Can a Robot Be Perceived as a Developing Creature?
Effects of a Robot’s Long-Term Cognitive Developments on Its Social Presence and People’s Social Responses Toward It

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This study tests the effect of long-term artificial development of a robot on users’ feelings of social presence and social responses toward the robot. The study is a 2 (developmental capability: developmental versus fully matured) x 2 (number of participants: individual versus group) between-subjects experiment (N = 40) in which participants interact with Sony’s robot dog, AIBO, for a month. The results showed that the developmental capability factor had significant positive impacts on (a) perceptions of AIBO as a lifelike creature, (b) feelings of social presence, and (c) social responses toward AIBO. The number of participants factor, however, affected only the parasocial relationship and the buying intention variables. No interaction between the two factors was found. The results of a series of path analyses showed that feelings of social presence mediated participants’ social responses toward AIBO. We discuss implications of the current study on human–robot interaction, the computers are social actors (CASA) paradigm, and the study of (tele)presence.

Robots, once imagined only in science-fiction films, are now being used for various purposes. New applications of robots in therapeutic, educational, and entertainment environments have caused an important shift in the study of human–robot interaction (HRI). Rather than viewing robots as mere tools or senseless machines, researchers are beginning to see robots as social actors that can autonomously interact with humans in a socially meaningful way. In this study, we use the term “social robots” to refer to these new types of robots whose primary purpose is social interaction with humans.

The term social robots was initially applied to multirobot or distributed robotic systems where multiple robots interact with one another and accomplish collective goals. The inspiration for the multirobot systems came from the observation of collective behaviors of insects, birds, fish, and other primitive social animals (see Brooks, 2002; Fong, Nourbakhsh, & Dautenhahn, 2003). For example, Duffy (2003) defined a social robot
as “a physical entity embodied in a complex, dynamic and social environment sufficiently empowered to behave in a manner conducive to its own goals and those of its community” (pp.177–178). Dautenhahn and Billard (1999) expanded the domain of social robots and proposed that social robots are embodied agents that are parts of a society of either robots or humans and are able to recognize one another, engage in social interaction, and explicitly communicate with and learn from one another.

Focusing primarily on human–robot interaction, rather than interrobot interaction, Breazeal (2003b) provided four categories of social robots: socially evocative, social interface, socially receptive, and sociable robots. As the most primitive social robots, socially evocative robots utilize the human tendency to anthropomorphize objects and rely heavily on users’ affective responses, which occur when they are emotionally attached to—or involved with—an object. If robots can recognize and manifest natural human-interaction modalities such as speech and gestures, they become social interface robots. Like the program in Searle’s (1981) Chinese room, however, they do not possess deep social cognition or understanding. Socially receptive robots have at least a modest level of social cognition, which enables them—through a simple mechanism such as imitation—to learn things (or modify their internal representation of the world) from social interaction. Nevertheless, they are not as fully socially functional as human beings. With sophisticated models of social cognition, some robots can even proactively seek social interaction to satisfy their internal states replicating human goals and desires. According to Breazeal (2003b), these are sociable robots.

In this article, social robots are defined as robots designed to evoke meaningful social interaction (e.g., anthropomorphic shapes, commands of natural communication modalities such as speech and gestures, and artificial intelligence) with users who actually manifest some types of social responses (e.g., affection for and bonding with robots, ontological perception of robots as social actors, and expectations and applications of complicated social rules in human–robot interaction). According to this definition, assembly robots in factory lines or utility robots such as iRobot’s vacuum cleaning robot, Roomba, are not social robots. Thus, the usability of those robots is not the major interest of the current study. Our major interest is the social interaction between humans and social robots such as Sony AIBO or Qurio, Samsung April, MIT Kismet, Carnegie Mellon Vikia, and Honda Asimo.

Our definition of social robots implies that, in order to create successful human interaction with social robots, interdisciplinary approaches mixing engineering and social sciences are required (for a similar claim, see Arkin, Fujita, Takagi, & Hasegawa, 2003). That is, successful human interaction with social robots depends not only on the robots’ engineering
capabilities of conducting a wide range of social functions [e.g., speech recognition, speech generation, visual recognition, affective responses, turn-taking (interactivity), and artificial intelligence] but also on the intelligent use of social scientific findings in the design of the robots’ interaction behaviors.

**HRI AS A TEST-BED FOR THEORIES ON VIRTUAL EXPERIENCE**

Human interaction with social robots provides a unique opportunity for communication scholars to test theories on virtual (including both mediated and artificial) experiences (see Lee, 2004, for a typology of virtual experience) in a radically new domain. HRI is fundamentally different from other types of virtual experiences in that social robots stand in a mixed reality situation. Similar to software agents, avatars, and people or objects on the screen, social robots are not ontologically real social actors. They are virtual social actors simply designed to create an illusion of real social interaction. Unlike mediated or artificial objects, however, social robots are physically real and tangible because they are embodied (see Ziemke, 2001, for five different notions of embodiment in robotics and artificial intelligence. In this article, we are mainly concerned about physical instantiation). In short, social robots are actual in the domain of physical experience and virtual in the domain of social experience (see Lee, 2004, for the explanation of three domains of human experience: physical, social, and self). Interactions with social robots therefore provide unique opportunities and challenges to test and expand theories on virtual experience.

Among the many theories on virtual experience, particularly relevant to the current study are the media equation (ME) theory and the theory of social presence. Using the ME theory, Reeves, Nass, and their associates have conducted a series of studies showing that human responses to mediated or artificial objects are fundamentally natural and social (see Reeves & Nass, 1996, for a synthesis of their studies). In other words, people respond to mediated (e.g., moving objects on screen) and artificial objects (e.g., computers manifesting personality) as if they were real. Nass and his colleagues have focused their research on human–computer interaction (HCI) and suggested the CASA (computers are social actors) research paradigm (see Nass & Moon, 2000, for a summary). This research paradigm suggests that human interaction with a computer is fundamentally social and that humans apply wide sets of social characteristics to a computer when the computer manifests human-like characteristics such as language, social roles, gender, ethnicity, and personality. For instance, research performed under this paradigm has shown that people treat computers as teammates (Nass, Fogg, & Moon, 1996), exhibit
moral obligations toward computers (Reeves & Nass, 1996), and apply personality-based social rules (Nass & Lee, 2001) and gender stereotypes (Nass, Moon, & Green, 1997) to computers.

