Are physically embodied social agents better than disembodied social agents? : the effects of physical embodiment, tactile interaction, and people's loneliness in human–robot interaction

Lee, Kwan Min; Jung, Younbo; Kim, Jaywoo; Kim, Sang Ryong

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Corresponding Author: Dr. Kwan Min Lee, PhD

Corresponding Author's Institution: University of Southern California

First Author: Kwan Min Lee, PhD

Order of Authors: Kwan Min Lee, PhD; Younbo Jung, MA; Jaywoo Kim, PhD; Sang Ryong Kim, PhD

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Running Head: EMBODIMENT OF SOCIAL AGENTS

Are Physically Embodied Social Agents Better Than Disembodied Social Agents?: The Effects of Physical Embodiment, Tactile Interaction, and People's Loneliness in Human-Robot Interaction

Kwan Min Lee*

Younbo Jung

Annenberg School for Communication, University of Southern California,

3502 Watt Way, Los Angeles, CA 90089-0281, USA

Email: kwanminl@usc.edu, younboju@usc.edu

Telephone: 1-213-740-3935

Jaywoo Kim, Ph. D.

Sang Ryong Kim, Ph. D.

Samsung Advanced Institute of Technology (SAIT)

San 14-1, Nongseo-ri, Giheung-eup, Yongin-si, Gyeonggi-do, S. Korea

Email: jaywoo@sait.samsung.co.kr; srkim@sait.samsung.co.kr;

Telephone: 82-18-251-0427

* Corresponding Author

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Abstract

Two experiments were conducted to investigate the effects of physical embodiment in human-agent interaction. Experiment 1 (N = 32) shows positive effects of physical embodiment on the feeling of an agent's social presence, the evaluation of the agent, the assessment of public evaluation of the agent, and the evaluation of the interaction with the agent. A path analysis reveals that the feeling of the agent's social presence mediates the participants' evaluation of the social agent. Experiment 2 (N = 32) shows that physical embodiment with restricted tactile interaction causes null or even negative effects in human-agent interaction. In addition, Experiment 2 indicates that lonely people feel higher social presence of social agents, and provide more positive social responses to social agents than non-lonely people. The importance of physical embodiment and tactile communication in human-agent interaction and the diverse role of social robots, especially for the lonely population, are discussed.

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Are Physically Embodied Social Agents Better Than Disembodied Social Agents?: The Effects of Physical Embodiment, Tactile Interaction, and People's Loneliness in Human-Robot Interaction

1. Introduction

In the movie "A.I." directed by Steven Spielberg, Cybertronics, a firm that manufactured robots, created a new social robot—David—whose main purpose was to share emotional bonding (especially the feeling of love) with human beings. In reality, we have not seen such a sophisticated social robot as David. Nevertheless, the movie successfully informs the public of the possibility that social robots could be as successful social actors as human beings.

Social robots are new types of robots whose major purpose is to interact with humans in socially meaningful ways (Breazeal, 2002; Fong et al., 2003; Lee et al., 2004). In other words, social robots are a special type of robots designed to evoke meaningful social interaction with their users. Given the above definition, social robots, unlike utility robots, do not necessarily need to have physical embodiment to accomplish their purpose. Physical embodiment is a mandatory requirement for utility robots, because they are built to accomplish labor-intensive *physical* work, ranging from household chores (e.g., cleaning, mowing, cooking) to industrial manufacturing (e.g., product assembly and delivery) and military operations (e.g., tele-surveillance, bombing and destroying). For social robots, however, physical embodiment may not be mandatory, because their major purpose—social interaction—is not directly related to physical activities per se; social interaction can be accomplished in both *embodied* and *disembodied* ways.

Therefore, one of the most fundamental questions about social robots is whether or not physical embodiment is required for successful social interaction between humans and robots.

This is a critical question to industry practitioners, due to the high costs for manufacturing physically embodied robots, not to mention the technical difficulties. This is theoretically important also, because it tackles one of the core issues in human-agent interaction—the role of physical embodiment in social interaction between humans and technology agents (see Dautenhahn, 1997). Despite the practical and theoretical importance of physical embodiment in human-robot interaction, there are very limited empirical studies on this issue. In the current study, we directly address this issue with two experiments.

2. Literature Review

2.1 Physical embodiment

Embodiment is a loaded term and has various meanings in philosophy, phenomenology, psychology, engineering, and everyday life. The explication of this concept is beyond the scope of the current paper. Instead, we are focusing on widely accepted meanings of embodiment in the fields of A.I. (Artificial Intelligence) and Robotics.

Ziemke (2001) identifies five different notions of embodiment in A.I. and Robotics—a) embodiment as structural coupling between agent and environment; b) historical embodiment as the result of a history of structural coupling; c) physical embodiment; d) organism-like bodily form (e.g., humanoid robots); and e) organismic embodiment.

The first notion of embodiment as structural coupling posits that embodiment is a basis for structural coupling between systems and their environment. An agent (or a system) is considered embodied if the agent (or the system) and its environment mutually perturb each other (Fong et al., 2003). Given the definition, virtual embodiment (e.g., software agents) is possible despite its seemingly oxymoronic characteristic. This notion of embodiment raises an important question of whether or not physical embodiment is essential for designing social robots. The second notion adds the dimension of time to the first notion. It views embodiment as a result of a history of agent-environment interaction. An agent should establish a history of mutual perturbation with its environment in order to gain the state of full embodiment. According to the third notion, physical instantiation, or more simply, bodily presence is required for an agent to be embodied (Franklin, 1997). According to Brooks (2002), in addition to bodily presence, embodied agents or systems need to have embedded sensors and motors—sensorimotor embodiment—so that they can physically connect with their environment. The fourth notion—organism-like bodily form—is a more restricted view of embodiment than the third notion. It maintains that an organism-like bodily form is required in order to achieve organism-like cognition. According to this notion, the mere equipping of a body, sensors, and motors into an agent or a system cannot achieve a full-scale embodiment. An agent as an artificial counterpart of a living organism should have the same, or at least similar, form as the living organism. A recent trend of building humanoid robots (e.g., Honda Asimo) is based on this notion of embodiment. Finally, the notion of organismic embodiment is the strictest view of embodiment. It essentially posits that an agent or a system should be exactly like a living organism in order to achieve embodiment. For an agent or a system to be exactly like a living organism, it must have intentionality and be able to grow (both physically and mentally) based on environmental inputs, both of which the current robotics cannot provide. In the current paper, we focus on the third notion—physical embodiment—and examine the effects of bodily presence in human-agent interaction.

