How Certain Robot Attributes Influence Human-to-Robot Social and Emotional Bonds

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Abstract

A growing population of humans are feeling lonely and isolated and may therefore benefit from social and emotional companionship. However, other humans cannot always be available to fulfill these needs, and such in-need individuals often cannot care for pets. Therefore, we explore how robot companions may be designed to facilitate bonds with humans. Our preliminary examination of 115 participants in a scenario based quasi-experimental study suggests that humans are more likely to develop social and emotional bonds with robots when those robots are good at communicating and conveying emotions. However, robots' anthropomorphic attributes and responsiveness to external cues were found to have no impact on bond formulation.

Keywords: human-robot-interaction, social bonds, emotional bonds, empathy

1. Introduction

There is a need for greater focus on designing robots that are more successful at creating positive relationships with users (Leite et al. 2013b). Today more than a quarter of the population experiences some form of mental illness (Kazdin 2017). To cope, many resort to forming relationships with non-human companions, such as dogs and cats, which require a lot of physical energy and mental attention to maintain (Kazdin 2017); resources which many lonely people, including the elderly and sick, do not always have in abundance. Robots, however, require very little day-to-day maintenance and can take care of themselves. On the one hand, we have warm and naturally loving biological companions that require a lot of maintenance, and on the other we have cold and logical companions that can take care of themselves (and possibly care for their owners). We see little headway possible for reducing the maintenance of biological companions and, since owners that have been given biological companions (e.g., dogs) generally experience health benefits, we expect when given a social artificial companion will have similar effects. Therefore, we turn our research to the task of increasing the social and emotional affordances of robotic companions.

Abundant research on this topic exists; however, most of it is focused on the software – such as AI (Dautenhahn 2007; Leite et al. 2013a; Leite et al. 2011) – or the hardware – the robot parts (e.g., Fong et al. 2003). Conversely, our focus is on the human response through relationship development and creating a new framework for measuring human's emotional and social bonds with robots without seeing these relationships through the lens of bonds created between humans. All of these areas are critical to research moving the field towards more relatable robotic companions. Our contributions will sit at the intersection of all three by focusing on the human response to specific hardware and software features. While others have researched human-robot interaction and acceptance quite extensively, we were unable to find research focusing specifically on humans forming social and emotional bonds with robots. We specifically will be attempting to determine what affordances of social robots facilitate social and emotional bonds with humans.

We define a social robot as one that "is able to communicate and interact with us, understand and even relate to us, in a personal way" (Breazeal 2004). It is this connection that forms social and emotional bonds.

To begin our exploration of forming social and emotional bonds between humans and robots, this preliminary study aims to identify the strength of specific, theoretically selected predictors of human-to-robot relationship development. The four predictors identified in extant literature include anthropomorphism, communication ability, environmental responsiveness, and emotional

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conveyance. These constructs were primarily derived from an adaptation of those identified in Leite et al. (2013b. The adaptations we made to their list were informed by a thorough literature review on human-robot relationship development.

Findings from this study should help to focus the design and development of social robots on the factors that will bear the most weight on the formulation of human-to-robot bonds. We next review pertinent literature and then explain our exploratory scenario based quasi-experimental study design, in which we collected a preliminary dataset from 115 undergraduate students. We then provide an analysis of the findings, and we discuss implications for research and practice.

2. Literature review

Historically, in the information systems discipline, human-robot interaction (HRI) research has been viewed through a technological acceptance lens. One of the initial models used was the Technology Acceptance Model (TAM), which measures a user's perceived usefulness of a technology (e.g., robots) and their intention to use it (Bröhl et al. 2019). To increase user acceptance of robots, some research suggests robots should have their own beliefs, desires, and intentions, enabling more complex interactions

between humans and their robot counterparts (Breazeal and Scassellati 1999). Others have focused on robot hardware, intending to properly balance its design to both mimic the social behavior found in living creatures while also designing for the robot's intended functionality (Fong et al. 2003). Many have also strived to improve AI, enabling robots to attain new standards of social skills while also establishing set social rules for human-robot interaction (Dautenhahn 2007). Findings produced by these studies have even led researchers to create updated robot acceptance models, such as the Social Robot Acceptance Model (SRAM) (de Graaf et al. 2019).