Existing CASA studies are mostly about human interaction with physically disembodied social actors, because their domain of research has been HCI. Disembodied social actors can be either explicitly manifested, as in the case of agent-based HCI (e.g., Isbister & Nass, 2000), or implicitly manifested, as in the case of direct interaction between humans and computers through speech (Lee & Nass, 2004) or text (Nass, Moon, Fogg, Reeves, & Dryer, 1995; see Clark, 1999, also for the explanation of how people imagine implicit virtual social actors based on linguistic cues provided by computers). In both cases, social actors that individuals interact with are devoid of actual physical instantiation; they are physically disembodied. As a result, little has been known about human responses to physically embodied artificial social actors such as social robots. Studies on human interaction with social robots, thus, will be critical tests for the applicability of the CASA paradigm to this new domain of social interaction.

Recently, the concept of social presence has received a great amount of research interest from communication scholars, thanks to the growing trend of mediated communication (e.g., instant messaging, online games, the Internet, virtual reality) in virtual environments (Bailenson, Blascovich, Beall, & Loomis, 2003; Biocca, 1997; Lombard & Ditton, 1997; Lee, 2004; Turkle, 1995). Social presence is defined as either “mental simulation of other intelligence” (Biocca, 1997) or “a psychological state in which virtual social actors are experienced as actual social actors in either sensory or non-sensory ways” (Lee, 2004). In plain terms, social presence is technology users’ feeling that other (human or human-like) intelligences are interacting with or reacting to them when they use technologies such as traditional media, computers, and telecommunication devices (see Biocca, 1997; Biocca, Burgoon, Harms, & Stoner, 2001).

Feelings of presence play a significant role in shaping technology users’ attitudes, evaluations, and social responses toward the technology. For example, two recent studies successfully show that feelings of presence play a mediating role in shaping consumers’ attitude toward e-commerce sites and products (Klein, 1999; Lee & Nass, 2004). Another study shows that the enjoyment and the evaluation of video games are mediated by feelings of presence during game playing (Lee, Jin, Park, & Kang, 2005). Based on the above studies showing the significant role of social presence in HCI and media use, we can argue that feelings of social presence might play a similar important role in HRI.

According to Lee (2004), feelings of social presence occur when people experience two types of objects: para-authentic social actors and artificial social actors. Paraauthentic social actors are mediated representations
of other humans who are connected by technologies. Studies on social presence in telecommunication, computer-supported cooperative work (CSCW), computer-mediated communication (CMC), and video conferences are usually about para-authentic social actors. Artificial social actors are artificially created objects manifesting some characteristics of humanness. Artificial social actors can be either embodied (e.g., social robots) or disembodied (e.g., software agents). The current literature on social presence of artificial social actors is predominantly about disembodied social actors (see Lee & Nass, 2005). Studies on social presence of embodied social actors such as social robots are quite limited, probably because there has been little collaboration between social presence scholars and robotics researchers.

The lack of research on social presence of embodied social actors is lamentable, because both robotics and social presence literature can be greatly advanced by studies that apply social presence to HRI situations. We believe social presence can be used as an effective variable to measure the success of a social robot. The measure of social presence also makes it possible for researchers to discover an underlying psychological process in HRI. For example, researchers can test how social responses toward robots (e.g., affection for and bonding with robots as well as the expectation and application of complicated social rules to robots) are mediated by users’ feelings of social presence during HRI.

In short, we believe HRI is a great interdisciplinary test ground with which scholars of virtual experience can confirm, adjust, and advance theories on virtual experience. In doing so, the design of social robots will also be better informed and advanced. In the current study, we try to achieve the above goals by applying the CASA research paradigm and testing the mediating effects of social presence in the context of HRI.

KEY DIMENSIONS OF SOCIAL ROBOTS

Three key dimensions—(a) anthropomorphic forms and behaviors, (b) emotion, and (c) personality—have been identified as critical factors for social robots. First, the employment of anthropomorphic (or sometimes zoomorphic) qualities in forms and behaviors increases natural social responses toward robots (Duffy, 2003; Fong et al., 2003). For example, anthropomorphic forms such as human faces (MIT Kismet; iRobot’s My Real Baby), human-like body shapes (Honda ASIMO; Sony SDR-4X), and even animal-like faces and shapes (Sony AIBO; Omron NeCoro) have been continuously utilized in robot design. In addition, state-of-the-art robots are capable of employing various anthropomorphic behaviors such as eye direction detection (MIT Kismet), bipedal walking (Honda
ASIMO), gestures (Sony SDR-4X and AIBO), and speech recognition and generation (most current robots, including even some robot toys). Given that humans are evolutionarily hardwired to pay high attention to eye movements, face-like objects (Baron-Cohen, 1995) and speech-like sounds (Cooper & Aslin, 1990; Fernald, 1992), the use of anthropomorphic features can be a very effective way to accomplish meaningful social interaction between humans and robots. In fact, in a survey of people’s attitudes toward intelligent robots, Khan (1998) found that a robot with verbal communication using a human-like voice is highly desired. Thus, many robots are equipped with faces, speech recognition, and other features and capabilities that make robots more “human-like” (Dautenhahn, Ogden, & Quick, 2002). One caveat is that there is a nonlinear relationship between the degree of human-likeness (or lifelikeness) and people’s emotional reactions to robots. When a robot is almost fully human-like, but not quite perfect, the subtle imperfection of the robot becomes highly disturbing and even evokes repulsive responses from users—a phenomenon known as Mori’s “Uncanny Valley” or simply the “Zombie Effect” (see Dautenhahn, 2002; Fong et al., 2003).

