fantastic opportunity to… prevent unethical keeping of pets (like hamsters in very small cages etc.)"* (29). Additionally, a few participants recognised that in some cases, the alternative to a robot might be loneliness – and in such cases a robot might be preferable. For example - *"I think robots for companionship for elderly people is a good idea, especially if the alternative is loneliness (in places like nursing homes, or for those aging at home who are alone)."* (31)

Numerous people recognised the potential of robotic animals as an alternative for those who cannot have a dog for some reason. In many cases, participants explicitly mentioned how robotic pets could lead to similar benefits as real pets - *"I understand that there may be those who are simply not able to physically look after a real dog and this could offer them something in place of that."*. In some cases, participants suggested that a robotic dog might be preferable to a real dog – particularly in terms of the amount of responsibility, and caring responsibilities associated with owning a real dog - *"It would be a great idea for somebody who works long hours in the office and not being able to look after a real dog…"* (26) and *"They're much less commitment than something that lives and breathes because you don't need to feed it or teach it not to poop on the carpet or find someone to look after it whilst you're on holidays."* (10). Participants also referenced to how robotic pets could allow individuals in clinical settings, or specialist populations, to reap the benefits associated with animal interaction.

> *"They might do well in clinical settings, care homes or schools because this robot in the videos looks like it can be wiped clean and kept germ-free, which is a problem with furry animals particularly with COVID risk, e.g. it's unfair to keep bathing therapy animals who visit multiple people in one day and need to be kept free from bacteria or viruses."* (9)

> *"I think they would be great idea for somebody who's suffering from loneliness and not being able to look after a dog or pet full time not having not being able to pick up after them that are being able to feed them it would be a great companion for somebody who is suffering for example from Alzheimer's dementia."* (27)

5.5. Discussion

By speaking to dog owners, previous work identified numerous dog behaviours apparently important for building social bonds between pet and owner (Riddoch, Hawkins & Cross, 2021). In this study, our main aim was to explore perceptions of such behaviours, when expressed by a robotic platform. In addition to finding an overarching comparison between the robot and real animals (to be expected given the experiment design), the results illustrate the reality of human social perception as being complex and malleable, varying across and within individuals. In addition to demonstrating individual differences, we identified purpose and context as important factors in terms of judgement formation (of robots, and robot users). Moving forwards in the development of animal-inspired social robots, several findings are particularly important to highlight: 1) the desire for what is "natural", 2) perceptions of the robot as like a toy, and 3) the need to consider the purpose or functionality of the robot. Below, we consider the implications of these findings, as well as reflecting on the strengths and limitations of our research approach.

Major Themes and Implications for Future Research and Development

In this section we highlight key findings and consider how the insights might be useful for those developing animal-inspired robot companions.

The Desire for "Natural"

When recreating dog behaviours within the robot, we had to omit or adjust the dog behaviours, due to the physicality of the robot. For example, due to its lack of limbs, we could not recreate MiRo jumping up to greet a person. Additionally, due to its inability to turn quickly on certain surfaces (particularly on carpet, or smooth flooring), we were unable to convey responsive behaviours within a typical home environment. In terms of developing robots which realistically behave like dogs, such limitations are important to consider for managing peoples' perceptions and expectations of the robot. The latter example (the robot struggling on carpeted flooring) highlights the importance of considering the environment of the user. Without early consideration of the typical user space (e.g. the flooring, lighting, space, and obstacles, for example), one risks impairing the robot's performance. The former example (with regards to the lack of limbs) is also valuable to emphasise, as it highlights the need for form which closely resembles that of a real dog (if pursuing the approach of implementing realistic dog behaviours). Without mimicking the form of a dog, there is a risk of limiting the quality and quantity of the robot dog's behaviours, which, as our work shows, could hamper user experiences of the robot and its suitability for domestic environments.

Despite its limitations (due to its design as a "generally mammalian" rather than a dog-inspired robot; Collins et al., 2015), MiRo was able to engage in a range of animal behaviours that pet dogs might naturally engage in– many of which were clearly recognised by participants. For example, a large number of participants commented on the expressive ear and tail movements, and the small hesitations of the robot (which we intentionally programmed, to improve resemblance to the real dog videos). The majority of participants emphasised that nuances *were* missing however, and they desired more "natural" behaviours. Specifically, less robotic sounds, increased fluidity of movement, the presence of soft texture, and expressive eyes, were repeatedly mentioned as desirable. This desire for such realism, as opposed to mechanical features, presents a considerable challenge for those developing animal-like robots.

In addition to the costs associated with creating hyper-realistic animals (due to the complexity of biological organisms), such robots could fall into pitfalls associated with user perceptions. For example, if robotic animals are imperfect (even subtly) users might become disappointed and unsatisfied with the interactions, as their high expectations (based on real animals) will not be met (Šabanović & Chang, 2016). The lack of life within a realistic form could also lead to what is sometimes known as the "zombie effect" – a negative reaction to something which appears to be alive, but is found not to be (Dautenhahn et al., 2002; Fong, Nourbakhsh & Dautenhahn, 2003). Alternatively, slight imperfections could lead to "uncanny valley" effects – feelings of dismay or revolt resulting from the lack of perfect replication (Mori, 1970). To avoid triggering such effects and expectations, we would argue the following moving forwards: 1) explore if and how we can reduce user expectations from those demonstrated in our study, particularly in relation to 'naturalness' and 'realness'; and 2) consider moving away from human or animal-inspired robots, and towards more abstract forms. Both points would ideally need to be addressed in tandem, given how our results show that there is a relationship between user expectations and robot appearance/design in shaping perceptions of the robot and relationships with it.

Toy-Like Perceptions

Many scientists agree that for social interaction to be meaningful and engaging, all interaction partners should be perceived as having intentions, emotions, and desires (sometimes termed "mind perception" or "theory of mind", although there is some debate regarding the specifics) (Apperly, 2012; Lin, Abney & Jenkins, 2017; Schaafsma et al., 2015; Waytz et al., 2010). Such qualities facilitate feelings that one is being genuinely listened to, and that the other person is able to empathise with how we are thinking and feeling (Ensink & Mayes, 2010; Singer & Tusche, 2014). In addition to enhancing human social interactions, the attribution of mental states (termed 'anthropomorphism') is proposed to add value to human-dog relationships. For example, Mithen (1996) proposes that "without the beliefs that our dogs 'enjoy' our company, 'miss us' when we are gone, or feel affectionate towards us, our relationship with dogs would lose much of its value, becoming superficial and essentially meaningless". Given the apparent importance of mind perception in social interactions, one might be concerned that participants repeatedly referred to the robot as "*toy-like*" or an "*object*". Studies have, however, demonstrated that humans are able to attribute mental states (e.g. intentionality and emotions) to inanimate objects including toys (Gjersoe, Hall & Hood, 2015; Severson & Woodard, 2018).