2.1. Expression of emotion

In addition to these traditional models of acceptance, researchers have focused on how psychological constructs, such as empathy, affect an individual's acceptance of a robot. Research has shown that artificial companions capable of behaving in an empathic manner, which involves the capacity to recognize another's affective state and respond appropriately, are more successful at establishing and maintaining a positive relationship with users (Leite et al. 2013b). In that study, an autonomous robot responded to users playing chess against each other. These users later indicated that when the robot behaved emphatically towards them, they perceived the robot as more friendly. This is a key finding in recognizing the preferences of humans in their robot counterparts. However, empathy is only a single piece of the puzzle when it comes to a robot's ability to form meaningful bonds with humans.

Other researchers have also examined emotional conveyance, including gestures, both non-verbal and non-facial modes of expression, that are effective methods of conveying robot emotions (Sial et al. 2016). While some variability in robot behavior is important, incongruence in a robot's emotional expression and contextual stimuli tends to confuse users and lead them to perceive the robot as unintelligent or incapable, and leads to profoundly adverse effects on likability and believability (Tsiourti et al. 2019). The findings from these studies reinforce the need for proper design of emotional expression for robots that use several channels to communicate their emotional states clearly and effectively.

2.2. New framework for human-robot interaction

Throughout many studies performed in the last 20 years, a common assumption is that social robots should mimic humans, such that human–robot interaction closely resembles human-human (i.e., interpersonal) interaction (Leite et al. 2013b). This assumption is now being refuted by some researchers who argue that many of the rules and theories that apply to interpersonal interaction need not apply to human-robot interaction (Fox and Gambino 2021). They question the relevance and applicability of our knowledge about personal relationships when it comes to our interactions with social robots. For example, precise human facial features and expressions do not need to be replicated when rough approximations (while avoiding the uncanny valley) will suffice (Walters et al. 2008).

In summary, the pursuit of understanding human-robot interaction is not new. However, prior research focuses primarily on the software or hardware to make robots more accepted, useful, and used. For interpersonal human relationships, we would not think of other humans as "useful." Instead, we seek to develop social and emotional bonds with others. In this same way, in this paper we hope to begin the conversation around establishing these meaningful bonds with robots, rather than just seeking better designs for increased acceptance or intention to use.

3. Study design

This exploratory study aims to identify the effect of four specific predictors of human-to-robot relationship development; namely: communication ability, anthropomorphism, environmental responsiveness, and emotional conveyance. These constructs were derived from those identified variously in Leite et al's work (Leite et al. 2013a; Leite et al. 2011; Leite et al. 2013b), as well as informed by a thorough literature review on human-robot relationship development.

Our quasi-experimental design includes sixteen social robot design configurations, each exhibiting a unique permutation of high or low anthropomorphism, communication ability, environmental responsiveness, and emotional conveyance. These robots pictured and described were designed to mimic a social companion robot that could potentially be a friend to its user and provide positive interaction leading to emotional and social bonds. To avoid the variability in the production quality of existing real robot promotional videos, and to enable the presentation of all 16 theoretical design configurations, we decided to make basic visual representations of the robots accompanied by simple explanations of their functionality. This enabled us to portray all 16 robots in a consistent way such that users could easily recognize if a robot was high or low in each of the four constructs while also helping us to reduce confounds through uncontrollable exogenous factors associated with real robots (cf Leite et al. 2013a). Below are four examples of different robot configurations. We manipulated anthropomorphism and emotional conveyance through visual design as well as written descriptions. Communication ability and environmental responsiveness were manipulated through the descriptions only, rather than through visual cues (as these are less visually-representable constructs). These robots were then accompanied by four written descriptions, either high or low in each of the four constructs. These consistent description segments are listed in Table 1.

3.1. Survey design

We designed our survey so that each participant would be randomly assigned to one of the 16 treatments. Figure 2 provides an example of one of the permutations participants were given. To avoid recall bias, participants were asked to take a screenshot of the robot and its description to facilitate recall as they completed the survey.