Second, as we can see from well-documented social responses to MIT Kismet (Breazeal, 2002, 2003a, 2003b), people tend to show natural social responses to a robot when the robot can recognize their emotional states and manifest emotion-like internal states through various verbal and nonverbal cues (see also Brooks, 2002; Ogata & Sugano, 2000). This is not so surprising, given that the human ability to recognize and manifest emotion is critical for successful social interaction. Moreover, humans have a strong tendency to attribute intentionality and emotions to various objects, even to seemingly self-propelled dots or geometrical shapes displayed on a screen (Heider & Simmel, 1944; see Bloom and Veres, 1999, for recent replication and Dautenhahn, 2004, for a similar argument). Given that robots can manifest emotion-like internal states much more sophisticatedly than self-propelled dots or geometrical shapes do, it is highly likely that people will show natural social responses to robots manifesting emotion-like internal states through various verbal and nonverbal cues (Breazeal, 2002; Bruce, Nourbakhsh, & Simmons, 2001). Furthermore, it is suggested that having emotion-like internal states (e.g., fear) helps robots coordinate their motivational systems and effectively deal with unprogrammed situations, resulting in a better survival rate in hostile environments such as Mars (see Brooks, 2002, for the explanation of how having an internal state replicating fear increased the survival rate of Mars exploration robots; see Picard, 1997 for a similar claim in affective computing).

Finally, research shows that people prefer to interact with a robot that manifests a compelling personality (Breazeal, 2002; Kiesler & Goetz, 2002). Confirming common sense, a friendly robot personality prompts...
a qualitatively better HRI than a nonfriendly robot personality (Scheeff, Pinto, Rahardja, Snibbe, & Tow, 2002). In human–human social interaction, the categorization of other people based on personality types such as the big five traits—extroversion, agreeableness, dependability, neuroticism, and openness (Digman, 1990)—provides an easy way to summarize one’s impression of others, helps to predict others’ future behaviors, and, thus, significantly reduces cognitive loads when one engages in social interaction (Persson, Laaksolathi, & Lönnqvist, 2001). Similarly, we believe a personality-rich robot can reduce its users’ cognitive loads in HRI and makes it possible for the users to predict the robot’s behaviors in novel situations. There are many ways for establishing a robot’s personality (see Fong et al., 2003). For example, emotional responses, physical attributes (e.g., size, shape, and color), motions, and communication styles of robots can effectively change the way their personalities are perceived (see Isbister & Nass, 2000, for a similar claim).

LIMITATIONS OF PREVIOUS RESEARCH

Even though significant progress has been made toward the development of compelling social robots, previous studies have some limitations. In this section, we briefly review those limitations: (a) little empirical research on the effects of robotic cognitive development, (b) few studies on human–robot interaction in a group situation, and (c) limited research on long-term human–robot interaction.

First, there have been limited attempts to study the effects of a robot’s developmental capability. In addition to anthropomorphic characteristics, emotion, and personality, the ability to develop or grow (either physically or cognitively) is one of the key characteristics of a social creature. Arguably, the ability to grow is the most fundamental among the four characteristics, because it is the defining characteristic of a living creature. We therefore expect that robots with a developmental capability will have stronger social presence and yield more social responses from users than robots without the developmental capability. Unlike other characteristics, however, the effects of a robot’s developmental capability have rarely been tested. Of the two types of development—physical and cognitive—we will focus on cognitive development in the current study, because current robotic technologies cannot effectively manipulate physical development.

Second, most existing empirical studies on HRI are based on experimental situations in which a participant interacts with a robot individually. As a result, we know little about group-based human–robot interaction.
Given that a robot is increasingly used and designed for interaction with a group of individuals—for example, helper robots in public places such as museums, hospitals, and schools (see Burgard, Cremers, Fox, Hahnel, Lakemeyer, & Schulz, 1999; Nourbakhsh, Bobenage, Grange, Lutz, Meyer, & Soto, 1999)—studies on group-based, human–robot interaction should be conducted. With regard to the comparison between group-based HRI and individual-based one, we can reasonably predict that group-based social interaction with a social robot will produce less intense feelings of social presence and lower levels of social responses than individual-based interaction. The reason is that people in the group-based interaction situation will have significantly less time to interact with a social robot directly and personally, thus having more chance to ignore the existence of the social robot in a shared space than people in the individual-based interaction situation.

Finally, previous studies of human–robot interaction have focused mainly on short-term interaction. Similar to typical psychological experiments, short-term one-time-based social interaction has been a dominant research method in HRI studies. Those studies explore whether people can recognize the robot’s emotions (Cañamero, 2001), personality (Kiesler & Goetz, 2002), and communicative intents (Breazeal, 1998, 2002) on a short-term basis. This, however, is a perplexing situation in that social interaction may be better understood on a long-term basis; a short-term study cannot effectively measure deep levels of social responses. The current study, therefore, focuses on long-term human–robot interaction.

To sum up, the current study tries to deal with the aforementioned limitations in previous research by applying the CASA research paradigm and the theory of social presence to HRI. More specifically, the current study tested the effects of a robot’s developmental capability on its social presence and users’ social responses toward it. The test occurred in both individual and group interaction settings on a relatively long-term basis: 4 weeks. Most importantly, the current study tested how the social presence of a robot mediates users’ social responses toward the robot.

THE CURRENT STUDY: HUMAN–AIBO INTERACTION

AIBO, Sony’s entertainment robot, was used in the current study, because it enabled us to manipulate artificial cognitive development. AIBO is one of the most successful social robots currently in the market. Ever since AIBO was introduced in 1999, about 100,000 AIBOs have been sold despite its high price ($1,500–$2,500). The first 3,000 units sold in Japan were snapped up in 20 minutes, and 2,000 robots were sold in the United States within 4 days. One of the main reasons that AIBO became the most popular entertainment robot is its technological capacity for long-term
cognitive development based on social interaction with its users. Fujita (2001), the inventor of AIBO at Sony Corporation’s Digital Creatures Laboratory, states that developmental adaptation through learning is one of the main technological factors that contributes to the lifelikeness of AIBO. In the case of an infant-like humanoid robot, Kozima and Yano (2001) made a similar claim that a robot’s ability to change and develop its behaviors according to its interaction with users will allow the robot to be viewed as truly a social being.