The perception of the robot as a toy is, however, potentially detrimental in terms of the target audience, due to the stigma associated with playing with toys as an adult (discussed in greater detail in the results section - "Perceptions of Users"). Many participants expressed that they thought it would be "*strange*" or "*odd*" for an adult to use a robot (particularly if the person was not disabled or in great need), so a need exists to better understand such stigma if marketing to an adult audience. It could be the case that we can negate such stigma – for example, by changing the appearance of the robot. In this study, however, we cannot shed light on this question as 1) we only used one type of robot in the clips, and 2) the questions were not designed in such a way to encourage reflection about the impact of robot appearance.

A Longing for Purpose

The majority of participants appeared to accept that robots could play an important role in the lives of vulnerable people – for example, those in clinical settings, lonely individuals, or older people at risk of a fall or heart attack. In most instances, however, people also suggested that the robot should be multi-purpose. For example, a companion robot could not only assist with easing loneliness, but also in monitoring a person's health and assisting with household tasks. For many, companionship alone was not considered a sufficient purpose. One could argue that dogs (particularly in the western world) exist solely for the purpose of companionship, and our expectations of robot as high in comparison. In reality however, there are a multitude of roles that a dog can play in a person's life (e.g. companion, social facilitator, entertainer, source of exercise, and protector) (Blouin, 2013; Greenebaum, 2004; Maher & Pierpoint, 2011; Nobayashi, 2006). In some communities, dogs are also used as a status symbol (Maher & Pierpoint, 2011), and a companion during hunting (Nobayashi, 2006). Given the range of roles that a real dog can fulfil, and the costs associated with purchasing a robot, it is understandable that people desire a robot which is multi-purpose and capable of providing numerous tangible benefits.

Key Methodological Reflections

Qualitative Methods

Within the scientific community, there is a concern that participants might be deceptive when answering questions, due to social desirability effects or some unknown bias or motivation (Kim & Kim, 2016; Krumpal, 2013). Although a valid concern of qualitative methods, we would argue that it is possible to reduce the likelihood of such comments. For example, researchers could create thoughtful advertisements, engage in diverse recruitment, and foster an atmosphere where a participant feels comfortable to speak openly and honestly. Alternatively, in some cases we would argue that it could be incredibly valuable and insightful to consider answers driven by such factors.

The suggestion could be made that answers driven by biases and social pressures are insightful to consider, as they offer insight into what a person is feeling, the societal context they find themselves in, or a power dynamic that exists in the experimental setting (e.g. between experimenter and participant). The challenge with this approach is in creating an atmosphere that the participant feels comfortable to disclose such thoughts and feelings. In addition to rapport-building and patience when the participant is responding, open questions would likely be useful in the pursuit of such truths – as they give the participant the opportunity to freely discuss their perspective. Mixed methods (for example, a combination of behavioural measures and open questions) could also be useful in such a pursuit, as they offer the opportunity for implicit and explicit insights (Riddoch & Cross, 2021).

Remote Testing

One of the main proposed and perceived benefits of social robots, compared to screen-based interventions, is the fact that they are physically present in a person's space. Such physicality enables the robot to interact with the user and their space, and is proposed to encourage feelings of a social presence within the environment (Jung & Lee, 2004). In this study, we intended for participants to experience the robot in person – allowing them to feel the robot and potentially experience the robot as a social presence. Unfortunately, due to the ongoing Coronavirus pandemic (COVID-19) in person testing was prohibited, and we had to adapt the study as a result.

To make scientific progress, whilst protecting researchers and participants alike, we made the decision to record the robot exhibiting the behaviours. In an attempt to create a feeling of observing a real robot, and the illusion that they were in the room together, videos were recorded from the first-person point of view. Looking back however, the shots contain a human voice and hand that was different to that of the participant. In addition, participants did not gain any tactile feedback upon observing the robot being stroked in the video. Such features were unavoidable due to the nature of the chosen behaviours (responsiveness when called, and affection in response to touch), however they did reduce the extent to which the person authentically experienced the robot and its behaviour.

Despite the physical limitations, the responses of participants were still incredibly insightful and detailed – referencing to small movements of the ears, and the sounds of the motors, for example. On the one hand, this is positive as it suggests that participants were still able to have a detailed sensory experience with the robot. On the other hand, it could be the case that when interacting with a real robot, the object is viewed more holistically, and such details are not particularly important. Moving forwards, it would be valuable to repeat an experiment such as this, in order to better understand how in-person interaction influences one's perceptions of a robot.

Video Stimuli

Reflecting back on the videos created, and bearing in mind participant feedback regarding context and deception, we have a few recommendations for future work. First, when capturing the original dog behaviours, we received a couple of apologetic messages from the dog owners. For example – "*I think [dog name] has sensed that I am doing something deliberate and she is hesitant and looking a bit suspicious*.". Such comments suggest that some dog videos (used as a model for the robot's behaviour) were not a true representation of natural animal behaviour. To negate such issues, we collected videos of numerous dogs, however in future we would recommend that researchers consider more natural recording methods (e.g. installing a camera within the home, with the importance of the first-person perspective in mind). Such research would be more complex in terms of gaining ethical approval, however increased ecological validity would be valuable in the pursuit of modelling natural dog behaviour. Secondly, by showing only two videos it was possible to have discussions which were deep and insightful. However, the restricted number of examples could have contributed to participants' perceptions that the robot had limited behavioural repertoire. As a result, in future, if researchers were to repeat such work again, we would recommend 1) including a wider range of behaviours, or 2) providing participants with an introductory video of the robot, to give participants insight into the range of sensors and behaviours.

Additionally, we have a couple of recommendations (moving forwards) that emerge from our findings about the apparent importance of context. First, following on from participant comments regarding the importance of context in terms of forming their impressions (e.g. outside, in a clinical setting, in the home…) there seems a need to conduct research in various settings. In doing so it would be possible for researchers to better understand further how context impacts perceptions of robots and behaviours towards them. Secondly, we would advise that future researchers be mindful of biasing perceptions of participants when presenting the robot behaviours. In our study, we made a conscious effort to remain neutral when addressing the robot (e.g. not using positive language such as "good boy" after the behaviour) however one participant still commented that they felt the video was trying to bias them. Specifically, they commented on how the person interacting with the robot had a positive tone of voice. To avoid such issues in the future, an argument could be made for the removal of certain aspects of the audio (e.g. the sounds of individuals interacting with the robot).

Conclusion

By showing participants videos of robots engaging in pet dog behaviours, we have built a better understanding of the expectations and perceptions of potential end users. Crucially, we learnt that many people have a tendency to compare robots to real companion animals, and many people have a strong desire for features that are perceived as natural. We also showed how context and purpose alter opinions of robots and their users, and how members of the general public have an awareness of many major ethical issues that will develop in parallel with an increasing presence of robots in human society. Looking toward the future, these findings suggest the need for further exploration into how we might manage public expectations and ultimately reduce the need for hyper-realistic robotic animals.