The survey included reflective latent measures adapted from extant literature to capture each of the four manipulated attributes. Beyond this, we also included direct, single-item measures to conduct manipulation checks. We then asked questions to measure the extent to which the participant thought they would be able to build social and emotional bonds with the robot. These measures are shown in Table 2 and were each half adapted from extant literature and half developed by the research team. The new measures are shown in italics.

Lastly, we also asked participants about their mental health, social health, tech familiarity, age, and gender, to control for potentially confounding effects.

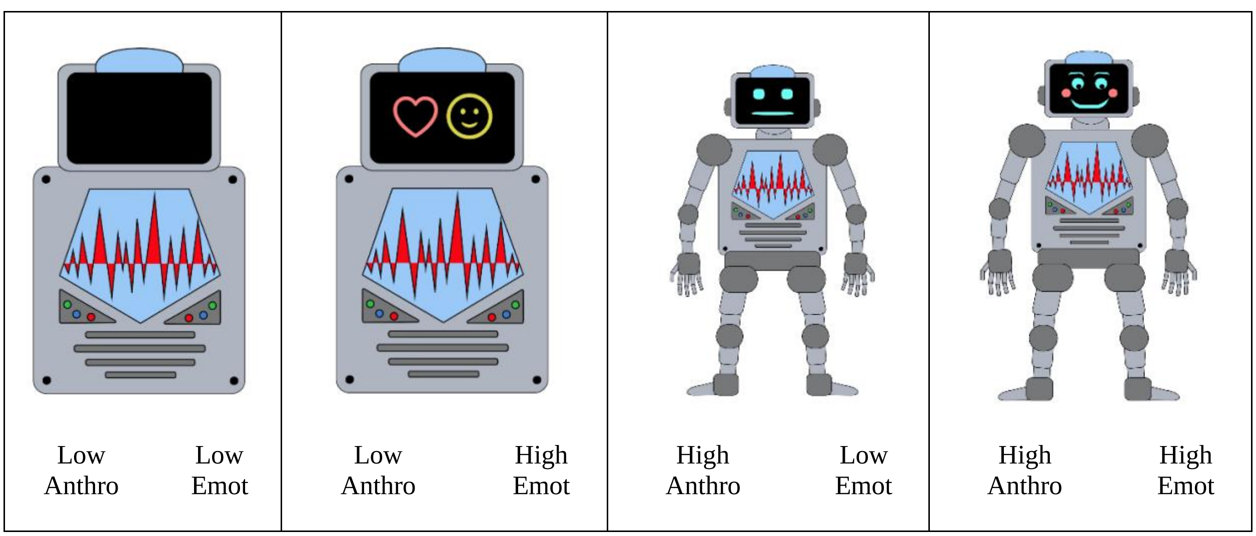

Figure 1. Examples of robot designs

Table 1. Manipulations

Anthropomorphism	High	Robo is designed to be humanlike, with a face and voice that mimic human expression, as well as arms and legs to interact with the world around it.
	Low	Robo is a basic robot, with sensors and cameras built to help with navigation and communication, but no human-like parts or features (such as a face or arms).
Communication Ability	High	Robo is designed to be able to easily hold a natural conversation. It can respond appropriately to questions and demonstrate understanding throughout a conversation. Owners have said interactions with this robot are engaging.
	Low	Robo acknowledges commands with a simple beep or bong (for positive or negative). It does not use words to communicate needs, intent, or responses to others.
Environmental Responsiveness	High	Robo is designed to be aware of its environment. It improves its interactions with humans when given feedback.
	Low	Robo is not aware of its environment. It can do what it is programmed to do very well but cannot adjust its tasks or learn without software changes.
Emotional Conveyance	High	Robo can use emotional cues and tones to interact with humans. As you interact with it, it will recognize what emotions you are expressing and react appropriately.
	Low	Robo is unable to communicate emotions. It also does not recognize emotions in face or voice cues.