AIBO’s behaviors and developments are learned through continuous social interaction with users. AIBO has a 64-bit RISC processor and 16 megabytes of internal memory, and its behaviors are programmed into an 8-megabyte removable Memory Stick. AIBO Life, a Memory Stick Open-Robotics software, controls AIBO’s behaviors and induces AIBO to grow from a baby dog (i.e., puppy) to a fully matured adult dog based on the interaction with its users over time. AIBO contains sensors in its head, chin, back, and feet, and these enable interaction with humans by distinguishing admonishing strokes from affectionate pats. It can manifest emotion-like internal states through flashing lights on its face and various sounds. With repeated interaction with its users, AIBO will avoid actions that were punished with strong and short strokes (admonishing strokes) and will repeat what has been rewarded with long and soft taps (affectionate pats). As a result, each AIBO gradually develops from a puppy to a fully matured dog, reflecting its long-term interaction with users.

Using AIBO, we tried to answer the following questions in the current study: (a) Can a robot be perceived as a developing creature in a long-term human–robot interaction situation? (b) What are the effects of users’ perception of a robot’s cognitive developmental capability on users’ feelings of social presence and social responses toward the robot? (c) What are the effects of group interaction with a robot on users’ feelings of social presence and social responses toward the robot? and (d) Do users’ feelings of social presence during HRI mediate the effects of the robot’s cognitive developmental capability?

Based on the previous discussions, the following hypotheses were set:

H1: People who interact with an AIBO that has a developmental capability will perceive the AIBO as a developing creature more than people who interact with an AIBO without the developmental capability.

H2: People who interact with an AIBO that has a developmental capability will have a greater feeling of AIBO’s social presence than people who interact with an AIBO without the developmental capability.

H3: People who interact with an AIBO that has a developmental capability will have more positive social responses toward the AIBO than people who interact with an AIBO without the developmental capability.
H4: People who interact with an AIBO individually will have a greater feeling of the AIBO’s social presence than people who interact with an AIBO in a group.

H5: People who interact with an AIBO individually will have more positive social responses toward the AIBO than people who interact with an AIBO in a group.

H6: People’s social responses toward an AIBO will be mediated by their feelings of social presence during their interaction with the AIBO.

METHOD

Overview

The experiment was a 2 (developmental capability: developmental versus fully matured) x 2 (number of participants: individual versus group) between-subjects design. Participants assigned to the “developmental” conditions interacted with an AIBO that was programmed to gradually develop, from infancy to full maturity, over the course of 4 weeks. Participants in the “fully matured” conditions, however, interacted with an AIBO that was programmed to remain in the fully matured stage from the beginning to the end of the experiment. (The manipulation section below provides details of the developmental capability manipulation.) Participants in the “individual interaction” conditions played in a room alone with an AIBO, whereas participants in the “group interaction” conditions played with an AIBO in a room with other people (in groups ranging from four to six participants). Participants in the group interaction conditions did not know each other before the experiment.

Participants

Forty college students (ages ranging from 19 to 24) in two large introductory communication courses were recruited. Ten participants were assigned to each of the four conditions. Gender was balanced in each of the four conditions. None of the participants had interacted with AIBO before the experiment and none of them were affiliated with computer or robot industries. All participants were asked to complete a pre-experiment test. The pretest showed that there were no significant differences among participants with regard to feelings of loneliness (as measured by the UCLA loneliness scale, Version 3; Russell, Peplau, & Cutrona, 1980; Russell & Cutrona, 1988), self-efficacy in technology, or history of pet ownership. Those scales were pretested because it was believed that such factors could lead people to evaluate an AIBO more positively. All participants interacted with an AIBO for 4 weeks and they were not told of the purpose of the study until the end of the whole experiment. All
participants received $20 bookstore certificates and course credits at the end of the whole experiment.

Procedure

Participants were asked to come to the lab once a week over the course of 4 weeks and interact with an AIBO for 30 minutes during each visit. Upon arrival at the laboratory, each participant was assigned to a room and an experimenter brought an AIBO into the room. The participants were asked to train the AIBO to perform certain simple tasks such as standing up, sitting down, and lying down. Participants were told that they could train an AIBO by giving verbal commands and patting the AIBO’s chin and head multiple times. At the end of the fourth week, participants were asked to fill out a survey questionnaire measuring a set of mediating and dependent variables (for detail, see Measurement section below).

Manipulation of AIBO’s Developmental Capability

Manipulation of developmental capability was done by carefully programming AIBO’s chronological developmental stages. We used Sony’s AIBO Master Studio to program Open-R (robotics) language. Four developmental stages were designed: Baby (D1), Kid (D2), Adolescent (D3), and Adult (D4). To create a strong sense of the robot’s cognitive development, four factors were simultaneously manipulated (see Table 1 and Table 2): (a) the number of tasks, (b) the sophistication of tasks (from simple to complicated), (c) the speed of learning as manipulated by the number of verbal and touch commands required to train each task (see Table 2), and (d) the sophistication of random and spontaneous behaviors (i.e., facial and audio responses to head and chin sensor inputs). Each of these four factors was manipulated to change in a corresponding fashion at the transition of developmental stages. As the level of development increased throughout the four stages, for example, an AIBO would gain a greater capacity to learn and perform many sophisticated behaviors in a shorter period of time.

As another part of the developmental change, the AIBO would remember what it had learned in previous sessions. For instance, an AIBO in the adult stage would perform all the behaviors that it had learned in its baby, kid, and adolescent stages. As we can see from Table 2, no repetition of verbal commands and petting touches were required in order for the AIBO to perform the behaviors learned in the previous stage.