What will be the effects of an agent's physical embodiment—more specifically bodily presence—in human-agent interaction? One possible positive effect of an agent's physical embodiment is that physical embodiment may result in better affordance (Norman, 1998), which leads to less frustration for people. In fact, it is well known among the robotics community that the form and structure of a robot can easily establish some sort of social expectations from its users (Fong et al., 2003). Therefore, physically embodied agents can provide better affordance to users than disembodied agents, especially for social interaction. For example, Bartneck (2002) found a social facilitation effect in his study with an emotional robot, eMuu. In his study, participants who engaged in a special form of social interaction—negotiation—spent significantly more effort and time when they interacted with an actual eMuu—a physically embodied agent—than when they interacted with a screen character version of eMuu—a disembodied agent. The result clearly indicates that physical embodiment facilitates social interaction. We believe that the social facilitation effect comes from both enhanced affordance and increased social presence (see the next section for a detailed discussion on the concept of social presence in human-agent interaction) which are made possible by physical embodiment. Based on the above discussion, we set the following hypotheses:

H1-1: People will evaluate a physically embodied agent—a social robot—more positively than a disembodied agent—a screen character version of the social robot.

H1-2: People will be more socially attracted to a physically embodied agent—a social robot—than a disembodied agent—a screen character version of the social robot.

H1-3: People will evaluate their interaction with a physically embodied agent—a social robot—more positively than their interaction with a disembodied agent—a screen character version of the social robot.

One’s own personal evaluation of an agent and one’s assessment of other people’s evaluation of the agent might differ due to the third-person effects (see Perloff, 1993). Thus, we set a separate hypothesis on participants’ assessments of other people’s evaluation of the agent:

H1-4: People will assess that other people will evaluate a physically embodied agent—a social robot—more positively than a disembodied agent—a screen character version of the social robot.

2.2 Social presence

Researchers have realized that the feeling of presence—the perceptual illusion of non-mediation (Lombard et al., 2000)—lies at the heart of almost all mediated experiences, from reading a novel to interacting with computers (Lee, 2004a). According to Lee (2004a), there are three types of presence—physical, social, and self presence. Physical presence is the feeling that virtual objects are real. Physical presence occurs when technology users do not notice either the para-authentic nature of mediated objects (or environments) or the artificial nature of simulated objects (or environments). For example, when users of a virtual reality system try to avoid virtual rocks moving toward them, they are experiencing a strong sense of physical presence of the rocks. That is, they respond to the virtual rocks as if those were real ones, when they feel a strong sense of physical presence. Social presence, in short, is a mental simulation of other intelligences (Biocca, 1997). Successful simulation of other intelligences occurs when technology users do not notice either the artificiality or para-authenticity of experienced social actors (both humans and non-human intelligences). For example, when people respond to avatars or agents as if they were actual humans, they are feeling strong social presence (see Nass & Moon, 2000; Lee & Nass, 2004; Lee, 2004b for a list of social responses to virtual agents). Finally, self presence is a psychological state in which virtually constructed self/selves are experienced as the actual self in real life (Lee, 2004a). In other words, self presence occurs when technology users do not notice the virtual nature of artificially constructed identities inside virtual environments and act as if those identities were real (e.g., Turkle, 1995).

Of these three types of presence, social presence is most relevant to the study of human-agent interaction. Lee (2004a, p. 45) defines social presence as "a psychological state in which virtual (para-authentic or artificial) actors are experienced as actual social actors in either sensory or non-sensory ways." Social presence occurs when technology users do not notice the para-authenticity of mediated humans and/or the artificiality of simulated non-human social actors. Thus, the feeling of social presence can play an important role in successful social interactions with even non-human beings such as robots or disembodied software agents. When a person interacts with a social robot, the person may respond to the social robot—an artificial social actor—as if it were an actual human. For example, although David in the movie, "A.I.," is not a real boy and is only a robot, the mother more often than not responds to David as if it were her real son. It means that she feels a strong social presence of her real son—an actual social actor—when she interacts with David—an artificial actor—in sensory ways.

Physically embodied agents can provide their users with richer sensory outputs (e.g., vision, audition, touch, smell, taste) through their bodily presence than disembodied agents. The richer sensory inputs coming from bodily presence in turn will create a compelling sense of the agent's being socially present. In fact, the existence of a body (especially a moving body [cf. Hider & Simmel, 1944]) is one of the most prominent cues for the existence of a social actor. Based on this assumption, we set the following hypothesis:

H1-5: People will feel a stronger sense of social presence when they interact with a physically embodied agent—a social robot—than when they interact with a disembodied agent—a screen character version of the social robot.

Lee and Nass (2004) provide statistical evidence for the mediating role of social presence in people's social responses to synthetic voices. They found that people's social responses to computers and artificial social actors are in fact mediated by people's feeling of social presence during the interaction. Based on this recent discovery in the study of social presence, we hypothesize that people's social responses to social agents will show a similar pattern:

H1-6: People's social responses to a social agent (as measured by the general evaluation of the social agent, the social attraction toward the social agent, the general evaluation of the interaction with the social agent, and the assessment of public evaluation of the social agent) will be mediated by people's feeling of social presence during the interaction.

3. Experiment 1: Effects of Physical Embodiment of Social Robots

3.1 Method

3.1.1 Experiment design

A one-way between-subjects analysis of variance (ANOVA) design was used to test the hypotheses in a laboratory environment. A total of 32 undergraduate students enrolled at a major university in the West Coast of the United States participated in the experiment.

3.1.2 Procedure

The whole experiment process consists of three steps. First, one half of participants (n=16) were randomly assigned to one of the two conditions (physical embodiment vs. physical disembodiment). The remaining half (n=16) were assigned to the other condition, with gender balanced across the two conditions. Then, participants came to a laboratory where they individually interacted with either a physically embodied agent—an actual social robot—or a disembodied agent—a screen character version of the social robot—alone for about 10 minutes. Finally, participants completed a paper-based survey questionnaire.

3.1.3 Manipulation

In the physical embodiment condition, participants interacted with an actual Sony Aibo. We chose Aibo because it is one of the most successful social robots currently on the market (Lee et al., 2004). Aibo contains sensors in its head, chin, and back that enable its interactions with people. We programmed Aibo to perform singing and dancing for 2 minutes and 20 seconds. After the performance, participants interacted with Aibo by touching its three sensors. Aibo was programmed to provide a unique behavioral output for each sensory input. Participants were told to try all three sensors of Aibo.

In the disembodiment condition, participants interacted with a disembodied version of an actual Aibo—i.e., virtual Aibo—on a 17-inch flat screen monitor. We created a virtual Aibo by using animation-making software, Director™, in the following way. First, we recorded Aibo's actual performance and responses with a digital camcorder. Then, we imported the recorded digital files into Director™ and created a shockwave file. The shockwave file showed the performance and responses of a virtual Aibo, which were exactly the same as those of an actual Aibo. That is, the virtual Aibo first performed singing and dancing for 2 minutes and 20 seconds, and also showed a unique behavioral response when participants clicked on one of its three sensory input areas—head, chin, and back—using a mouse. The behavioral responses from the virtual Aibo for the three sensory inputs were exactly the same as those of the actual Aibo (visit XXX site for a demo of the virtual Aibo. The site name is deleted to preserve the anonymity of this paper. It will be added later.)