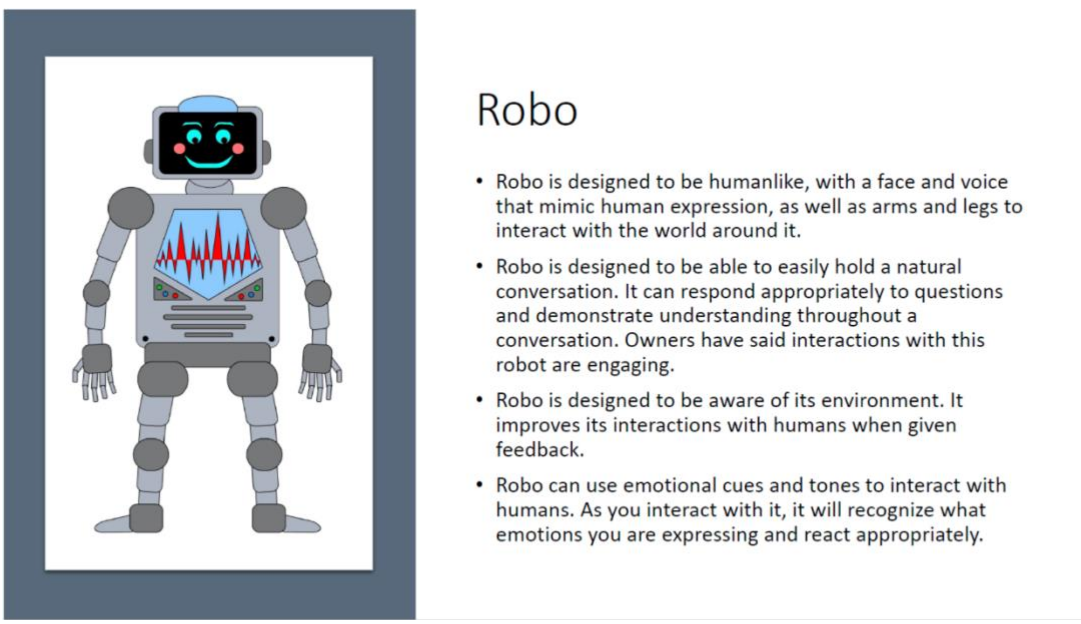

Figure 2. Permutation example

Table 2. Survey Constructs & Measures

Construct	Measures	Mean	StdDev	Source
Anthropomorphism	I believe this robot has its own preferences and mood.	2.289	1.355	