AIBO’s spontaneous random behaviors in a situation when there was no direct user input also demonstrated the level of development. For example, an AIBO in the baby stage could not even stand up; by the last
Make AIBO understand its name  AIBO  Answers with a simple melody

Make AIBO learn how to say good-bye  See you  Waves its front paw left and right

Make AIBO sit down  Sit down  Sits down

Make AIBO stand up  Stand  Stands up

Make AIBO lie down  Lie down  Lies down

Make AIBO walk forward  Go forward  Walks forward

Make AIBO walk backward  Go backward  Walks backward

Make AIBO turn right  Turn right  Turns right

Make AIBO turn left  Turn left  Turns left

Make AIBO cheer you up  Cheer up  Shakes its shoulders and tries to cheer you up

Make AIBO sing a song  Sing a song  Sings a song

Make AIBO dance  Dance  Dances by lifting and shaking its two front legs

Make AIBO proud of itself  Show time  Opens its mouth and makes the sound of clapping

Make AIBO wish you a happy day  Happy day  Dances with happy music

NOTE: Tasks that AIBO can do were cumulative. That is, AIBO in Week 2 can do all tasks in Week 1. Thus, AIBO in Week 4 can do all tasks listed above.

stage of its development, it was able to run and dance spontaneously without direct user input.

Participants in the developmental conditions were asked to train AIBO in each stage. They were instructed that if they gave verbal commands and patted their AIBO’s chin and head more frequently, it would learn the given tasks much faster (check http://www-rcf.usc.edu/~kwanminl/research/Aibo/sample_interaction.wmv for an actual demo of AIBO’s
## TABLE 2
The Number of Verbal and Touch Commands Required in Each Developmental Stage

<table>
<thead>
<tr>
<th>Developmental Stage</th>
<th>Baby (D1: Week 1)</th>
<th>Kid (D2: Week 2)</th>
<th>Adolescent (D3: Week 3)</th>
<th>Adult (D4: Week 4)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Verbal commands</td>
<td>Speed of learning</td>
<td>Verbal commands</td>
<td>Speed of learning</td>
</tr>
<tr>
<td>AIBO</td>
<td>V=6</td>
<td>AIBO</td>
<td>V=0</td>
<td>AIBO</td>
</tr>
<tr>
<td></td>
<td>H=6</td>
<td></td>
<td>H=0</td>
<td>H=0</td>
</tr>
<tr>
<td></td>
<td>C=6</td>
<td></td>
<td>C=0</td>
<td>C=0</td>
</tr>
<tr>
<td>See you</td>
<td>V=6</td>
<td>See you</td>
<td>V=0</td>
<td>See you</td>
</tr>
<tr>
<td></td>
<td>H=6</td>
<td></td>
<td>H=0</td>
<td>H=0</td>
</tr>
<tr>
<td></td>
<td>C=6</td>
<td></td>
<td>C=0</td>
<td>C=0</td>
</tr>
<tr>
<td>Sit down</td>
<td>V=5</td>
<td>Sit down</td>
<td>V=0</td>
<td>Sit down</td>
</tr>
<tr>
<td></td>
<td>H=5</td>
<td></td>
<td>H=0</td>
<td>H=0</td>
</tr>
<tr>
<td></td>
<td>C=5</td>
<td></td>
<td>C=0</td>
<td>C=0</td>
</tr>
<tr>
<td>Stand</td>
<td>V=5</td>
<td>Stand</td>
<td>V=0</td>
<td>Stand</td>
</tr>
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<td></td>
<td>H=5</td>
<td></td>
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<td></td>
<td>C=5</td>
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<td>C=0</td>
<td>C=0</td>
</tr>
<tr>
<td>Lie down</td>
<td>V=5</td>
<td>Lie down</td>
<td>V=0</td>
<td>Lie down</td>
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<tr>
<td></td>
<td>H=5</td>
<td></td>
<td>H=0</td>
<td>H=0</td>
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<td></td>
<td>C=5</td>
<td></td>
<td>C=0</td>
<td>C=0</td>
</tr>
<tr>
<td>Go forward</td>
<td>V=3</td>
<td>Go forward</td>
<td>V=0</td>
<td>Go forward</td>
</tr>
<tr>
<td></td>
<td>H=4</td>
<td></td>
<td>H=0</td>
<td>H=0</td>
</tr>
<tr>
<td></td>
<td>C=4</td>
<td></td>
<td>C=0</td>
<td>C=0</td>
</tr>
<tr>
<td>Go backward</td>
<td>V=3</td>
<td>Go backward</td>
<td>V=0</td>
<td>Go backward</td>
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<tr>
<td></td>
<td>H=4</td>
<td></td>
<td>H=0</td>
<td>H=0</td>
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<tr>
<td></td>
<td>C=4</td>
<td></td>
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<tr>
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<td>C=4</td>
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<tr>
<td>Turn left</td>
<td>V=3</td>
<td>Turn left</td>
<td>V=0</td>
<td>Turn left</td>
</tr>
<tr>
<td></td>
<td>H=4</td>
<td></td>
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<td>H=0</td>
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<td></td>
<td>C=4</td>
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<tr>
<td>Cheer up</td>
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<td>V=0</td>
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<td></td>
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</tr>
<tr>
<td></td>
<td>C=0</td>
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<td>C=0</td>
<td></td>
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<tr>
<td>Sing a song</td>
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<td></td>
<td>V=0</td>
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<td>H=0</td>
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<tr>
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<td>C=0</td>
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<td>C=0</td>
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<td>V=0</td>
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<td>V=0</td>
<td></td>
</tr>
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<td></td>
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</tr>
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</table>

**NOTE:** V = the number of verbal commands needed to accomplish the task; H = the number of patting touches on head needed to accomplish the task; C = the number of patting touches on chin needed to accomplish the task.
During the experiment sessions, all participants were able to successfully train AIBO with some slight variations in time, because the given tasks were easy to master.

Participants in the fully matured conditions (in both the individual interaction and the group interaction manipulations) interacted with an AIBO with D4 program from the first to the last week. The AIBO in the fully matured conditions was able to carry out all preprogrammed behaviors from the first week. Just as with the developmental conditions, participants in the fully matured conditions were told that if they gave verbal commands and patted its chin and head more frequently, the AIBO would do the given tasks much faster.

**Measurement**

The following items were measured at the end of the fourth week. All measures are analytically distinctive and highly reliable (see Cronbach’s \( \alpha \) for each measure).