3.1.4 Measures

All dependent measures were based on items from paper-based questionnaires. Five questions concerning *the general evaluation of Aibo* were asked using a 10-point semantic differential scale: bad/good; bitter/sweet; distant/close; not loving/loving; unpleasant/pleasant

(Cronbach's α = .85). This is a modified measure from the study of Perception of Pets as a Companion by Poresky et al. (1987).

Social attraction toward Aibo was measured by a modified version of McCroskey and McCain's Interpersonal Attraction Scale (McCroskey & McCain, 1974). Participants were asked to indicate their level of agreement to the following three statements: I think this Aibo could be a friend of mine; I think I could spend a good time with this Aibo; I would like to spend more time with this Aibo (Cronbach's α = .92). The 7-point response scales were anchored by "Very Strongly Disagree" (1) and "Very Strongly Agree" (7).

Participants were asked to show their *general evaluation of the interaction with Aibo* by indicating how well the following six adjectives describe their interaction with Aibo—enjoyable; entertaining; exciting; fun; interesting; and satisfying (Cronbach's α = .88). The 10-point response scales were anchored by "Describes Very Poorly" (1) and "Describes Very Well" (10).

The assessment of public evaluation of Aibo was measured by participants' level of agreements on the following three statements: People will find it interesting to play with this Aibo; People will find this Aibo attractive; People are likely to buy this Aibo (Cronbach's α = .79). The 10-point response scales were anchored by "Very Strongly Disagree" (1) and "Very Strongly Agree" (10).

Eight questions about *social presence* were asked using a combination of 10-point semantic differential scales and independent 10-point scales: unsociable/sociable; machine-like/life-like; insensitive/sensitive; While you were interacting with this Aibo, how much did you feel as if it were an intelligent being?; While you were interacting with this Aibo, how much did you feel as if it were a social being?; While you were interacting with this Aibo, how much did you feel as if it were communicating with you?; While you were interacting with this Aibo, how much attention did you pay to it?; While you were interacting with this Aibo, how much did you feel involved with it? (Cronbach's α = .90).

3.2 Results

Table 1 shows a full correlation matrix of the measured variables in Experiment 1.

Table 1 About Here

We used one-way, between-participants ANOVAs to test the first five hypotheses (see Table 2 for the complete results). A path analysis was conducted to test Hypothesis 6.

Table 2 About Here

Consistent with Hypothesis 1-1, the participants evaluated the physically embodied Aibo (M = 8.23, SD = 0.92) more positively than the disembodied Aibo (M = 7.08, SD = 1.37), $F(1, 29) = 7.65$, $p < .05$.

Hypothesis 1-2 was not supported. There was not a significant main effect of physical embodiment on the participants' evaluation of the social attraction of Aibo, $F(1, 29) = 0.08$, *n.s.*.

Consistent with Hypothesis 1-3, the participants evaluated the interaction with Aibo more positively when they interacted with the physically embodied Aibo (M = 8.11, SD = 1.14) than with the disembodied Aibo (M = 7.13, SD = 0.72), $F(1, 29) = 8.41$, $p < .01$.

The physical embodiment of Aibo influenced not only the participants' own personal evaluation of Aibo but also their assessment of other people's evaluation of Aibo. Consistent with Hypothesis 1-4, the participants judged that other people would evaluate Aibo more positively when they interacted with the physically embodied Aibo (*M* = 7.98, *SD* = 1.06) than with the disembodied Aibo (*M* = 7.21, *SD* = 1.09), $F(1, 29) = 4.11$, $p < .06$.

Consistent with Hypothesis 1-5, participants felt a stronger sense of social presence when they interacted with the physically embodied Aibo (*M* = 7.59, *SD* = 0.91) than with the disembodied Aibo (*M* = 5.97, *SD* = 1.45), $F(1, 29) = 14.35$, $p < .01$.

A path analysis was conducted to test Hypothesis 1-6 which predicted the mediating effect of social presence on other dependent variables. The result is illustrated in the following path model (see Figure 1).

Figure 1 About Here

Five things need to be confirmed in order to demonstrate mediation (Baron & Kenny, 1986, p.1177). First, the independent variable has a significant effect on the mediating variable. In the current experiment, physical embodiment (independent variable) was a significant predictor for the feeling of social presence (mediating variable), the standardized regression coefficient (β) = .57, $p < .01$. Second, the mediating variable has a significant effect on the dependent variables. The feeling of social presence was a significant predictor for all dependent variables when it was the only predictor in the regression equations: the general evaluation of Aibo (β = .74, $p < .01$); social attraction of Aibo (β = .35, $p = .05$); the evaluation of interaction with Aibo (β = .38, $p < .05$); and the assessment of public evaluation (β = .43, $p < .01$). Third, when the dependent variables are regressed on the independent variable alone, the independent variable has a significant effect. With the exception of the social attraction of Aibo (β = -.28, *n.s.*), physical embodiment was a significant predictor for all dependent variables when it was the only predictor in the regression equations: the general evaluation of Aibo (β = .45, $p < .05$);

the evaluation of interaction with Aibo ($\beta = .47$, $p < .01$); and the assessment of public evaluation ($\beta = .35$, $p < .06$). 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 keep significant. With the exception of the evaluation of interaction with Aibo ($\beta = .17$, *n.s.*), the effect of social presence remained significant for all dependent variables when both the independent variable (physical embodiment) and the mediating variable (social presence) were entered into the regression equations: the general evaluation of Aibo ($\beta = .72$, $p < .01$); social attraction of Aibo ($\beta = .56$, $p < .01$); and the assessment of public evaluation of Aibo ($\beta = .48$, $p < .05$). 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. A series of regression analyses confirmed this final requirement for mediation. The effects of physical embodiment on the general evaluation of Aibo ($\beta = .041$, *n.s.*), the evaluation of interaction with Aibo ($\beta = .37$, *n.s.*), and the assessment of public evaluation of Aibo ($\beta = .07$, *n.s.*) declined as to loose their previous statistical significances. For the social attraction of Aibo ($\beta = -.37$, *n.s.*), the effect remained non-significant.

Put together, the series of the regression analyses reported in Figure 1 provide strong evidence for the mediating effect of social presence on people's general evaluation of a social agent and people's assessment of public evaluation of the social agent.

3.3 Conclusions

A number of conclusions can be drawn from the results of Experiment 1. First, people evaluate a physically embodied social agent more positively than a disembodied social agent (H1-1). Physical embodiment also influences people's evaluation of the interaction with a social agent (H1-3). In addition, people predict that other people will also evaluate a physically embodied agent more positively than a disembodied agent (H1-4). These results imply that physical embodiment is an important factor for people's evaluation of social agents, despite the fact that social agents are not related to any physical function. Put together, physical embodiment is an important factor for people's social interaction with agents, even though on face level it does not provide any obvious value for social interaction.

