Comparing Robot Embodiments for Social Human-Robot Interaction of a Health Coach Service

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The Asian Conference on Arts & Humanities 2017
Official Conference Proceedings

Abstract
As robotics technologies are advancing at an ever increasing rate, various types of service robots have emerged in the market and focused on assisting people through social interaction. This study aims to investigate the effects of robotic platforms on users' perception of a socially assistive robot, to better understand whether people respond differently to a physical robot versus its digital representation on screen. By applying the Wizard of Oz method, a three-condition experiment was conducted to compared participants' responses in a health coaching session with (a) a physical, humanoid robot coach, (b) its full size, 3D animated agent coach displayed on a 37-inch TV screen, or (c) a much smaller animated agent coach on a mobile.
The results showed that participants' responses to the physical robot coach differed from their responses to its digital representations (agent coaches). In addition, the display device for an agent coach also affected participants' subjective and behavioral responses to the health coach service. Participants appreciated more and disclosed more with the physical robot coach and the agent coach on TV, than with the agent coach on mobile device.
In all subjective evaluations, the attitudes of the participants were most positive toward physical robots, except trust. Instead, the agent coach on the TV was the most trusted. To conclude the study, implications for robotic platforms in HRI were discussed.

Keywords: Human-Robot Interaction, Social Robot, Digital Agent; Wizard of Oz Experiment

Introduction

The advent of automatic technology and artificial intelligence has gradually affected people's daily life. Socially assistive robots could be used as potential touchpoints in future services. Statistics on consumer technology usage and adoption predicts that service robots and software agents for personal assistance, entertainment, or other social purposes will become a common scene in our future life (Ericsson Consumer Lab, 2015; Haden, 2016). Studies have shown that autonomous artificial entities, such as robots and embodied agents, elicit social behavior on their human counterparts (von der Pütten, Krämer, Gratch, & Kang, 2010; Reeves & Nass, 1996), and that people respond to physical robots and their virtual representation on computer displays differently (Powers, Kiesler, Fussell, & Torrey, 2007; Fasola & Matarić, 2013). Hence advices and guidance for human-robot interactions regarding robot embodiments for social interaction and potential applications are provided. However, in current Human-Robot Interaction (HRI) literature there is still little discussion about whether people respond differently to a physical robot versus its digital representation on smartphones. With the technological advancements in mobile devices, smartphones and internet are changing the way people do things and connect with others (Levin, 2014). People own multiple devices and use them interchangeably, not only because multi-devices allow users act spontaneously, but they make people feel a sense of accomplishment as well; and smartphones are the "backbone" of people's daily media interactions (Google, 2012). In order to explore the possibilities of integrating physical robots and virtual agents into a seamless service, firstly we need to understand how users react differently to robotic assistants based on their platforms. Therefore, in the present research, we studied the effects of robotic platforms on users' perception of a socially assistive robot by applying the Wizard of Oz experiment method. The Wizard of Oz method is an experimental user interface testing method in which subjects of the system are made to believe that they are interacting with a autonomous system though the system is actually being operated or partially operated by an unseen experimenter, or several of them (Dahlbäck, Jönsson, & Ahrenberg, 1993; Steinfeld, Jenkins, & Scassellati, 2009).

Related Studies

Social robots are believed to be users' capable partners rather than tools because of their potential to be perceived as trusting, helpful, reliable, and engaging (Breazeal, 2004). Empirical studies have shown that autonomous artifacts can elicit social behavior of their users, no matter whether users believe they were interacting with another mediated remote user or a virtual person, but with a subtle difference (Reeves & Nass, 1996; von der Pütten et al., 2010). Previous experimental studies comparing physical robots with virtual agents have claimed that people respond to physical robots and virtual agents differently, and physical robots are seen as more engaging, credible and informative, and enjoyable to interact with (Paauwe, Hoorn, Konijn, & Keyson, 2015; Powers et al., 2007; Fasola & Matarić, 2013; Y Shinozawa, Naya, Yamato, & Kogure 2005; Komatsu, 2010). A comprehensive literature review and investigation on comparing co-present robots, telepresent robots and virtual agents was carried out by Li (2015), and the result suggests that even when the robot and the virtual agent have similar appearance and identical behavior, co-present robots are more persuasive, receive more attention, and are perceived more positively than virtual agents.