Moving forwards in developing social robots to serve as social companions for the general public, our work here has highlighted the need to drill down into the opinions and concerns detailed by participants who took part in this study (particularly those in the "Key Findings" section of this Discussion). Future work should also consider how context and culture might influence such perceptions (Lim, Rooksby & Cross; 2020; Cross & Ramsey, 2021), in addition to including a greater appreciation of how behaviours can be perceived differently depending on their presentation (e.g. due to variations in frequency and intensity; Riddoch & Cross, 2021).

Developing social robots, particularly for companionship and comfort, is a complicated pursuit that requires consideration of user needs and desires, expectations, purpose, audience, stigma, and ethics, all of which have been touched upon by findings from our study. We are hopeful that this research can serve as a springboard for those wishing to advance this endeavour by keeping human users' thoughts, wishes, and fears front and centre while negotiating the benefits and challenges of human-robot relationships and, crucially, engaging with the various perceptions of those relationships.

GENERAL DISCUSSION

In this final section, I summarise key findings of thesis. Based on the findings from the empirical chapters (Chapters 2-5), I will also provide recommendations for industry professionals and academics continuing the study of human—robot companionship. To conclude, there is thoughtful discussion regarding our future with robots, and the potential consequences of human—robot companionship.

Chapter 6 General Discussion

Summary of Thesis Findings

The aims of this thesis were twofold: 1) to explore our capacity to become attached to social robots, and 2) to determine which features might facilitate meaningful social interactions between humans and robots. To do so, I conducted three experiments (Chapters 2-5) using a range of methods: reaction time paradigms, fixed-choice questionnaires, semi-structured interviews, and focus groups. By drawing from different disciplines, and adopting several complementary approaches, the overarching aim of this research was to contribute to a fuller understanding of the potential of robots as companion to ease loneliness.

In Chapter 2, I reported results from a lab-based experiment in which a robot's lights (located within the shoulders) were programmed to illuminate in a synchronous or asynchronous manner relative to the participant's heart rate. I aimed to determine whether such a synchrony manipulation might increase prosocial behaviours and improve attitudes towards a social robot - based on prior work showing that experimentally induced movement synchrony can improve rapport between people, and liking of social robots (Hove & Risen, 2009; Lehmann et al., 2015, Mogan, Fischer & Bulbulia, 2017). Results showed that, contrary to predictions, the synchronous lights had no significant effect on liking, intention attribution, or empathy for the robot (as measured by questionnaires, a gaze cueing paradigm, and the hesitance to hit task). Following on from this initial study, I was eager to better understand the varieties and qualities of the participants' experiences. This curiosity led to the research reported in Chapter 3, in which I scrutinised the qualitative data from Chapter 2.

By comparing the behavioural and qualitative results collected in the first study, I gained an appreciation for the value of open questions – particularly in terms of method validation. The results were also incredibly insightful with regards to our capacity for human—robot attachment, and apparent individual differences (despite undertaking very similar, controlled, interactions). Such findings are discussed in greater detail in the upcoming Key Findings section. After Chapter 3, I shifted perspectives from a focus on humanoid robots (and manipulations based on human social behaviours), to human—dog bonding. This shift was motivated by the desire to better understand how non-human agents form deep and enduring social bonds with humans – as opposed to basing the thesis on human interpersonal relationships alone.

In Chapter 4 I detailed a study in which dog owners answered questions regarding their relationship to their dog. Through this study, we identified 7 groups of behaviours that participants reported as crucial to establishing and maintaining the human-dog bond. In the final empirical chapter (Chapter 5), I then modelled two of these behaviours (animal-initiated affection and responsive communication) into an animal-inspired robot, and undertook focus groups to explore people's perceptions of these behaviours. The key findings of each study are summarised in the table below (Table 6.1), and in the following sections I thoughtfully consider noteworthy findings which I believe most relevant to our future with robot companions.

Table 6.1. Summary of the main conclusions from each thesis chapter

Chapter	Study Overview	Robotic Platform	Participants*	Main Findings
2	Mixed methods study in which participants interacted with a robot for 10 minutes. The robot illuminated in a synchronous or asynchronous way, relative to the participant's heart rate.	Pepper (Softbank Robotics). Category – humanoid.	77 individuals aged 18-83.	1) Cardio-visual synchrony manipulation had no impact on self-reported liking, gaze cueing effects, or the extent to which participants hesitated to hit the robot. 2) To deeply understand liking and perceptions of the robot and attachment to it, thorough piloting and qualitative approaches will be valuable moving forwards.
3	In the previous study, participants were asked questions after being asked to hit the robot with a mallet. In this piece, we analysed the interview data thematically.	Pepper (Softbank Robotics). Category – humanoid.	65 individuals aged 18-83.	1) Hesitation time is not simply an indicator of empathy/mind perception, it also reflects other factors including (but not limited to) task processing, hit strategizing, and cost awareness. 2) Despite being a short impersonal interaction, some people reported feeling attached to the robot.
4	Interviewed dog owners to identify behaviours perceived as crucial to the human-dog bond.	NA	153 dog owners aged 21-62.	Thematic analysis identified 7 categories of behaviours perceived as important to human-dog bonding, including: attunement, communication, consistency and predictability, physical affection, positivity and enthusiasm, proximity, and shared activities.
5	Following on from the previous study, we implemented dog behaviours into an animal-inspired robot. Focus groups were undertaken to understand perceptions of the general public.	MiRo-E (Consequential Robotics). Category –animal-inspired.	31 individuals aged 22-65.	1) Respondents used their knowledge of real animals to judge the robot, and had a preference for animal-like and "natural" features. 2) Attachment to a robot was judged differently depending on context, user demographics, and the purpose of the interaction. 3) There was an awareness of many ethical issues associated with robots in the home, or robotic animal for companionship.

*Note – participant numbers refer to the total sample size, after the removal of incomplete datasets.

Key Findings

Desired Functionality

Across the empirical chapters of this thesis, participants expressed a liking of five specific behaviours or qualities. Firstly, across Chapters 3 -5, participants reported that the eyes of the robot were important in terms of developing attachment. Specifically, in addition to feeling a fondness for eyes that appeared emotionally expressive, participants expressed liking for eyes responsive to changes in the environment (e.g. a noise or an approaching person). The apparent importance of such eye behaviours is not surprising, given the extensive literature regarding the significance of eye gaze with respect to social communication and mind perception (e.g. Kompatsiari et al., 2017; Macrae et al., 2002; Mason, Tatkow & Macrae, 2005). Secondly, given the importance of reciprocity in the development of friendships with human companions (Laursen & Hartup, 2002), it is also unsurprising that participants expressed a desire for two-way interactions with robots – as opposed to people talking to a robot, and the robot not responding in a relevant way.

