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

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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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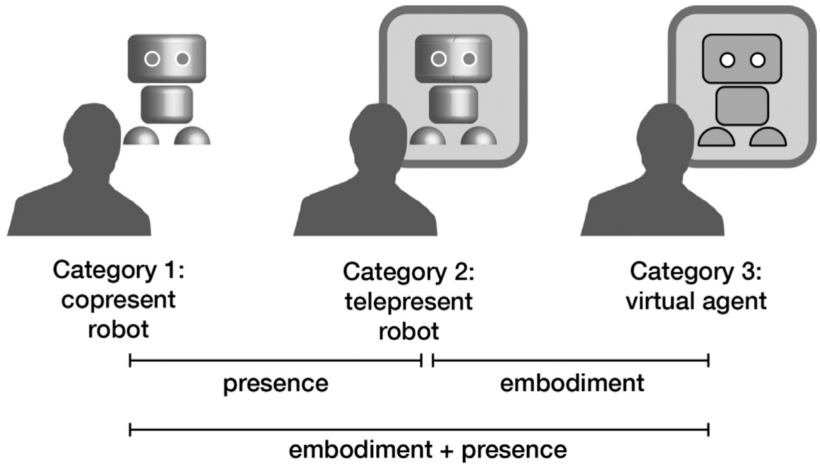

Fig. 1. Comparison of presence and embodiment dimensions across three categories of experimental stimuli. In Category 1 ("copresent robot"), a person interacts with a robot face-to-face. In Category 2 ("telepresent robot"), a person interacts with a robot that is physically embodied in the real world 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 communicates with humans by following the behavioral norms expected by the people with whom the robot is intended to interact" (Bartneck and Forlizzi, 2004, p. 592). Conversely, "digitally-embodied agent" or "virtual agent" is used to refer to an animated rendering of a character that is created using computer graphics. It is similar to terms used in past literature such as "embodied conversational agent" (ECA) (Cassell, 2000, p. 2), "animated interface agent" (Dehn and van Mulken, 2000) and "interface agent" (Laurel et al., 1990; Serenko et al., 2007), though the agent need not be human-like in appearance or engage in verbal communication. Agents can also consist of a blend of physical and digital components, as is the case with robots that use a digital screen to display a face.

An agent's embodiment also consists of its morphology – its form and structure. While embodiment presupposes that an agent has a "body," the body need not be human-like to be perceived as a social actor (Heider and Simmel, 1944; Reeves and Nass, 1996). A robot's morphology can be characterized into one of several groups: anthropomorphic, zoomorphic, caricatured and functional (Fong et al., 2003). Anthropomorphism is the tendency to attribute human characteristics to objects. Having agents employ human-like forms has been suggested as a means of facilitating social interaction between people and robots (Duffy, 2003) as well as virtual agents (Cassell, 2000). However, the "uncanny valley" effect suggests that artificial agents may reach a point where their resemblance to humans is high but not quite perfect, and that those imperfections make people uncomfortable (Mori, 1970). For example, virtual agents that have high anthropomorphism can lead to poorer performance than those with lower anthropomorphism, perhaps because of unmet expectations (Nowak and Biocca, 2003). Similarly, zoomorphic agents are designed to imitate living creatures, such as dogs or cats. Biological systems are increasingly being used to inspire robot design (Pfeifer et al., 2007), while people in virtual worlds often choose zoomorphic self-representations that perform social tasks as well as human ones (Zanbaka et al., 2006). One advantage of zoomorphic agents is that the "uncanny valley" effect may be less prevalent with such agents (Fong et al., 2003). Caricatured agents do not necessarily resemble living things, although caricature may be employed to create believable agents; for example, a virtual agent in a video game may take on the form of a flying ball. Finally, the form of functional agents reflects the task to be performed; for example, a service robot employed for health care may have bins for the storage of equipment.

Another factor is the extent to which an agent is embodied, which is important to how it can engage with its environment (Dautenhahn et al., 2002). Robots or virtual agents vary in terms of the types of modalities that are supported (e.g., speech, gesture, movement) and the extent to which those modalities are realized (e.g., DoF or degrees of freedom for movement). Greater expressivity in terms of both number and degree of modal capabilities affords greater opportunity for a robot to interact with people and the environment. The Sony AIBO robotic dog, for example, has a greater range of capabilities than BeatBots' Keepon dancing robot. Related to this factor is whether an agent's entire body is implemented or only part of it (just the head or the torso for instance), which impacts the expressive capabilities at its disposal.