In order to effectively compare the effects of different robotic embodiments, it is important to select a feasible context for the use of social robots. In previous studies, health care-related activities were often used as the experimental context for social HRI studies (Fasola & Matarić, 2013, Paauwe et al., 2015; Powers, et al., 2007; Feil-Seifer & Matarić, 2005). In addition, the instrument for assessing the social quality of human-robot-interaction is also critical in the investigation of users' acceptance on assistive social robots, several methods and toolkits have been developed based on different theoretical frameworks (Dautenhahn, 2007; Fong, Nourbakhsh, & Dautenhahn, 2003; Heerink, 2010; Lombard, Ditton, Crane, Davis, Gil-Egui, Horvath, Rossman, & Park, 2000).

Research Questions

By taking three robotic platforms (humanoid robot, home TV, and smartphone) into account, this study aims to provide an empirically grounded answer to the question how does the platform of robotic assistants affect people's reaction to a health coach service. Based on the above-mentioned literatures, we predicted physical robot would have more social impact, and be more lifelike and engaging, and that the virtual robot on a TV monitor or mobile screen would seem less lifelike and would lead to less engagement, but would elicit more participant's self-disclosure, than the physical robot. Although there is few previous study on virtual embodiment involving smartphones as robotic platforms, with the continuing growth of smartphone ownership and penetration (Martin, 2011), we believe using mobile devices as robotic platforms could be better accepted and considered useful. However, the size of a robotic assistant could affect people's perception on its social presence; hence the virtual robot on mobile screen would seem less real and would have less social impact than full-sized robot, either physical or virtual. If so, social impact of different platforms should be ordered as follows: humanoid robot > virtual robot on TV > virtual robot on mobile. Therefore, we hypothesized that:

- H1: The physical humanoid robot as compared with the virtual robots will be more engaging, enjoyable, and command more social influence. It will increase the accuracy of participants' performance on physical movement related tasks.
- H2: The full-size virtual robot displayed on TV monitor will be more trustworthy and acquire more disclosure of personal information than the physical humanoid robot.
- H3: The smaller virtual robot displayed on smartphone screen will be rated more useful, but with the least social presence.

Figure 1. The three conditions: a physical robot, a virtual robot on TV monitor, and a virtual robot on smartphone screen.

Study Design and Method

In this study, our focus is on the social human-robot interaction in the context of a health coach service. We compare a physical robot coach with its virtual embodiments on two different devices, TV and smartphone. The experiment was a between-group design; each participant was randomly assigned to one of the three conditions. The three conditions were a physical robot, a full-sized virtual robot on TV monitor, and a smaller, about one-third the size, virtual robot on smartphone screen (Figure 1).

Experiment Setup

This experiment involved a semi-structured human-robot dialogue phase, and some simple physical-assessment-like tasks in a laboratory setting. Therefore, we decided to adopt the Wizard of Oz experiment method (Steinfeld, Jenkins, & Scassellati, 2009) where the robots were controlled remotely by experimenters while the participants perceived them to be autonomous. Figure 2 shows a floor-plan representation of the laboratory environment. When the participants arrived at the lab, they were initially welcomed at the reception area. After the experimenter explained the goal of the study to him/her, they were sent to the observation room, and asked to have a discussion with a robotic health coach about their general health habits. Then the experimenter entered the control room to control the robot and observe the participant's behavior through a one-way-mirror. After participants finished their health-related discussion with the coach, they were asked to fill out a questionnaire and had a short interview with the experimenter.

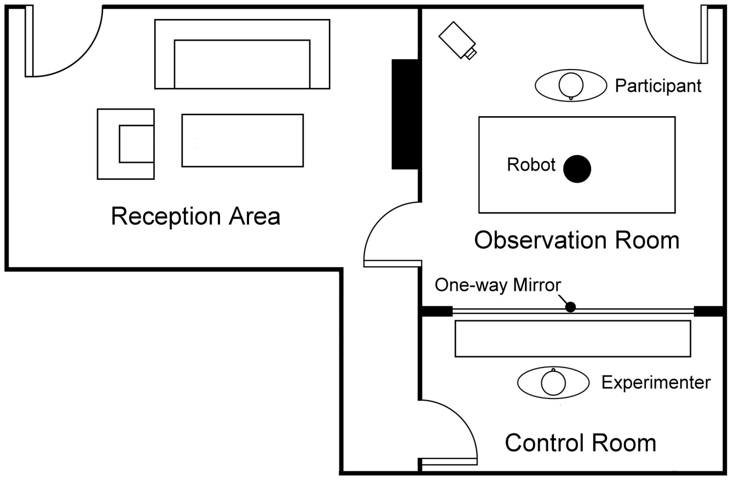

Figure 2. Schematic overview of the laboratory setting for the experiment

Participants

Eighty participants were recruited from the campus of National Taichung University of Science and Technology in Taiwan. Participants were 56% female, with an average age of 23.7 years (range 20-32). Each participant was randomly assigned to one of the three conditions, and received $3.5 compensation for taking part in the 20-minute experiment.