People’s perception of AIBO as a developing creature was measured by two factors: (a) perceived development of AIBO and (b) perceived lifelikeness of AIBO. Perceived development of AIBO was measured based on the level of agreement (1 = very strongly disagree, 10 = very strongly agree) with the following statements: This AIBO has developed its skills over the course of four sessions because of my interaction with it; This AIBO’s behavior has changed over the course of four sessions because of my interaction with it; This AIBO’s intelligence has developed over the course of four sessions because of my interaction with it; This AIBO has matured over the course of four sessions because of my interaction with it; This AIBO has become more competent over the course of four sessions because of my interaction with it (\( \alpha = .92 \)). Perceived lifelikeness of AIBO was an index based on the level of agreement (1 = describes very poorly, 10 = describes very well) with the following adjectives describing AIBO: lifelike, machine-like (reverse coded), interactive, responsive (\( \alpha = .76 \)).

Social presence of AIBO was measured by two factors: co-presence and psychological involvement. A modified version of Biocca et al.’s (2001) social presence measures was used to measure both factors. Co-presence (\( \alpha = .89 \)) was measured by the following four questions: (a) While you were playing with this AIBO, how much did you feel as if you were interacting with an intelligent being? (b) While you were playing with this AIBO, how much did you feel as if you were alone? (reverse coded) (c) While you were playing with this AIBO, how much did you feel as if you were with an intelligent being? (d) While you were playing with this AIBO, how much did you feel as if you and the AIBO were communicating with each other? Psychological involvement (\( \alpha = .82 \)) was measured by...
the following two questions: (a) While you were playing with this AIBO, how much attention did you pay to it? and (b) While you were playing with this AIBO, how much did you feel involved with it? Response scales for the two factors were anchored by 1 = not at all and 10 = very much.

People’s social responses toward AIBO were measured by the following four factors: social attraction, physical attraction, closeness of parasocial relationship, and buying intention. Social attraction and physical attraction were measured by a modified version of McCroskey and McCain’s (1974) interpersonal attraction scale. Both social attraction (α = .95) and physical attraction (α = .91) had a 7-point Likert-type scale. The social attraction scale measured the level of participants’ agreement with the following items: (a) I think this AIBO could be a friend of mine, (b) I think I could have a good time with this AIBO, (c) I could establish a personal relationship with this AIBO, and (d) I would like to spend more time with this AIBO. The physical attraction scale had the following sentences: (a) I think this AIBO is quite pretty, (b) This AIBO is very good looking, (c) I find this AIBO very attractive physically, and (d) I don’t like the way this AIBO looks (reverse coded).

Closeness of parasocial relationship (α = .78) was a modified version of Poresky, Hendrix, Mosier, and Samuelson’s (1987) self-bonding scale, composed of the following questions: (a) How often did you feel that you were responsible for this AIBO? (b) How often did you touch, stroke, or pet this AIBO? (c) How often did you feel that this AIBO was responsive to you? (d) How often did you feel that you had a close relationship with this AIBO? Each question had an independent, 5-point scale.

Buying intention (α = .86) was an index composed of the following three questions: (a) How likely would you be to recommend this AIBO to your friends? (b) How well do you think this AIBO will sell? (c) How likely would you be to buy this AIBO? Each question had an independent, 10-point scale.

RESULTS

A series of full factorial 2 (development: developmental versus fully matured) x 2 (number of participants: individual versus group) ANOVAs were conducted to test H1, H2, H3, H4 and H5. A path analysis was conducted to test H6, which is about the mediating effect of social presence.

As explained before, two variables (perceived development of AIBO and lifelikeness of AIBO) were measured to test H1. With regard to the perceived development of AIBO variable, participants in the developmental conditions had a stronger perception that their AIBO had developed
over the course of 4 weeks ($M = 7.35; SD = 1.56$) than participants in the fully-matured conditions ($M = 4.39; SD = 2.32$), $F(1, 39) = 22.44, p < .01, \eta^2 = .37$. This result confirms that our manipulation of AIBO’s developmental capability was successful. Neither the main effect of the individual interaction factor, $F(1, 39) = .80, ns$, nor the interaction between the two independent variables (developmental capability x number of participants), $F(1, 39) = 1.17, ns$ was observed. A similar pattern was observed with regard to the lifelikeness of AIBO variable. There was a significant main effect of the developmental capability factor, $F(1, 39) = 5.47, p < .05, \eta^2 = .13$. The AIBO in the developmental conditions was regarded as more lifelike ($M = 5.85; SD = 1.78$) than the AIBO in the fully-matured conditions ($M = 4.50; SD = 1.60$). Neither the main effect of the individual interaction factor, $F(1, 39) = .03, ns$, nor the interaction between the two independent variables, $F(1, 39) = 1.50, ns$, was observed.

Consistent with H2 and H3, the results showed that the developmental capability factor had significant impacts on social presence and other social response variables. Specifically, participants in the developmental conditions felt a stronger sense of co-presence ($M = 6.37; SD = 2.00$) than those in the fully matured conditions ($M = 4.93; SD = 1.95$), $F(1, 39) = 5.15, p < .05, \eta^2 = .13$. Also, participants in the developmental condition ($M = 7.71; SD = 1.92$) felt a higher sense of psychological involvement than participants in the fully matured conditions ($M = 6.05; SD = 2.30$), $F(1, 39) = 5.89, p < .05, \eta^2 = .14$. In addition, participants in the developmental conditions showed more positive social responses toward AIBO than participants in the fully matured condition: social attraction [$F(1, 39) = 20.38, p < .001, \eta^2 = .36$], physical attraction [$F(1, 39) = 4.16, p < .05, \eta^2 = .10$], closeness of parasocial relationship [$F(1, 39) = 5.50, p < .05, \eta^2 = .13$], and buying intention [$F(1, 39) = 15.90, p < .001, \eta^2 = .31$]. In all cases, the developmental conditions yielded significantly more positive responses than the fully matured conditions (see Table 3 for the means and the standard deviations of all dependent variables).

