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The benefit of being physically present: A survey of experimental works comparing copresent robots, telepresent robots and virtual agents ☆

Jamy Li *

Department of Communication, Stanford University, 450 Serra Mall, Building 120, Stanford, CA 94305, USA

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ABSTRACT

The effects of physical embodiment and physical presence were explored through a survey of 33 experimental works comparing how people interacted with physical robots and virtual agents. A qualitative assessment of the direction of quantitative effects demonstrated that robots were more persuasive and perceived more positively when physically present in a user's environment than when digitally-displayed on a screen either as a video feed of the same robot or as a virtual character analog; robots also led to better user performance when they were collocated as opposed to shown via video on a screen. However, participants did not respond differently to physical robots and virtual agents when both were displayed digitally on a screen – suggesting that physical presence, rather than physical embodiment, characterizes people's responses to social robots. Implications for understanding psychological response to physical and virtual agents and for methodological design are discussed.

1. Introduction

Intelligent robotic agents are being designed for everyday life (Goodrich and Schultz, 2007) while virtual agents are already prevalent in online and gaming domains (Blascovich and Bailenson, 2011). Physical robots and virtual agents are both defined and distinguished by the nature of their embodiment (Dautenhahn, 1999): a robot's body is made of metal and plastic parts while a virtual agent's body is digitally generated using computer algorithms. This demarcation in embodiment lends robots and virtual agents unique qualities. While a robot in the real world is uniquely able to touch and be touched by people, a virtual agent in a simulated world can perform activities not possible in real life. For example, a healthcare robot can pick up and deliver a patient's medication, gently tap on a patient's shoulder, and respond to a patient's touch. Conversely, a virtual healthcare assistant can alter its gender, age, height and other visual characteristics on-the-fly in order to suit a patient's preferences.

Today the choice of whether to implement a robotic or virtual agent is largely governed by the requirements of the tasks to be performed. A robot may be used in situations where physical objects such as beverages or hospital equipment need to be delivered, while a virtual agent may be employed on a website to aid in teaching an online learning course. As robotic technologies are developed that focus on general social interaction with people, however, the choice of what type of agent to use becomes less clear. Consider, for example, a virtual agent displayed on a computer screen that acts as a receptionist and a similar-looking robot designed for the same role: is there a difference in their ability to engage patrons? Given the enormous flexibility and prevalence of digitally-rendered agents that can dynamically change their appearance, are readily transportable across distances and live on relatively inexpensive digital screens, such questions are of particular importance to roboticists interested in exploring the consequences of introducing socially-competent robots as well as to researchers interested in interactions with physical and virtual media.

Previous experimental work that has compared social robots with virtual agents has claimed that the physicality of the robot is beneficial to user interaction (e.g., Wainer et al., 2006; Kiesler et al., 2008). However, many such studies conflate two different dimensions of physicality: the physical embodiment of the robot, and the fact that it is physically present in front of the user. Is a collocated robot advantageous because it has a physical body or because it is physically collocated in a person's space? Is the recognition that an agent has a physical body sufficient or must the physical body be present in front of a user? If both the embodiment and presence of an agent influences people equally, it may mean that interaction design of social agents is more complex than previously thought.

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* Tel.: +1 323 474 1084.
E-mail address: jamy@stanford.edu

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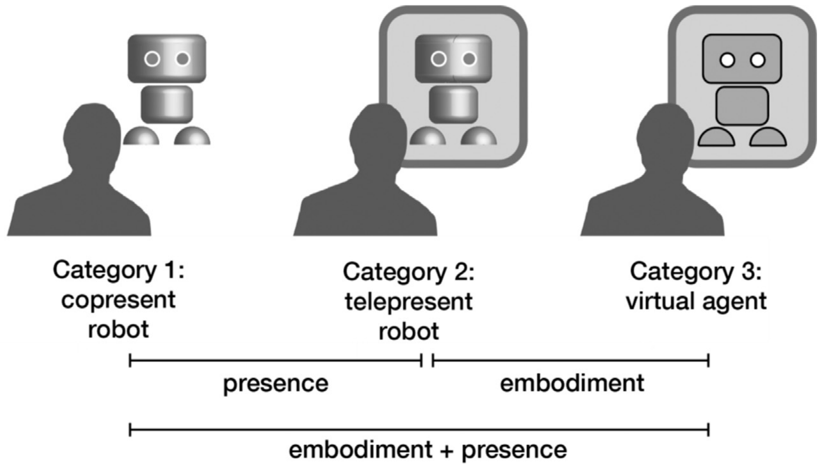

Fig. 1. Comparison of presence and embodiment dimensions across three categories of experimental stimuli. In Category 1 ("copresent robot"), a person interacts with a robot face-to-face. In Category 2 ("telepresent robot"), a person interacts with a robot that is physically embodied in the real world as in Category 1, but the interaction is mediated using a computer monitor, television or projector screen. In Category 3 ("virtual agent"), a person interacts with a virtually embodied agent using a computer monitor, television or projector screen.