Second, physical embodiment yields a greater sense of social presence in human-agent interaction (H1-5). The result confirms that physical embodiment is an effective tool to increase the social presence of an object. In addition, the feeling of social presence is a key mediating variable for the effects of physical embodiment on the general evaluation of a social agent and the assessment of public evaluation of the social agent (H1-6). These findings replicate the results reported by Lee and Nass (2004) and provide strong evidence that social responses to virtual objects are mediated by the feeling of social presence of the objects.

Finally, it should be mentioned that physical embodiment in Experiment 1 is manipulated in two ways—a) the manipulation of the ontological nature of Aibo—actual Aibo vs. virtual Aibo, and b) the manipulation of the nature of human-agent interaction—actual touch (i.e., participants actually touched Aibo sensors by hand) vs. virtual touch (i.e., participants clicked on Aibo sensors using a mouse). We could not test the effect of each manipulation separately, because under a normal condition, the two manipulations cannot be separated. That is, the manipulation of the nature of human-agent interaction is almost always nested within the manipulation of the ontological nature of an agent. Therefore, we should be cautious about making a conclusion about the effects of the ontological nature of a social agent (actual vs. virtual) on social presence and other social responses based on the results of Experiment 1 only. In order to deal with this problem, we conducted Experiment 2, in which only the nature of objects was manipulated by preventing all participants from touching a social agent. Even though this strict manipulation somewhat lacks ecological validity, it is the only way for us to test the effect of the ontological nature of a social agent separately from the effect of human-agent touching. In Experiment 2, we also test a popular assumption that lonely people such as the old and the hospitalized are more likely to be susceptible to the effects of social agents. In order to eliminate the effects of participants' prior attitudes toward Aibo which might add errors to the results of Experiment 1, we used a non-commercialized social robot—Samsung April—in Experiment 2. No participant in Experiment 2 had been exposed to April before the experiment and thus had no prior attitude toward April.

4. Experiment 2: Physical Embodiment without Touch Interaction

Based on the literature review and the results of Experiment 1, we set the following hypotheses, which are exactly the same as those of Experiment 1:

H2-1: People will evaluate a physically embodied agent—a social robot—more positively than a disembodied agent—a screen character version of the social robot.

H2-2: People will be more socially attracted to a physically embodied agent—a social robot—than a disembodied agent—a screen character version of the social robot.

H2-3: People will evaluate their interaction with a physically embodied agent—a social robot—more positively than their interaction with a disembodied agent—a screen character version of the social robot.

H2-4: People will assess that other people will evaluate a physically embodied agent—a social robot—more positively than a disembodied agent—a screen character version of the social robot.

H2-5: People will feel a stronger sense of social presence when they interact with a physically embodied agent—a social robot—than when they interact with a disembodied agent—a screen character version of the social robot.

H2-6: People's social responses to a social agent (as measured by the general evaluation of the social agent, the social attraction toward the social agent, the general evaluation of the interaction with the social agent, and the assessment of public evaluation of the social agent) will be mediated by people's feeling of social presence during the interaction.

4.1 Loneliness

Dominant forms of social agents and social robots are assistants, companions, or pets (Fong et al., 2003). In fact, pet-like social robots are similar to actual pets in the sense that both of them provide people with companionship. Similar to the findings that interaction with pets would be complementary to or even substitute for traditional interpersonal interaction (Veevers, 1985), social robots may be able to satisfy one's need for social interaction, especially if one is a part of the lonely population. Rook (1987) found a significant negative relationship between loneliness and companionship. It is not so surprising to find that more frequent companionship with other people was associated with less loneliness. Conversely, a lonely person is likely to appreciate the interaction with social robots more positively than a non-lonely person, because the former is more in need of social companionship. Based on this assumption, we added loneliness as the second independent variable for Experiment 2. Based on the above discussion, the following hypotheses in relation to loneliness were proposed in Experiment 2.

H2-7: Lonely people will evaluate a social agent more positively than non-lonely people.

H2-8: Lonely people will be more socially attracted to a social agent than non-lonely people.

H2-9: Lonely people will evaluate their interaction with a social agent more positively than non-lonely people.

H2-10: Lonely people will assess other people's evaluation of a social agent more positively than non-lonely people.

H2-11: Lonely people will feel a stronger sense of social presence when they interact with a social agent than non-lonely people.

H2-12: The effects of loneliness on the general evaluation of a social agent, the social attraction toward the social agent, the general evaluation of the interaction with the social agent, and the assessment of public evaluation of the social agent will be mediated by people's feeling of social presence during the interaction.

4.2 Method

4.2.1 Experiment design

A 2 (embodiment vs. disembodiment) x 2 (lonely vs. non-lonely) between-subjects factorial analysis of variance design was used to investigate the importance of touch-input capability and the effects of loneliness in human-robot interaction. Again, a total of 32 undergraduate students enrolled in a major university in the West Coast of the United States participated.

4.2.2 Procedure

In Experiment 2, April, a prototype robot manufactured by Samsung Electronics, was used. By using a prototype social robot—"April"—we were able to eliminate a potential bias in the participants' evaluation.

The experiment process consists of four steps. First, a survey of the UCLA Loneliness Scale (Version 3) was administered in a larger data pool of 62 people to measure the participants' perceived loneliness prior to Experiment 2 (Cronbach's $\alpha = .62$). The scale has been tested in many studies and is regarded to be highly reliable in terms of internal consistency (coefficient α ranging from .89 to .94) and test-retest reliability over a 1-year period ($r = .73$) (Russell, 1996, p. 20). From a total of 62 students, 32 participants with the most extreme scores on the scale—16 lonely ($M = 2.93$, $SD = 0.17$) and 16 non-lonely ($M = 2.57$, $SD = 0.10$) participants, $F = 53.04$, $p < .001$—who had English as a first language were invited to participate in the experiment.

Second, 16 participants within each group (lonely vs. non-lonely) were randomly assigned to the two different embodiment conditions (embodiment vs. disembodiment), with gender balanced across conditions.

Third, participants were asked to go to a laboratory where they individually interacted with Samsung April alone, for about 10 minutes. Finally, participants were asked to complete a paper-based survey.

4.2.3 Manipulation

The two embodiment conditions were manipulated in a similar way to Experiment 1. In the physical embodiment without touch condition, April was programmed to play a particular song and to perform a dance based on the song—"When She Loved Me" by Sarah McLachlan from the Toy Story 2 soundtracks—for three minutes. In the disembodiment condition, the pre-programmed performance was shown as a digital movie on a 17-inch flat-screen monitor (visit XXX site for a demo of the disembodied April. The site name is deleted again to preserve the anonymity of this paper. It will be added later.) Unlike Aibo in Experiment 1, we disabled all the sensors of April and strictly instructed the participants in the physically embodied condition not to touch April. Therefore, the only difference between the embodiment and disembodiment conditions in Experiment 2 was the ontological nature of April—actual April vs. virtual April.

