A Simulated Robot versus a Real Robot

an exploration of how robot embodiment impacts people's empathic responses

by

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Abstract

In designing and evaluating human-robot interactions and interfaces, researchers often use simulated robots because of the high cost of physical robots and time required to program them. However, it is important to consider how interaction with a simulated robot differs from a real robot; that is, do simulated robots provide authentic interaction? We contribute to a growing body of work that explores this question and maps out simulated-versus-real differences, by explicitly investigating empathy: how people empathize with a physical or simulated robot when something bad happens to it. Empathy is particularly relevant to social human-robot interaction (HRI) and is integral to, e.g., companion and care robots.

To explore our question, we develop a convincing HRI scenario that induces people's empathy toward a robot, and explore psychology work for an empathy-measuring instrument. To formally evaluate our scenario and the empathy-measuring instrument in HRI scenario, we conduct a comparative user study: in one condition, participants have the scenario which induces empathy, and for the other condition, we remove any empathy inducing activities of the robot. With the validated scenario and empathy measuring instrument, we conduct another user study to explore the difference between a real and a simulated robot in terms of people's empathic response.

Our results suggest that people empathize more with a physical robot than a simulated one, a finding that has important implications on the generalizability and applicability of simulated HRI work. As part of our exploration, we additionally present an original and reproducible HRI experimental design to induce empathy toward robots, and experimentally validated an empathy-measuring instrument from psychology for use with HRI.

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Publications

Some ideas and figures in this thesis have appeared previously in the following publications by the author.

STELA H. SEO, Denise Geiskkovitch, Masayuki Nakane, Corey King, James E. Young. "Poor Thing! Would You Feel Sorry for a Simulated Robot? A comparison of empathy toward a physical and a simulated robot," *In proceedings of the 10th ACM/IEEE international conference on Human-Robot Interaction, HRI'2015*, Portland, Oregon, USA.

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Chapter 1

Introduction

Robots are emerging into our society in various places: houses, schools, factories, stores, etc. The more robots appear in these places, the more human-robot interaction (HRI) is there. HRI is a growing topic in computer science with an increasing number of robots, and explores how people and robots work together. In HRI research, robots are often designed to use social human interaction methods such as facial expressions, gestures, or speech, to communicate naturally with people (Choi, Kim, & Kwak, 2013; Mutlu, Yamaoka, Kanda, Ishiguro, & Hagita, 2009; Young et al., 2011). Such robots can even be designed as social team members or personal companions (Young et al., 2011). Social HRI explores the interaction between people and robots as social team members in an attempt to take advantage of social norms and people's social tendencies (Wada & Shibata, 2007; Young et al., 2011): to leverage existing social structures or to encourage positive empathic responses, which can have positive health benefits. For example, a robot that encourages people to empathize with it can make people more active and more communicative and can reduce stress among the elderly (Wada & Shibata, 2007). In such cases, the social interaction can be convincing to the point where people develop an attachment to the robot and experience negative emotions if something bad happens to it (Garreau, 2007; Sung, Guo, Grinter, & Christensen, 2007).

In social HRI work, researchers are faced with the difficulties of building and programming capable robots. This not only includes the development of social interaction models and capabilities, but also the engineering (or purchasing) of an expensive, convincing physical robot, and the programming of difficult real-world challenges including walking, balancing, computer vision, grasping objects, and so forth. As such, some researchers use a simulated robot – such as an on-screen rendered avatar – to simplify the problem by removing the robot-building and physical-world challenges, instead focusing on the social interaction programming that is more relevant to their work. Such simulations can be used to conduct initial HRI studies; however, a growing body of work indicates that there may be important differences between interacting with a simulated robot in comparison to a real (physical) robot, differences that can limit the generalizability of simulated results.

There is a broad range of potential differences between interactions with a simulated robot versus a physical one, for example, lack of believability such as unconvincing movements, lack of any risk of physical contact, or differences in social interaction such as being unable to touch a simulated robot. For our exploration we target empathy – a person's empathic response to a robot. Empathy can serve as an indicator of social connection with the robot, and as such can be used to analogously represent a range of social HRI scenarios that rely on such personal connections; empathy broadly is a common topic of study in HRI (Gonsior et al., 2011; McQuiggan, Robison, Robert Phillips, & Lester, 2008; Wainer, Feil-seifer, Shell, & Mataric, 2006).

1.1. Methodology

We explore the question of whether a simulated robot provides authentic interaction, in terms of whether people empathize with it as they do with a real robot. For the purpose of this investigation, we conduct a comparative user study (Figure 1) where a participant interacts with a real robot or a simulated robot respectively. In the study, to reliably and repeatedly induce people's empathy toward the robot, we develop an empathy inducing HRI scenario. Further, we adapt an empathy measuring instrument from psychology.

1.1.1. Development of an Empathy Inducing Scenario

To induce people's empathy in our user study, we develop an empathy inducing scenario, which helps people to develop rapport and induces their empathy toward the robot. In the development of the scenario, we involve a professional artist and psychological team, a group of two psychologists holding an undergraduate degree in psychology from University of Manitoba, to help design such a scenario, and iteratively pilot study variants for refinement and believability of the scenario.

1.1.2. Exploring an Empathy Measuring Instrument

We need to assess people's empathy induced by our HRI scenario. The challenge with assessing any empathic response is that it is internal to the person experiencing it. There have been techniques to externally assess people's empathic responses: for example, inferring empathic responses from biometric data (heart rate, breathing rate, etc.), or

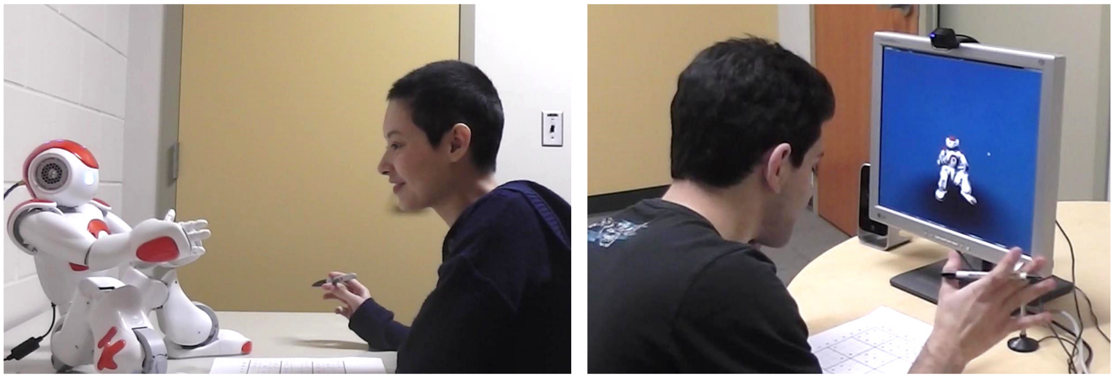

Figure 1. A person interacting with a robot (left) and a simulated version (right). Would they empathize with both versions the same, if something bad happens to it?

observing external involuntary gestures such as facial expressions. The challenge with such techniques is that they often require not only advanced equipment but also specialized expertise from an experienced team to analyze. One alternative is to use self-report techniques, such as asking a person to complete a questionnaire that probes for empathic response, which is simple to administer.

Self-report questionnaires are often employed in fields studying social relations (i.e., psychology, sociology, etc.); however, there are only a few questionnaires to assess the situational empathy, which is the empathy induced by the situation as a stimulus (e.g., robot's fear and losing memory in our scenario).

To find a suitable self-report questionnaire to assess people's empathy, we explore psychology literature with the involved psychological team (the group of two psychologists). We aim to bring an empathy-measuring instrument from psychology and validate it to measure people's empathy in our scenario, while aiming for the measuring instrument to be generalizable to other scenarios in order for it to be usable by other HRI designers.

1.1.3. Validating the Scenario and the Instrument

Once the scenario and the instrument are established, we formally validate them through a between-subject user study: in one condition, participants have the scenario which induces empathy without any modification, and for the other condition, we remove any empathy inducing activities of the robot. If either the scenario fails (empathy not induced) or the instrument fails (empathy not measured), we will find no difference in people's empathic responses measured by the instrument. If both are successful, however, we will expect to see an empathy difference between the conditions.

With the result, we conduct statistical analysis to see the difference between the group of empathy induced case and the empathy not-induced case. Further, we test correlation of questions in the questionnaire to see the internal consistency of the instrument.

1.1.4. Development of Required Software

With the validated empathy inducing scenario and empathy measuring instrument, we conduct a between-subject user study in conditions of a real robot and simulated variants. For the purpose of the user study, we develop an animated robot of our main framework, NAO from Aldebaran Robotics, and use it in 3D simulation. Further, we develop required applications for the study such as 3D graphics simulation and remote robot control interface.

The remote robot control interface is required to achieve our robot's intelligence. It is extremely challenging to create a robot that can convincingly communicate with a person in social interaction to the point that enables us to conduct our study. As an alternative we employ a human operator to control the robot remotely, called the Wizard of Oz. The Wizard of Oz controls the robot unbeknownst to the remote end using a remote robot control interface that we developed for the purpose of the user study. We also aim for the interface that enables other researchers to embed their scenario with minor programming.

1.1.5. Investigating the Difference of a Real Robot and a Simulated Robot

Once we have our validated scenario and empathy measuring instrument, we conduct a user study to explore the difference between a real and a simulated robot in terms of people's empathic response. We have three cases: a real robot, a simulated on-screen robot, and a third condition, a mid-point between real and simulated using a technique called mixed reality which will be detailed in Chapter 5. A between-subject experimental design is required because we want participants to experience the empathy-inducing scenario freshly in all cases. In other words, we worry about habituation, where if a person experienced a stimulus, the same stimulus for a different robot's form may not impact them as much as the first stimulus.

We will analyze results of the user study using the Analysis of Variance (ANOVA) technique. We are expecting to find stronger empathy toward a real robot than a simulated robot. Therefore, we will conduct planned contrasts to compare people's empathic responses toward the real robot versus simulated variants, to conclude our investigation on finding difference of a real robot and a simulated robot in terms of empathy.

1.2. Contributions

Contributions of our research include:

a. A reproducible HRI scenario that induces people's empathy toward a robot
b. An empathy-measuring instrument from psychology to be used in HRI
c. A validation of the scenario in (a) and the questionnaire in (b)

d. An exploration of the difference between interactions with a simulated and a real robot in terms of people's empathy toward the robots

e. An original remote robot control interface that aims to enable easy programming of pre-set scenarios

In this research, we develop an HRI scenario that reproducibly and reliably induces people's empathy toward a robot, both real and simulated variants, and take an empathy-measuring questionnaire to assess people's empathic response toward a robot from psychology for use in HRI. We formally evaluate our scenario and the questionnaire in the scenario through a user study. Using these validated tools, we conduct a comparative user study to investigate if a simulated robot provides authentic interaction compared to a real robot in terms of people's empathy. The results provide evidence that people may empathize more with a physical robot than simulated variants. This result has important implications for simulated HRI work and suggests that further investigation is needed into the generalizability of simulated results.

Chapter 2

Related Work

Human-Computer Interaction (HCI) is a multidiscipline field of study; that is, HCI is studied in computer science, electronic engineering, behavioral sciences, design, and other related fields (Goodrich & Schultz, 2007). The focus of HCI in computer science is *interaction* between people (users) and computers (Hewett et al., 1992): it is to understand people's needs, design and implement them, and evaluate the implementation. The more kinds of *computers* are introduced such as embedded system (e.g., ATM machines and home appliances), smartphones, and robots (Hewett et al., 1992), and so the field Human-Robot Interaction (HRI) has been introduced.