H4, however, was not supported. Participants in both the individual interaction conditions and the group interaction conditions felt comparable amounts of social presence—both co-presence and psychological involvement (see Table 4).

H5 was partially supported. The number of participants factor positively affected two dependent variables: closeness of parasocial relationship, [$F(1, 39) = 5.76, p < .05, \eta^2 = .14$] and buying intention [$F(1, 39) = 15.08, p < .001, \eta^2 = .30$] (see Table 4 for the means and the standard deviations of all dependent variables). In all the significant cases, the individual interaction with AIBO yielded more positive responses than the group interaction. With regard to social attraction and physical attraction, no significant differences were found between the individual interaction and the group interaction conditions (see Table 4).
For all variables, no interaction effect was found. Table 5 shows F values of the interaction effects for all mediating and dependent variables.

A path analysis was conducted to test H6, which predicted the mediating effect of social presence on other dependent variables. The results are illustrated in Figure 1.

In general, five criteria should be satisfied in order to demonstrate mediation (Baron & Kenny, 1986, p.1177). The first criterion is that the independent variable—the developmental capability [for this particular analysis, we dummy coded this factor (1 for the developmental manipulation and 0 for the fully-matured manipulation)]—should have a significant effect on the mediating variable (i.e., social presence as measured

<table>
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<th>η²</th>
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<td>5.89*</td>
<td>.14</td>
</tr>
<tr>
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<td>2.23</td>
<td>20.38***</td>
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<td>Physical attraction</td>
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<td>3.43</td>
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</table>

NOTE: *p < .05, ** p < .01, *** p < .001.

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<table>
<thead>
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<th>Group</th>
<th>F</th>
<th>η²</th>
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<td>15.08***</td>
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</table>

NOTE: *p < .05, ** p < .01, *** p < .001.
by copresence and psychological involvement). We omitted the number-of-participant factor for this mediation analysis, because this factor did not have an effect on social presence and showed inconsistent effects on other dependent variables. Secondly, the mediating variable should have a significant effect on the dependent variables. Third, the independent variable must have a significant effect on the dependent variables when the dependent variables are regressed on the independent variable without the mediating variable. Fourth, when the dependent variables are regressed on both the mediating variable and the independent variable, the effect of the mediating variable on the dependent variables should remain significant. Finally, the effect of the independent variable on the dependent variables should decline when the dependent variables are regressed on both the mediating variable and the independent variable.

From Figure 1, we can easily confirm the first two conditions for mediation (by checking the significance of the standardized coefficient for each prediction). To confirm the third condition, a series of simple linear regressions were done. As can be inferred from the results of previous analyses, the independent variable (the development capability factor) had significant positive effects on social attraction ($\beta = .59, p < .01$), physical attraction ($\beta = .32, p < .05$), closeness of parasocial relationship ($\beta = .33, p < .05$), and buying intention ($\beta = .48, p < .01$). These analyses indicate that the data supported the third condition for mediation. The fourth and final conditions for mediation can be confirmed by examining the changes of standardized coefficients reported in the path diagram (see Figure 1). When both the mediating variables (social presence as measured by copresence and psychological involvement) and the independent variable (the developmental capability factor) were entered into
Figure 1. Mediating Effect of Social Presence
NOTE: Standardized coefficients are inside arrows. Numbers inside parentheses are standardized coefficients when dependent variables are regressed on the independent variable alone without including social presence variables (co-presence and psychological mediation) in the equations. *p < .05, **p < .01.

a series of regression equations simultaneously, the effects of social presence on social responses toward AIBO remained stable, keeping most of their significance levels. The effects of the independent variable on the dependent variables, however, dropped significantly, even losing statistical significance. We can easily check this drop by comparing the standardized coefficients of the independent variable reported either inside or outside the parentheses in Figure 1. In conclusion, the current path analysis provides very strong evidence of the mediating role of social presence in people’s social responses toward robots. These results, as a whole, support H6.

GENERAL CONCLUSIONS AND DISCUSSION

Based on the results of the current experiment, we summarize the following findings. First, a robot can be perceived as a developing creature
with relatively simple manipulation of its behaviors. Second, people experience stronger feelings of social presence when interacting with a developing robot than when interacting with a nondeveloping one. Third, people show more positive social responses toward a developing robot than a nondeveloping one—as confirmed by stronger social and physical attraction, closer parasocial relationship, and higher buying intention. Fourth, feelings of a robot’s social presence are not affected by the number of people in the interaction. People feel similar levels of social presence when they interact with a robot individually or in a group situation. Fifth, people feel closer to a robot and show more buying intention when they interact with a robot alone than when with other people. Finally, people’s social responses toward a robot are mediated by their feelings of social presence during HRI.

The implications of the above findings relate to three different area: the CASA research paradigm, the theory of social presence, and the field of robotics. The current study is one of the first attempts to directly test the CASA research paradigm in a HRI situation. As discussed before, most previous CASA studies were based on human interaction with disembodied social actors. By critically testing the CASA paradigm in human–robot interaction, the current study expands the applicability of the paradigm to human interaction with embodied social actors. One remaining open issue is possible main and interaction effects of the embodiment. Future studies should test whether embodied agents produce more positive social responses from their users than disembodied agents for similar social interaction behaviors. Possible interaction effects between the embodiment and the manipulation of a particular human-like characteristic such as personality, gender, social roles and ethnicity should also be tested.

The current study attempts to link social presence literature to the field of HRI. By showing the importance of social presence in HRI, the current study calls for more systematic applications of the social presence literature to the field of robotics. A major finding of the current experiment is that feelings of social presence play a major role in mediating user responses to social robots. Future studies on HRI should pay special attention to this issue. Another important finding of the current study is that feelings of social presence were not affected by the group interaction factor. This result implies that the feeling of the robot’s social presence might be separate from one’s emotional attachment to the robot. That is, some objective characteristics of a robot such as the developmental capability might produce a compelling sense of social presence, regardless of people’s individual emotional attachment toward the robot. This result can be used as indirect evidence against the emotional attachment explanation to the CASA phenomena, which is one of the strongest alternative explanations to the CASA paradigm. Future studies
should directly address this issue by creating conditions in which emotional attachment and feelings of social presence are independently manipulated.