2.2. Agent presence

While embodiment of an agent necessarily focuses on the agent and its relationship to its environment, presence refers to how that agent is presented to others – in the case of experimental studies, to participants. Several concepts in the literature are relevant here. The term "copresence" refers to an active and reciprocal perceiving between a person and others, which "renders persons uniquely accessible, available, and subject to one another" (Goffman, 1963, p. 22). Presence is similar to the concept of "directness" in literature on mixed reality, described as "whether primary world objects are viewed directly or by means of some electronic synthesis process" (Milgram et al., 1995, p. 287). Presence is also related to "distance" in Zhao's (2003) taxonomy of copresence, which is dichotomized into physical proximity (within range of the naked senses) and electronic proximity (outside the range of the naked senses but within the range of senses extended through electronic media). Physical presence necessarily implies that the user and agent are within physical proximity, while an agent that is digitally present is essentially in electronic proximity to the user. In real-world environments, physical and digital presence correspond to "copresence" and "telepresence," respectively. (Zhao, 2003) Copresence may also be related to whether the same environment or "substrate" (Milgram et al., 1995, p. 287) is shared between a person and others.

Here an agent that is in the same physical space as the user is considered to be "copresent" or "physically displayed" and one that is being shown as a live video feed on a screen or projection is "telepresent" or "digitally displayed." This latter concept is distinguished from "telepresence robots" – mobile platforms that display a human operator on a screen. Physical embodiment is distinct from physical presence, since an agent that has a physical embodiment (i.e., a robot) may not be displayed in its physical form to a user (e.g., it may be shown digitally on a screen instead of co-present). Physically-displayed virtual agents are excluded from consideration because it is unclear what would constitute a physical presentation of a virtual agent. These definitions are applicable to users in a physical (i.e., real world) substrate; in a virtual substrate, a virtual agent may be considered copresent if it is perceived to be together with a user in the same virtual space (Schuemie et al., 2001).

2.3. Research questions

Based on the above, we asked the three research questions below.

RQ1 (effect of physical presence): Do people respond to robots that are copresent differently than when they are telepresent?
RQ2 (effect of physical embodiment): Do people respond to a telepresent robot differently than a simulated agent with a similar appearance?
RQ3 (effect of physical presence and embodiment): Do people respond to a copresent robot differently than a simulated agent with similar appearance and behavior?

RQ1 looked at the effect of an agent's presence. It asked whether the "unmediated" experience of a person interacting with a copresent physical agent differs from the "mediated" experience of seeing the same agent through a digital display (such as a television screen). Psychological response to copresent robots may differ from telepresent ones for a variety of reasons. Copresent robots can appear larger than telepresent ones presented on a screen due of screen size (Hoffmann and Krämer, 2011). As taller individuals tend to have greater social influence than shorter ones (Huang et al., 2002), the larger size of copresent robots may translate into greater influence over telepresent robots. Another possibility is the shared physical space between the person and a copresent robot (Shinozawa et al., 2005), as physical proximity is important for collaboration (Kraut et al., 1988). The physical presence of an agent also affords viewers with improved depth perception and motion parallax, which are not possible with conventional screens or projectors.

RQ2 looked at embodiment. It asked whether people respond differently to a physical agent compared to a virtual agent, when the dimension of presence was held constant. One reason why an agent's physical or virtual embodiment may matter to psychological processing is a difference in realism – i.e., whether an agent appears real or fictional (Hoffmann and Krämer, 2011). Han et al. (2005) had people view either movie clips or cartoon clips and found that perception of real-world humans engages an area of the brain linked with representation of the mental states of others, while virtual-world humans engage an area of the brain related to attention to actions. It may be that the mere recognition that an entity has a physical form in the real world – even though that form is not present – influences human perception. While in theory a virtual agent rendered with sophisticated graphical technology may appear so realistic as to be indistinguishable from what it is representing in real life (as seen with human characters in modern video games, for instance), in practice there is often an observable difference (as with the corpus in this work). This question is only investigated for agents that are digitally present (i.e., shown on a screen), as it is unclear how a virtual agent could be physically present.

Although these two dimensions can be treated as independent, they may not actually be so. To test this, RQ3 investigated the combined effect of embodiment and display by looking at results from comparisons for a physically present (i.e., co-present) physical agent and a digitally present (i.e., telepresent) virtual agent. Although these two categories differ along two instead of a single dimension, comparison between them enables the testing of the combined effect.