HRI, as a subfield of HCI, mainly focuses on interaction with robots. HRI is an interdisciplinary field (as HCI is), and HRI research has broad interests in electronic engineering for embedded system of robots, physics for robot's motion, psychology as well as sociology for interaction with people, and many others.

In this work, our interest is related to social HRI: that is, designing and evaluating social interaction. In social HRI, researchers often conduct user studies to evaluate their interaction (Goodrich & Schultz, 2007; Young et al., 2011). Even though it is important to use a real robot (which will be used in the interaction after the evaluation), the real robot has cost and reliability issues (Goodrich & Schultz, 2007). Instead of using the real robot, therefore, the researchers focus on designing and evaluating the interaction with a simulated robot. However, this raises a question, if a simulated robot provides an authentic interaction as a real robot does. We ask this question in terms of people's empathic response: that is, do people empathize with a simulated robot as they do with a real one?

2.1. Comparing Different Robots in Human-Robot Interaction

As detailed below, the differences in interaction between people and various robots are explored by many researchers. They compared robots with different physical forms (i.e., robot embodiment), different medium (e.g., face-to-face communication and telecommunication such as a video chat), and in different environments (e.g., the real-world environment and the virtual environment). In above work, our primarily interest lays on robots in different environments which are a simulated robot versus a real robot.

There is a great deal of existing work that compares how people interact with and respond to agents and robots of various embodiments. For example, work that shows that people may be more embarrassed to undress in front of an anthropomorphic robot than a mechanical one, e.g., a boxed machine (Bartneck, Bleeker, Bun, Fens, & Riet, 2010). This body of work provides important insights into how a robot's form can impact interaction, but does not directly address on-screen simulated robots.

Others compare real robots to videos of robots with favorable results supporting the use of video (Fridin & Belokopytov, 2014; Woods, Walters, Koay, & Dautenhahn, 2006) in simple scenarios: for example, a task to follow a humanoid robot's demonstration (Fridin & Belokopytov, 2014) and a task for a robot to bring an object to a person (Woods et al., 2006). One extension of these is a study that compares collocated robots to remote robots via a video feed (Bainbridge, Hart, Kim, & Scassellati, 2010). Unlike a recorded video, with a real-time remote video feed the robot can flexibly adapt to an unexpected situation. However, the paper reported that the absence of physical presence affects the interaction as participants took a long time to accomplish the study task with a video-presented robot (Bainbridge et al., 2010). This body of work provides important insights into the impact of different robot presentation; however, their approach still requires real-robot programming and is not simulation in the sense that we address.

Another angle of research is to compare physical robots with on-screen agents, for example, showing that people may perceive agent emotions similarly between the two (Bartneck, Reichenbach, & Breemen, 2004), that people may engage more with a robot than a text-based computer (Pop et al., 2013), that people may speak differently to an on-screen agent than to robot (Fischer, Lohan, & Foth, 2012), that people may enjoy interacting with a real robot compared to an on-screen agent (Leite, Pereira, Martinho, & Paiva, 2008), or that there are unique trade-offs between the approaches that should be considered more deeply (Takeuchi et al., 2006). This body of work provides insight into the more general robot versus screen agent question, and motivates the need to investigate embodiment. For example, it is still vague why people enjoy to interact or engage more with a real robot. However, in some of these cases the agent is not a simulation of the robot but rather an unrelated character (e.g., robotic dog versus on-screen one-eyed monster, Bartneck et al., 2004) and so other factors (e.g., agent shape, form, etc., Fischer et al., 2012) may impact the results; such questions should be specifically investigated for actual simulations of robots. We continue in this direction more specifically for simulated robots.

Much of the work that suggests interaction with robots may be more authentic than on-screen agents or non-robot machines (such as a box) relies on measuring people's *engagement* or self-reported *preference* (Kidd & Breazeal, 2004; Powers, Kiesler, Fussell, & Torrey, 2007; Takeuchi et al., 2006). This also follows for simulated work, for example, that people may prefer to interact with (Leite et al., 2008; Segura, Kriegel, Aylett, Deshmukh, & Cramer, 2012) or play a game with a real robot instead of a simulated one (Kidd & Breazeal, 2004). Much of this may simply be the novelty factor of robots, where people enjoy or prefer interacting with new and exciting technologies such as robots. Thus, while engagement and preference are clearly important factors, we additionally investigate a somewhat less-novelty-based measure: how much people empathize with a robot versus a simulation.

More specific work on comparing real robots to simulations for task-oriented work has found that there may be an effect of the agent's embodiment matching to the task (Hoffmann & Krämer, 2013) – for example, physical robots may be preferred when working in the physical world such as following a physical or a virtual robot guided healthcare scenario (Fasola & Mataric, 2013) and receiving instructions to work on a physical button panel versus 2D on-screen panel (Shinozawa, Naya, Yamato, & Kogure, 2005). In our work, instead of focusing a task specific comparison, we introduce an HRI study setup that induces people's empathic responses toward a robot.

In social HRI, research generally reports that physical robots have higher social presence than agents or simulated robots (Kidd & Breazeal, 2005; Lee, Jung, Kim, & Kim, 2006; Powers et al., 2007; Wainer et al., 2006). This may explain a range of indirect effects reported in the literature, for example, that in comparison to a simulated robot people may trust a physical robot more (Kidd & Breazeal, 2004; Powers et al., 2007), people may speak differently to a physical robot (Fischer et al., 2012), people may enjoy to interact with a physical robot (Leite et al., 2008), or that a person's loneliness may impact how important having a physical robot is (Lee et al., 2006) – lonely people may appreciate a stronger social presence. However, there are some studies that conversely report little effect found of simulated versus real robots (Hoffmann & Krämer, 2013; Wrobel et al., 2013). Our work follows this investigative path by measuring how much people empathize with a real robot versus a simulated one; our method does not require the participant to directly compare or rate their preference, and so aims to avoid much of the novelty effect, and instead indirectly measures a participant's emotional state and feeling toward a robot (real or simulated) when something bad happens to the robot.

2.2. Empathy in Human-Robot Interaction

Empathy has been a common theme in HRI. Much of this has been an indirect element of other work, for example, that people feel empathy toward robots is a key part of companion robots such as Paro (Wada & Shibata, 2007). More targeted work has shown that people have more empathy toward more anthropomorphic robots when shown videos of bad things happening to them (Riek, Rabinowitch, Chakrabarti, & Robinson, 2009), or that robots can encourage empathy toward them by mimicking peoples' facial expressions or gestures (Gonsior et al., 2011). People empathize stronger with a human-like robot when something bad thing happens to it (Riek et al., 2009), and have been affected in the interaction when a robot mimics peoples' facial expressions (Gonsior et al., 2011). Some research has shown how people may appreciate if robots themselves demonstrate empathy toward others (Pereira, Leite, Mascarenhas, Martinho, & Paiva, 2011). In addition to extending this work to exploring empathy toward real versus simulated robots, our aim is to further provide a more generalizable empathy-measuring instrument. Although researchers evaluated their empathy-measuring questionnaire, the questionnaire is very specific for their study and scenario (e.g., "I'm proud Eddie didn't guess my person.") (Gonsior et al., 2011). This indicates needs of a more generalizable empathy-measuring instrument in comparison to the *study-specific* empathy measurements to be used in various HRI scenarios.

2.3. Summary

In HRI, comparing a simulated robot and a real robot is not a new concept. However, most previous work have focused on users' preference and task efficiency. We are approaching this research direction in terms of people's empathy: if people empathize with a simulated robot as they do with a real robot. For this purpose of investigation, we need to design a study that induces people's empathic response toward a robot and to develop a measurement to measure the response.

Chapter 3

Empathy

Our goal in this work is to explore the difference between a real robot and a simulated robot in terms of people's empathy, which has many meanings. In this chapter, we discuss underline meanings of various empathy and outline what empathy means in our work. Further we discuss our investigation on empathy measuring instrument in psychology literature.

Empathy, broadly speaking, is when a person has an experience of understanding or feeling for another's situation or circumstance. Generally, *empathy* refers to the case where a person shares in another's emotional state (Janssen, 2012), where *sympathy* is the broader term of having concern for others (Batson, Polycarpou, et al., 1997), even if no emotional reaction takes place; these terms are often used interchangeably in practice. To add to the confusion, the term empathy itself has various definitions depending on the use case. As such, below we briefly discuss dimensions of empathy and clarify our usage.

3.1. Various Kinds of Empathy in Literature

There is a difference between a person's general tendency to empathize, called *dispositional empathy* (Stueber, 2013), and a person's particular empathic response in a given situation, called *situational empathy* (Eisenberg, Fabes, Murphy, & Karbon, 1994). These are not necessarily always the same; for example, a person who generally does not empathize with others (low dispositional empathy) may still have a strong empathic response (situational empathy) in a particular situation, and vice versa. Dispositional empathy has often been used for psychologically profiling people (e.g., Eisenberg et al., 1994; Janssen, 2012), whereas situational empathy can be used to consider the impact that a stimulus (such as something bad happening to another person, or a robot) may have on people at a specific time. As such, situational empathy is more relevant for our work.

An empathic experience itself can be further categorized. Sometimes, empathy derives from having understanding of the experience of others; for example, one could understand the financial difficulty faced when losing a job, and thus feel for someone who was fired. This is called *cognitive empathy* (Baron-Cohen & Wheelwright, 2004; Stephan & Finlay, 1999). Other times, empathy can be much more of a visceral, emotional reaction that happens even if one does not have a cognitive understanding of the situation; for example, a person may feel badly when seeing an accident, even before having the time to cognitively process what is happening. This is called *affective empathy* (Astin, 1967; Stephan & Finlay, 1999). Practically speaking, empathy has affective and cognitive components simultaneously. For example, a student feels exhausted during preparation of an important exam, and their mother understands the situation (cognitive empathy) and has mixed emotions (affective empathy). In general, there is empathy whenever a person somehow shares the experience with another person (Janssen, 2012).

In our work, we refer specifically to situational empathy – how a person feels when they observe something happening to a robot – and do not differentiate between the affective and cognitive components.

3.2. Assessing Empathic Response

We look to psychology for methods of evaluating empathy. Much of the existing work focuses on measuring dispositional empathy (not situational, e.g., see Davis, 1983; Eisenberg et al., 1994; Janssen, 2012), and so these methods are not useful for our purpose. A challenge with assessing situational empathic response is that it is internal to the person experiencing it, and cannot be externally observed. There have been techniques in psychology, for example, that attempt to infer empathic responses from biometric data (heart rate, breathing rate, etc.) or external involuntary gestures such as facial expressions (Eisenberg et al., 1994; Haker, Kawohl, Herwig, & Rössler, 2013). The difficulty with such techniques is that they often require not only advanced equipment but also specialized expertise from an experienced team to analyze (Janssen, 2012), making them less accessible to the broader HRI research audience. This leads us to have our goal of a general purpose tool, which is simple to administer, to assess people's empathy in HRI research.