Another feature important to participants (emphasised in Chapters 4 and 5) was behavioural variability. Specifically, although participants expressed a liking for behavioural predictability the majority of the time, occasional unpredictability was also considered highly desirable. Such behavioural unpredictability, among robots and actual dogs, was reported as giving the impression that the agent has some intelligence, intentionality, and sense of free will. In the future, to create robots perceived in such ways, it would be valuable (though challenging) to conduct work to determine the ideal ratio of behavioural predictability (for example, 90% predictable responses vs 10% unpredictable responses).

Other qualities important to participants (Chapters 2 and 5) were that: 1) the robot should address a need and provide tangible benefit(s) to the human user; and 2) the robot should be multi-purpose (providing e.g. fall-detection and health-monitoring in addition to comfort and entertainment). Both points are unsurprising given the tendency of consumers to want value from high-cost purchases, and products which address a specific need or problem (termed Problem or Need Recognition) (Munthiu, 2009; Qazzafi, 2019).

Finally, numerous participants expressed concerns relating to the ethics of robots in their home (Chapters 2 and 5)– concerns about privacy, data protection, and robots replacing humans (e.g.

as carers or friends). To address consumer concerns, robot developers should consider engaging in ethical and responsible design practices – that is, considering what is good for individuals, society, and the environment during the design process. Leikas, Koivisto and Gotcheva (2019) provide an insightful real-world example of responsible design – outlining how they consider factors including (but not limited to) privacy, safety, and sustainability, in the concept design of an autonomous system. With regard to ethical design thinking, the 'Ethical by Design' manifesto (Mulvella, Boger & Bond, 2017) is particularly insightful – outlining how we should be engaged in empathy for users, in addition to planning for failure. For a diagram illustrating the wants of users across the various studies conducted in this thesis, see Figure 6.1.

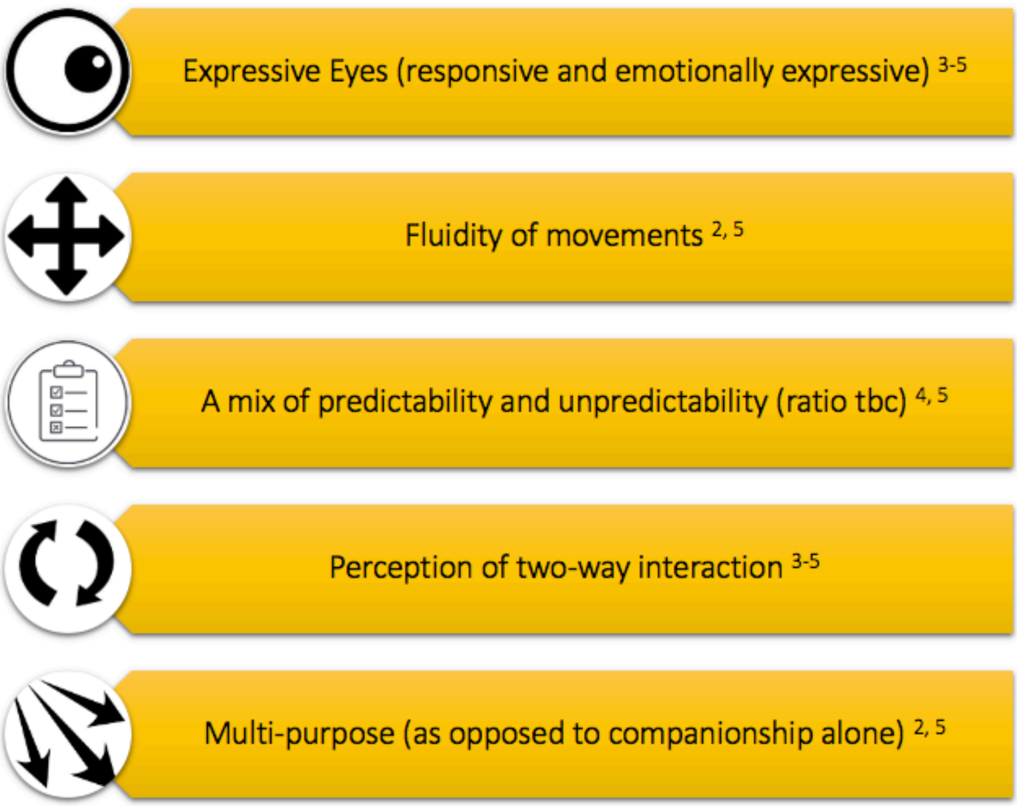

Figure 6.1. Illustrating key recommendations, moving forwards in developing companion robots. Based on the studies in this thesis, collectively. The numbers denote the evidencing chapters.

When considering these recommendations, it is important to emphasise that although insights were collected from participants who spanned a range of demographics (e.g. different ages, genders, occupations), we must be careful not to over-generalise. Our sample sizes were appropriate for our study questions of interest, but do not enable us to generalise to the population at large. Furthermore, it is important to keep in mind that the work reported here focused on two robotic platforms, out of the hundreds (or thousands) that are currently available (Cross & Ramsey, 2021). It is therefore important to keep these limitations in mind, while also recognising the value of this work for contributing to meta-analyses in the future, which have the potential to make more generalised claims (Barari et al., 2021).

Human—Robot Attachment

Looking back at the results from the first experiment (Chapters 2 and 3), it is apparent that some individuals became attached to the Pepper humanoid robot after a mere ten-minute interaction - using words such as "*connection*", "*fondness*", and "*attached*" to describe their feelings towards the robot. The perception of the robot as a meaningful social connection (as opposed to a shallow conversational partner) is positive in terms of using robots as part of a loneliness intervention – since meaningful interactions are proposed to negate feelings of loneliness (Smith, Steinman & Casey, 2020; Wigfield et al., 2020). Although such insights lack clarity regarding changes in attachment over time, I find the words of such participants compelling, as they reinforce recent findings showing that people have the capacity to feel attached to robots (c.f. Van Maris et al., 2020; Yamazaki et al., 2021). These quotes from Chapter 3 illustrate this well:

"Although he's a robot, but, you begin to like him. You know, you begin to have a bit of friendship, affection..."