3. Methodology

3.1. Overview

A survey of empirical studies involving social robots and virtual agents was conducted between January and April 2013. First, searches of online academic databases such as Google Scholar and ACM digital library were performed. The keywords used included: physical vs. digital; physicality; embodied; embodiment; tangible; robot; screen; on-screen; agent; virtual agent; study; trial; experiment; condition; participant; effect; comparison; compare. Second, the citations of the corpus were identified, and the citations of those citations, recursively to find the oldest relevant works. Third, works which cited the works in the corpus were looked at, and the works which cited those works, recursively to identify the most recent relevant works.

The inclusion criteria were: (1) work must include empirical evaluation in the form of an experiment; (2) work must include at least two experimental conditions that differ in embodiment and/or presence; (3) statistical tests must be reported that compare at least two conditions that differ in embodiment and/or presence; (4) the interaction evaluated in the experiment must include a substantial social component (e.g., robots used for surgical applications were excluded); and (5) work must not employ agents with mixed states, such as a robot with a physical torso and a digital face, as experimental stimuli (this criterion was added to isolate the dimensions of embodiment and display).

3.2. Categorization of experimental conditions

Experimental conditions involving physical and virtual agents were classified along three variables, each of which may be either physical or digital: (1) the substrate of the participant; (2) the presence of the agent (whether it is copresent or telepresent); and (3) the embodiment of the agent, which is considered to be the same as its substrate. Table 1 provides practical examples of each classification. Participant substrate was considered physical when participants were in the real world or digital when their perceived environment was created artificially by a computer. Agent presence was treated as physical when the agent was shown to participants without a media device (such as a television, computer or projector screen) and digital when the agent was shown with such a device. Agent embodiment was classified as physical when the agent was a robot constructed with mechanical parts and digital when the agent was a virtual character rendered using computer graphics. Fig. 1 illustrates three key categories explored in this work.

It is noted that the physical-digital state of the agent (i.e., its embodiment) and its substrate do not necessarily have to match; i.e., a digitally-embodied agent may be displayed in a physical substrate (for example, a virtual agent that is projected into a real-world environment), or a physically-embodied agent may be displayed in a virtual substrate (for example, a physical robot that is collated with a user in a CAVE virtual reality environment). For simplicity, this work excludes cases of mismatched agent embodiment and substrate, as well as agents that have both physical and virtual embodiment (such as a mechanical robot that displays its face on a digital screen). It is also assumed that a digitally-embodied agent cannot be physically present; no extant work contained such a condition.

3.3. Study corpus

The search phase resulted in 64 works. Nineteen papers were omitted due to absent statistical tests comparing physical and virtual agent conditions or conditions that did not match our categorization (e.g., videos of the robot interacting with a confederate, comparison of two different simulated agents). Twelve works were found to be duplications, such that all their reported results were also reported in our included works. Thirty-three manuscripts were ultimately selected for inclusion. They ranged in publication year from 2001 to 2013, with a peak of eight works published in 2010. Of the 33 included works, there were 38 unique studies ($k=38$) due to five works reporting two studies each. Summary information for included studies is shown in Table 2, including specific platforms used in each study, the mappings

Table 1
Classification of experimental conditions based on agent presence and embodiment.

Category	Label	Participant substrate	Agent presence	Agent embodiment	Experimental condition examples
1	Copresent robot	Physical	Physical	Physical	Co-present social robot
2	Telepresent robot	Physical	Digital	Physical	Live camera feed of social robot on computer screen Video of social robot on computer screen Video projection of social robot
3	Virtual agent	Physical	Digital	Digital	Animated character on television screen Animated character on computer screen Projection of animated character Projection of live camera feed of a computer screen displaying an animated character
4	Virtual reality copresent robot	Digital	Physical	Physical	Co-present social robot inside VR CAVE HMD incorporating optical see-through of social robot
5	Virtual reality telepresent robot	Digital	Digital	Physical	Video of social robot displayed in VR world HMD incorporating video see-through of social robot
6	Virtual reality agent	Digital	Digital	Digital	VR agent in VR world

Table 2
Studies evaluating physical embodiment and presence included in this work.