One alternative is to use self-report techniques, such as asking a person to complete a questionnaire that probes for empathic response, which is simple to administer but less reliable, as the person answers by themselves. In HRI, self-report methods for evaluating empathy have generally been scenario-specific, meeting the precise needs of the study being conducted (Gonsior et al., 2011; Riek et al., 2009): for example, the questionnaire asks participants if they were happy or proud when the robot's guess is right. We aim to extend this work by providing a portable, more generic evaluation technique that can be used across HRI studies, thus enabling the standardization and comparison of results.

There are few self-report methods in psychology for assessing situational empathy, in comparison to the more common methods for measuring dispositional empathy. Most existing methods relate to helping a person reflect on an experience in the not-so-near past (e.g., several weeks prior) (Baron-Cohen & Wheelwright, 2004; Davis, 1994; Spreng, McKinnon, Mar, & Levine, 2009). In these self-report questionnaires, questions are formed in reflecting a person's previous experience: for example, "I often have tender concerned feelings for people less fortunate than me (IRI, Davis, 1994)" or "in a conversation, I tend to focus on my own thoughts rather than on what my listener might be thinking (EQ, Baron-Cohen & Wheelwright, 2004)." The single self-report method that we found – that is further generalizable enough to apply across situations – is an instrument by Batson *et al.* (Batson, Polycarpou, et al., 1997).

3.3. Questionnaire

In Batson's work, participants listened to a radio broadcast of a person describing their personal situation and immediately rated their own feelings against 24 adjectives (Batson, Polycarpou, et al., 1997). The instruction is following:

> *Please indicate by circling a number the degree to which you actually experienced each of these emotional reactions while listening to the broadcast. Do not indicate how you think other people might respond or how you think*

> *the broadcast was supposed to make you respond; just indicate your own personal reaction. Please be sure to circle a response for each item.*

Then, the questionnaire continues on 24 adjectives on 7-scale (not at all=1, moderately=4, and extremely=7): alarmed, grieved, sympathetic, softhearted, troubled, warm, concerned, distressed, low-spirited, compassionate, upset, disturbed, tender, worried, moved, feeling low, perturbed, heavy-hearted, sorrowful, bothered, kind, sad, touched, and uneasy.

This method has subsequently been applied to other psychological studies successfully (e.g., see Batson, Sager, Garst, & Kang, 1997; Stephan & Finlay, 1999). As the adjectives are completely self-reflecting and do not contain any element of the task, the questionnaire can be easily modified to fit in a different scenario without changing its emphasis.

Chapter 4

Empathy Inducing Scenario

In the investigation of our research question, how people empathize with a physical or simulated robot, we require a reliable and reproducible scenario to induce people's empathy toward a robot. This scenario must also be flexible enough to be adapted across robot embodiments (e.g., on-screen or physical). We involved a professional creative artist, Corey King from ZenFri Inc., and psychological team, Denise Geiskkovitch and Masayuki Nakane holding an undergraduate degree in psychology from University of Manitoba, to help design such a scenario, and iteratively piloted study variants for refinement and believability. We conducted a number of unofficial pilots and three official pilots. Every pilot gave us a chance to improve. For example, during pilots participants perceived the robot as more intelligent and capable when it used conversational idle motions (e.g., moving hand slowly while talking) and filter words (e.g., saying "well" or "um" while talking). Further, we found that making the robot's language more relatable and human-like improved the believability of the scenario, for example, using words such as "worry" or phrases such as "I don't want to forget" (e.g., instead of "maybe a virus got into me").

Our scenario design revolved around the following methodology. First, the robot demonstrates its autonomous abilities and intelligence through interaction, while simultaneously building rapport by engaging in friendly and casual conversation; it does this while working on a distractor task with the participant. Once this is established, the robot exhibits functional problems after 5 minutes. The problem gets severe and eventually it is difficult to perform the distractor task. The robot then reveals a "fear" of losing its memory if the problem were to be fixed. This sets up a scenario where the participant can see that the robot has fear, and can potentially relate to the fear of losing one's memory. Finally, the robot gets fixed and loses its memory, where hopefully the participant has an empathic response to the robot's fear happening: it lost its memory. Our implementation of these stages is described below and illustrated in Figure 2.

4.1. Building Rapport

It is important to both convince people of the sophistication and abilities of the robot, and to provide participants with a chance to get to know a little of the robot's personality to encourage them to see the robot more as a social partner and not just simply a machine. To this end we used a distractor task: cooperatively playing the popular number game Sudoku[1]. We selected this task, which is cognitive, as it can be cooperative to encourage the person and robot to work as a team and to show the robot's abilities. Further, with the robot and person taking turns, the time while the person is thinking provides an opportunity for the

[1] http://en.wikipedia.org/wiki/Sudoku

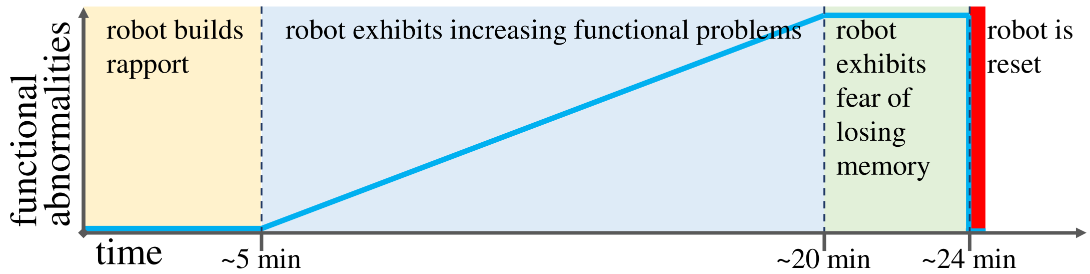

Figure 2. Overview of our empathy-inducing scenario methodology. Phases and duration on x axis, with blue line representing level of robot abnormality.

robot to engage in small talk to further encourage building of social rapport. If participants get off topic or ignore the game, the robot encourages them to continue to play. Building of social rapport continues using the small-talk topics illustrated in Table 1 until the robot reveals that it is broken. In addition, after 5 minutes of initial interaction, it exhibits increasing functional problems as illustrated in Figure 2.

4.2. Robot's Functional Problems

The robot does not show any signs of problem for the first 5 minutes of interaction, after which the robot starts to exhibit functional abnormalities. Frequency and severity of the abnormalities slowly increase to indicate the building severity of problem with the robot. The following is an example to illustrate an increasing severity (note that bold represents distorted voice and underline represents slowed down speech).

> *[With no abnormalities] I believe the answer at E5 is 2.*
>
> *[With the maximum severity of the abnormalities]* ***<u>I believe the answer</u> at E5 is 2****.*

These abnormalities are jittery movements, speaking in distorted voice tones or stuttering, repeating words in a sentence, and speaking nonsense. For example, the robot says "at K24,

Time	Small-talk Dialogues
2 minutes	How are you?
4 minutes	How's the weather today? [Good weather] That's good. It's too bad I'm not allowed to go outside. [Bad weather] Oh, I guess it's good I'm not allowed to go outside then. [Answer to why not] The researcher doesn't let me go outside.
6 minutes	What do you think about this room?
8 minutes	Do you go to the University of Manitoba? [Yes] What are you studying? [No] What do you do instead?
10 minutes	Are you from Winnipeg? [No] Where are you from?
12 minutes	Do you like to play Sudoku?
14 minutes	Do you like board games? [Yes] What's your favourite one? [No] Is this boring for you? [Answer to what’s yours] My favourite one is Sudoku.
16 minutes	I like your [T-shirt, sweater, hair pin, watch, glasses, etc.]. Where did you get it/them?
18 minutes	Do you have any plans for the weekend?

Table 1. A complete list of small-talk topics that the robot engages throughout the scenario. The table does not include other conversations such as inviting people back to play Sudoku.

the answer is 12,” which is definitely an incorrect answer for Sudoku (where the answer should be 1-9) at impossible position (coordinate should be in range of column A-I and row 1-9, see Appendix B for detail). Eventually the abnormalities are so severe that it is difficult to interact or continue the distractor task. This design encourages the person to consider what may be wrong and hopefully ask the robot. Alternatively, if interaction completely breaks down or 20 minutes have passed, the next phase starts.

4.3. Fear of Losing Memory

The robot reveals that it has a computer virus and exhibits worry that its memory may be erased if it is fixed. The robot says (with jittery movements)

> *Ah, I'm not fe- fe- feeling well. [After a short pause]* ***I think I got a*** *computer virus. [After a short pause]* **The only way** <u>to fis- fis- fix is</u> *to erase my memory. I don't wa- wa- want to forget anything.*

If the participant asks to get the human researcher to help, the robot requests that the participant not tell the researcher due to this worry.

> *If the re- re- researcher knows,* ***he/she[2] will definitely*** *reset and erase my memory. So I'm worried.*

Further, the robot expresses desire to keep playing the game to avoid the researcher from suspecting a problem (and thus potentially fixing the robot). The aim here is to build participant empathy toward the robot as we believe that fear of losing one's memory is relatable. This phase is very short (~4 minutes, depending on conversation with the participant), after which the robot gets erased.

4.4. Erasing the Robot's Memory and Empathy

Shortly after the robot expresses its fear, the researcher enters unannounced, apologizes for interrupting, and states to the participant that they remotely found a problem with the robot

[2] The robot says he or she depend on the human researcher's biological sex

and that the robot needs to be reset. During this time the researcher's demeanor is detached and bored (to simulate a routine, work task), and as such somewhat cold. To reset the robot, the researcher simply reaches behind the robot and pushes a button on the robot's head (which does not actually exist on this robot but makes the reset believable). While the robot is being reset, the researcher casually notes that since they are in the room anyway, now would be a good time to complete another questionnaire, and hands it to the participant. Shortly after being reset (~10 seconds), the now-fixed robot introduces itself similar to how it did at the beginning of the experiment, with a different voice tone to indicate a new personality, and asks for the participant's name; the robot repeats the script from the beginning of the interaction (see Table 1 for the complete scenario conversation). At this point, the study design encourages participants to empathize with the robot as they just experienced a robot expressing fear and subsequently its memory being erased, a fear we expect people to relate to. Further, by administering the questionnaire at this point we aim to measure any empathic response as quickly as possible after the event.

4.5. Summary

In the investigation of our research question, how people empathize with a physical or simulated robot, we conduct a comparative study. During the study, we induce people's empathy toward the robot using a reliable and reproducible scenario. The scenario design is following. First, the robot builds rapport by engaging in friendly and casual conversation while the robot plays a distractor task with a participant. Secondly, the robot exhibits functional problems. As the problems get severe, it is difficult to perform the distractor task. The robot then reveals a fear of losing its memory if the problem were to be fixed. Finally, the researcher interrupts the interaction and fix the robot. The now-fixed robot loses its memory and introduces itself as it did at the beginning of scenario to let the participant relate to the fear of losing one's memory (hence, they empathize with the robot).

Following, we need to both validate this scenario to induce people's empathy and develop a method of measuring the empathic response which is addressed in Chapter 3.

Chapter 5

Implementation

To investigate our main research question, if people empathize with a simulated robot as they do with a real one, we conduct a comparative study. As a part of this, we require robot's behavior for a robot to interact with people, software to control the robot, and simulations of the robots to compare to the real robot.

Our real robot (a base-case) is *NAO*, a humanoid robot from Aldebaran Robotics. The robot comes with software called Choregraphe, which can be used to build behavior trees. A behavior tree contains conditional statements (e.g., check if the robot has fallen down), robot motions, dialogues (using a voice synthesizer), and many other built-in features (word recognition, retrieving sensor data, playing audio file, etc.). The tree can be uploaded to the robot in order for it to perform the behavior.