Conversely, if one factor has a greater impact on user response than the other, development of social agents may be simplified. While these questions are not new (e.g., Kidd and Breazeal, 2004; Wainer et al., 2006; Kiesler et al., 2008 and other authors have addressed them to varying degrees), a systematic survey provides an original perspective on these questions by capturing the corpus of past work, introducing and applying a common framework to its analysis and identifying themes across studies.

The current paper investigates whether people respond differently to physical vs. virtual agents by presenting a survey of past experimental work. Experimental stimuli are classified into three categories to independently investigate the effect of physical embodiment and presence on human response (see Fig. 1): "copresent robots" that are physically embodied as well as physically present in a user's space (i.e., a physical robot that is in front of a person); "telepresent robots" that are physically embodied but displayed on a screen (i.e., a live or recorded video feed of a physical robot); and "virtual agents" that may have similar appearance and behavior to a robot but are digitally embodied (i.e., a computer graphics model of a robot). Its main contributions are an explication of embodiment and presence from a theoretical standpoint to support the development of structured research questions (Section 2); a comprehensive survey identifying 33 key works comparing physical and virtual agents (Section 3); a searchable table of past work to aid the research community (Section 3); the finding that physical presence, not embodiment, governs psychological response to agents across a variety of dependent measures (Section 4); and a discussion of implications for experimentation and suggestions for future investigation (Section 5).

2. Interactions with physical and virtual agents

An agent can be defined as "a physical or virtual entity that can act, perceive its environment (in a partial way) and communicate with others, is autonomous and has skills to achieve its goals and tendencies." (Ferber, 1999, p. 9) In practice, agents exist in a wide range of forms (Franklin and Graesser, 1997), some of which have visually-observable bodies (such as a robot) and some which interact with others using only voice or text (such as Siri or the hypothetical player in Turing's imitation game). Additionally, people may perceive an agent to be autonomous when in fact it is not: agents that are controlled using the "Wizard-of-Oz" technique, in which users are told an agent is autonomous when it is actually controlled by a human operator, are commonly employed in study trials to effectively simulate autonomous intelligent systems (Dahlbäck et al., 1993; Riek, 2012). As this work focuses on the effect of physicality on user response, we consider agents to have a visible physical or virtual embodiment and to be perceived as autonomous.

2.1. Agent embodiment

Embodiment has long been viewed as a critical feature of intelligent systems (Brooks, 1990). Past work has emphasized the importance of embodiment in both the domains of physical robots (e.g., Dautenhahn et al., 2002) and virtual agents (e.g., Cassell, 2000). As a general construct, embodiment can refer to a progressively "tighter coupling of the [human] body to the interface," (Biocca, 1999, p. 114) as in the connection one has to an avatar in a virtual reality environment. Embodiment can also refer to a "total body communication" (Poyatos, 1975, p. 287) involving both verbal and nonverbal behaviors to create a face-to-face interface, as is the case with embodied conversational agents, which "have bodies and know how to use them for conversation." (Cassell, 2000, p. 2) In robotics, embodiment emphasizes the "dynamical coupling among brain (control), body, and environment" (Pfeifer et al., 2007, p. 1088) – particularly how a robot's physical morphology shapes interaction dynamics with its environment as well as sensory inputs to its control infrastructure. Embodiment has also been defined more generally as "that which establishes a basis for…mutual perturbation between system and environment" (Dautenhahn et al., 2002, p. 400). Ziemke (2003) identified physical embodiment as the need to have a "physical instantiation" or "physical body." Most applicable to this work, Pfeifer and Scheier (1999) gave the following definition of physical and digital embodiment with artificial agents:

> "Embodiment: A term used to refer to the fact that intelligence cannot merely exist in the form of an abstract algorithm but requires a physical instantiation, a body. In artificial systems, the term refers to the fact that a particular agent is realised as a *physical robot* or as a *simulated agent*." (p. 649; italics added)

This survey focuses on "embodiment" as the physical or digital state of an agent independent of how it is displayed to a user. An agent's embodiment can be physical, virtual or a blend of both. "Physically-embodied agent" or "physical agent" is used here to mean a robot with motors and actuators constructed from metal, plastic and other materials. It is similar to "social robot," defined as "an autonomous or semi-autonomous robot that interacts and