Effects of Physical Embodiment on Social Presence of Social Robots

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Abstract

Two experiments were conducted to investigate the relative effectiveness of physical embodiment on social presence of social robots. The results of Experiment 1 show positive effects of physical embodiment of social robots (PESR) in the feeling of social presence, the general evaluation of social robots, the assessment of public opinion of social robots, and the evaluation of interaction with social robots. The result of a path analysis also provides the evidence of the mediating effect of social presence in people's general evaluation of social robots. However, the results of Experiment 2 show that PESR without touch-input capability causes negative effects. Implications for the relative effectiveness of PESR, the importance of tactile communication in human-robot interaction, as well as the market potential for social robots in relation to loneliness are discussed.

Keywords---Physical embodiment, touch, human-robot interaction, companionship, social robots, tactile communication.

1. Introduction

In the movie "A.I." directed by Steven Spielberg, Cybertronics, a firm that manufactures robots, creates a new boy robot to both give and elicit the genuine emotion of love. Its name is David. The major purpose of David is to share emotional reciprocity with human beings, which is totally different from the purpose of utility robots such as cleaning, cooking, or industrial manufacturing. Although we do not have social robots as sophisticated as David in "A.I." yet, researchers and practitioners have begun to realize that robots can be social actors whose major purpose is to interact with humans in a socially meaningful way.

Lee et al. [7] define social robots as "new types of robots whose primary goal is social interaction with humans." In other words, a social robot is a robot designed to evoke meaningful social interaction with its users. Given the above definition, social robots do not necessarily need physical embodiment to accomplish their goals unlike other functional robots. Physical embodiment is a mandatory requirement for functional robots because the purposes of them are mostly related to labor-intense works such as cleaning, destroying, or lifting. However, the purposes of socially interactive robots are research platform, toys, educational tools, and therapeutic aids including emotional supports [4]. Most of these goals are not directly related to physical activities per se, thus can be delivered via virtually embodied social robots.

One of the most fundamental questions on social robots is whether or not physical embodiment is required for the successful social interaction between human and social robots. This is a critical question to both researchers and practitioners due to high costs for manufacturing physically embodied social robots, not to mention technical difficulties. Nonetheless, there are only a few empirical studies investigating the effects of *physical embodiment of social robots* (PESR) in human-robot interaction.

Two experiments were conducted in this study in order to investigate the relative effectiveness of PESR. In addition, the feeling of social presence is examined in a path analysis to investigate its mediating effects in human-robot interaction. Finally, we discuss how lonely and non-lonely people respond differently to social robots such as Sony Aibo or Samsung April.

2. Literature review

2.1. Embodiment

Fong et al. [4] define embodiment as "that which establishes a basis for structural coupling by creating the potential for mutual perturbation between system and environment." Given the definition, as long as the relationship between a system and its environment is perturbative, physical embodiment is not necessary any more. Thus, this relational definition of embodiment raises an important question whether or not a physical embodiment is essential in designing social robots.

The positive expectation about physical embodiment is that PESR may result in better affordance, thus lead to less frustration from people. In fact, the form and structure of a robot is important because it helps establish social expectations [4]. Therefore, the following hypotheses are proposed:

H1: People will evaluate a social robot more positively when they interact with a physically embodied social robot than when they interact with a physically disembodied social robot.

H2: People will assess other people's evaluation of a social robot more positively when they interact with a physically embodied social robot than when they interact with a physically disembodied social robot.

H3: People will evaluate the interaction with a social robot more positively when they interact with a physically embodied social robot than when they interact with a physically disembodied social robot.

2.2. Social presence

Lombard et al. [8] define presence as "the perceptual illusion of non-mediation." Similarly, Lee [5] 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 nonsensory ways." Given the above definitions, the feeling of social presence can play an important role in successful social interactions with even non-human beings. 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 social actor. For example, although David in the movie, "A.I.," is not a real boy, the mother is satisfied with her emotional fulfillment from social interaction with David. It means that she feels strong social presence of her real son—an actual social actor—when she interacts with David—an artificial actor—in sensory ways.

Bartneck [2] found social facilitation effect in his study with an emotional robot, eMuu. In the study, participants acquired higher score in the negotiation game when they interacted with a robot character—physically embodied character—than when they interacted with a screen character—physically disembodied character. Although Bartneck did not use a specific term of "social presence" in his study, the finding of social facilitation effect can be explained in terms of social presence. Participants in the experiment put more effort into the negotiation when they interacted with the physically embodied character because they felt strong social presence.