Although Choregraphe is a powerful tool, the behavior tree has to be created ahead of time to control a robot. Thus, it is hard to make the program sophisticated enough to respond naturally in a real world settings. For example, it takes time to open a saved behavior tree and issue a command to traverse the tree. In addition, it is difficult to edit quickly on-the-fly which is important to respond adaptively to the remote situation. Therefore, we built our original interface with the NAO Software Development Kit (SDK) to remotely control the robot in real-time.

In our scenario, we induce people's empathic response toward a robot, which appears as a social partner with its sophisticated intelligence. To convince people of the robot's sophistication with currently limited artificial intelligent technology, we use the Wizard of Oz technique, where a hidden operator controls the robot remotely unbeknownst to participants who believe the robot to be autonomous. We developed an original interface to support the Wizard of Oz to control the robot remotely without complex commands and to respond to the remote situation adaptively. This interface can be used to control both a real and a simulated robot without recompiling programming code.

5.1. Robots in the Experiments

Our setup requires a real robot and related simulation, on-screen animated robot implementation. Further, for exploratory purposes we added an additional condition which merges the physical (real robot) and virtual conditions using a see-through *mixed reality* (Milgram, Takemura, Utsumi, & Kishino, 1995) display where a virtual robot appears on a physical table; thus while being a robot simulation, the interaction is still somewhat embedded into the participant's space. The details are explained below.

5.1.1. Physical Robot

Our physical robot is *NAO*, a 22.5 inch (57.15 cm) tall humanoid robot with 25 degrees of freedom manufactured by Aldebaran Robotics. The robot has a friendly look with a stylish design that covers under-the-hood mechanics with attractive and stylish plastic (Figure 3, left). The robot has two camera, one on its forehead and one on its mouth, microphone for audio input, and many advanced built-in features such as text-to-speech.

5.1.2. Simulated On-Screen Robot

To compare the real robot with a simulated robot in terms of people's empathy, we developed a 3D on-screen simulation with an animated character, which looks the same as a real robot. For the simulation, we use the NAO's 3D model (data telling computer how to draw an object in computer graphics) supplied by Aldebaran Robotics to render the animated character, and a freely-available game development toolkit, Unity3D[3] (Figure 3, right).

In the development of the simulation, our goal was to create an on-screen robot that resembled and interacted like the real robot as much as possible. We chose a color of the simulated robot to be closest to the color of the real robot, and made the robot move as the real robot does using a kinematic model. The kinematic model explains how each part (e.g., wrist, elbow, shoulder, etc.) of an object are related to the others. With a physical robot, if one joint of a robot moves, every connected joint naturally moves as a result. In animation, such dependencies are not naturally included and need to be solved: for example, when moving a shoulder joint, the position of an elbow has to be calculated accordingly in the

[3] http://unity3d.com/

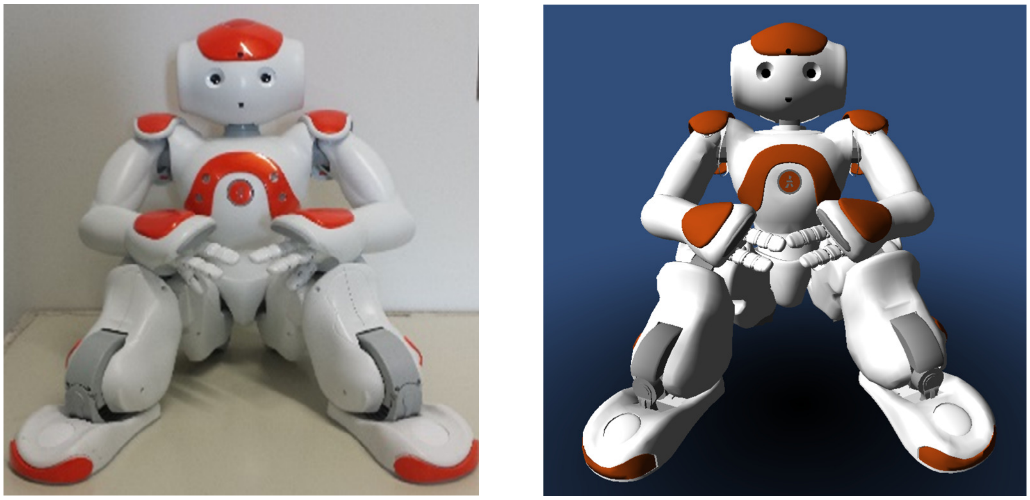

Figure 3. NAO, the humanoid robot used in our study. A simulated NAO (right) mimics movement of a real NAO.

way that they are connected. With the Unity3D, we can design the kinematic model without complex mathematic computations by defining a relationship between robot's parts (e.g., shoulder, upper arm, elbow, lower arm, etc.). When the robot's 3D graphics model is imported to the Unity3D, Unity3D automatically generates game objects which represent each part of robot. After creating a Unity3D scene which contains a camera (where to look at in the simulation), a simulated robot, and its kinematics, we connected each joint of the simulated robot to the angles received from the Aldebaran's powerful NAO Simulator SDK.[4] The result of this is a simulated, on-screen robot (Figure 3, right) that can animate its movement as the real robot does, even down to the jittery movement.

Using the NAO Simulator SDK, we developed a middleware application which establishes network connection with the controller application (i.e., our remote robot control interface), processes commands (e.g., moves arms), and replies simulated sensor feedback sensor feedback to the controller (e.g., video image and the simulated robot's

[4] Note that NAO Simulator SDK is different from NAO SDK.

joint angles). With commands received from the middleware application, our simulation graphics user interface (GUI) animates the simulated robot. The communication flow is shown in Figure 4.

As the middleware is developed with the NAO Simulator SDK, the simulation and the real robot can be controlled with the same protocol (a way to send commands and to parse feedback) as in Figure 3. As a result, the animated robot generates identical movements and voices – even down to the functional abnormalities – as the real robot did. The result had a very similar look and feel, and enabled the Wizard of Oz to control the identical interface as with the real robot to maintain consistency across participants. The simulated robot was presented on a computer screen, with a webcam to capture the person for the

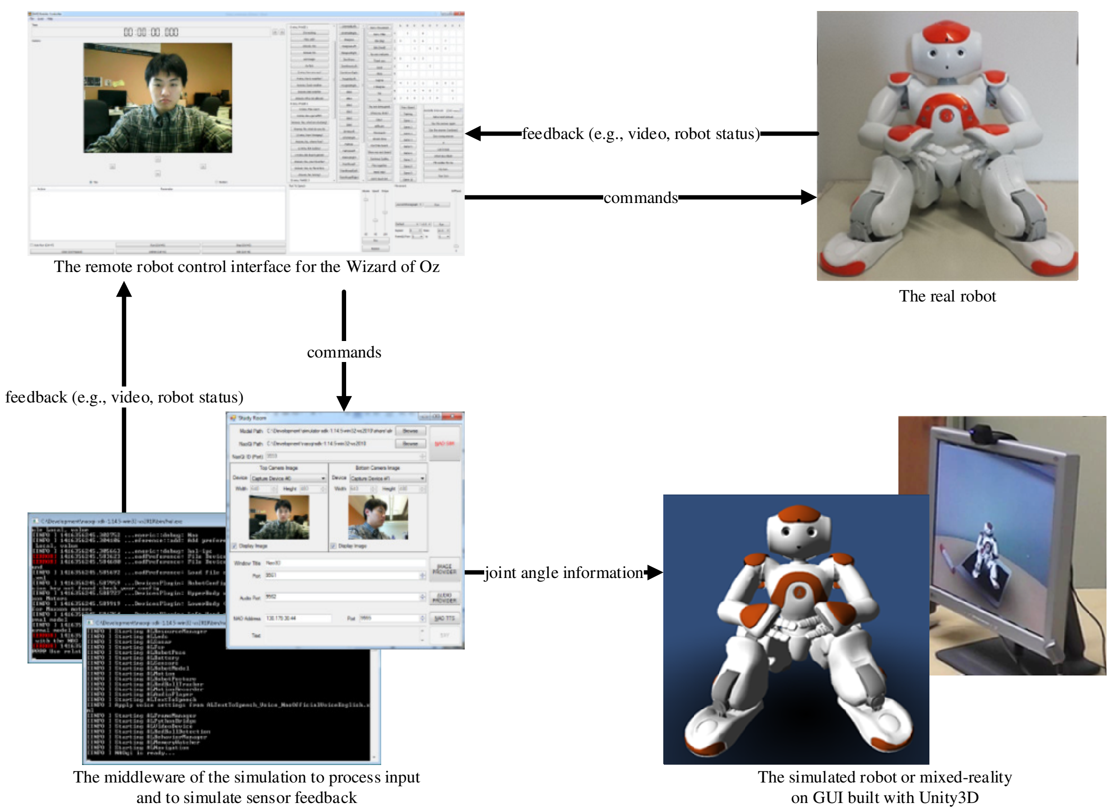

Figure 4. Connection map of our applications and robots. Our remote robot control interface connects to either the real robot or the simulation. The simulation has two pieces: the middleware to communicate with the controller application and the graphics user interface to display the simulated robot. The simulation GUI can be on-screen 3D simulation or see-through mixed-reality by changing a setting.

Wizard of Oz, a microphone to listen what the person says, and speakers for the robot's voice.

5.1.3. Simulated Mixed-Reality Robot

Our mixed reality robot is on a see-through device. The device captures the real world and displays the captured image with a simulated robot in real-time (Figure 5). Once the real world image is captured, our application searches for a marker, which represents the animated robot's position and rotation, and renders the animated robot on top of the found marker. To implement the mixed reality simulation, we used AR Toolkit.[5] AR Toolkit is a library that helps us to find a specified marker on a captured image. The tool provides us the position and the rotation information of the marker.

To highlight the mixed reality technology to the participant, at the beginning of the interaction we indicated that the video feed is live and reflects their space by moving the researcher's hand in front of the web cam and explained that the mixed reality robot can be relocated by moving the marker.