Equipment

For the physical robot condition, the humanoid robot Alpha 1S, a programmable home entertainment robot developed by UBTECH (http://www.ubtrobot.com/product/detail2.html) was used. It featured editing software for 3D visual actions and was equipped with a Bluetooth module, which allowed us to control remotely via its mobile application and made it a suitable robot platform for this study. An elaborate script with the possible scenarios in a health coaching session was carefully planned. Based on the script, a set of pre-programed robot behaviors with synthesized voice were then carefully prepared, so the hidden experimenter in the Wizard of Oz experiment could decide to play any suitable robot behavior according to the situation. For the other two virtual robotic platforms, virtual robot on TV and virtual robot on smartphone, we directly recorded the 3D simulation from Alpha 1S's editing software to build two sets of video clips, one for TV monitor and one for mobile screen. Then post-production software was used to add synthesized voice in to each clip. The experimenter could control the behavior of virtual robots just like the way he/she controlled the humanoid robot.

Figure 3. Participants and the three robotic coaches in the study.

Procedures

The procedure for each session was as following:

1. Each participant was explained about the task in the experiment and signed the consent form.
2. The participant was led to the observe room, in which one of the robotic coaches, four colored card, and a copy of questionnaire were on a desk, as show in Figure 3. The experimenter instructed the participant to sit in front of the desk and wait, and left the room.
3. When the participant was alone in the room, the robotic coach started the one-on-one coaching session: the robot introduced itself to the participant, instructed him/her to perform some simple physical tasks for physical assessment, and asked questions about their general health habits, such as sleep, diet, exercise.
4. When the participant finished all of the tasks, the robotic coach indicated the session finished, and asked the participant to fill out a questionnaire for measuring his/her impression of the coach.
5. Finally, the experimenter interviewed the participant about the coaching experience and the experiment.

Dependent Variables

We measured the social effects of robotic platforms as revealed in participants' behavior and attitudes toward the robotic coaches, drawing from existing HRI literature for conceptual and operational measures. The main behavioral measures are described in Table 1. There are four categories of behavior measured directly from participants' performances: engagement (willingness to work with the robotic coach); disclosure (how much they revealed about their bad health habit); conversational memory (how much participants remembered what the robot told them); and coaching service recognition (how much they agreed orally upon the helpfulness of the robots in physical assessment tasks on a 5-point Likert scale during the post-experiment interview).

Behavioral Response Categories	Variable	Measure
Engagement	Willingness to work with robot	How many physical assessment tasks was the participant willing to participate?
Service Recognition	Approval of the clarity of robot's spatial instruction	How much did the participant agree that the robot was helpful in giving instruction during physical assessment?
Disclosure	Disclosure of personal bad health habits	How much did the participant reveal about his/her bad health habits?
Conversational Memory	Memory of information from robot	How much did participant remember what robotic coach said about health?

Table 1. Dependent Behavioral Variables

A self-report questionnaire was prepared based on Powers et al. (2007) and Heerink (2010) to obtain participants' subjective experience of the HRI and their attitudes about the robotic health coach. Some questions were not applicable in the context of health coaching, hence removed. The subjective experience questionnaire includes questions about participants' emotional state and their attitudes toward a robotic coach, each measured on a 5-point Likert scale (1 = absolutely not, 2 = preferably not, 3 = indifferent/neutral, 4 = possibly, or 5 = definitively). We used factor analysis to confirm reliability of the questionnaire, reported as Cronbach's alpha in Table 2.

Attitude/ Emotional Response Categories	Subscale	No. of item	Cronbach's alpha
Emotional state	Anxiety	4	0.712*
	Social Presence	4	0.816*
	Perceived Enjoyment	5	0.831*
Attitudes toward robotic coach	Perceived Ease of Use	4	0.653
	Perceived Usefulness	3	0.755*
	Social Influence	3	0.693*
	Perceived Sociability	3	0.707*
	Trust	5	0.837*

* Indicates internal consistency of the set of test items is acceptable.