	I believe this robot has its own intentions.	2.270	1.273	Pelau et al (2021)
	I believe this robot has its own personality.	2.588	1.381	
	I believe this robot has a human look.	2.409	1.344	
	I believe this robot has a friendly voice.	3.078	1.215	
Communicative Ability	I feel this robot could show me they understood what I said.	3.632	1.091	Dickinson (2012)
	This robot would likely communicate things frequently that add little to our interaction.	3.148	1.102	
	I would be satisfied with an interaction with this robot.	3.470	1.180	
	An interaction with this robot would go smoothly.	3.191	1.091	
	If this robot communicated with me, I feel there would be a great deal of understanding.	2.868	1.259	
	I would need to adapt my style of communication to effectively communicate with this robot.	3.843	1.152	
	I feel this robot would facilitate bi-directional communication.	3.191	1.206	
	I feel that conversation with this robot could be captivating.	3.017	1.155	
	I feel I would need special mental effort in order to communicate with this robot.	2.983	1.221	
	Interaction with this robot would be easy.	3.254	1.174	
Environmental Responsiveness	This robot could quickly adapt as it interacts with me.	3.061	1.154	Self-developed
	This robot could alter its communication with me based on our surroundings.	3.026	1.300	
	This robot would adjust its communication based on who it was interacting with.	2.684	1.385	
Emotional Conveyance	I believe this robot can have feelings of remorse.	2.921	1.409	Pelau et al (2021)
	I believe this robot has its own emotions.	1.800	1.133	
	I feel I could understand what emotions the robot is trying to convey.	1.696	1.061	
	I feel this robot would express its emotions in a way that I could understand.	2.649	1.408	
	I feel this robot would express emotions in a way consistent with how I would express emotions.	2.661	1.432	
Emotional Connection	I could feel a real emotional attachment to Robo.	2.409	1.389	Breazeal (2003), Breazeal and Scassellati (1999), Walters et al (2008)
	I could feel a strong sense of belonging with Robo.	7.713	1.369	
	Robo could have a great deal of personal meaning for me.	7.435	1.222	
	I feel like Robo could be a large part of my life.	7.670	1.289	
	I could feel a strong connection to Robo.	7.557	1.299	
	I would take care of Robo.	7.518	1.264	
	I would miss Robo it if broke.	8.518	1.192	
	Robo could cheer me up if needed.	8.365	1.307	
	Robo would be a good friend.	7.965	1.389	
	I would develop a meaningful emotional connection with Robo.	7.748	1.394	
Social Connection	There is a sense of human-like contact in Robo.	7.417	1.324	Fong et al (2003), Dautenhahn (2007)
	There is a sense of social ability in Robo.	7.826	1.333	
	There is a sense of human-like warmth in Robo.	7.896	1.353	
	There is a sense of human-like sensitivity in Robo.	7.322	1.239	
	I would take care of Robo.	7.461	1.272	
	I would enjoy talking with Robo regularly.	8.687	1.119	
	I would find value in my interactions with Robo.	8.104	1.119	
	I would confide in Robo about things on my mind.	8.106	1.168	
	I would chat with Robo if I needed someone to talk to.	7.670	1.419	
Manipulation Check – Robot Attributes	Robo was designed to have human-like attributes.	7.947	1.381	Self-developed
	Robo is able to communicate in a relatable, articulate manner that provides for a stimulating two-way conversation.	16.226	1.408	
	Robo is able to take feedback from its environment and conversations to personalize its interaction with humans.	16.061	1.286	
	Robo effectively conveys its emotions.	16.017	1.357	
Manipulation Check – Mental Health	Please indicate the extent to which you have agree with the following statements. During the past two weeks…	15.565	1.325	Standard practitioner mental
	How much of the time have you felt calm and peaceful?	39.426	0.937	
	How often have you felt emotionally stable?	39.643	0.975	

	How often have you felt sad or depressed?	3.487	0.931	health survey
	How often have you felt lonely?	3.478	1.150	
	How often have you lost sleep due to worrying?	3.835	1.067	
	How often has your mental health interfered with your personal relationships?	3.667	1.070	
	How often has your mental health interfered with your ability to get work done or accomplish tasks?	3.522	1.157	
Manipulation Check – Mental Health 1	How would you rate your mental health?	24.843	1.081	Self-developed
Manipulation Check – Sociality	Please indicate the extent to which you agree with the following statements.	16.713	1.160	Anderson et al 2008
	I am satisfied with my social life.	16.835	1.169	
	I am satisfied with my friend network.	17.211	0.746	
	Other people like me.	17.386	0.770	
	I am a good friend.	17.296	0.713	
	Other people enjoy being around me.	3.443	1.086	
Tech Familiarity	Please indicate the extent to which you agree with the following statements.	3.939	0.958	Parasuraman 2000
	Digital technologies give people more control over their daily lives.	4.035	0.936	
	Digital products and services that use the newest technologies are much more convenient to use.	3.702	1.038	
	I like the idea of doing business via digital technologies because I'm not limited to regular business hours.	4.243	0.733	
	I prefer to use the most advanced digital technologies available.	4.263	0.729	
	I like digital technologies that allow me to tailor things to fit my own needs.	3.835	1.034	
	Digital technologies make me more efficient in my work.	4.113	0.803	
	I find new digital technologies to be mentally stimulating.	3.765	1.054	
	Digital technologies give me more freedom of mobility.	3.852	0.976	
	Learning about digital technologies can be as rewarding as the technology itself.	28.523	11.020	
	I feel confident that digital technologies will follow through with what I instructed them to do.	1.496	0.553	
Demographics	What is your age?	9.296	1.284	Standard measures
	What is your gender?	2.289	1.355	
	Please rate your English Fluency (1=Very Low, 10=Native Language)	2.270	1.273	