Indeed, the feeling of social presence is highly likely to be related to the richness of sensory inputs because the more a person feels, the stronger the person believes (see [18]). PESR can provide people with richer sensory inputs than *physically disembodied social robots* (PDSR), which may result in people's strong feeling of social presence. The strong feeling of social presence, then, may result in positive effects of social robots. Therefore, social presence could be a mediating factor in the effectiveness of PESR. Based on this assumption, the following hypotheses are proposed:

H4: People will feel stronger social presence when they interact with a physically embodied social robot than when they interact with a physically disembodied social robot.

H5: The effects of physical embodiment on general attraction of a social robot, assessment of public opinion of a social robot, and evaluation of the interaction with a social robot will be mediated by users' feeling of social presence.

2.3. Loneliness

Social robots are similar to pets in a way that both of them provide people with companionship. Similar to the findings that interaction with pets would be good complementary to or even substitute for traditional interpersonal interaction [19], social robots may be able to satisfy one's needs for social interaction.

We are not surprised to see that Rook [15] found a significant negative relationship between loneliness and companionship. In his study more frequent companionship with other people was associated with less loneliness. Therefore, 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, the last hypothesis is proposed:

H6: Lonely people will feel more socially attracted to a social robot than non-lonely people.

3. Experiment 1: Effects of physically embodied social robots

3.1. Experiment design

A 2 (embodiment vs. disembodiment) x 2 (lonely vs. non-lonely) between subjects factorial analysis of variance (ANOVA) design was used to test the hypotheses in a laboratory environment. A total of 36 undergraduate students enrolled at a major west-coast university were participated in the experiment.

3.2. Procedure

The whole experiment process consists of three steps. First, a survey of UCLA Loneliness Scale (Version 3) was administered in a larger data pool of 62 people. Then, 16 participants were selected from each extreme end of the scale based on their survey scores.

Second, 16 participants within each group (lonely vs. non-lonely) were randomly assigned to one of the two different embodiment conditions (embodiment vs. disembodiment). For example, 8 participants in the lonely group were randomly assigned to the embodied condition. The other half (8 participants) in the lonely group were also randomly assigned to the disembodied condition.

Finally, participants were asked to come to a laboratory where they individually interacted with a social

robot, Sony Aibo, for about 10 minutes alone. Then, participants were asked to complete a paper-based survey.

3.3. Manipulation

Two conditions of physical embodiment were manipulated for Experiment 1. First, Sony Aibo was selected to represent a physically embodied social robot because Aibo is one of the most successful social robots currently on the market [7]. Aibo contains sensors in its head, chin, and back that enable interactions with people by affectionate pats. For the experiment purpose, Aibo was programmed to perform singing and dancing for 2 minutes and 20 seconds. After its performance, Aibo was also programmed to interact with participants by responding to its sensory inputs in limited and constant ways. Participants in the physically embodied condition interacted with actual Aibo.

Second, physically disembodied Aibo was manipulated by using animation-making software, Director. Aibo's performances were pre-recorded in a digital camcorder. Then, the digital video files in AVI format were imported to Director for final manipulation. The created program was shown in a shockwave player on a 17 inch flat-screen monitor. When participants in the physically disembodied condition clicked any of Aibo's sensory input areas, they saw a virtual hand pushing the sensory area on the screen, and then saw a particular response from Aibo just like they would have seen from Aibo in the physically embodied condition.

To summarize, the main difference between two embodiment conditions was whether or not participants interacted with actual Aibo or virtual Aibo that was digitally programmed.

3.4. Measure

All dependent measures were based on items from paper-based questionnaires.

UCLA Loneliness Scale (Version 3) was used to measure participants' perceived loneliness. The scale has been tested in many studies and regarded to be highly reliable in terms of internal consistency (coefficient α ranging from .89 to .94) and test-retest reliability over a one-year period (r = .73) [16].

Seven questions concerning the general evaluation of Aibo were asked using 10-point Semantic-differential scale: *bad/good; bitter/sweet; cruel/kind; distant/close; not friendly/friendly; not loving/loving; unpleasant/pleasant* (Cronbach's α = .91). This is a modified measure from the study of Perception Of Pets As A Companion by Poresky et al. [13].