Table 2. Internal consistency reliabilities (Cronbach's α) of the subjective experience questionnaire

Results

In order to understand the effect of different embodiments on human-robot social interaction, first, we used one-way analysis of variance (ANOVA) to investigate whether there were any significant differences in variable measurements among the three robotic embodiments. As the data shown in Table3 and Table4, there were some attitude/ emotional response variables, in which p-values of significant were larger than 0.05, the null hypothesis were to be rejected at the 5% significance level; hence the three conditions did not differ. For those variables reaching a statistically significant level, then, we examined differences of participants' ratings and behavioral measurements across three robotic platforms.

Perceptual Measurements	Physical Robot	Virtual Robot on TV	Virtual Robot on Smartphone	*P* Values of Significant Test
Anxiety	2.69	2.29	2.58	0.093
Perceived Enjoyment	3.62	3.21	3.19	0.018*
Perceived Sociability	4.09	3.27	3.35	0.000*
Perceived Usefulness	3.96	3.45	4.00	0.001*
Social Influence	4.07	3.59	4.01	0.001*
Social Presence	3.74	3.19	3.16	0.019*
Trust	3.39	4.09	3.31	0.000*

* Indicates significant *p* value at the 0.05 level

Table 3. Means of participants' perceptual ratings of three conditions, and *P* Values of Significant Test

Behavioral Measurements	Physical Robot	Virtual Robot on TV	Virtual Robot on Smartphone	*P* Values of Significant Test
Disclosure	3.11	3.10	2.17	0.013*
Conversational Memory	2.41	2.59	2.38	0.371
Engagement	3.81	3.79	3.92	0.602
Service Recognition	3.67	3.69	2.71	0.000*

* Indicates significant *p* value at the 0.05 level

Table 4. Means of participants' behavioral measurements on three conditions, and *P* values of significant test

Effects of Robotic Platform on the Participants' Behavior

(1) Engagement

In the study done by Powers et al. (2007) the measurement for engagement was the time spent with robots (physical or virtual), and the result showed the physical embodiment was most engaging. In our study, we directly counted how many physical assessment tasks each participant willing to executed and completed as the measurement of engagement. However, there were only four simple physical assessment tasks in the session, and participants' willingness was high in all condition. Average number of tasks completed for three robotic coaches were 3.81 (physical robot), 3.79 (virtual robot on TV) and 3.92 (virtual robot on smartphone). As a result, we found no significant differences across three platforms.

(2) Service Recognition

Instead of using self-report questionnaire, the behavioral measurement for the service recognition of robots was taken directly from participants' answers in the post-experiment interview, by asking participants how much they agreed upon robots' helpfulness in spatial activities on a 1-to-5 disagree-agree response scale. We found significant differences in participants' recognition of helpfulness form robotic coaches. The participants in physical robot condition and full-sized virtual robot on TV conditions significantly orally agreed more (rating 3.67 on average to the physical robot; 3.69 to the virtual robot on TV) than those in the small-sized virtual robot on smartphone conditions (rating 2. 71 on average).

(3) Disclosure
According to previous studies, the physical embodiment enhanced the feeling of social presence, and people's feelings of social presence inhibited disclosure (Powers et al., 2007). We hypothesized participants would disclosed less about their bad health habits to physical robots than to virtual robot. In this study by directly counting how many bad health habits participants revealed about themselves during the experiment, we found significant differences in the number of bad behaviors revealed (not word counts) during the human-robot dialogue phase across three platform. The participants in the physical robot and full-sized virtual conditions (TV) conditions revealed more (3.11bad behaviors on average to the physical robot; 3.10 to the virtual robot on TV) than those in the small virtual robot on smartphone (2.17 bad behaviors on average). Therefore, H2 is rejected.

(4) Conversational Memory
We counted the number of health tips participants recalled from the human-robot dialogue phase. However, we found no significant differences across three platforms.

Effects of Robotic Platform on the Participants' Perception of Robots

After their coaching session with the robots, participants were requested to complete a paper questionnaire. The questions addressed participants' subjected feeling during the engagement with the robotic coaches, including "anxiety", "perceived enjoyment", "perceived ease of use", "perceived usefulness", "social influence", "perceived sociability", and "trust". As shown in Table 3, six out of seven perceptual measurements did reach a statistically significant level; only "anxiety" did not differ significantly across conditions.

For variables reaching a statistically significant level, we examined differences of participants' ratings across three robotic platforms. There were consistent and significant differences in how participants rated the robotic coaches on different devices. As shown in Table 3, the physical robotic coach was rated higher in scale than virtual coaches in all other dependent measures, except "trust". The full-sized virtual coach on TV was rated highest in "trust", however, lower in other measures. The small-sized virtual coach on smartphone were rated higher in "perceived usefulness" and "social influence", but, lower in "social presence", "perceived enjoyment", "perceived sociability", and "trust".