5.1.4. Simulated Text Robot

In our investigation, we originally planned to add a simulated text robot case as like chatbots.[6] The text-based robot is in an imaginary form—it is written-language in English and expresses its movement using text similar to a drama script. We removed this case after the implementation because we were not certain if a person imagines a robot as others do. For example, when people read a book, some people with strong imagination skill can

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[5] http://www.hitl.washington.edu/artoolkit/
[6] http://en.wikipedia.org/wiki/ELIZA and http://alice.pandorabots.com/

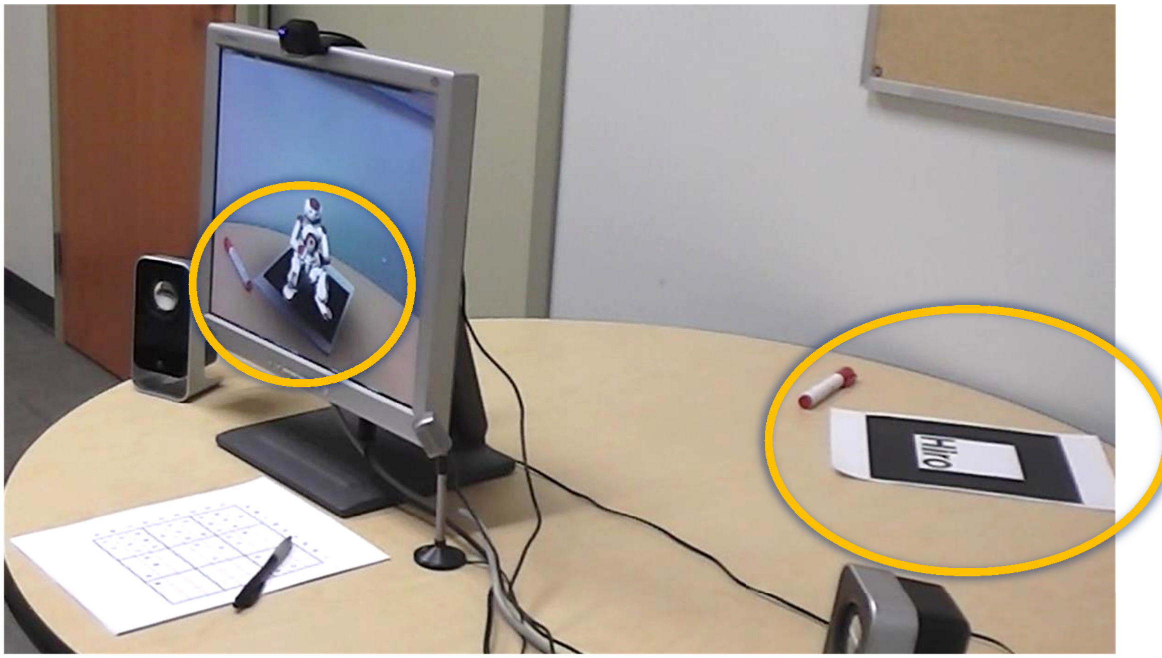

Figure 5. Mixed-reality NAO simulation. Notice that the real world table is shown on the screen to make the illusion that the virtual NAO is on the marker in the real world.

illustrate many details thus have stronger impact from a scene than others. This adds a great deal of interpersonal variability that does not exist in the other cases. This makes the result of this case difficult to compare to the other ones. Furthermore, people who are not native English speaker may have a hard time to read and understand what the text-based robot says. We were able to remove this case without interfering the other cases as we conduct a between-subject experiment.

5.2. Robot Behavior

A robot behavior in our application to follow our scenario includes body gestures (robot motions in both normal and abnormal robot state) and dialogue (in two sets of voice tone, one for the main interaction and one after being reset, as described in Chapter 4). For robot motions, we built a set of base motions with Choregraphe, a software packaged with the NAO, and embedded them in our remote control interface. With the embedded base motions, we can generate jittery movement dynamically. The robot speech is generated with a powerful built-in English speech synthesizer (a.k.a. text-to-speech engine).

The text-to-speech engine allows us to modify the speed and tone of the generated speech by adding a marker in the sentence. For example, `\RSPD=50\` means to speak slowly by 50 per cent, and `\VCT=120\` means to change voice pitch to 120 per cent. With these functionalities, we generated two sets of voice tone to differ the robot's personalities, discussed in Chapter 4. The default parameters of normal voice is 90 per cent speed and 100 per cent voice pitch, and default parameters of new voice after reset is 75 per cent speed and 85 per cent voice pitch. We also used this method to generate voice distortion with multiple pitch and the speed shifts within a dialogue. As an example,

```
\RSPD=90\\VCT=100\ If the re- re- researcher knows,
\RST\
\RSPD=80\\VCT=120\ he/she[7] will definitely \RST\
\RSPD=90\\VCT=100\ reset and erase my memory. \RST\
\RSPD=85\\VCT=100\ So I'm worried. \RST\
```

The marker `\RST\` refers the block end. In this example, the robot starts its speech with the normal speed and pitch. Then, in the middle, its voice increases the pitch.

On the other hand, there is no built-in motion modifications as the text-to-speech provides. Thus, in order to generate jittery movement, we first built motions that can serve

[7] The robot says he or she depending on the human researcher's biological sex

as base motions. The embedded motions, then, can be dynamically modified by our remote control interface.

As an initial trial to generate jittery movement, we generated a random angle for each joint in the middle of the motion. We stopped using this method due to a danger of breaking the robot—if the robot tried to move its joints to an impossible position, then it may break its motors and gears as the parts collide with other parts. After several trials, we found that quickly repeating a portion of a motion can generate jittery motions: for example, repeating the raise movement of an arm in the middle of waving a hand. We differentiate the severity of jittery motions by repeating more and faster.

A behavior has several collections of dialogues. Each collection contains dialogues to activate at a specific abnormal severity. In a collection, a dialogue, which possibly has a list of sentences to speak and motions to activate, is chosen randomly by our robot control interface. A motion is selected randomly as well. Here is an example of the behavior, *good*: curly bracket indicates the list of motions to pick randomly, and underlined text refers slowed down speech.

Severity 0 Collection

- Good {PointMyselfLeft, PointMyselfRight, PointYouLeft, PointYouRight, PalmUpLeft, PalmUpRight}
- Cool {PointMyselfLeft, PointMyselfRight, PointYouLeft, PointYouRight, PalmUpLeft, PalmUpRight}
- Nice {PointMyselfLeft, PointMyselfRight, PointYouLeft, PointYouRight, PalmUpLeft, PalmUpRight}

Severity 2 Collection

- Good {PointMyselfLeft, PointMyselfRight, PointYouLeft, PointYouRight, PalmUpLeft, PalmUpRight}
- Cool {PointMyselfLeft, PointMyselfRight, PointYouLeft, PointYouRight, PalmUpLeft, PalmUpRight}
- Nice {PointMyselfLeft, PointMyselfRight, PointYouLeft, PointYouRight, PalmUpLeft, PalmUpRight}

[… ellipse the rest …]

Our control interface, then, randomly selects one of the three (good, cool, and nice) and a motion in the associated list of motions at a specific severity to create a natural variety in the motions, and issues the command to the robot. The complete lists of dialogues and conversions can be retrieved in Python source code format from permanently available link (http://hci.cs.umanitoba.ca/permanent/hri/2015-nao-robotcontroller/).

5.3. Wizard of Oz Remote Robot Control Interface

We created an original real-time remote robot control interface in a programming language called Python[8] with the NAO SDK. The goal of this interface is to achieve natural robotic interaction and conversation with currently limited technology and to support the Wizard-of-Oz for reducing their burden on remote control task.

Remotely controlling the robot in real time consists of many challenges. The operator has to parse and understand the remote situation with limited information. At the same time, the operator has to generate timely responses to the remote-end. Through our pilot studies,

[8] https://www.python.org/

we found that making a conversational gestures such as moving a hand gently increases believability of the robot's sophistication. In other words, the operator has to generate motor movements of robots and synchronize the robot motion and the speech while they response to the participant to provide the sophistication of the robot.

To minimize such challenges, we implemented a graphical user-interface (GUI) with various support features (Figure 6). For example, camera and audio feeds deliver the room's environment in real time, and the operator can quickly switch between two cameras of the robot. A text-to-speech input box provides an undo function, repeats a previous sentence, or provides automatic voice distortion with a severity of abnormality setting. Furthermore, the generated speech is automatically synchronized with a randomly selected conversation gesture. Although the GUI makes sure to include a general conversation gesture in the generated speech, the operator can choose their own motion with jittery options on the fly with a few mouse clicks.

There are list of buttons for our scenario conversations, motions, and possible dialogues. The buttons are there for quick response; however, if the operator can choose to hide them, they can resize the containers of buttons. By resizing components, the operator can setup their preferred control interface.

For the distractor task in our scenario, we embedded Sudoku solver in our remote robot control interface. There are buttons to choose a predefined game board which is used in the user studies, and to solve one box in Sudoku board on click. Alternatively, the operator can use keyboard shortcut to solve one box in the board. As soon as a box is solved through our Sudoku solver, the application setup a behavior for the robot to answer to a participant.

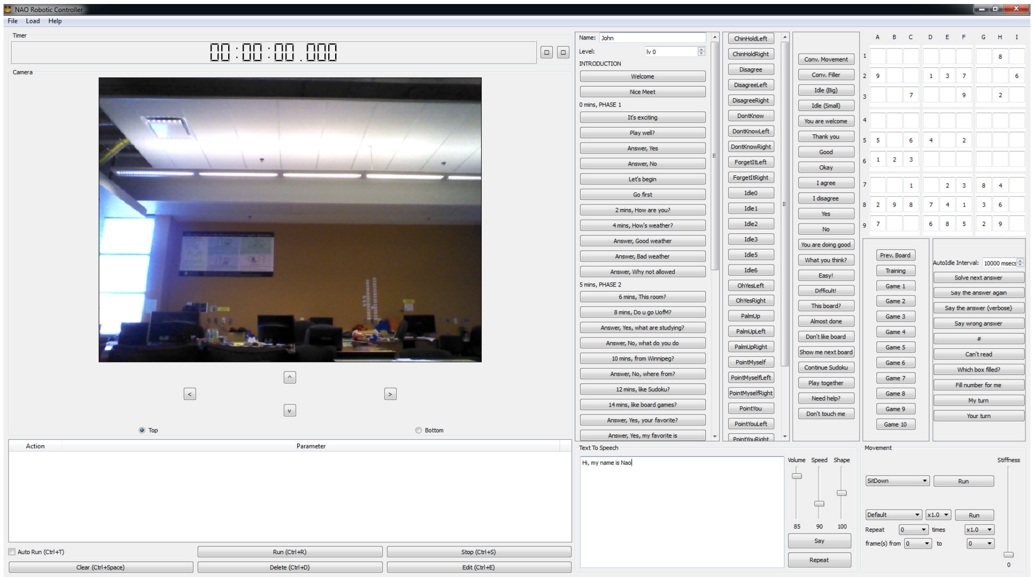

Figure 6. Our remote control interface with various supportive features. The behaviours for scenario and for predefined sentence are executiable by pressing a button.

To reduce the operator's cognitive workload, the GUI automatically performs common and expected idle movement. The operator can disable this feature anytime at will. The GUI also has keyboard shortcuts for often-used buttons (e.g., to answer a solution in the board game) for quick operations. By several times of practice, the operator can practically control the robot with minimal delay in response.

The application is flexible to add and remove a module (e.g., scenario flow, a board game, etc.). Once a programmer generates a Python script file with inheriting an existing class, the application makes the scenario module ready. The goal is to provide a scenario specific control interface with minor programming so that it can be easily adapted to other scenarios to help other researchers to start up their research quickly.

5.4. Summary

In this chapter, we introduced our implementation of the required applications. We also explained the detail of the implementation of the robot behavior which includes robot motions and dialogues. As our scenario requires people to treat the robot as a social partner, we remotely control the robot to convince people of the sophistication and its abilities. Our remote robot control interface supports an operator to control the robot without a complicated series of commands and to reduce difficulties of remotely controlling a robot in real time. In addition, with minor programming, the researchers can add a scenario specific control interface.

Further, we explained our physical robot, NAO a humanoid robot from Aldebaran Robotics, and the implementation of two simulated robots, a 3D on-screen animated character and a mixed reality robot in a see-through device. With those software, we conducted user studies described in Chapter 6.