4. Analysis

Our sample for this study included 115 valid responses from students, mostly sophomores, from a large private university in the western United States. From an original 140, a total of 25 responses were either incomplete or completed unreasonably quick to be considered valid. Of the valid responses we received, the breakdown of how many participants received each robot treatment is shown in Figure 3. The labels on the x-axis are encoded as "h" signifying high and "l" signifying low. The order of the encoded elements is anthropomorphism, communication ability, environmental responsiveness, and emotional conveyance. For example, the second column in Figure 3 has a label of "hhhl" and has a frequency of nine. This means that nine participants received a robot that was high in each of the first three constructs and low in emotional conveyance. Table 3 shows the distribution across high/low for each robot attribute.

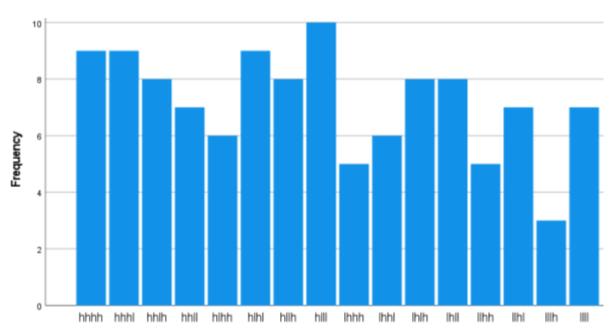

Figure 3. Frequency of Treatment Allocation

Table 3. Attribute Frequency Allocation

Robot Attribute	Participants
Anthropomorphism	Low: 49 High: 66
Communication ability	Low: 55 High: 60
Emotional conveyance	Low: 63 High: 52
Environmental responsiveness	Low: 59 High: 56

We performed a univariate normality check. All skewness and kurtosis values were within recommended thresholds (+/- 3.3), except for age (5.914), which is expected for a population of sophomores. After cleaning the data, we checked the reliability of the reflective latent factors. Table 4 shows our Cronbach's alpha for each factor. All exceed the recommended threshold of 0.700.

To further test the soundness of our factors, we also ran tests for convergent and discriminant validity in a structural equation model in SmartPLS 4. Our test of discriminant validity failed between social and emotional bonds due to high correlations between them. Therefore, we modeled a second-order construct "Bond" with two first-order dimensions, one each for social and emotional bonds. Validity tests and subsequent structural tests were assessed using this second-order model. For convergent validity, all AVE values for our key constructs were greater than the target threshold of 0.500 (ranging from 0.545 to 0.703) and all composite reliability values were greater than the target threshold of 0.700. For discriminant validity, all the HTMT ratios were less than the target maximum of 0.900, and all of the square roots of the AVEs were greater than correlations with other factors. Thus, our factors passed all validity and reliability tests.

Table 4. Cronbach's Alphas

Construct	Cronbach's Alpha
Anthropomorphism	0.799
Communication Ability	0.871
Environmental Responsiveness	0.790
Emotional Conveyance	0.884
Emotional Bond	0.936
Social Bond	0.916
Mental Health	0.866
Social Health	0.779
Tech Familiarity	0.824

5. Findings

To make sure our manipulations worked, we performed manipulation checks on anthropomorphism, communication ability, environmental responsiveness, and emotional conveyance. One-way ANOVAs were used to discriminate between low and high treatments of each construct. For all configurations, the manipulations were successful, as indicated by a statistically significant difference between high and low treatments on that construct. For all manipulation checks, the biggest difference observed was consistently for the construct being manipulated. In all tests, except for emotional conveyance, the manipulated construct was the only construct to show a significant difference. For emotional conveyance, the ANOVA also showed a significant difference for anthropomorphism (p=.030), indicating some overlap, rather than mutually exclusive, orthogonal manipulations.

Through our structural analysis (PLS algorithm with 5000 bootstraps), shown in the model below (path coefficients are standardized regression weights with p-values in parentheses), we found that communication ability and emotional conveyance have the strongest positive impacts on social and emotional bonds. We also found that anthropomorphism and environmental responsiveness have no significant effect on social and emotional bonds. In addition, none of the control variables had a significant effect on our dependent variable, except for mental health, which seems to have a mild negative effect, indicating those who consider their mental health to be low have an easier time imagining forming bonds with robots. The R-square for our dependent variable was large, at 62.8% variance explained.