4.2.4 Measure

All dependent measures were based on items from the same paper-based questionnaires used in Experiment 1 (the general evaluation of April [Cronbach's α = .74]; the social attraction of April [Cronbach's α = .92]; the evaluation of interaction with April [Cronbach's α = .92]; the evaluation of other people's evaluation of April [Cronbach's α = .83]; and social presence [Cronbach's α =.89]).

4.3 Results

Table 3 shows a full correlation matrix of the measured variables in Experiment 2.

Table 3 About Here

We used between-participants factorial ANOVAs to test the first five hypotheses for each independent variable (see Table 4 for the complete results). A path analysis was conducted to test Hypothesis 2-6 and Hypothesis 2-12.

Table 4 About Here

We were rather surprised to find that most of the results for the effects of physical embodiment in Experiment 2 were either non-significant or opposite to the results of Experiment 1. More specifically, Hypothesis 2-1 and 2-2 were not supported. There was not a significant main effect of physical embodiment on the participants' general evaluation of April, $F(1, 29) = 0.95$, *n.s.*, and the social attraction of April, $F(1, 29) = 2.40$, *n.s.* (see Table 4).

Opposite to Hypothesis 2-3, the participants evaluated the interaction with April more positively when they interacted with the disembodied April (M = 6.62, SD = 1.27) than when they interacted with the physically embodied April (M = 5.26, SD = 2.03), $F(1, 29) = 7.15$, $p < .05$.

The physical embodiment of April influenced the participants' assessment of other people's evaluation of April. Opposite to the direction of Hypothesis 2-4, however, the participants who interacted with the disembodied April assessed other people's evaluation of April more positively (M = 6.77, SD = 1.61) than participants who interacted with the physically embodied April (M = 4.48, SD = 1.65), $F(1, 29) = 20.18$, $p < .001$.

The physical embodiment of April influenced the participants' imagination of a social actor. However, opposite to the direction of the relationship in Hypothesis 2-5, the participants felt a stronger sense of social presence when they interacted with the disembodied April (M = 5.91, SD = 1.46) than when they interacted with the physically embodied April (M = 4.86, SD = 1.62), $F(1, 29) = 4.26$, $p < .05$.

Partially supporting Hypothesis 2-6, the effects of physical embodiment without touch on the evaluation of interaction with April and the assessment of public evaluation of April were mediated by participants' feelings of social presence during the interaction (see Figure 2; see our previous explanation of the mediation analysis in Experiment 1 to check why Figure 2 shows mediation effects for the two dependent variables). We were able to find a similar mediation pattern for the general evaluation of April and the social attraction of April (see the changes in beta coefficients in Figure 2), even though physical embodiment without touch was initially not a significant predictor for the general evaluation and the social attraction variables. One important thing to note is that the embodiment without touch variable was a significant *negative* predictor for social presence (see the test result of Hypothesis 2-5 above). Even though the direction of Hypothesis 2-5 was exactly opposite to our initial hypothesis, we were still able to find the mediation effect of social presence as we originally hypothesized (see Figure 2). To sum up, physical embodiment without touch negatively affects participants' feelings of social presence. Nevertheless, social presence was still a significant mediator for the effects of physical embodiment without touch on other dependent variables.

Figure 2 about here

There was a significant main effect of loneliness on most of the dependent variables (see Table 4).

Hypothesis 2-7 was not supported. There was not a significant main effect of loneliness on the participants' general evaluation of April, $F(1, 29) = 2.36$, *n.s.*.

Consistent with Hypothesis 2-8, participants in the lonely group ($M = 3.65$, $SD = 1.41$) were more socially attracted to April than participants in the non-lonely group ($M = 2.31$, $SD = 1.35$), $F(1, 29) = 7.57$, $p < .05$.

Consistent with Hypothesis 2-9, participants in the lonely group ($M = 6.73$, $SD = .0.84$) evaluated their interaction with April more positively than participants in the non-lonely group ($M = 5.15$, $SD = 2.16$), $F(1, 29) = 9.71$, $p < .01$.

Loneliness influenced the participants' assessment of other people's evaluation of April. Consistent with Hypothesis 2-10, participants in the lonely group ($M = 6.43$, $SD = 1.51$) judged that other people would evaluate April more positively than participants in the non-lonely group ($M = 4.82$, $SD = 2.11$), $F(1, 29) = 10.06$, $p < .01$.

Consistent with Hypothesis 2-11, loneliness influenced the participants' imagination of a social actor. Specifically, participants in the lonely group ($M = 5.98$, $SD = 0.93$) felt a stronger sense of social presence than participants in the non-lonely group ($M = 4.78$, $SD = 1.92$), $F(1, 29) = 5.64$, $p < .05$.

A path analysis was conducted to test Hypothesis 2-12, which predicted the mediating effect of social presence on other dependent variables (see Figure 2). Hypothesis 2-12 was supported for almost all dependent variables. The effects of loneliness on the social attraction of April, the evaluation of interaction with April, and the assessment of public evaluation of April were clearly mediated by participants' feelings of social presence (see Figure 2). With regard to the general evaluation of April, we found a very similar pattern of mediation (see the changes in beta coefficients in Figure 2), even though loneliness was not a significant predictor for this variable initially. Put together, the path diagram (Figure 2) vividly shows that the effects of loneliness on participants' social responses to April were clearly mediated by participants' feelings of social presence during the interaction.

The path model in Figure 2 is somewhat different from the previous path model in Experiment 1 in that it includes a new factor—loneliness. Therefore, the new path model explains a human-agent interaction in which both physical embodiment without touch and loneliness are addressed. Nonetheless, the patterns in Figure 2 clearly indicate the strong mediating effect of social presence. The current experiment, thus, shows that social presence is the key mediating variable for people's social responses to social agents even when the agents are physically embodied but not touched.

There was a moderate interaction effect between physical embodiment and loneliness in the evaluation of interaction with April, $F(1, 28) = 8.511$, $p < .06$ (see Figure 3). The pattern shows that non-lonely participants evaluated the interaction with April more positively when they interacted with the disembodied April (*M* = 6.35, *SD* = 1.65) than with the physically embodied April (*M* = 3.96, *SD* = 2.01). In contrast, lonely participants did not show any notable discrimination. In general, lonely participants evaluated their interaction with April somewhat positively whether it was physically embodied (*M* = 6.57, *SD* = 0.95) or disembodied (*M* = 6.90, *SD* = 0.75). Although it was marginally significant, this pattern of interaction between physical embodiment without touch and loneliness was consistent across all the dependent variables in Experiment 2. We believe that non-lonely participants were more frustrated by their restricted interaction (i.e., You may see it dance, but please do not touch!) with social agents. Lonely participants in general liked a social agent more than non-lonely participants whether it was embodied or disembodied.