Author (study #)	Year	*N*	Pop'n	Morphology	Robot	Virtual agent	Conditions	Other IV	Task	T	M	S
Bainbridge et al.	2010	65	US adults	Humanoid (torso)	Yale U Nico		CR vs. TR vs. augmented video		Office tasks		●	
Bartneck	2003	53	NL adults	Caricature	TUE eMuu teardrop	TUE eMuu teardrop	CR vs. VA vs. no character	Emotion expression (present vs. not)	Negotiation		●	
Brooks et al.	2012	11	US students	Humanoid (full body)	Georgia Tech Darwin-OP	Kyosho Manoi	CR vs. VA		Physical exercise		●	
Fasola and Mataric	2010	33	US elderly	Humanoid (torso)	USC+BlueSky Robotics Bandit	USC+BlueSky Robotics Bandit	CR vs. VA		Physical exercise		●	○
Fischer et al.	2012	44	DE students, staff	Humanoid (head)	Giorgio Metta's iCub I/II robots	Akachan	CR vs. VA	DoF (hi vs. lo)	Description		●	
Fujimura et al.	2010	18	JP adults	Humanoid (full body)	Honda's ASIMO robot	Keio University ASIMO-like virtual agent	CR vs. VA vs. projected VA		Object selection		●	○
Hasegawa et al.	2010	75	US JP students	Humanoid (full body)	Kondo Kagaku KHR2-HV	NUMACK	CR vs. VA vs. GPS	Gesture (speaker-perspective vs. listener-perspective vs. none)	Direction giving		●	○
Heerink et al.	2009	42	NL elderly	Zoomorphic/ Humanoid (torso)	Philips iCat	IIE Annie	CR vs. VA		Conversation (various)		●	○
Hoffman and Kramer	2013	85	EU students	Zoomorphic	Violet's rabbit robot Nabaztag	Violet's rabbit animation Nabaztag	CR vs. VA	Interaction scenario	Conversation (health) game (Towers of Hanoi)		●	○
Jost et al.	2012b	52	FR children	Humanoid (full body/torso)	Robotis bioloid	Telecom ParisTech GRETA	CR vs. VA		Game (education)		●	○
Jost et al.	2012a	51	FR children	Humanoid (full body/torso)	Robotis bioloid	Telecom ParisTech GRETA	CR vs. VA		Game (education)		●	○
Ju and Sirkin (1)	2010	179	US adults	Humanoid (arm)	Stanford kiosk arm	Stanford kiosk arm animation	CR vs. VA	Morphology (arm vs. arrow)	Attention to kiosk		●	
Ju and Sirkin (2)	2010	457	US adults	Humanoid (arm)	Stanford kiosk arm	Stanford kiosk arm animation	CR vs. VA	Morphology (arm vs. arrow)	Attention to kiosk		●	
Jung and Lee (1)	2004	32	US students	Zoomorphic	Sony Aibo Dog	Sony Aibo Dog animation	CR vs. VA	Participant loneliness (hi vs. lo)	Entertainment		●	○
Kidd	2003	82	US adults	Humanoid (head)	MIT 5 DOF robot head		CR vs. TR		Desert Survival Task Teaching Task		●	○
Kidd and Breazeal (1)	2004	32	US adults	Humanoid (eyes)	MIT robot eyes	MIT animated eyes	CR vs. VA vs. human		Moving blocks		●	○
Kidd and Breazeal (2)	2004	82	US adults	Humanoid (head)	MIT 5 DOF robot head		CR vs. TR		Desert Survival Task Teaching Task		●	○
Kiesler et al.	2008	113	US adults	Humanoid (full body/head)	Nursebot robot	Nursebot animation	CR vs. TR vs. VA vs. projected VA		Interview		●	○
Komatsu (1)	2010	20	JP students	Caricature	NEC Corp. PaPeRo	NEC Corp. RobotStudio	CR vs. VA		Game			○
Komatsu (2)	2010	40	JP students	Caricature	NEC Corp. PaPeRo	NEC Corp. RobotStudio	CR vs. VA	Character of agent	Game			○
Komatsu et al.	2011a	20	JP students	Functional	LEGO Mindstorms robot	On-screen navigation agent	CR vs. VA	Pitch of audio tones	Game			○
Kose-Bagci et al.	2009	66	UK children	Humanoid (full body)	U Hertfordshire KASPAR		CR vs. TR vs. hidden robot	Gestures	Game (drumming)		●	○
Lee et al. (1)	2006	32	US students	Zoomorphic	Sony Aibo		CR vs. TR		Entertainment	●	●	○
Lee et al. (2)	2006	32	US students	Humanoid (full body)	Samsung April		CR vs. TR	Participant loneliness (hi vs. lo)	Entertainment		●	○
Leite et al.	2008	18	PT children, adults	Zoomorphic	Philips iCat	Philips iCat animation	CR vs. VA	Emotion model	Game (chess)		●	○
Li and Chignell	2011	12	JP students, staff	Zoomorphic	Keio U Robotphone	Keio U Robotphone animation	TR vs. VA	Situational context Emotional valence	Gesture recognition		●	
Looije et al.	2012	11	NL children	Humanoid (full body)	Aldebaran Robotics Nao	Aldebaran Robotics Nao software	CR vs. VA		Game (educational)		●	○
Looije et al.	2010	24	NL elderly	Zoomorphic	Philips iCat	Philips iCat animation	CR vs. VA vs. text interface	Behavior (social vs. non-social)	Conversation (health)		●	○