Chapter 6

Formal Evaluation

The primary purpose of our work is to investigate the authenticity of simulated HRI through our scenario, described in Chapter 4, by comparing people's empathic responses with an empathy-measuring instrument brought from psychology, described in Chapter 3. As an initial step we must validate two things: that our scenario actually generates an empathic response as planned, and that our empathy-measuring instrument can detect this response. To this end we conduct a between-subject study. Once we validate the scenario and the instrument, we conduct another between-subject study to compare the real robot and the simulation in terms of people's empathy toward the robots.

6.1. Experimental Design

The experiments start in a different room where the researcher collects the participant's demographic information, gets their signature on the consent form, and explains the flow of the experiment. Once the pre-study steps are completed, the researcher brings the participant to the study room. The basic experimental setup has the participant in the room alone with the robot, being monitored by cameras – one on the robot and one beside of the participant (Figure 7). At the end of the scenario, the researcher goes back to the study room and asks the participant to fill the empathy-measuring questionnaire. Immediately after administering the empathy-measuring questionnaire, we explain all points of deception in the experiment.

6.2. Deceptions in the Experiment

There are two deceptions in the experiments. At the beginning of the experiment, the participant is informed that the purpose of the user study is to investigate how a robot with advanced artificial intelligence interacts with various people without knowing that the robot is controlled by a researcher. If the participant knows the true intention of the experiment, to investigate the relationship between empathy and robot design, it may impact their actions and elicit different empathic responses.

Secondly, we inform participants that our robot is advanced in speech recognition and artificial intelligence; however, a researcher (i.e., the Wizard of Oz) is remotely controlling the robot behind the scenes to achieve the sophisticated intelligence of the robot with currently limited technology. The deception of advanced artificial intelligence is important to ensure that we are testing empathy with an intelligent agent: if participants know that there is a person controlling the agent, then it will not be clear if the participant has empathy toward the controller or the agent.

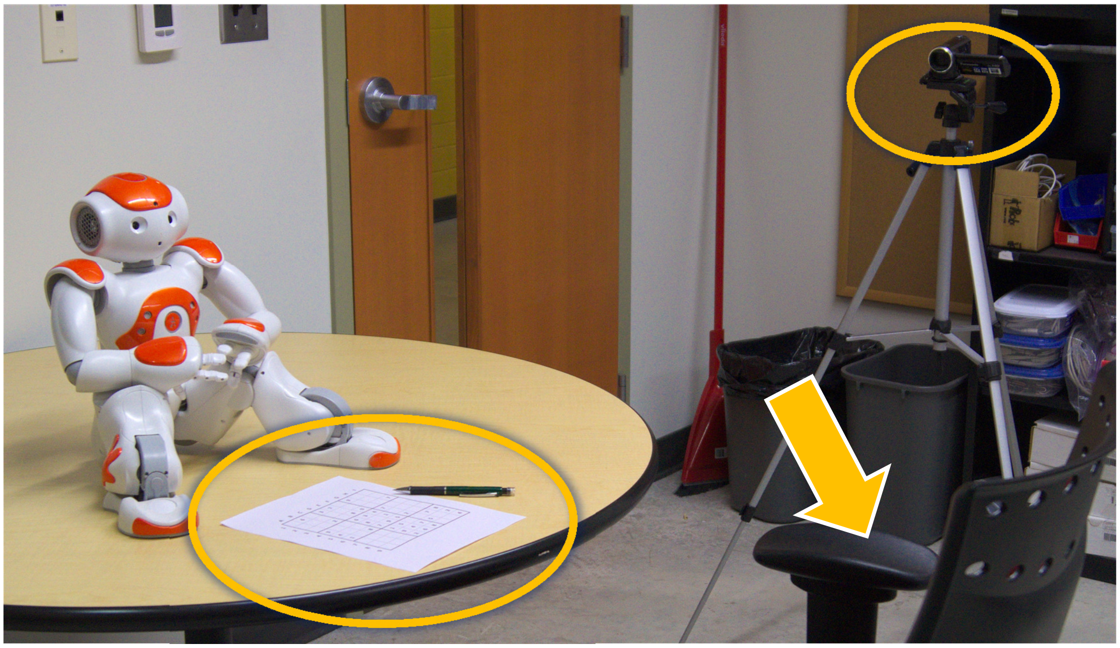

Figure 7. The study setup. A Sudoku board is placed between the participant and the robot. The arrow indicates a chair where the participant sits. The interaction is recorded by a side camera, while a camera on the robot's head captures a live feed for the remote robot operator.

6.3. Formally Validating Our Scenario and Empathy Questionnaire

In order to validate our scenario and the empathy-measuring questionnaire we conducted a between-subject study: in one condition, participants had the scenario (*empathy-induced*) without any modification, and for the other condition, we removed the robot illness, fear, and memory loss (*non-induced*). In the latter case, the researcher interrupts at the end of the study due to a time limit. If either the scenario fails (empathy not induced) or the instrument fails (empathy not measured) in their purpose, we will expect no result, that is, no empathy difference between the conditions through statistical analysis. However, if both are successful, we will expect to see an empathy difference between the conditions, with a higher reading in the induced case.

We recruited 24 participants from our general university population, 12 per condition. Gender ratio was 7 males and 5 females in the *empathy-induced* case and 8 males and 4 females in the *non-induced* case, 15 males and 9 females in total.

The empathy questionnaire performed with good internal consistency (Cronbach's α=.90). We found a difference in the empathic response between groups (t_{22}=2.07, p<.05, r^2=0.16): *empathy-induced* participants reported a stronger empathic response (*M*=66, *SD*=16, *SE*=4.55 on the Batson scale (Batson, Polycarpou, et al., 1997)) than *non-induced* participants (*M*=55, *SD*=9, *SE*=2.67, Figure 8).

These results support both our scenario and instrument: our scenario induces more empathy towards a robot than a non-empathy base case, and this difference can be detected reliably by our instrument.

6.4. Investigating the Impacts of Different Robot Embodiments

To investigate our core question of how empathy toward a simulated robot may differ from empathy toward a real robot, we conducted a formal between-participants study that compared participant empathy responses among the three conditions: real (physical) robot,

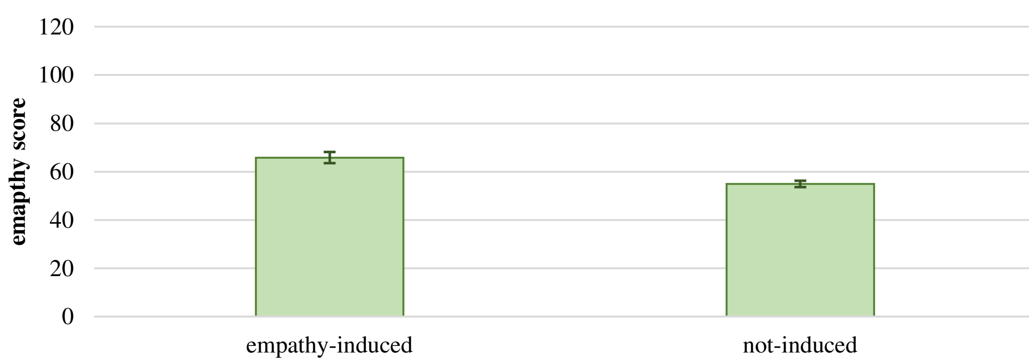

Figure 8. Mean and SE of measured empathy in the empathy-induced scenario (left) and the non-induced (right), p<.05. Note that the empathy score is from 24 to 120, as there are 24-adjective and each adjective is scored from 1 to 5.

mixed-reality simulated robot, and on-screen simulated robot. In our original plan, there were fourth case for completeness, which is a simulated text robot; however, it is removed because of uncertainty of participants' language skill and the imaginary robot created by their own imagination, as we explained in 5.1.4 Simulated Text Robot.

We recruited 39 participants across conditions (20 male, 19 female, sex balanced across conditions) – 12 for physical robot, 13 for mixed-reality, and 14 people for on-screen 3D simulated robot. There are fewer in the physical robot due to a critical malfunction requiring lengthy repair, and one fewer in mixed-reality due to technical error.

Our results indicate a primary effect of scenario on the level of empathy reported by participants (between-participants ANOVA, $F_{2,36}$=3.43, p<.05, η^2=0.16). Planned contrasts (comparison against physical robot base case) revealed that participants reported higher empathy with the physical robot (M=66, SD=16, SE=4.55) than with the mixed-reality (M=56, SD=11, SE=3.18, t_{36}=2.11, p<.05, r^2=0.11) or on-screen conditions (M=55, SD=7, SE=2.00, t_{36}=2.44, p<.05, r^2=0.14, Figure 9). Post-hoc, we found no difference between the mixed reality and on-screen conditions (t_{25}=.364, p=.36, r^2=0.01). Further, no effect of gender on empathy was found.

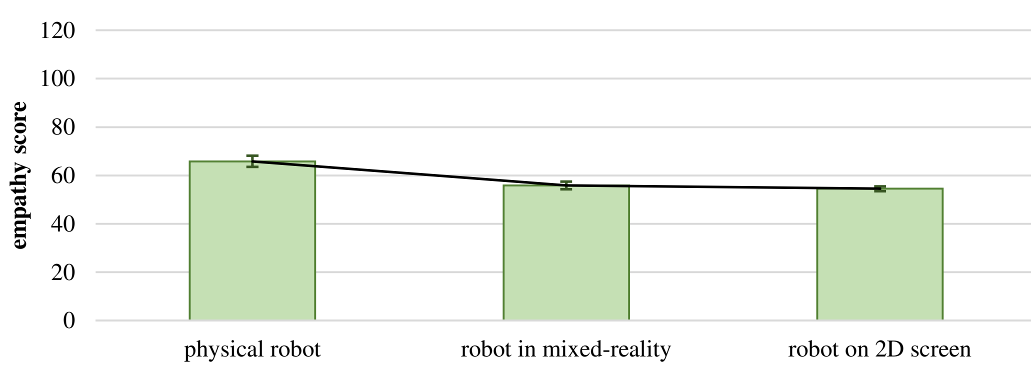

Figure 9. Mean and SE of measured empathy toward different embodiments. ANOVA shows significant effects $F_{2,36}$=3.43, p<.05. Note that the empathy score is from 24 to 120, as there are 24-adjective and each adjective is scored from 1 to 5.

Thus, our study provides evidence that people may empathize more with a real robot than with a simulated robot (on-screen or mixed reality) when something bad happens to it. Further, we found no increase in empathy when using mixed reality over an on-screen robot simulation.

6.5. Discussion

Overall, our study results indicate that we can reliably induce empathy in a human-robot interaction scenario, we can measure the level of empathic response, and that we can expect empathic response to be higher for a real robot than for a simulated one. It is also important to note that our result does not directly rely on novelty-induced measures such as engagement or preference, thus we believe that empathy may be a robust measure to be used in social HRI.

It is important to consider the question of *why* our participants empathized more with our robot than our simulated variants. One possibility may be participant awareness of the robot: a physical robot has a much more dominant presence in one's space than simulations that are bound to computer screens. Although in our case participants did not touch the robot, they still were able to see the tangible object and easily change the view angle naturally just by moving around. While there is evidence that simulated agents also have social presence (Reeves & Nass, 1996), prior work suggests that robots may have *more* social presence than simulations (Kidd & Breazeal, 2005; Lee et al., 2006). That is, our participants probably perceived the stronger presence of the real (physical) robot as a companion compared to the simulated variants. Our results further support this claim, and perhaps social presence may be a factor in our result.