Figure 3 about here

4.4 Conclusions

We were able to find a possible explanation for the surprising results of Experiment 2 in post-experiment interviews with participants who interacted with the physically embodied April. Followings are excerpts from the in-depth interview with participants: “I thought it was going to talk to me.”; “I expected interaction such as sensing users’ movement.”; “I want it to have sensors for interaction rather than to do the same thing over and over again.”; “I expected it to talk to me. It appears to have personality but repeats the same thing; unsatisfying.”; “I want to touch its hand.”; “I expected it to say “Hi” and shake my hands.”

As shown above, most of the participants expected to have some level of interactions with April when they first saw it because of its anthropomorphic shape. However, participants could only see April's performance and were not allowed to touch it. Although a minimum level of interactivity was provided by allowing participants to push a button on a remote control to make April start its dance performance again, participants did not regard it as a meaningful social interaction. The human-robot interaction in Experiment 2 lacked sensory (touch) interaction despite April's highly anthropomorphic shape. According to the uncanny valley effect suggested by Mashiro Mori (see Fong et al., 2003), the subtle imperfection of a human-like creature becomes highly disturbing or even repulsive. Certainly, the anthropomorphic shape of April could set up high expectations (see Slater & Steed, 2002). However, the anthropomorphic-physical embodiment without touch-input capability might lead to the sudden drop from participants' high expectations to frustration and disappointment, which, in turn, might result in the general negative effects of physical embodiment.

The results of Experiment 2 show that physical embodiment does not always result in positive effects. We were surprised to find that physical embodiment without touch-input capability causes negative effects. This finding of Experiment 2 suggests that it is important for physically embodied social robots to have a touch-input capability. It also implies that the importance of tactile communication in interpersonal relationship holds up as well in a new type of relationship—human-robot interaction. The importance of tactile communication in interpersonal relationships has been addressed in many studies. Nguyen et al. (1975) found that touching larger skin surfaces signified playfulness, warmth/love, and friendship/ fellowship. Similarly, Burgoon et al. (1992) also found that the combination of touch and high communicator valence produced the highest credibility and attraction ratings. The current study shows that positive effects of touch in interpersonal communication extend to human-robot interaction. Put together, the effects of physical embodiment may become highly positive when users are able to fully interact with embodied social agents by touching and feeling them.

The results of Experiment 2 also indicate that social agents are more socially attractive to lonely people. This finding supports more diverse roles of social agents and their market potential. Social agents can provide social companionship, thus can be used as therapeutic aids for lonely people. One more interesting finding is the pattern of interaction effects between physical embodiment and loneliness. Lonely people may appreciate social agents more positively than non-lonely people, even without tactile communication with social agents, due to their relatively stronger needs for companionship.

5. General Conclusions and Discussion

In summary, the findings of Experiment 1 elucidate the importance of physical embodiment in the design of social agents. The physical embodiment of a social agent enhances its social presence. The increased social presence contributes to people's positive social responses to the agent, as measured by the following four variables: a) the general evaluation of the agent; b) social attraction of the agent; c) the general evaluation of human-agent interaction; and d) the assessment of public evaluation of the agent. Therefore, physical embodiment as a bodily presence plays an important role in social interactions between human and social agents. Physical embodiment is not a luxurious option but an essential dimension of social agents in order to facilitate meaningful social interactions.

The findings of Experiment 2 doubly confirm the mediating effects of social presence found in Experiment 1. In contrast to Experiment 1, however, the results of Experiment 2 show that physical embodiment with no possibility of tactile interaction decreases an agent's social presence.

The main effects of loneliness found in Experiment 2 also imply a possible important role of social agents in therapeutic aids, especially for the lonely population. As indicated in the results of Experiment 2, the more a person feels lonely, the more the person feels social presence when he or she interacts with a social agent. Thus, bodily presented social agents (social robots) that are capable of *tactile interaction* with humans can provide substantial values, especially to the lonely population such as isolated patients who have immune-deficiency problems. We believe social robots can provide patients and/or the isolated population with not only physical supports (e.g. giving people their medicine on time as well as pertinent medical reminders, or guiding seniors when they go for a walk) but also emotional supports (e.g. playing games with people, or becoming a pet or dependable companion to isolated patients). Pearl, a nurse-bot developed by researchers from the University of Pittsburgh and Carnegie Mellon University, is a good example.

One of the key findings in the current study is that tactile interaction is a key factor in human-agent interaction. Why is tactile interaction so important in human-agent interaction? Based on the media equation paradigm (Reeves & Nass, 1996), we believe that the reason for the importance of tactile interaction in human-agent interaction comes from the importance of tactile interaction in interpersonal relationship. Tactile interaction is deeply involved in interpersonal relationships, ranging from confirming agreement by shaking hands to expressing love by hugging. Tactile interaction and communication can help people lower their guards and open up their minds easily regardless of cultural differences. Until recently, tactile interaction had been a remote possibility in technology-mediated interaction. Thanks to current developments in haptic technologies (see McLaughlin et al., 2002, for a general review of haptic technologies), however, tactile interaction is being successfully simulated, even in mediated interaction situations. For example, researchers at Carnegie Mellon University have designed a huggable pillow, called *Hug*, to provide distant family members with simulated tactile interactions, and thus “better social and emotional support” (Selingo, 2004). *Hug* can send and receive voices, simulate hugs with different vibration patterns, and also radiate heat from its belly. We believe physically embodied social agents equipped with the state-of-art haptic technologies will create a very compelling sense of social presence in the near future.

As a final remark, we would like to raise ethical issues in regard to embodiment. As technologies evolve, it may be impossible to distinguish real humans from embodied social agents (e.g. organismic embodiment [see Ziemke, 2001]). For example, if stem-cell research could successfully clone or cultivate humans for medical or other purposes, do we need to treat the clones as real human beings or organismically embodied social agents? Where should we draw a line for distinction? Or is it necessary to have such a distinction? What about the potential abuse of embodied social agents to persuade people with certain intentions (see Fogg, 1998 for a discussion about the endogenous and exogenous intent in persuasive computers)? Who should be responsible for social agents' malfunctions or even crimes (see Dennett, 1997), the creators or the embodied agents themselves? Although these questions are based on extreme cases, philosophical and ethical discussions about embodiment should be advanced along with technological developments. We hope that the current paper contributes to not only the practical design of social agents and robots, but also the theoretical and ethical discussions on the implications of embodiment in human-agent interaction and relationship.