The current study provides many new insights for the development of social robots. The findings of the current study imply that even relatively simple behavioral manipulations can produce a convincing sense of a robot’s artificial developments without using actual artificial intelligence systems. As Nass and Moon (2000) suggest, the cues for provoking anthropomorphism toward an artifact can be remarkably thin. Even simple manipulations of shapes, facial expressions, gestures and behaviors can successfully trigger the tendency to anthropomorphize artifacts. These relatively small manipulations can be effective enough to generate strong feelings of social presence in HRI (see below for more detailed discussion on the social presence issue). Also, the finding that seemingly developing robots received much more positive social responses from users than fully-functional, yet nondeveloping, robots provides many practical implications for the design of social robots. Obviously, robot designers should carefully manifest a robot’s developmental changes, especially when the robot is designed for long-term interaction with people. Equipping a robot with a full functional capability from the beginning of interaction might not be a good choice for the design of social robots. Finally, the finding that feelings of social presence were not affected by the group interaction factor suggests that designers of social robots can successfully produce strong feelings of social presence even in group-based HRI situations. Given the fact that social presence is the key mediator for people’s social responses to robots, designers need to build seemingly developing robots even when their robots are designed solely for group-based HRI (e.g., museum or tour-guide robots). The developmental capability of robots matters in both one-to-one and many-to-one HRI situations.

The finding that individual interaction with a robot, rather than group interaction, yielded more positive social responses toward the robot in terms of closeness of parasocial relationship and buying intention is not surprising. A sense of responsibility or attachment after the 4 weeks of individual interaction with the robot can explain this result. After training the same robot individually once a week for 4 weeks, participants might develop a sense of responsibility for the robot’s cognitive development or at least a feeling of emotional attachment to the robot. This sense of responsibility and attachment might induce participants to feel close to the robot and increase their buying intention. In contrast to participants in the individual interaction conditions, participants in the group conditions might not develop a strong sense of responsibility and attachment, because they shared the robot with other group members (ranging from four to six participants).
Participants in these conditions spent less time individually in training the robot than participants in the individual interaction conditions. As a result, they might have a weaker sense of responsibility and a lower level of buying intention than those in the individual interaction conditions.

In general, the current study justifies the importance of an interdisciplinary approach to the development of social robots. The development of fully autonomous robots for exploring Mars and other dangerous territories was possible after the realization of robotic engineers about the importance of emotional capability in preserving the survival of a robot in dangerous and unpredictable areas (Brooks, 2002). Likewise, exciting and important discoveries about social robots can be achieved when the fields of robotics and other academic fields collaborate with one another. For example, the current study was able to give some new insights on HRI by applying the concept of social presence to the study of social robots.

**LIMITATIONS OF THE CURRENT STUDY AND SUGGESTIONS FOR FUTURE RESEARCH**

There are some methodological limitations in the current study. First, we did not measure participants’ actual behaviors during the interaction because of the difficulty in measuring behavioral responses in group conditions. Future studies should include behavioral response measures in order to enhance the validity of the findings suggested in the current study. Second, the current experiment was conducted only over 4 weeks. The findings from the current study therefore cannot be fully applied to HRI situations lasting more than a month. Given that social robots will be used on a relatively long term basis usually exceeding a month period in real life, future studies should lengthen the experimental period to ensure better generalizability.

In addition to the methodological limitations, there is a possible alternative explanation to the current study. The alternative explanation is that participants in the fully-matured conditions became bored after interacting with the same AIBO over the course of four weeks. Participants in the fully-matured conditions were distracted from, and felt less interested in, their interaction with AIBO because of the boredom. As a result, they felt less social presence, thus showing less positive social responses toward AIBO.

We believe the boredom explanation is weak for the following reasons. First, interacting with a robot dog for 30 minutes once a week for a 4-week period is far from being dull. In fact, almost all participants had consistently shown great enthusiasm in interacting with AIBO. Second, when we debriefed the experiment, we did not find a systematic difference
between participants in the developmental conditions and participants in the fully-matured conditions in terms of boredom. Finally, and most importantly, the boredom explanation cannot effectively explain the nonsignificant main effect of the number of participant factor and the nonsignificant interaction between the number of participant factor and the developmental capability factor on social presence. Participants in the group conditions were more likely to be distracted from their interaction with AIBO than participants in the individual conditions, owing to the interpersonal interactions in the group (which were frequently observed by experimenters each week) and possible group dynamics. The lack of personal involvement with AIBO could easily lead to the perception of AIBO as a boring machine. In other words, participants in the group conditions were more likely to be disinterested in their interaction with an AIBO than participants in the individual interaction conditions. Nevertheless, neither the main effect of the number of participants, nor the interaction effect between the two independent factors on social presence was discovered. Based on this, we reject the boredom hypothesis in the current study. Future studies, however, should directly test this alternative hypothesis by designing a condition in which participants interact with an AIBO that simply changes its behaviors without manifesting any cognitive or behavioral developments: a simple change condition. A direct comparison between the developmental condition and the simple change condition will end the argument.

Another important area that future studies should investigate is the long-term psychological impact of HRI on human-to-human interaction and self-development. From studies of human-animal (usually, pet) interaction, we know that adults who, as children, had a more interactive relationship with their pets would have more positive interpersonal relationships and more positive self-concepts than those who had a lesser relationship with a pet (Poresky, Hendrix, Mosier, & Samuelson, 1988). Pet owners have a higher level of social sensitivity and interpersonal trust than nonowners (Hyde, Kurdek, & Larson, 1983). Whether our increasing interaction with social robots produces such positive effects as listed above or yields the gloomy negative effects often depicted in science-fiction films and novels is an open question. It is both an enormous challenge and an opportunity waiting for future investigations.

NOTES

1. We also conducted ANCOVAs with the three pre-test variables—loneliness, technology self-efficacy, and pet ownership experience—as covariates. None of them was a significant covariate. We will therefore not report the results of the ANCOVA analyses.
REFERENCES