*"I didn't think that I would be that attached. Or get that attached to it just because we had a wee convo. A conversation about dinner. *laughs*"*

Reflecting on the context of such results (a ten-minute interaction, the majority of which was observation), it might also be somewhat surprising that people can begin to form this type of social attachment so quickly. In the literature, researchers have proposed that attachment to robots should be measured over the long-term – specifically, across months or years; Dziergwa et al., 2018; McDorman, Clabaugh & Mataric, 2016). Given the long-term nature of our future interaction with robots, naturally a case exists for measuring changes in human—robot attachment over time (e.g. months or years, as proposed). However, I would also argue that characterising social attachment in the early stages (how quickly it develops, builds, plateaus, declines, etc.) is extremely relevant. While it will likely be the case that the interactions people might have with a robot will change over time (e.g. increasing or decreasing in frequency or intensity), a better understanding of fluctuations in objective and subjective measures of social attachment might further aid in the development of socially useful machines (e.g. robots for loneliness interventions). Regular (as well as unobtrusive and participant-friendly) measurement of social attachment will naturally provide logistical challenges for researchers, but doing so will enable us to build an even clearer understanding of the trajectory and dynamic nature of human—robot attachment.

Individual Differences in Attachment

Interestingly, despite the fact they participated in very similar interactions with the robot (heavily controlled by the experimenter), considerable differences in attachment amongst individuals were reported. Notably - in contrast to the aforementioned quotes indicating human—robot attachment, numerous individuals reported feeling little emotion when asked to hit the robot. For example, one participant stated - "*I was just looking at it as it if was just a thing... an object that I was hitting. There was no emotion, at all.*". While the aim of the present thesis was not to address individual differences per se, our findings nonetheless point to the important role of such differences in attachment to robots.

Due to our limited sample size, and the lack of spread within the sample (with the majority scoring similarly on questionnaires measuring anthropomorphic tendency and negative attitudes towards robots), our study was not sufficiently powered to explore why this was the case. As a result, a question remains as to why some people reported quite strong attachment to a robot after a short intervention, while others did not. To build a more complete understanding of individual differences in attachment, large-scale studies specifically designed to tackle such questions would be helpful. By conducting such large-scale studies, it may be possible to tease apart the contributing influence of a range of factors, including the influence of an individual's attributes (e.g. age, attitudes towards robots, and personality traits) and their history (e.g. cultural background and experience with robots).

Although it would be potentially useful with respect to building a better understanding of individuals' propensity to form attachment to robots, I would advise caution when embarking on work exploring individual differences. One reason for doing so is the particular kinds of ethical issues which individual difference work raises. For example, there is a real possibility that such knowledge could be used to inform targeted advertising – that is, a form of advertising which is directed towards an audience with certain traits (in this case, individuals with a natural tendency to become attached to robots) (Nwachukwu et al., 1997; Ullah, Boreli & Kanhere, 2020). On the one hand, targeted advertising is a widely used method of reaching potential users and could potentially lead to useful matching between a human user and the most relevant robotic platform - while also facilitating financial gain for robotics companies (Plane et al., 2017). On the other hand, however, due to the population being targeted (potentially vulnerable people) and the potential for harm (e.g. overdependence on robots; Sharkey & Sharkey, 2012), the ethics underpinning targeted advertising can start to become questionable (Nwachukwu et al., 1997). When publishing results which indicate between-group differences, there also is the potential for the results to be used in malicious ways – fuelling discrimination against others (e.g. against certain age, gender, or racial groups) (Meisenberg, 2019). This issue is arguably more relevant in other fields (e.g. intelligence studies, Cofnas, 2020; Meisenberg, 2019), though this does not negate our duty as researchers to consider the possibility of such eventualities (BPS, 2014).

The ethical issues associated with individual difference studies are complex – tapping into the rights of researchers, the public, and industry professionals (Cognas, 2020; Nwachukwu et al., 1997) – and future research should deeply consider the value of such knowledge. It could be argued that rather than focusing on individual differences, we should concentrate our research efforts on better understanding the trajectory and consequences of attachment. Additionally, rather than attempting to manipulate attachment to robots, perhaps we should place greater emphasis on creating machines which are perceived as useful and usable. Such qualities have been found to encourage acceptance to technologies more broadly (Technology Acceptance Model; Davis, 1985; Davis, 1989).

Potential Barriers to Robots as Companions

In contrast to Chapters 2 and 3 (demonstrating attachment to a social robot), later thesis chapters highlighted potential barriers for robots as companions in the future. First, participants demonstrated high expectations of robots - desiring behaviours and forms that closely resemble those of real animals (Chapter 5). The technical complexities associated with creating such realism are immense and, as home robots develop, decisions must be made whether to pursue other robot aesthetics (e.g. mechanical or novel forms; Cross & Ramsey, 2021; Hortensius &

Cross, 2018). Alternatively, if investing time and resources into hyper-realistic robots, developers should consider how we might reduce and manage user expectations (discussed at length in Chapter 5). Secondly, participants expressed concerns relating to novelty effects - specifically, worries that the robot would become boring over time (Chapters 2 and 5). Only a small number of research studies have investigated how robot novelty effects change over time, and such results are conflicted (e.g. Bradwell et al., 2020; Tanaka, Cicourel & Movellan, 2007; Cross, Riddoch et al., 2019). As a result, it is difficult to say whether robot use will persist over time, and how different visual or behavioural features might impact the trajectory of engagement.

In terms of facilitating meaningful long-term use of social robots (important in terms of developing a loneliness intervention; Perlman & Peplau, 1982), this thesis illuminated a couple of potentially important areas of focus. Specifically, novelty concerns appeared to result from the perception of the robot having a limited behavioural repertoire, or reactions which were overly predictable. With thoughtful design and programming, as well as advances in AI and machine learning, robots could be endowed with a behavioural repertoire designed to constantly evolve across time. Finally, participants across both robot studies (Chapters 2 and 5) mentioned that they might think negatively of someone with a robot. Specifically, the idea emerged that robot use might be more acceptable by a child compared to an adult - and that the latter might be "*sad*", "*strange*" or "*odd*" somehow. Context appeared important in terms of judgement-formation - for example, a robot might be acceptable in a case where someone could not keep a real animal. Regardless, to protect robot users, researchers should further explore the impact of negative perceptions. Such research could illuminate whether people have an aversion to robot ownership due to fear of stigmatisation – and insights into such concerns and judgments would undoubtedly be valuable for commercial entities to understand.

The Value of Qualitative Approaches

Another key finding to emerge across all chapters was that qualitative data (specifically, responses from the semi-structured interviews) were incredibly insightful. While some insights related to this point are discussed in Chapter 3, it is worthwhile to return to this point in the general discussion – considering how qualitative insights inform the thesis as a whole. Particularly in the first study (Chapter 2), if we had conducted only behavioural testing, we might have made the assumption that none of the participants felt attachment to, or empathy for, the robot - since the majority of people did not protest against hitting the robot. However, by including measures that gave participants time to voice their thought process and feelings about the experience, and engaging in active listening as participants shared these insights, we realised that the story was much more complex. In addition to gaining insight into participants' thought processes and feelings, our findings underscored the value of qualitative approaches in terms of method validation.