Table 2 (*continued*)

Author (study #)	Year	*N*	Pop'n	Morphology	Robot	Virtual agent	Conditions	Other IV	Task	T	M	S
Nomura and Sasa	2009	37	JP elderly, students	Humanoid (full body)	vs.tone Corp. Robovie X	Shusaku Co. Hexa 3D software	CR vs. VA	Population (students vs. elderly)	Moving objects		•	○
Pereira et al.	2008	18	PT children, adults	Zoomorphic	Philips iCat	Philips iCat animation	CR vs. VA		Game (chess)		•	○
Reeves et al.	2003	36	US students, staff	Zoomorphic	NTT Cyber Solution Lab robot		CR vs. TR	Scenario (retail vs. nutrition vs. survey)	Information Recall		•	○
Shinozawa et al.	2005	178	JP adults	Zoomorphic	NTT Cyber Solution Lab robot	NTT Cyber Solution Lab animation	CR vs. VA	Task physicality (physical vs. virtual)	Color selection task		•	○
Wainer et al. (1)	2007	21	US adults	Functional	ActivMedia's Pioneer 2 DX vehicle robot	Gazebo simulation	CR vs. TR vs. VA		Game (Towers of Hanoi)		•	○
Wainer et al. (2)	2007	32	US adults	Functional	ActivMedia's Pioneer 2 DX vehicle robot	Gazebo simulation	CR vs. TR vs. VA		Game (Towers of Hanoi)		•	○
Wainer et al.	2006	11	US adults	Functional	ActivMedia's Pioneer 2 DX vehicle robot	Gazebo simulation	CR vs. TR vs. VA		Game (Towers of Hanoi)		•	○
Wrobel et al.	2013	19	FR elderly	Zoomorphic/ Humanoid (torso)	Robotsoft Robulab	TELECOM ParisTech Greta	CR vs. VA vs. laptop		Game (trivia)			○
Yamato et al.	2001	150	JP adults	Zoomorphic	NTT Cyber Solution Lab robot	NTT Cyber Solution Lab animation	CR vs. VA	Agent (no agent vs. agent) Agent Strategy	Color selection task		•	○
Zlotowski	2010	16	FI adults	Zoomorphic	Violet's rabbit robot Nabaztag	3D Studio Max model of Nabaztag	CR vs. VA		Math task		•	○
Total (k=38)		2299								1	34	32

Notes: CR=copresent robot, TR=telepresent robot, VA=virtual agent. T=touch, M=movement/gesture, S=speech/audio included in interaction. In cases where data was combined from two studies, the resulting data set was treated as a separate study; e.g., Wainer et al. (2007) combined study data with data from Wainer et al. (2006).

of experimental conditions to three categories: copresent robot ("CR" or Category 1 in Table 1), telepresent robot ("TR" or Category 2) and virtual agent ("VA" or Category 3).

3.3.1. *Study population*

Seventeen studies were conducted with participants in the US, 7 in Japan, 5 in the Netherlands, 3 in France, 2 in Portugal and 1 in each of the UK, Finland, Germany and Europe in general. Fifteen studies used the general adult population, 12 used university students and/or staff, 4 involved the elderly, 4 involved children and 3 included mixed populations. The total number of participants was 2299.

3.3.2. *Study stimuli*

Table 2 lists the physical robot and virtual agent platforms used as experimental stimuli in the studies. The telepresence methods for a robot included: live video feed from a camera shown on a television; live video feed from a camera projected on a projection screen; live video feed from a camera shown on a computer; and pre-recorded video displayed on a monitor. Virtual agents were displayed on a computer screen, projected on a projector screen, projected dynamically in the environment or shown as a live video feed of a computer screen that was projected onto a projector screen. As no works conducted in a virtual environment matched our inclusion criteria, the effect of participant substrate was excluded from analyses.