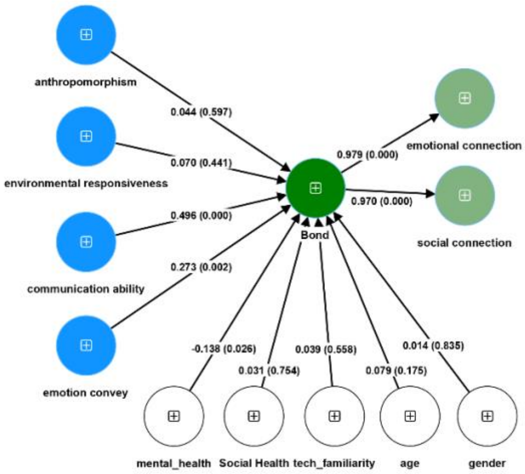

Figure 4

6. Discussion

The findings from our preliminary study suggest that the two most important robot attributes for forming bonds with humans are first communication ability and second emotional conveyance. Surprisingly, anthropomorphism and environmental responsiveness did not affect forming bonds. These findings have implications for research and practice.

Our findings run somewhat counter to the literature on system personification led by Reeves and Nass (e.g., Reeves and Nass 1996), which tend to argue that technology personification is natural for humans interacting with technology. However, that literature is primarily unidirectional, with humans applying anthropomorphic attributes to technology, rather than examining, as we did, whether intentional anthropomorphic attributes engender bond formulation. Thus, while humans may naturally treat technology as they would treat other humans, these attributes, when intentionally designed into the robot, do not necessarily aid in forming social and emotional bonds with the robots.

The (non) finding around environmental responsiveness also seem to run somewhat counter to extant literature on human-computer-interaction (HCI), which suggest that interaction satisfaction decreases when technology does not pick up on social cues (Leite et al. 2011; Leite et al. 2013b; Reeves and Nass 1996). However, satisfaction is not the same as a social or emotional bond, and no research (that we can find) has explored this specific relationship. Thus, our findings may simply clarify and extend these prior efforts in HCI. For social robot designers and developers, our findings have particular interest. If the primary goal of the social robot is to provide companionship (i.e., fulfill needs for social and emotional connection), then resources should be focused on amplifying the robot's communication ability and emotional conveyance, rather than anthropomorphic qualities or the software around environmental responsiveness. Focusing in this way may result in more successful deployment around the goal of robotic companionship.

7. Limitations and conclusion

Our study is certainly limited in scope and generalizability. Specifically, we are focused solely on social robotic companions, rather than the broad spectrum of robots, including industrial robots or robots for productivity (such as intelligent drones). No attempt should be made to generalize these findings to non-social robots. Additionally, as this is simply a preliminary and exploratory study, our initial sample is rather small and not representative of the target population. We used highly able college students, rather than the sick, lonely, or elderly. Future research should extend these efforts to those relevant populations. We did include attention checks and removed those who failed them. This was done to remove those undergrads who were not taking our study collection seriously.

Our study also employed fictitious robot designs, rather than real robots that exist in the market. While this was useful to suit our theoretical purposes of testing high and low values of specific constructs, it is not realistic. Future research may benefit from using actual robots. We also only used a scenario based quasi-experimental design with manipulated scenarios/descriptions. Thus, findings are limited to only the imagined perceptions of participants, rather than based on actual interactions with actual robots. This is an effective way of exploring future possibilities within this domain and reliably obtaining usable data (Lowry et al. 2015). Future research should consider employing an experimental observation approach, in which participants are given time with a randomly assigned robot, and then they discuss or report on their interactions. A longitudinal approach at an elderly care facility, or an extended stay children's hospital, may also prove much more readily applicable to the target population.

Despite these limitations, we have endeavored to begin a conversation around the formation of social and emotional bonds with social robots, rather than simply increasing the utility or acceptance of those robots.

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