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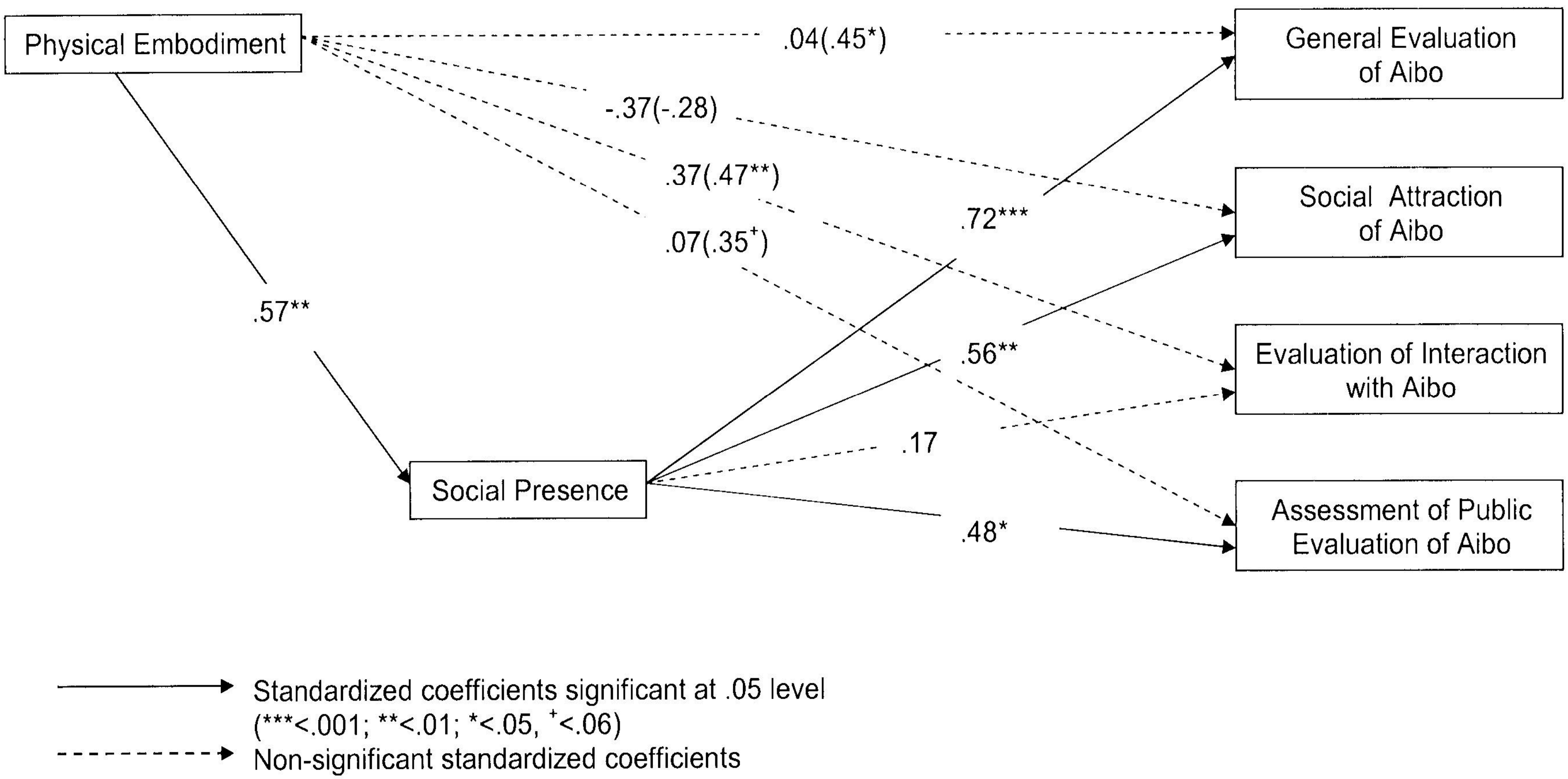
Figure Captions

Figure 1. Path analysis of the mediating effect of social presence in the evaluation of Aibo: Experiment 1.

Figure 2. Path analysis of the mediating effect of social presence in the evaluation of April: Experiment 2.

Figure 3. Interaction effect of embodiment and loneliness on the evaluation of interaction with April: Experiment 2.

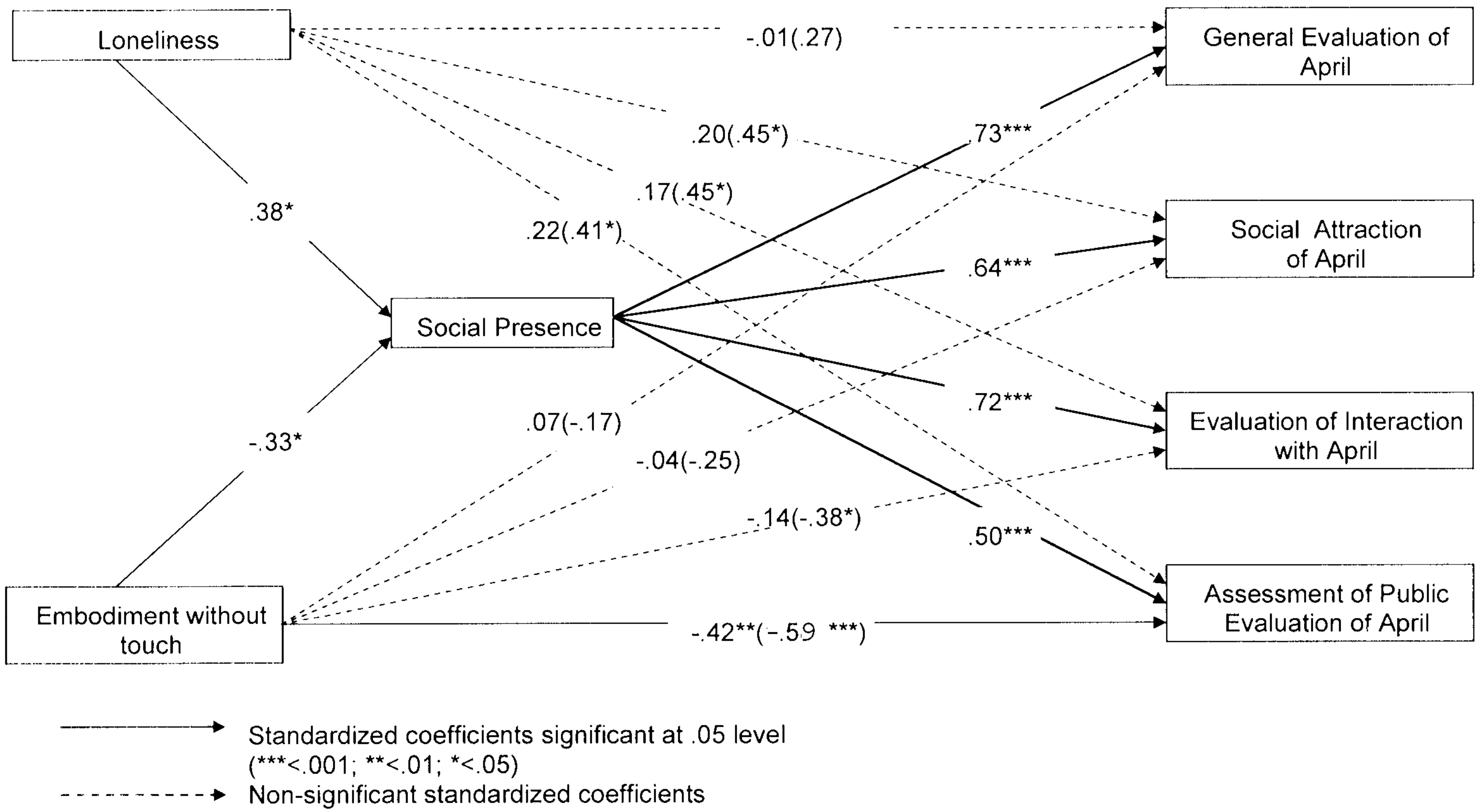
Figure1



Note: Numbers inside arrows are standardized coefficients for each regression. Numbers inside parentheses are standardized coefficients when the evaluation of Aibo was regressed on physical embodiment alone. The two conditions of physical embodiment were dummy coded: 0 disembodied; 1 embodied.