Agent morphology varied across studies. Eighteen studies employed a humanoid agent (seven had a full body, two implemented a torso only, three used a head only, two used an arm only, one used eyes only, three used a mix of full body and head/torso), 11 studies employed a zoomorphic agent, three used a caricature agent and four used a functional robot. Two studies used a mix of zoomorphic and humanoid agents for their conditions. No studies used highly realistic humanoid agents.

Interaction modalities also varied across studies. Thirty-two studies included agent speech, thirty-four used gestures and only one explicitly included touch interaction in their procedure.

4. Results

To investigate the research questions, all works that included each pair of experimental conditions among copresent robot, telepresent robot and virtual agent were identified. A simple count of the direction of significant effects reported in the works is presented for each pair in Table 3. Although this method ignores effect and sample sizes, it provides a general indication of the direction of effects based on multiple studies. Results are organized by type of measure (behavioral or attitudinal) as well as specific variable (e.g., performance) in a manner similar to Dehn and van Mulken (2000).

In total 101 significant differences between physical and virtual agents were reported in the corpus of experimental studies (most studies measured multiple dependent variables). When results from a single study were reported across multiple publications, redundant statistical tests were recorded in the table only once. Each significant result is shown as a separate row to facilitate the search of specific dependent measures. Plus and minus signs indicate the directionality of effects between the categories, with "+/−" indicating a crossover interaction effect between the category and the variable listed in the "moderator" column in which the direction of the effect reverses depending on the value of the moderator variable. Periods indicate nonsignificant effects.

Table 3
Assessment of the direction of statistical effects by specific DV.

Dependent Variable	Study	Operationalization	Result				Moderator
			+ve Effect	−ve Effect	Crossover effect	No effect	
RQ1: Physical presence							
Performance							
	Kose-Bagci et al. (2009)	Error in sum of beats played (rev)	+				
	Kose-Bagci et al. (2009)	Error in total number of beats played (rev)	+				
	Kose-Bagci et al. (2009)	Error in number of turns taken (rev)			+/−		Gestures present/absent
	Reeves et al. (2003)	Test questions correct			+/−		Male/female
Persuasion							
	Bainbridge et al. (2010)	Percentage of participants who threw out books	+				
	Bainbridge et al. (2010)	Percentage of participants who questioned robot (rev)	+				
	Kiesler et al. (2008)	Choice of snack bar; calories consumed	+				
Response speed							
	Bainbridge et al. (2010)	Response time (rev)	+				
Personal space							
	Bainbridge et al. (2010)	Percentage of participants who walked around robot	+				
Arousal							
	Reeves et al. (2003)	Skin conductance		−			
All behavioral							
by result	10 Results		7	1	2	0	
by study	4 Studies		3	1	2	0	
Enjoyment							
	Kose-Bagci et al. (2009)	Enjoyment	+				Gestures present
	Wainer et al. (2007) (2)	Enjoyment	+				
	Wainer et al. (2006)	Enjoyment	+				
Attraction							
	Kidd and Breazeal (2004) (2)	Likeability				.	
	Kiesler et al. (2008)	Liking	+				
	Kose-Bagci et al. (2009)	Social attraction	+				
	Reeves et al. (2003)	Liking	+				
	Wainer et al. (2007) (1)	Appeal	+				
Trust							
	Kidd and Breazeal (2004) (2)	Trustworthiness				.	
	Kiesler et al. (2008)	Trustworthiness	+				
	Kidd and Breazeal (2004) (2)	Reliability				.	
	Reeves et al. (2003)	Credibility	+				
Utility							
	Kidd and Breazeal (2004) (2)	Informativeness				.	
	Wainer et al. (2007) (2)	Helpfulness	+				
Social presence							
	Lee et al. (2006) (1)	Social presence	+				
	Lee et al. (2006) (2)	Social presence		−			
Other							
	Bainbridge et al. (2010)	Naturalness	+				
	Bainbridge et al. (2010)	Overall impression	+				
	Jung and Lee (2004)	Evaluation of interaction			+/−		Lonely/non-lonely participants
	Kidd (2003)	Altruism	+				
	Kidd and Breazeal (2004) (2)	Sincerity				.	
	Kidd and Breazeal (2004) (2)	Dominance				.	
	Kidd and Breazeal (2004) (2)	Openness				.	