The use of mixed methods further enabled us to build a more complete understanding of why participants responded in a specific way based on task instructions. This was not only applicable to the hesitation time results (influenced by task processing, cost awareness, and empathy for the robot; discussed in Chapter 3), but also the gaze cueing task and questionnaire results. By building rapport with participants and creating an atmosphere where they felt comfortable to be open about their experiences, we learnt that some people felt fatigued during the long reaction time tasks. Additionally, we realised that some of the questions were confusing to participants, due to their abstract nature - specifically, the Inclusion of Other in Self questionnaire, in which participants specify the "overlap" between the robot and their self. Without such qualitative insights, we would likely have placed other assumptions upon the result - basing them on what previous researchers suggest, or our own biases/opinions, as opposed to actual participant insights. On balance, we would argue that the additional insights provided by participant feedback via qualitative approaches can greatly enhance researcher understanding and awareness of the psychological processes and factors underpinning participant responses (particularly for explicit paradigms, as opposed to those tapping into reflexive or implicit processes). The novel and valuable insights we gained from including qualitative approaches in our research lead us to recommend greater consideration of qualitative approaches in future human—robot interaction research. For more detailed suggestions, refer to the upcoming Research Recommendations sub-section.

Considerations for Future Research

Measuring Attachment

Early in the thesis, when planning the first experiment, it became apparent that measures of attachment were lacking. First, due to the relevance of parent-child relationships to mental health outcomes, many measures were focused on the attachment styles of babies and children (Ainsworth, Blehar, Waters & Wall, 1978; Bowlby, 2008). The focus of this thesis on adults (as opposed to children) and friendship (rather than parental relationships), meant that examination of such methods of attachment was not appropriate. Second, a large number of questionnaires focus on developing an understanding of romantic relationships between two people (e.g. Sibley, Fischer & Liu, 2005; Zacchilli, Hendrick & Hendrick, 2009). While such questions are valuable in the context of relationship conflict and therapy, they are not suitable within the context of studying platonic human—robot attachment. Third, questionnaire items often reference the "other" having freedom of choice, in some respect. For example, the Relationship Structures Questionnaire (Fraley & Heffernan, 2008) asks the participant to rate the extent to which the following is true - "I worry that they will abandon me". Such questions are also not suitable in the context of studying human—robot relationships, due to technological constraints associated with current social robots. For example, the previous question is unsuitable as the robot may be programmed to physically stay within the environment – and it cannot abandon the person as a result.

Finally, many existing measures of attachment were inappropriate as they referenced scenarios outside of the research context. For example, asking people to rate the extent to which they felt the other person "was there for them, in times of need" (Fraley & Heffernan, 2008). As a result of never experiencing such a scenario, and a lack of history between the person and the robot, such questions are irrelevant. Revisiting such literature now, I see the same limitations can apply to attachment/relationship measures. As a result of the limitations of existing questionnaires, I understand my past decision to explore more alternate measures in Experiment 1 – specifically, the Gaze Cueing task and the Hesitance to Hit paradigm (See Chapter 2). With the knowledge that such measures were inappropriate in the present context in terms of measuring mind perception and aversion to harm a robot (Chapter 2 Discussion and Chapter 3), the need to develop new measures of human—robot companionship is clear.

Novel Approaches to Studying Human—Robot Attachment

One could argue that current measures of attachment do not apply to robots, as they ask questions which assume a history between the agents, and reference real-world contexts. For example, asking people to rate the extent to which they felt the other person "was there for them, in times of need" (Fraley, 2008). However, when we consider the literature regarding attachment, such factors are extremely influential in terms of the extent to which we become attached to another being (Asendorpf & Wilpers, 2000; Sarason, Pierce & Sarason, 1990). As a result, perhaps we need to change our experiments, or better yet, conduct additional experiments so that we can understand how social attachment changes across time, in real-world contexts. If we really want to measure attachment (in the human sense), perhaps we need to stop trying to change the measures, and facilitate the conditions associated with attachment in the real world.

Alternatively, when thinking about human—robot attachment, it could be suggested that we cease comparisons to human social relationships (cf. Cross & Ramsey, 2021). Perhaps researchers should embrace the prospect that robots will retain their status as an object, and that people will become attached to the robot regardless – as individuals become attached to teddies and other possessions (Bell & Spikins; 2018; Lee & Hood, 2021). Alternatively, given the unique nature of social robots among other object classes, there is a case for exploring the possibility that robots may be treated as a distinct class of being (not strictly appliance or human). It could be the case that our relationships to robots will be special, but by using measures focused on existing agents (e.g. humans, animals, objects) we are restricting our understanding of such potential (see Henschel, Hortensius & Cross, 2020).

Research Recommendations

Drawing from my training in experimental psychology research, I would suggest that in order to collect data that are insightful and valid (in terms of measuring human—robot attachment), current methods need to change. Specifically, we must move away from experiments which are underpowered and lab based. Instead, we should conduct power analyses to determine appropriate sample sizes, and perform testing in the real world (e.g. by testing home robots within realistic home environments). In doing so it is possible to reduce the likelihood of type 2 errors (that is, false positives), and gain insights with improved ecological validity. Additionally, there should be greater consideration of qualitative methods, and the avoidance of research studies which are restricted to one setting/session. By adopting qualitative approaches (e.g. diary entries; Bradwell et al., 2020) and collecting data over multiple time points, this should help researchers to uncover insights into changes in people's perceptions over time. Such longitudinal work is naturally time and resource intensive, but one could argue that the benefits (in terms of increased scientific understanding relevant to our future with robots) outweigh the costs. Finally, to protect participants from harm, we must also carefully consider whether attachment studies are ethically justifiable (e.g. robot abuse studies).

For a summary of key recommendations, and the rationale for each, see Table 6.1 below.

Table 6.2 - 11 methodological recommendations for future *HRI* attachment work

Recommendation	Rational	Additional Considerations
1. Clear definitions prior to experiment conception	By <u>not</u> clearly understanding what one wishes to know or better understand, there is an increased risk of measuring the wrong thing.	To ensure you are measuring what you intend to, "manipulation checks" can be a useful addition.
2. Physically present robots	Robots presented on a screen do not provide an authentic experience of real-world human—robot interaction.	Depending on the intervention, screen-based interventions (e.g. phone, tablet, virtual/augmented reality) might be more appropriate.
3. Different types of robots	The appearance of a robot could impact how the robot is perceived, and the attachment that forms as a result.	In addition to using different types of robots (e.g., animal like vs humanoid) there should be scrutiny regarding the impact of changing individual features (e.g., just the eyes).
4. Mixed methods (e.g. behavioural + qualitative)	By using mixed methods, it is possible to measure explicit (e.g. subjective, conscious) and implicit (reflexive, unconscious) processes.	The addition of qualitative measures can be useful in terms of understanding participant thought processes.
5. Consult with Ethics Guidelines	By consulting with ethics guidelines, it is possible to better understand potential violations.	The BPS Code of Ethics and Helsinki ethical guidelines are free to access and are particularly relevant.
6. Longitudinal studies	Conducting studies across various time points allows for insight re. changes over time. Useful in terms of relationship development work, to assure results are reliable.	If relevant, it could also be valuable to conduct testing in a range of settings (e.g. different homes or laboratories).
7. International collaborations and diverse recruitment	Diverse participation facilitates findings applicable to more individuals. Diverse research teams (e.g. across cultures and specialisms) could lead to the generation of novel questions and approaches.	Important to note is that "diversity" is not limited to cultural background – people vary in many ways including their socioeconomic status and education, for example.