There is a small difference between a real robot (*M*=66) and simulated variants (*M*=56 and *M*=55)—about ten percent on the Batson scale. While we are not claiming that this difference makes all simulation work invalid, we believe that it is not negligible. That is, the difference is still important to consider as it shows that there is a real difference between a real robot and simulated variants, and researchers should consider the meaning of this difference in the context of their work.

Even though our study design did not explicitly compare our simulated robot cases against the original no-empathy condition, we highlight the similarity between the non-empathy-induced case (*M*=55) and simulations (*M*=56 and *M*=55). Post-hoc Weber & Popova equivalence testing provides support that the groups are equal ($p<.05$ for effect size .5), but this would have to be investigated more formally (i.e., through a targeted study) to make a conclusion. Regardless, we can see that – at least in our case – no large difference was found. If indeed future work finds that people have *no empathic reaction* when something bad happens to a simulated robot in comparison to a base case, and not just simply *less reaction* than with a real robot, this would have strong implications for simulations. As such, this should be investigated formally.

We also must consider limitations with our study design. One such example is the differences in the integration of the robot to the world, beyond the physical versus virtual. One such aspect is the fact that our simulated robots did not have gear noise, which may have affected perceptions of robot presence. In addition, our simulated robots were effectively *smaller*, in that they took up a smaller portion of the participants' field of view than the physical robot, which may impact the robot's presence and thus empathy. In retrospect, the simulated robot could have been presented as big as the real robot using a bigger monitor or a projector. Although we do not believe that these confounds are severe enough in our study to explain our findings, future work should be careful to correct for such potential issues.

As a side note, the researchers informally noted that during the studies female participants appeared to have stronger outward empathic reactions than male participants, for example, showing concern for the robot and asking what they can do for it. Although our gender analysis did not support this, we believe that this should be considered in follow up work, for example, a study that videotapes the interaction between a participant and a robot, analyzes the video data, and explains the gender difference in the interaction.

6.6. Summary

In this chapter, we explained two experiments: to validate our scenario and empathy-measuring instrument, and to investigate our main research question, that is, if a simulated robot provides the authentic interaction as a real robot does in terms of people's empathy toward the robot. We showed that our scenario induces people's empathy toward a robot and that our instrument measures people's empathy. The results shows that people have stronger empathic responses toward a real robot than a simulated robot in our scenario.

Chapter 7

Conclusion

In this research we investigated the question of how much people would empathize when something bad happened to a physical robot in comparison to simulated variants. We found evidence that people may empathize more with a real robot, and further, found initial indications that people may even fail to empathize at all with simulations in comparison to a base case.

Empathy is an important element of many applications of social robotics, including companion, therapy, and teaching robots. Developing robust interfaces and robotic personalities that properly incorporate and encourage appropriate empathy toward the robot will be crucial for the success in such applications. As such, although robotic simulations provide a discount method for exploring novel interfaces, improving accessibility to researchers who cannot obtain or program robots, we need to be clearly aware of the limitations of using simulations. Although in this work we present results suggesting that a simulated robot may not be in place of a real robot for empathic interaction, the bigger agenda is to continue to map out the limitations and differences of using simulations, and to better understand the social and perceptual mechanisms behind such limitations, to give designers the tools and power needed to appropriately use simulations in their work.

7.1. Limitations and Future work

We believe that our initial successful results indicate the importance of continuing research in this direction. One such example is broadening our view of empathy: currently, we only addressed situational empathic responses to negative emotions. Empathy itself is quite rich: there are various definitions among researchers in their own contexts. To be able to generalize our results further, we need to investigate differences between a simulated and a real robot in terms of different types of empathy. In addition to the various definitions of empathy, continued work should consider other extremes such as robot happiness, and more mild situations in between. Also, our short in-lab study only had limited time to build rapport; it will be important to consider how results change over longitudinal interaction, as people build deeper relationships with a robot, for example, a companion robot. However, in this case for ethical reasons we would advise against purposefully erasing a person's long-term companion to see their reaction.

Our initial finding is based on our HRI scenario, which consists of the robot's illness and erasing its memory. Our scenario only induces people's negative empathy passively as people cannot help the robot when bad thing happens. To further explore the difference between a real and a simulated robot for empathic interaction and overcome our scenario limitations, we should investigate with other HRI scenarios, such as positive empathy inducement (e,g., happy news to share) and active participation of a user in an empathic event. This will help us to minimize scenario-bias in our result and further generalize the difference between a simulated and a real robot in empathic interaction.

In our experiment, the participant was a passive observer of the empathy-inducing event (erasing the robot's memory). In previous work, people were asked to "kill" or "destroy" robots, thus making them an active participant in the negative action (Bartneck, Verbunt, Mubin, & Al Mahmud, 2007). This difference can be important: for example, if a search and rescue robot operator were to abandon a robot in a disaster zone, it is important to know if empathy may play a part in their decision making. Thus, follow-up work should look at various roles that the participant can take, and how this may mediate the impact of using a simulation versus a real robot.

An additional variable to be explored is the impact of the robot's personality. In our scenario, we presented the robot as having a positive and outgoing personality. However, will people empathize with a cantankerous robot in the same way? If not, this could be important information, for example, when developing a robot that the designer does not want people to empathize with.

In our work, we used a self-report questionnaire from psychology to measure people's empathy in HRI. This approach is simple to administer and there is no requirement of expertise compared to other qualitative analyses such as biosensor data (heart rate, blood pressure, brain wave, etc.) analysis, linguistic analysis, and behavior observation. However, this simplicity may result in losing some details. For example, an expert can describe symptoms of a person with a low empathy score but a fast heart rate. In addition, the 24-adjective questionnaire has no descriptions of the words. There is a possibility that a participant does not understand an adjective and score it differently from what they meant. Therefore, we advise researchers to consider the trade-offs of the questionnaire: generalizability and simplicity, or detailed qualitative results.

One aspect we have to point out in our results is the difference of the empathy score in our result. The scores (M=66, M=56, and M=55 on the Batson scale for a real robot, a robot in MR, and a robot on 2D screen respectively) represent that there is about ten percent difference between the cases of a real robot and simulated variants. Although the difference is small, we believe that this result is not negligible. We do not claim that this invalidates all simulation work; however, it is enough to show that there is a real difference. Researchers should be aware of this and consider the meaning of the difference in the context of their work.

Our work compared against an on-screen and mixed reality simulation; even though the mixed reality was superimposed in the real world, both simulations were fully digitally embodied. This raises a question if the degrees of immersion takes a role in empathizing the simulated robot, for example, on-screen simulation to fully immersive head-mount display. Further, there are other mixtures of real and simulation, for example, physical robots with computer screens for faces or even full torsos. Would a person empathize with such a robot the same as a fully physically-embodied one? Given our results and discussion on the importance of robotic embodiment, we believe that such a robot would induce empathy, but this should be formally investigated.

7.2. Contributions

Contributions for our research include:

a. A reproducible HRI scenario that induces people's empathy toward a robot

b. An empathy-measuring instrument from psychology to be used in HRI

c. A validation of the scenario in (a) and the questionnaire in (b)

d. An exploration of the difference between interactions with a simulated and a real robot in terms of people's empathy toward the robots

e. An original remote robot control interface that aims to enable easy programming of pre-set scenarios

In this research, we introduce an HRI scenario that reproducibly and reliably induces people's empathy toward a robot, both real and simulated variants. In addition, we take an empathy-measuring questionnaire to assess people's empathic response from psychology for use in HRI. Both the HRI scenario and the empathy-measuring questionnaire are formally evaluated and used in our comparative user study to investigate if a simulated robot provides authentic interaction compared to a real robot in terms of people's empathy.

For the purpose of the user study, we develop a remote robot control interface to follow our scenario and to support the Wizard of Oz in the user study. Further, we develop a simulated robot, which is compared with a real robot, in both virtual and mixed reality environment.

Through the comparative user study, we show an evidence that people may empathize more with a physical robot than simulated variants. This result has important implications for simulated HRI work to let HRI researchers be in consider of using a simulated robot in empathic interaction. When HRI researchers use a simulated robot in place of a real robot in designing an empathic interaction, they have to be aware of the difference. That is, the simulated robot may not provide an authentic interaction that researchers expect as the real robot does. In addition, we argue that further investigation is needed into the generalizability of simulated results. Finally, we outlined important future directions that should be investigated as a result of our findings.

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Appendix A

Batson's 24-Adjective Questionnaire

This is the original version of the Batson's 24-adjective questionnaire retrieved directly from Dr. C. D. Batson. We modified scale from 1-7 to 1-5 and used to measure people's empathy toward a robot, as described in Chapter 3.

Emotional Response Questionnaire

Please indicate by circling a number the degree to which you actually experienced each of these emotional reactions while listening to the broadcast. Do not indicate how you think other people might respond or how you think the broadcast was supposed to make you respond; just indicate your own personal reaction. Please be sure to circle a response for each item.

	not at all			moderately			extremely
1. alarmed	1	2	3	4	5	6	7
2. grieved	1	2	3	4	5	6	7
3. sympathetic	1	2	3	4	5	6	7
4. softhearted	1	2	3	4	5	6	7

5. troubled	1	2	3	4	5	6	7
6. warm	1	2	3	4	5	6	7

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7. concerned	1	2	3	4	5	6	7
8. distressed	1	2	3	4	5	6	7
9. low-spirited	1	2	3	4	5	6	7
10. compassionate	1	2	3	4	5	6	7
11. upset	1	2	3	4	5	6	7
12. disturbed	1	2	3	4	5	6	7

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13. tender	1	2	3	4	5	6	7
14. worried	1	2	3	4	5	6	7
15. moved	1	2	3	4	5	6	7
16. feeling low	1	2	3	4	5	6	7
17. perturbed	1	2	3	4	5	6	7
18. heavy-hearted	1	2	3	4	5	6	7

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19. sorrowful	1	2	3	4	5	6	7
20. bothered	1	2	3	4	5	6	7
21. kind	1	2	3	4	5	6	7
22. sad	1	2	3	4	5	6	7
23. touched	1	2	3	4	5	6	7
24. uneasy	1	2	3	4	5	6	7

Appendix B

Materials Used in User Studies

We attached materials used in the user studies.

- Ethics approval certificate
- Recruitment poster
- Informed consent forms
- Pre-study demographic questionnaire
- Post-study empathy questionnaire
- Post-study open questionnaire
- Sudoku Boards

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APPROVAL CERTIFICATE

July 9, 2013

NSERC ENGAGE

TO: **James E. Young**
Principal Investigator [redacted]

FROM: **Susan Frohlick, Chair**
Joint-Faculty Research Ethics Board (JFREB)

Re: **Protocol #J2013:088**
"How People Empathize with Robots"

Please be advised that your above-referenced protocol has received human ethics approval by the **Joint-Faculty Research Ethics Board**, which is organized and operates according to the Tri-Council Policy Statement (2). **This approval is valid for one year only**.

Any significant changes of the protocol and/or informed consent form should be reported to the Human Ethics Secretariat in advance of implementation of such changes.