Six questions about social presence were asked using a combination of 10-point Semantic-differential scale and independent 10-point scale: *unsociable/sociable; impersonal/personal; machine-like/life-like; insensitive/ sensitive; while you were interacting with this Aibo, how much did you feel as if it was a social being?; while you were interacting with this Aibo, how much did you feel as if it was communicating with you*? (Cronbach's α = .920). Psychological perspective of social presence such as attention and involvement were disregarded because 10 minutes of interaction time was too short to establish involvement. Besides, participants were asked to pay attention to Aibo and allowed to interact with Aibo alone in a laboratory room. Therefore, measuring participants' attention is considered to be inappropriate for the measure of social presence in this study.

Three questions concerning public opinion of Aibo were asked using independent 10-point scale: *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).

Six questions dealing with the evaluation of interaction with Aibo were asked using independent 10-point scale: *enjoyable; entertaining; exciting; fun; interesting; satisfying* (Cronbach's α = .88).

Social attraction and physical attraction were measure by a modified version of McCroskey and McCain's Interpersonal Attraction Scale [9]. Three questions about social attraction of Aibo were asked using independent 7-point scale: *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).

Finally, three questions concerning physical attraction of Aibo were asked using independent 7-point scale for the manipulation check: *I think this Aibo is quite pretty; This Aibo is very good looking; I find this Aibo very attractive physically* (Cronbach's α = .88).

3.5. Results

Table 1 shows a full correlation matrix of the measured variables in Experiment 1. Although personal evaluation and the assessment of other people's attraction may sound similar, they are different concepts due to the third person effects [12]. A person may not feel attracted to Aibo at all, but may think that other people would.

Hypotheses were tested with one-way between subjects ANOVA. Consistent with Hypothesis 1, participants evaluated the physically embodied Aibo more positively (M = 8.14, SD = 0.8499) than the physically disembodied Aibo (M = 7.34, SD = 1.0970), F (1, 28) = 5.141, $p < .05$, $\eta^2 = .191$.

Consistent with Hypothesis 2, participants assessed other people's evaluation of a social robot more positively when they interacted with the physically embodied Aibo (M = 7.98, SD = 1.0644) than when they interacted with the physically disembodied Aibo (M = 7.21, SD = 1.0829), F (1, 28) = 4.4, $p < .05$, $\eta^2 = .233$.

Consistent with Hypothesis 3, participants evaluated the interaction with Aibo more positively when they interacted with the physically embodied Aibo (M = 8.11, SD = 1.1395) than when they interacted with the physically disembodied Aibo (M = 7.13, SD = 0.7245), F (1, 28) = 15.28, $p < .01$, $\eta^2 = .599$.

Consistent with Hypothesis 4, participants felt stronger social presence when they interacted with the

Table 1

Correlation Matrix of Six Measured Variables in Experiment 1

Measured Variables	1	2	3	4	5	6
1. General Evaluation of Aibo		.228	.258	.374*	.584**	.337
2. Social Attraction of Aibo			.278	.188	.261	.096
3. Assessment of Public Opinion				.404*	.454**	.117
4. Evaluation of Interaction with Aibo					.469*	.250
5. Social Presence						.343
6. Physical Attraction of Aibo						

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

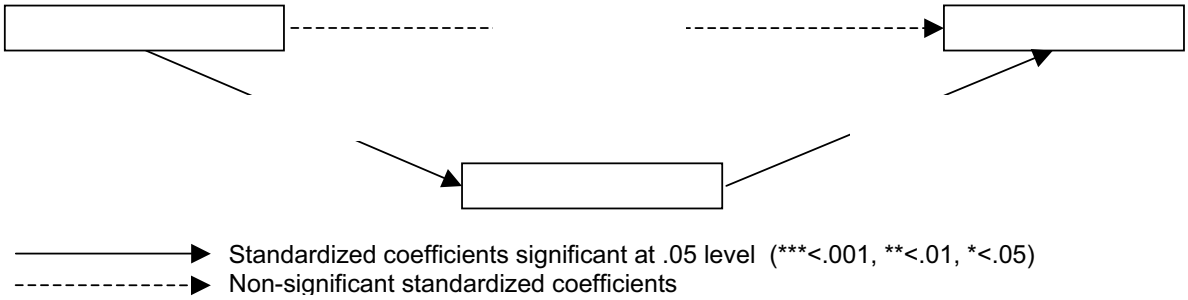

Figure 1. Path Analysis of the Mediating Effect of Social Presence in the Evaluation of Aibo: Experiment 1.