8. Piloting prior to main experiment	Piloting allows one to establish baseline measures (e.g. of liking) and determine appropriate manipulations and measures. One can also check that participants understand the questions being asked of them (helpful if the latter are abstract).	During piloting, open questions can be valuable. This gives the participant opportunity to share insights about their experience which are not constrained by the research team's point of view.
9. Conducting power analyses to inform sample size calculations	Power analyses can improve understanding re. the feasibility of an experiment. They can also help one to avoid undertaking underpowered studies (e.g. high risk of false negatives).	Consulting with statisticians can be insightful, however there are free tools online to conduct basic power analyses - such as G*Power. Helpful when resources are limited.
10. Active listening and rapport-building with participants	Making the participant feel valued, and listened to, can create an atmosphere in which they feel comfortable to be open and honest in their responding.	Be aware of how rapport-building might influence power dynamics within the experiment, and social desirability effects.
11. Honest reporting, engagement with Open Science Practices	Sharing data publicly can benefit the scientific community - data can be checked, used in future work, and provide learning opportunities for others.	The Open Science Framework is a free platform in which users can share their data publicly, and also pre-register their studies.

For those hoping to gain greater insight regarding common mistakes of HRI researchers the recent work of Tony Belpaeme (2020) provides a useful point of departure. In addition to addressing some of the aforementioned recommendations (e.g. 'Lab-Based or in the Wild', 'On-Screen or Real Robot?' and 'Single or Long-Term Interaction'), Belpaeme thoughtfully outlines how one can decide what level of autonomy a robot should have (e.g. Wizard of Oz vs Full Autonomy) and what sampling method to engage in (Belpaeme, 2020). Belpaeme also offers insight regarding broader issues within the scientific community, including common mistakes (e.g. "p-hacking" and social desirability effects), the replication crisis (widespread difficulties in replicating existing studies), and publication bias (specifically, the tendency to ignore or underplay insignificant findings). Such issues are beyond the scope of this thesis, but are nonetheless significant – both for individual researchers, and the reputation and progression of the field as a whole.

Broader Ethical Implications

Through conducting numerous experiments (Chapters 2-5), I have come to a much deeper understanding of how humans perceive social robots, and by collaborating with industry professionals I have gained insight into the complexities of real-world implementation. By engaging with experts from other disciplines (philosophy, computer science, law…), I have also developed an appreciation for the complexity of robot ethics (sometimes termed 'robo-ethics' or 'roboethics'). In addition to being a vast subject, encompassing topics from sex to war, robot ethics is often incredibly nuanced – requiring consideration of a huge range of approaches and intertwined factors (from an individual to a societal level). I have an immense amount of respect for individuals who can navigate such complex terrain, and I feel slightly overwhelmed by the possibility of engaging with discussions about robot ethics as a result. When thinking about robots for companionship, however, there are pertinent ethical issues which must be considered. Although privacy, infantilisation, and overdependence are relevant concerns (de Graaf, 2016; van Maris et al., 2021), due to the potential consequences for broader society I will thoughtfully engage with the following issues specifically: false beliefs about robots, and the 'digital divide' (Berde, 2019).

False Beliefs and Deception

Robots cannot think and feel as humans do. Despite this fact, some people appear to perceive robots as intentional, or as being able to feel hurt (emotionally or physically) (Marchesi et al., 2021; Swinderska & Küster, 2018). I made similar observations in the first study of this thesis, with participants expressing concerns related to the robot's capacity to feel pain – for example, *"oh that would be the worst thing if you can hit him while he's switched on - he can probably feel pain and react"*. Existing literature references how such false beliefs are the result of how the robot is designed/programmed, and suggests people are being "*deceived*" by robot developers (Collins, 2017; Sorell & Draper, 2017). Such research emphasises the need for ethical and responsible design practices when developing social robots, as discussed previously. It's important to note, however, that deception is not always intentional. For example, despite thoughtful attempts to avoid bias or deception (e.g., referring to Pepper as "*the robot*", and not giving Pepper a backstory), our participants nonetheless expressed false beliefs about the robot. As a result, the argument could be made that discussions regarding false beliefs should not exclusively be concerned with intentional deception (Sharkey & Sharkey, 2020). Instead, there should be recognition that deception can occur unintentionally, and end users should be mindful of changing perceptions towards the robot. For lonely individuals, where social support may not be available, such self-monitoring and reflection presents a novel challenge.

When considering the latter point, a related question arises– is there anything wrong with a person perceiving a robot as though it is a living being? Arguably, this is not a simple question to answer, due to differences in the needs of the individual, and the context of the interaction. For example, in relation to the first two points, it could be suggested that companion robots are appropriate for people with certain needs – e.g. isolated individuals living in rural communities, or those who struggle to relate to other humans (e.g., some individuals with severe autism; Melo et al., 2019). In contrast, the argument could be made that individuals with access to human social support should be encouraged to engage with people, as opposed to robots.

By making a distinction between high- and low-need individuals, it might be possible to promote beneficial applications, and avoid harmful ones (e.g. wide-scale reliance on robots, or replacement of human social companions). The implementation of such a division raises additional logistical and moral questions, however. First, where do we draw the line in terms of who is high- vs low-need, and might such a distinction lead to the stigmatisation of robot owners? Second, is it right to restrict a person's access to a robot, if they might benefit from it? Such questions are not trivial to answer, as they require consideration of our rights as human beings, and evaluation of what approach we want and need as a future society. Given the different approaches to healthcare across the globe (Basu et al., 2012; Vincent, 2001), it is likely that conversations and approaches may differ significantly around the world. In terms of agreeing on a collective vision for our future with robots (and relevant legislation), such diversity across cultures, socioeconomic circumstances, languages and values creates a significant challenge. One could argue that individual countries could develop distinct approaches, in line with their own values and motivations. However, this approach too is fraught with significant challenges – for example, if a country were to prioritise monetary gain over its citizens' wellbeing.