Table 3 (*continued*)

Dependent Variable	Study	Operationalization	Result				Moderator
			+ve Effect	−ve Effect	Crossover effect	No effect	
	Kidd and Breazeal (2004) (2)	Engagement				.	
	Kiesler et al. (2008)	Responsiveness	+				
	Kiesler et al. (2008)	Respectfulness	+				
	Kose-Bagci et al. (2009)	Intelligence			+/−		Gestures present/absent
	Kose-Bagci et al. (2009)	Appearance	+				Gestures absent
	Lee et al. (2006) (1)	General evaluation	+				
	Lee et al., 2006 (1)	Evaluation of interaction	+				
	Lee et al. (2006) (1)	Judged public evaluation	+				
	Lee et al. (2006) (2)	Evaluation of interaction		−			
	Lee et al. (2006) (2)	Judged public evaluation		−			
	Reeves et al. (2003)	Emotional response	+				
	Wainer et al. (2007) (1)	Perceptivity	+				
	Wainer et al. (2007) (2)	Watchfulness	+				
	Wainer et al. (2006)	Watchfulness	+				
All attitudinal							
By result	37 Results		24	3	2	8	
By study	12 Studies		9	1	2	1	
All Dvs.							
By result	47 Results		31	4	4	8	
By study	12 Studies		9	2	3	1	
RQ2: Physical embodiment							
Performance							
	Li and Chignell (2011)	Gesture recognition consistency				.	
	Li and Chignell (2011)	Gesture recognition accuracy				.	
	Wainer et al. (2007) (2)	Various				.	
Response speed							
	Wainer et al. (2006)	Time on task (rev)				.	
	Wainer et al. (2007) (2)	Total time (rev)				.	
All behavioral							
By result	5 Results		0	0	0	5	
By study	3 Studies		0	0	0	3	
Attraction							
	Li and Chignell (2011)	Liking				.	
	Wainer et al. (2007) (1)	Appeal				.	
Enjoyment							
	Wainer et al. (2007) (2)	Enjoyableness				.	
Utility							
	Wainer et al. (2007) (2)	Helpfulness				.	
Other							
	Li and Chignell (2011)	Lifelikeness				.	
	Wainer et al. (2007) (1)	Perception				.	
	Wainer et al. (2007) (2)	Watchfulness				.	
All attitudinal							
By result	7 Results		0	0	0	7	
By study	3 Studies		0	0	0	3	
All Dvs.							
By result	12 Results		0	0	0	12	
By study	4 Studies		0	0	0	4	
RQ3: Physical presence and embodiment							

Attention							
	Ju and Sirkin (2010) (1)	Percent looking at kiosk	+				
	Ju and Sirkin (2010) (2)	Percent looking at kiosk	+				
	Kidd and Breazeal (2004) (1)	Likert ratings; Viewing duration	+				
	Looije et al. (2012)	Number of glances at agent	+				
	Looije et al. (2012)	Mean duration of glance	+				
Performance							
	Bartneck (2003)	Value of stamps won	+				
	Brooks et al. (2012)	Error in movement time kinematics (rev)		–			
	Brooks et al. (2012)	Error in peak angular velocity (rev)		–			
	Brooks et al. (2012)	Error in movement jerkiness (rev)	+				
Persuasion							
	Ju and Sirkin (2010) (1)	Engagement with kiosk	+				
	Ju and Sirkin (2010) (2)	Engagement with kiosk	+				
	Komatsu (2010) (1)	Accept request to play game	+				
	Komatsu et al. (2011a)May	Accept agent request				.	
	Shinozawa et al. (2005)	Accept recommendation	+				Physical task
	Komatsu (2010) (2)	Accept request to play game	+				Personality prompt present
	Yamato et al. (2001)	Percent adoption of agent recommendation		–			
Response speed							
	Jost et al. (2012a)	Response time (rev)		–			
	Fujimura et al. (2010)	Task completion time (rev)		–			
	Zlotowski (2010)	Average time on single task (rev)		–			First 5 tasks
Complementary gesture use							
	Hasegawa et al. (2010)	n/a		–			
Language use							
	Fischer et al. (2012)	Mean length of utterance		–			iCub II
	Fischer et al. (2012)	Use of direct objects	+				
	Fischer et al. (2012)	Use of imperatives	+				
	Fischer et al. (2012)	Use of modal particles	+				
	Fischer et al. (2012)	Use of personal pronouns	+				iCub I
	Fischer et al. (2012)	Use of understanding checks	+				iCub II
	Fischer et al. (2012)	Use of vocatives	+				
	Fischer et al. (2012)	Utterances contain a “copula”	+				
All behavioral							
By result	28 Results		19	8	0	1	
By study	15 Studies		9	7	0	1	
Attraction							
	Wainer et al. (2007) (1)	Appeal	+				
	Fasola and Matarić (2010)	Social attraction	+				
Enjoyment							
	Hasegawa et al. (2010)	Enjoyability		–			Gestures absent
	Fasola and Matarić (2010)	Enjoyable	+				
	Wainer et al. (2007) (2)	Enjoyment	+				
	Wainer et al. (2006)	Enjoyment	+				
	Kidd and Breazeal (2004) (1)	Enjoyment	+				
	Leite et al. (2008)	Flow/enjoyment	+				
	Pereira et al. (2008)	Flow/enjoyment	+				
Trust							
	Kidd and Breazeal (2004) (1)	Credibility	+				
	Looije et al. (2010)	Trust	+				
Utility							
	Fasola and Matarić (2010)	Valuable/useful	+				
	Fasola and Matarić (2010)	Helpful	+				
	Wainer et al. (2007) (2)	Helpfulness	+				