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. Two conditions of physical embodiment were dummy coded: 0 disembodied; 1 embodied.

physically embodied Aibo (M = 7.81, SD = .8185) than when they interacted with the physically disembodied Aibo (M = 5.62, SD = 1.2903), F (1, 28) = 32.27, $p < .001$, $\eta^2 = .545$.

A path analysis was conducted to test Hypothesis 5, which predicted the mediating effect of social presence on other dependent variables (see Figure 1).

The physical embodiment was a significant predictor for the general evaluation of Aibo ($\beta = .385$, $p < .01$) and for the feeling of social presence ($\beta = .724$, $p < .001$) when it was the only predictor entered into a simple linear regression. The feeling of social presence was also a significant predictor when the evaluation of Aibo was the only predictor regressed on social presence ($\beta = .641$, $p < .01$). However, the effect of physical embodiment on the general evaluation of Aibo significantly dropped and became non significant when the dependent variable was regressed on both physical embodiment and social presence. Put together, the series of the regression analyses reported in Figure 1 provide a strong evidence for the mediating effect of social presence on people's general evaluation of social robots (for the statistical proof of why the above analyses provide a convincing evidence for mediation, see [1]).

For three other dependent variables both of the effects of embodiment and social presence became non significant when the dependent variables were regressed on both embodiment and social presence. In conclusion, the current path analysis provides evidence of the mediating role of social presence only in people's general evaluation of social robots.

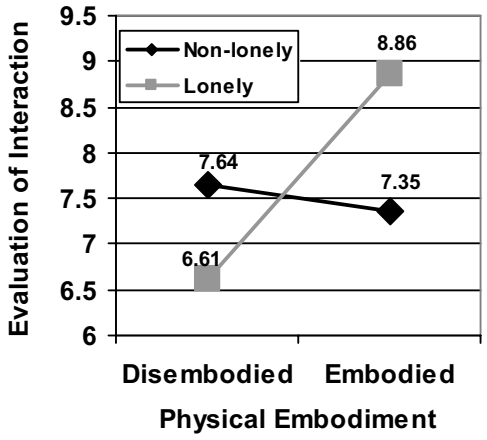

Figure 2. Interaction Effect of Embodiment and Loneliness in Experiment 1.

Note. The evaluation of interaction with Aibo was measured in 10-point semantic differential scale. Numbers above markers are means.

Consistent with Hypothesis 6, participants in the lonely group felt more social attraction to Aibo (M = 4.57, SD = 0.370) than participants in the non-lonely group did (M = 3.95, SD = 0.8151), F (1, 28) = 7.184, $p < .05$, $\eta^2 = .208$. In addition, a significant interaction effect between loneliness and embodiment in the evaluation of interaction with Aibo was found with two-way between subjects ANOVA, F (1, 28) = 25.607, $p < .001$, $\eta^2 = .599$ (see Figure 2). Specifically, under the disembodied condition, participants in the non-lonely group evaluated the interaction with Aibo more positively (M = 7.64, SD = 0.5523) than participants in the lonely group did (M = 6.61, SD = 0.4600). Alternatively, under the embodied condition, participants in the lonely group evaluated the interaction with Aibo more positively (M = 8.86, SD = 0.5664) than participants in the non-lonely group did (M = 7.35, SD = 1.0817).

Participants did not feel any difference in physical attraction between the physically embodied Aibo and the physically disembodied Aibo, F (1, 28) = 1.49, *n.s.* This non-significant finding suggests that the manipulation of two embodiment conditions is successful. Physical attraction should be same across two embodiment conditions because the physical shapes of Aibo in the two conditions are exactly same.

3.6. Discussion

A number of conclusions can be drawn from the results of Experiment 1. First, physically embodied social robots (PESR) are more attractive to people (H1 & H2). This result implies that physical embodiment is an important component in designing social robots although social robots are not particularly related to physical functions. People prefer interactions with physical social actors to interactions with virtual social actors.

Second, social robots are more socially attractive to lonely people (H6). This finding supports more diverse role of social robots and their market potential. Social robots can provide social companionship, thus can be used as therapeutic aids for lonely people. Indeed, social robots are not just toys for kids.

Third, physical embodiment yields higher social presence of artificial social robots than physical disembodiment (H4). The result implies that PESR influences people's imagination of actual social actors positively. In addition, the social presence is the key mediating variable for the effect of physical embodiment in the general evaluation of social robots (H5). The result also implies that people's social responses to artificial social robots are oriented toward imagined social actors. These findings support the *computers are social actors* (CASA) paradigm suggested by Nass and his colleagues [14, 10]. It also replicates the results reported by Lee and Nass [6].