Summary of Results

With this primary experiment, we examined the three hypotheses about the social impact of different robot embodiment. By comparing the measurements collected form the experiment, we found modest support for Hypothesis 1, that a physical humanoid robot would be more enjoyable and sociable and command more social influence and movement accuracy. In this study, participants found physical humanoid robot to be more socially present, enjoyable, useful, and socially influential. The subjective ratings from participants were encouraging. But in participants' behavioral data, measurement on engagement and movement accuracy did not differ comparing to the virtual robots. It was probably because that physical assessment tasks in the study were too easy to complete for young adults, hence the measurement for engagement and movement accuracy were indistinguishable.

From both participants' behavioral data and subjective ratings, we also found modest support for Hypothesis 2, that full-size virtual robot on TV monitor would be more trustworthy, but it did not acquire more participants' disclosure than the physical humanoid robot. The full-size virtual robot did received highest rating on participants' trust. Its coaching service was equally recognized and elicited equal disclosure as a physical humanoid robot. Even though a full-size virtual robot on TV is most trustworthy among the three condition, participants did not rate the TV displayed virtual robot as highly when they evaluated its social presence, enjoyment, usefulness, social influence and sociability.

Data shows inconsistent findings regarding Hypothesis 3, that a smaller virtual robot on smartphone screen was rated more useful, but with less social presence. Participants who interacted with a virtual robot on smartphone rated less on most of the subjective social experience, except "perceived usefulness" and "social influence". In other words, participants gave less positive sociability trait ratings to the smartphone robot, and found it less lifelike. It was equally useful and socially influential to a physical robot, which was modest support for Hypothesis 3. However, when we examined participants' behavior measurements, participants disclosed less of their negative habits to a smartphone virtual robot, which was interpreted by Powers et al. (2007) as indicating "they had greater evaluation apprehension of the robot", in other words, it was more lifelike. In addition, even though participants rated it higher in "perceived usefulness" than the full-sized virtual robot, its helpfulness in physical /spatial instruction was recognized the least among three, because the limited screen size and resolution could not display robot's movement clearly.

Conclusion

New technologies, such as robotic technologies, bring not only new opportunities but also new challenges to people's daily life. In this multi-device era, people own multiple devices and use them interchangeably. In order to integrate different devices with artificial intelligence into one consistent, human-centered service, we need to understand what are the advantages and disadvantages of different robotic platforms, and understand how people respond differently to robotic services across devices.

By adopting the theoretical frameworks and methodology from related studies, and adding a smartphone as one of the robotic platform, a three-condition experiment was conducted to test if participants respond differently to a physical robotic coach versus its digital representation on TV or smartphone. The results revealed embodied virtual robots on screen cannot fully substitute for physical robots, as what previous studies have suggested. But the differences are not that substantial in the context of our study. Contrary to the finding of similar inquiries in HRI literature that the physical robots are better liked and better engaging people, and the virtual robots could elicit more disclosure and enhance conversational memory. In this study, there were no significant differences between robotic coaches with respect to perceptual measurements, "anxiety" and "perceived ease of use", and the behavior al measurements, "engagement" and "conversational memory". And all of the ratings and measurements for robots across three devices as health coaches seem encouraging.

In addition, even the participants' assessments on lifelikeness and social presence of virtual representations were not as high as the assessments on a physical robot; we suspected that the inherent characteristics of existing customer appliances for displaying robots might compensate the shortage of virtual robots. For instance, the screen size indeed affected people's perception on robots' social presence, the virtual robot on mobile screen would seem less real and cause less social impact than full-sized embodiment; but in the study, participants rated the robot on mobile higher in "perceived usefulness" and "social influence" than the full-sized virtual robot. This finding opens up a possibility that people choose an existing and socially acceptable device as robotic platform is not for its social presence and lifelikeness, but for its convenience and usefulness.

In the multi-device world, a socially assistive robotic service should be connected and across multiple devices to provide a consistent HRI experience to its users. In this embodiment comparison study, we have no intention to select one best robotic embodiment for a health coaching service, but to point out a new practical direction for this type of HRI research. The presented study is just a preliminary work, HRI topics on why and how people respond to social robots across platform differently, and how to use existing knowledge to develop practical, multi-device services still await further long-term field studies.

Acknowledgments

This research was supported in part by the Ministry of Science and Technology in Taiwan (Grant MOST 105-2221-E-025-001). We thank all the participants and Ms. Pei-Yi Pan for their suggestions and help in this study.

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