Figure 1.

Figure2



Note: Numbers inside arrows are standardized coefficients for each regression. Numbers inside parentheses are standardized coefficients when the evaluation of April was regressed on loneliness and embodiment without touch (i.e., without social presence). The two conditions of loneliness were dummy coded: 0 non-lonely; 1 lonely. Similarly, the two conditions of embodiment without touch were dummy coded: 0 disembodied without touch; 1 embodied without touch.

Figure 2.

Figure3

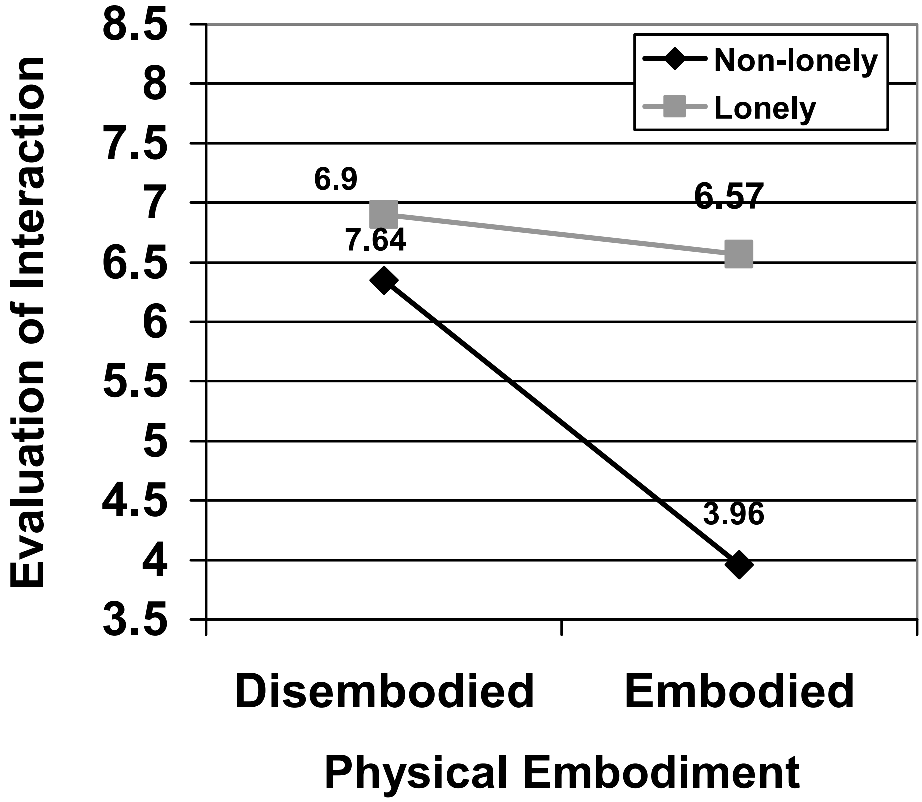


Figure 3.

Measured Variables	1	2	3	4	5
General Evaluation of Aibo		.228	.374*	.258	.584**
Social Attraction of Aibo			.188	.278	.261
Evaluation of Interaction with Aibo				.404*	.454**
Assessment of Public Evaluation of Aibo					.469*
Social Presence					

Note: * $p < .05$, ** $p < .01$ (2-tailed).

Table 1

Correlation Matrix of Five Measured Variables in Experiment 1

Table2

Measured Variable	Embodiment Mean (S.D.) (n = 16)	Disembodiment Mean (S.D) (n = 16)	F (1, 28)	η^2
General Evaluation of Aibo	8.23 (0.92)	7.08 (1.37)	7.65*	.203
Social Attraction of Aibo	4.22 (0.59)	4.29 (0.81)	.08	.003
Evaluation of Interaction with Aibo	8.11 (1.14)	7.13 (0.72)	8.41**	.219
Assessment of Public Evaluation of Aibo	7.98 (1.06)	7.21 (1.09)	4.11^+	.121
Social Presence	7.59 (0.91)	5.97 (1.45)	14.35**	.324

Note: $^+p < .06$, * $p < .05$, ** $p < .01$, *** $p < .001$, (all 2-tailed).

Table 2

Comparison of Embodiment and Disembodiment in Experiment 1: Means, Standard Deviations, and Analysis of Variance

Table3

Measured Variables	1	2	3	4	5
General Evaluation of April		.515**	.705**	.623**	.698**
Social Attraction of April			.643**	.529**	.733**
Evaluation of Interaction with April				.721**	.832**
Assessment of Public Evaluation of April					.721**
Social Presence					

Note: * $p < .05$, ** $p < .01$ (2-tailed).

Table 3

Correlation Matrix of Five Measured Variables in Experiment 2

Table4

Dependent variables	Means and standard deviations				F values and effect sizes		
	Embodiment without touch		Disembodiment		Main effects		Interaction effects
	Lonely group	Non-lonely group	Lonely Group	Non-lonely group	Embodiment without touch (E)	Loneliness (L)	E x L
General evaluation of April	7.54	6.38	7.33	7.33	0.95	2.36	2.36
	(1.03)	(1.18)	(0.72)	(1.25)	η^2 = .03	η^2 = .08	η^2 = .08
Social attraction of April	3.25	1.96	4.04	2.67	2.40	7.57*	.01
	(1.50)	(0 .86)	(1.28)	(1.70)	η^2 = .08	η^2 = .21	η^2 = .00
Evaluation of interaction with April	6.57	3.96	6.90	6.35	7.15*	9.71**	4.13^{+}
	(0.95)	(1.24)	(0.75)	(1.17)	η^2 = .20	η^2 = .26	η^2 = .129
Assessment of public evaluation of April	5.49	3.48	7.37	6.17	20.18***	10.06**	0.64
	(0.83)	(1.70)	(1.47)	(1.59)	η^2 = .42	η^2 = .26	η^2 = .02
Social presence	5.68	4.03	6.28	5.53	4.26*	5.64*	0.77
	(1.16)	(1.64)	(0.57)	(1.97)	η^2 = .13	η^2 = .17	η^2 = .03

Note. Standard deviations are in parenthesis. * $p < .05$, ** $p < .01$, *** $p < .001$

Table 4

ANOVA Results from Experiment 2