In addition to assessing the needs of the user and the context of the interaction, it is important to thoughtfully consider the extent to which a person believes a robot is thinking and feeling, and consequently treats the robot as if it were a living being. For example, one might consider such perceptions acceptable until they lead the person to neglect human social relationships (Brooks, 2021). Alternatively, such behaviours may be viewed as justifiable until they (negatively) impact how a person treats people or animals (Balkin, 2015). If going down the path indicated by such examples, there is a need for measurement techniques to determine whether such perceptions exist, and regular monitoring to detect changes over time. The first aspect (neglecting human social relationships) could be determined using self-reporting from the person or a family member – e.g., inputting how much time the person has spent with a human being within a period of time (e.g. a week). Measuring the second aspect (how a person treats people or animals) provides a more difficult challenge (particularly in relation to animals), but could again be reported by carers, relatives, or peers. Both such monitoring methods would require the input of people close to the individual; this is nonetheless a reduced responsibility compared to spending 24/7 talking to a person and monitoring their health.

Speaking about these issues, it becomes apparent that robots are not simply a solution for the problems associated with population aging and loneliness. Instead, implementing robots in society might actually lead to an increased need for human input in some respects – e.g. in terms of monitoring (as discussed previously) or mental health support (were the robot to be damaged or removed). A key question remains as a result – do we fully understand the consequences of robot implementation, and of a person befriending a robot? In previous sections I referenced how robot companionship might change how we interact with people, or alter a situation so that a person might start to neglect their human social relationships - but neither of these points is proven to be true.

To gain clarity on our future with robots, there is a need for rigorous study of human—robot companionship, drawing from the insights of multiple disciplines (e.g. cognitive science, Consumer Behaviour, computer science, philosophy, and psychology). Following such studies, it would be possible to identify strategies which balance the promotion of beneficial applications with the avoidance of harmful outcomes (Prescott & Robillard, 2020). Such strategies could then facilitate the formulation of legislation which protects individuals particularly vulnerable to negative impact. Without working with such policy makers, there is a risk that commercial entities will dictate our future with robots – clearly problematic as there is the potential to exploit vulnerable individuals (e.g. those who are likely to become heavily attached) for commercial gain.

Thus far, when talking about our future with robots, I have alluded to the idea that a consequence of robot implementation is widespread over-reliance upon robots. In reality, however, due to their high capital costs and reliance on the internet, robots are not accessible to all. Such inequality will be discussed in this concluding section.

Digital Divide

The digital divide refers to the gap between those who benefit from the digital age, and those who do not – e.g. low-income households, older adults, and many individuals who live in developing countries (Berde, 2019). The divide is associated with social and economic inequality, as individuals without access to the internet have reduced access to information (e.g. skills-training, education, job opportunities…) (Cullen, 2001). As current robots incur high costs, and often use the internet, batteries, or electricity to function, they too will be inaccessible for many. As a result, social robots have the clear potential to enhance the digital divide (Berde, 2019).

One could argue that robots could be designed, manufactured, and sold in ways to make them more affordable (e.g., renting, leasing, or on finance). However, the majority of humanity will still not be able to access them – e.g. those who must prioritise the essentials (Francis-Devine, Booth, & McGuinness, 2019; Speak, 2019). In the meantime, individuals with funds would have access to robots and their associated benefits (such as improved wellbeing, health-monitoring, and ageing in place for longer, potentially; Normie, 2011; Prescott & Robillard, 2020). Such inequality of access risks enhancing the digital divide, and the perception of a robot user as wealthy (discussed in Chapter 5) has potentially serious implications for society. Specifically, the association of robots with wealth could lead to stigma (e.g. 'poverty stigma') against those without access to the technology (Reutter et al., 2009). Participants in the first study were shocked upon hearing the price of the Pepper Robot (£17K at the time of writing), and individuals in the final study spoke about how they would perceive a robot owner as affluent. These insights suggest that it is clearly possible (if not likely) that social robots will become a status symbol.

To avoid deepening the digital divide, I would urge individuals to consider in what way (as a society) we want to continue down this path of using technology as a form of social support. In addition to investing in novel technologies, we should continue to advocate for investment in community-based interventions - e.g. support groups, community activities, and social prescribing (that is, signposting users towards appropriate social support; Foster et al., 2021). By allocating resources for both in-person and digital interventions, it should be possible to increase access to social support, and potentially reduce loneliness on a larger scale (Foster et al., 2021; Poscia et al., 2018).

Conclusions

Through the use of a range of approaches and methods, this thesis has produced novel insights regarding human—robot attachment. Overall, results suggest significant individual differences in feelings towards, and perceptions of, social robots. Although certain individuals reported becoming attached very quickly, and some felt positive about our future with robots, the converse is also evident. For many, high expectations of robots and ethical issues associated with their implementation are apparent barriers to acceptance and use. In the development of robots for companionship, there is a need for further work which places ecological validity, scientific rigour, and ethical practice at its heart. In doing so, it should be possible to build a more complete understanding of user expectations and needs, and make informed decisions about the role that robots can (and should) play in our future.

Final Thoughts

Over the past three years (since beginning this doctoral dissertation research). I have come to realise that human—robot companionship is a far more complex subject matter than I ever imagined it could be. From the definition of attachment, to the implementation of robots in the real world, there is so much to consider. Moving forwards in the study of human—robot interaction, I hope that the content of this thesis will act as a springboard for more thoughtful research approaches – particularly with regard to methods and the value of listening to research participants.

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Appendices

Appendix 1

Table summarising participant demographics, from Chapter 5.

Participant Number	Age	Gender Identity	Experience with Technology (work, programming, or studying)	Experience with Robots (meeting in person, or working with)	Experience with Dogs (ownership or work)
1	26	Female	Yes	None	None
2	39	Female	No	Yes, humanoid	None
3	34	Male	Yes	None	None
4	31	Female	Yes	None	Owner
5	22	Male	Yes	Yes, various	Owner
6	56	Female	No	None	None
7	60	Male	No	None	Work
8	28	Female	No	None	Owner
9	30	Male	Yes	None	None
10	25	Female	Yes	None	Owner
11	30	Male	Yes	None	Owner
12	36	Female	No	Yes, roomba	None
13	36	Male	Yes	None	None
14	65	Male	No	None	Owner
15	65	Female	No	None	Owner
16	37	Male	No	None	Owner
17	39	Female	Yes	None	None
18	27	Male	Yes	Yes, humanoid	None
19	60	Male	No	None	Owner
20	29	Male	Yes	None	None
21	29	Female	No	None	None
22	46	Female	Yes	Yes, various	Owner
23	27	Male	Yes	None	Owner
24	28	Female	No	None	None
25	26	Male	Yes	None	Owner
26	28	Male	Yes	None	None
27	34	Male	Yes	None	Owner
30	45	Female	Yes	Yes, various	Owner

Note: the green coloured boxes indicate that the individual does have potentially relevant experience (e.g. with technology, robots, or dogs).