Finally, an interaction effect between embodiment and loneliness was found in the evaluation of interaction with Aibo (see Figure 2 in Section 3.5.). The result shows that lonely people are more sensitive to PESR than non-lonely people. It implies that touch-input capability can be a potential factor that causes the major difference of effectiveness between physically embodied and disembodied social robots. The distinctive sensory difference between two embodiment conditions is touch. Participants in the physically embodied condition could touch and feel actual Aibo unlike participants in the physically disembodied condition where they saw a virtual hand touching Aibo. Participants in the lonely group might appreciate touch-input capability more positively than participants in the non-lonely group due to their relatively stronger needs for companionship.

However, we have to be cautious to draw a conclusion about the positive effects of touch-input capability in human-robot interaction from the results of Experiment 1. Physical embodiment has two major components: (1) visual embodiment; (2) touch. Of course, in future other human senses such as smell and taste can be incorporated into PESR. For now, however, the incorporation of other human senses is not the major concern for the development of social robots. There is no major difference between physical embodiment and disembodiment with regard to audio. Therefore, people can sense the physical embodiment of social robots by simply seeing them or by directly touching them. Due to the nature of "embodiness," the above two factors cannot be separated under a normal condition. In fact, touch is a nesting variable because there is no "touch" for physically disembodied conditions. As a consequence, we could not make separate conclusions on the effects of visual embodiment and the effects of touch-input capability based on Experiment 1.

In order to make a clear conclusion about the effects of PESR and to eliminate an alternative explanation of the effects of visual embodiment, we conducted Experiment 2 by manipulating physical embodiment only as a "visually embodied" factor. In Experiment 2 we focused solely on the effects of touch-input capability in human-robot interaction.

4. Experiment 2: Effects of touch-input capability in human-robot interaction

The importance of tactile communication in interpersonal relationship has been addressed in many studies. Nguyen et al. [11] found that "touching larger skin surfaces signified playfulness, warmth/love, and friendship/ fellowship." Similarly, Burgoon et al. [3] also found that the combination of touch and high communicator valence produced the highest credibility and attraction ratings in their empirical study. These findings from interpersonal communication may hold up in a new type of relationship, human-robot interaction. Therefore, Experiment 2 was conducted to examine the effects of touch-input capability in human-robot interaction.

4.1. Experiment design

The same 2 (embodiment vs. disembodiment) x 2 (lonely vs. non-lonely) between-subjects factorial analysis

of variance design with a total of 36 participants was used in Experiment 2.

4.2. Procedure

The procedures were same as Experiment 1, except the use of a new social robot. April, a prototype robot manufactured by Samsung Electronics, was used instead of Aibo in order to control touch-input capability in the physically embodied condition. April can play music and perform dance as programmed. Unlike Aibo in Experiment 1, we disabled all the sensors of April and instructed participants in the physically embodied condition not to touch April. By doing so, we could eliminate the potential effects of touch from the effects of PESR in Experiment 2. Therefore, the only difference between the embodiment and disembodiment conditions was whether or not participants saw actual dancing April or virtual dancing April.

4.3. Manipulation

Same as Experiment 1, two conditions of embodiment were manipulated. First, April was programmed to play a particular song and to perform a dance based on the song for two minutes. Then, the pre-recorded performance in a digital movie format was shown on a 17 inch flat-screen monitor for the physically disembodied condition.

4.4. Measure

In addition to the previous measures, three questions concerning the evaluation of music were asked using independent 10-point scale: *how much did you enjoy hearing this music?; how likely would you be to recommend this music to your friends?; how likely would you be to download this music?* (Cronbach's $\alpha = .79$).

Same six questions used in Experiment 1 regarding the general evaluation of April were asked (Cronbach's $\alpha = .86$). One question eliminated from the index used in Experiment 1 was *distant/close*. The question was regarded irrelevant because participants were not allowed to touch April in Experiment 2.

Same five questions used in Experiment 1 concerning social presence were asked (Cronbach's $\alpha = .79$). Once again, one question used in Experiment 1 was eliminated: *impersonal/personal*. Because April has an anthropomorphic shape of female body line with futuristic look, asking the question of impersonal/personal seemed to be meaningless.

Same three questions used in Experiment 1 were used to measure the assessment of public opinion (Cronbach's $\alpha = .83$).

Same six questions used in Experiment 1 concerning the evaluation of interaction with April were asked (Cronbach's $\alpha = .92$).