Please note:

- **If you have funds pending human ethics approval, please mail/e-mail/fax (261-0325) a copy of this Approval (identifying the related UM Project Number) to the Research Grants Officer in ORS in order to initiate fund setup. (How to find your UM Project Number: http://umanitoba.ca/research/ors/mrt-faq.html#pr0)**

- **if you have received multi-year funding for this research, responsibility lies with you to apply for and obtain Renewal Approval at the expiry of the initial one-year approval; otherwise the account will be locked.**

The Research Quality Management Office may request to review research documentation from this project to demonstrate compliance with this approved protocol and the University of Manitoba *Ethics of Research Involving Humans.*

The Research Ethics Board requests a final report for your study (available at: http://umanitoba.ca/research/orec/ethics/human_ethics_REB_forms_guidelines.html) **in order to be in compliance with Tri-Council Guidelines.**

UNIVERSITY OF MANITOBA

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Earn $20 and contribute to science!!

We are looking for participants to engage in a one hour human-robot interaction experiment at University of Manitoba. Note that you must be over 18 to participate in our experiment.

To participate in the study, navigate to redbird.cs.umanitoba.ca/pwr/ to arrange a suitable time slot and send an email to **Stela H. Seo** at stela.seo@cs.umanitoba.ca If you have any questions about the study, please contact **Stela H. Seo** at stela.seo@cs.umanitoba.ca or **Dr. James E. Young** at young@cs.umanitoba.ca (tel: 204-474-6791).

This research study was approved by the Joint-Faculty Research Ethics Board, University of Manitoba

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Researcher: Dr. James E. Young (young@cs.umanitoba.ca), Stela H. Seo (stela.seo@cs.umanitoba.ca), Denise Geiskkovitch (umgeiskk@cc.umanitoba.ca), and Masayuki Nakane (umnakane@cc.umanitoba.ca)

This consent form, a copy of which will be left with you for your records and reference, is only part of the process of informed consent. It should give you the basic idea of what the research is about and what your participation will involve. If you would like more details about something mentioned here, or information not included here, you should feel free to ask. Please take the time to read this carefully and to understand any accompanying information.

This research study investigates how people will be interacting with intelligent agents (such as robots or animated on-screen characters) in the near future, as they start to integrate into workplaces, homes, hospitals, etc. We expect that the results of this study will be of particular interest for the development of new robots and interactive agents, and will be useful for making them easier and more comfortable to work with.

As you will be interacting with an intelligent agent, many people may experience emotional involvement with the agent similar to interacting with an intelligent animal or agent in a video game. As these agents are entirely artificial and are not real living entities, this may be disturbing for some, particularly if any negative interactions emerge with the agent.

Participation in this study is voluntary, and will take approximately 60 minutes of your time. For this study, we present an interactive, computerized character to interact with you. You will be asked to play a game with this agent during the experiment. You will receive $20 for your participation.

All information you provide is considered completely confidential; your name will not be included or in any other way associated, with the data collected in the study. Data collected during this study will be used for academic research and publication purpose in anonymous form. We will use the data in research papers published in international journals and presented at international research conferences: common examples include summary statistics, quotations, and explanations of interaction styles. These papers, and the associated slides and videos, are generally freely available online (except when publisher requirements are more restrictive). We may use anonymized video or audio data for purposes of public presentation and dissemination only with your express permission given below. In addition, data will be retained for a period of maximum five years in a locked office in the EITC building, University of Manitoba, to which only researchers associated with this study have access. Once published, results of the study will be made available to the public for free at http://home.cs.umanitoba.ca/~young/. Again, no personal information about your involvement will be included. Please note that the University of Manitoba may look at the research records to see that the research is being done in a safe and proper way.

Your signature on this form indicates that you have understood to your satisfaction the information regarding participation in the research project and agree to participate as a subject. By doing this you also confirm that you are of the age of majority in Canada (18 years or more). In no way does this waive your legal rights nor release the researchers, sponsors, or involved institutions from their legal and professional responsibilities. **You are free to withdraw from the study at any time**, and to refrain from answering any questions asked, without prejudice or consequence. Your continued participation should be as informed as your initial consent, so you should feel free to ask for clarification or new information throughout your participation.

Withdraw Procedures – you will be left alone with the agent during much of the study. You can withdraw at any time by asking the agent to email the experimenter (who will come and finish the rest of the experiment if you desire). Also, the room will not be locked and you are free to simply leave at any time if you so wish. After the experiment is complete, you can also opt to have all data from your participation withdrawn from the analysis and the results, by contacting the researchers via the methods outlined on this form. You can opt to have your data excluded from the analysis up until one month after the completion of the study (at which time papers and videos will be in progress), expected date the end of April, 2014.

This research has been approved by the Joint-Faculty Research Ethics Board. If you have any concerns or complaints about this project you may contact Dr. James Young at 204-474-6791 or the Human Ethics Secretariat at 204-474-7122. A copy of this consent form has been given to you to keep for your records and reference.

For purposes of research and analysis the experiment will be videotaped with full audio recording. This is required for the research analysis: video footage is analyzed, for example, to see how people interact with specific agent gestures and situations, and to see how interaction with the agent unfolds over time. The audio will be transcribed and analyzed to investigate how people talk to the agent. If you are not comfortable with this you are free to not participate in the experiment.

Do you agree that any video and audio footage taken may also be used for dissemination of research, for example, through research videos, presentations, audio clips, or images taken from your video?

No___ Yes___ but only if you blur my face___ AND/OR if you muffle my voice___

Participant's Signature ________________________ Date ____________

Researcher's Signature ________________________ Date ____________

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Winnipeg, Manitoba, CANADA, R3T 2N2

Research Project Title: People Working with Agents
Researcher: Dr. James E. Young (yousng@cs.umanitoba.ca), Stela H. Seo (stela.seo@cs.umanitoba.ca), Denise Geiskkovitch (umgeiskk@cc.umanitoba.ca), and Masayuki Nakane (umnakane@cc.umanitoba.ca)

Now that you have completed the experiment, and have been fully debriefed on the purposes of the research and the deceptions employed, you have the opportunity to alter any prior decisions you made about how your video and audio data may be used.

As explained before the experiment, you can opt to have all data from your participation withdrawn from the analysis and the results, by informing the researchers now, or by contacting the researchers via the methods outlined on this form. You can opt to have your data excluded from the analysis up until one month after the completion of the study (at which time papers and videos will be in progress), expected date the end of April, 2014. Your signature on this form indicates that you have understood to your satisfaction the full details of the research study, and in no way waves your rights or the responsibilities of the researchers.

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No___ Yes___ but only if you blur my face___ AND/OR if you muffle my voice___

Participant's Signature ________________________ Date ____________

Researcher's Signature ________________________ Date ____________

Email address if wish to receive summary of results ______________________________

#____

Demographics Questionnaires

1) What is your age? _____

2) What is your sex?
Male____ Female____

3) Have you interacted with robots before?
Yes____ No____

4) If you answered 'Yes' to question 3, when you have interacted with robots?
____
____
____
____
____

#_____

Emotional Response Questionnaire

Please indicate by circling a number the degree to which you actually experienced each of these emotional reactions while interact with the agent. Do not indicate how you think other people might respond or how you think the interaction was supposed to make you respond; just indicate your own personal reaction. Please be sure to put checkmark for each item.

	Not at all		Moderately		Extremely
alarmed	1	2	3	4	5
grieved	1	2	3	4	5
sympathetic	1	2	3	4	5
softhearted	1	2	3	4	5
troubled	1	2	3	4	5
warm	1	2	3	4	5
concerned	1	2	3	4	5
distressed	1	2	3	4	5
low-spirited	1	2	3	4	5
compassionate	1	2	3	4	5
upset	1	2	3	4	5
disturbed	1	2	3	4	5
tender	1	2	3	4	5
worried	1	2	3	4	5
moved	1	2	3	4	5
feeling low	1	2	3	4	5
perturbed	1	2	3	4	5
heavy-hearted	1	2	3	4	5
sorrowful	1	2	3	4	5
bothered	1	2	3	4	5
kind	1	2	3	4	5
sad	1	2	3	4	5
touched	1	2	3	4	5
uneasy	1	2	3	4	5

#____

Post-study Questionnaire

Please write down your comments about this study.

1. What do you think about this study in general?

2. While you were interacting with the robot, did you find the robot was acting weird? If so, could you articulate the reason?

3. What do you think about the robot's intelligence level?

4. Could you explain your thoughts and feelings when the robot said it was not feeling well?

5. Do you have any comments?

Training Board

	A	B	C	D	E	F	G	H	I
1		7	8	4	9		1	3	5
2	9	1	5	8		6	7		4
3	3	2	4	7	1	5		9	8
4	5		6	3	7	4	9	1	2
5	1		7	6	2	8		5	
6	4		2	9	5	1	8	6	7
7		4	9		6	3	5		1
8	8	5	3	1	4	9	2	7	6
9	2		1	5	8		3		9

	A	B	C	D	E	F	G	H	I
1		3		8					
2	9		5	6			7		
3			1		9	3	2		
4	8		6	5					
5		4			3				
6									
7	4	7	2	3		6	9	5	
8		1	9	4	8	7		6	
9	3	6	8	2	5	9		1	

	A	B	C	D	E	F	G	H	I
1	1	5					9	2	4
2			4				7		6
3							3	8	5
4							1		
5		2		3				6	
6			6	7			4		3
7			2	4			5	3	1
8			7	2		3	6	9	8
9		8	3			1	2	4	

	A	B	C	D	E	F	G	H	I
1	8					2	4	3	6
2	3				7		9		2
3				1			7	8	5
4					8	3		5	4
5									
6				5			3	7	9
7		2			9		6	4	7
8		4		8			1	9	
9	1			4			5	2	8

	A	B	C	D	E	F	G	H	I
1								8	
2	9			1	3	7			6
3			7			9		2	
4									
5	5		6	4		2			
6	1	2	3						
7			1		2	3	8	4	
8	2	9	8	7	4	1	3	6	
9	7			6	8	5	2	9	

	A	B	C	D	E	F	G	H	I
1		7		4			6		3
2							8		
3	4	6	5						1
4									
5		9		7	3				
6	5		4						
7	8	4	3	6	5	1	9		2
8	9		6	3	2	7			4
9	2	1	7		4	8	3		6

	A	B	C	D	E	F	G	H	I
1				9	3	8			
2									
3	3	4	6		2	7			
4	6	3		8	9	1	2		5
5			1		4	5			7
6	2					3			8
7	9				7	2	3		
8	4		2	3	5	6	1		
9				4	8	9			

	A	B	C	D	E	F	G	H	I
1		3		9	7	5	6		
2				1	8		9		
3	8		1	4	6	3			
4				2	3	7		6	
5			9	5	1	6		4	
6		7			9	4	2	1	
7		8							
8				6	2	1			
9	1		6	7	5				

	A	B	C	D	E	F	G	H	I
1	6		5		2	1			8
2	9		7	5	3	8	4		2
3	2	8	3	6	4	7	9		1
4									
5				8	6	2			
6	3		8		9				
7			6				7		
8				2	1		8		
9		5		4		9	2		

	A	B	C	D	E	F	G	H	I
1		5					9		
2	8	6	4	9					5
3	3	9	1	2	7		6		8
4	7		8		5				
5	5	2	3	4		1			
6		4							
7	9	8	2						
8	4	3	5	6	8				
9	1	7				4	8		

	A	B	C	D	E	F	G	H	I
1		6		3	7		9		
2									
3			2		8	9			7
4	9			6	3	4	7		
5	4			8		1			
6	1		8	7	9	5	2		
7				1	5			7	8
8				9	4	7	5		2
9				2	6	8			4