Same three questions used in Experiment 1 regarding social attraction of April were asked (Cronbach's $\alpha = .92$).

4.5. Results

Table 2 shows a full correlation matrix of the measured variables in Experiment 2. Again, hypotheses were tested with one-way between subjects ANOVA.

We are rather surprised to find that the results of Experiment 2 were either opposite to the results of Experiment 1 or not significant. More specifically, participants evaluated music more positively when they interacted with the physically disembodied April ($M = 6.92$, $SD = 0.8801$) than when they interacted with the physically embodied April, ($M = 5.23$, $SD = 1.9196$), F (1, 28) = 11.78, $p < .01$, $\eta^2 = .393$.

There was no significant difference between two embodiment conditions with regard to the feeling of social presence. The non-significant pattern shows that participants felt moderately stronger social presence when they interacted with the physically disembodied April ($M = 5.72$, $SD = 1.4609$) than when they interacted with the physically embodied April, ($M = 4.75$, $SD = 1.5117$), F (1, 28) = 3.75, *n.s.*.

Participants assessed other people's evaluation of April more positively when they interacted with the physically disembodied April ($M = 6.77$, $SD = 1.6063$) than when they interacted with the physically embodied April, ($M = 4.48$, $SD = 1.6526$), F (1, 28) = 41.78, $p < .001$, $\eta^2 = .525$.

Participants evaluated the interaction with April more positively when they interacted with the physically disembodied April ($M = 6.62$, $SD = 1.2718$) than when they interacted with the physically embodied April, ($M = 5.26$, $SD = 2.0323$), F (1, 28) = 7.15, $p < .05$, $\eta^2 = .426$.

Table 2

Correlation Matrix of Six Measured Variables in Experiment 2

Measured Variables	1	2	3	4	5	6
1. Evaluation of Music		.355	.390*	.515**	.602**	.481**
2. General Evaluation of April			.438*	.609**	.651**	.557**
3. Social Attraction of April				.529**	.643**	.684**
4. Assessment of Public Opinion					.721**	.642**
5. Evaluation of Interaction with April						.773**
6. Social Presence						

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

Lastly, participants in the lonely group felt more social attraction to April (M = 3.65, SD = 1.4062) than participants in the non-lonely group, (M = 2.31, SD = 1.3525), F (1, 28) = 7.57, $p < .05$, $\eta^2 = .263$. This finding, which replicates the result of Experiment 1, shows a solid evidence for the strong needs of social robots to lonely people.

4.6. Discussion

We can find a possible explanation for the results of Experiment 2 in post-experiment interviews with participants. 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 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 even in the physical embodiment condition in Experiment 2. Although a minimum level of interactivity was provided by allowing participants to push a button on a remote control to make April start its dancing performance, participants did not regard it as a meaningful social interaction. The interaction that participants had in Experiment 2 lacked sensory touch despite April's highly anthropomorphic shape. According to the uncanny valley effect suggested by Mashiro Mori, the subtle imperfection of the recreation becomes highly disturbing, or even repulsive (see [4]). Certainly, the anthropomorphic shape of April could set up high expectations [17]. However, the anthropomorphic shape without touch-input capability might lead to the sudden drop of participants' high expectations to their frustration and disappointment, which, in turn, might result in the general negative effects of physical embodiment.

The results of Experiment 2 show that PESR does not always result in positive effects. We are surprised to find that PESR without touch-input capability causes negative effects. This finding in Experiment 2 suggests that it is important for physically embodied social robots to have touch-input capability. It also implies that the importance of tactile communication in interpersonal relationship holds up in a new type of relationship, human-robot interaction, as well. To put together, the effects of PESR may become synergetic when users are able to fully interact with social robots by touching and feeling them.

5. Conclusions

In summary, the findings of Experiment 1 elucidate the importance of physical embodiment in designing social robots. Physical embodiment usually enhances the feeling of social presence, which results in more positive evaluation of social robots. Furthermore, the findings of Experiment 2 indicate the relative effectiveness of PESR: without the power of touch-input capability and interaction, the effectiveness of PESR diminishes in human-robot interaction. Especially, Experiment 2 helped us to make a solid conclusion about the effects of touch-input capability in human-robot interaction by allowing us to separate two nesting component of physical embodiment: (1) visual; (2) touch. We hope the findings of this study shed light on the design of social robots, the importance of tactile communication in human-robot interaction, and the design of new interfaces for future technologies.

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