Table 3 (*continued*)

Dependent Variable	Study	Operationalization	Result				Moderator
			+ve Effect	–ve Effect	Crossover effect	No effect	
	Kidd and Breazeal (2004) (1)	Informative	+				
Social presence							
	Fasola and Matarić (2010)	Social presence	+				
Other							
	Hoffmann and Krämer (2013)	Task oriented attractiveness			+/−		Task-oriented /conversation-oriented
	Nomura and Sasa (2009)	Attachment			+/−		Students/elderly
	Kidd and Breazeal (2004) (1)	Multiple attribute ratings	+				
	Hoffmann and Krämer (2013)	Control over interaction		−			
	Hasegawa et al. (2010)	Desire to interact again			+/−		Gestures present/absent
	Fujimura et al. (2010)	Ease of interaction	+				
	Hasegawa et al. (2010)	Empathy			+/−		Gestures present/absent
	Kidd and Breazeal (2004) (1)	Engagement	+				
	Hasegawa et al. (2010)	Familiarity		−			Gestures absent
	Yamato et al. (2001)	Familiarity	+				
	Pereira et al. (2008)	Feedback	+				
	Wrobel et al. (2013)	Feedback.				.	
	Wrobel et al. (2013)	Immersion.				.	
	Wrobel et al. (2013)	Concentration.				.	
	Wrobel et al. (2013)	Intention to Use.				.	
	Wrobel et al. (2013)	Social interaction.				.	
	Pereira et al. (2008)	Immersion	+				
	Fujimura et al. (2010)	Intelligibility		−			
	Looije et al. (2010)	Personality		−			
	Jost et al. (2012b)	Preference	+				
	Pereira et al. (2008)	Social interaction	+				
	Fujimura et al. (2010)	Strength of impression	+				
	Heerink et al. (2009b)	User acceptance				.	
	Wainer et al. (2007) (2)	Watchfulness	+				
	Wainer et al. (2006)	Watchfulness	+				
All attitudinal							
By result	41 Results		26	5	4	6	
By study	20 Studies		11	4	3	2	
All Dvs.							
By result	65 Results		45	13	4	3	
By study	28 Studies		20	7	3	3	

Notes: Plus (+) and minus (−) symbols are used for visual clarity to indicate the directionality of reported effects. A period (.) indicates either a null effect or no effect was reported. The use of "+/−" indicates a crossover interaction effect with the moderator variable.
In cases of double-reporting, results from more recent works are presented first; double-reported results from earlier work are excluded; in some cases this leads to exclusion of the entire work (e.g., Komatsu and Abe, 2008; Bainbridge et al., 2008; Powers et al., 2007).
Multiple experimental conditions were grouped under one category in the following cases: iCub I and iCub II robots (Fischer et al., 2012); humanoid and animal robots (Jost et al., 2012b); PROT (projected virtual agent) and on-screen agent (Fujimura et al., 2010).
Null results are not reported, except when works reported no significant effects for a given research question.

4.1. Physical presence: comparing copresent robots to telepresent robots

RQ1 asked whether physical presence influenced participant response. To address this question, we looked at all studies that compared a robot that was copresent (Category 1 in Table 1) compared to when it was telepresent (Category 2). Twelve studies included these conditions (see Table 2). Out of 39 reported significant effects, 31 (79%) favored a robot that was copresent compared to telepresent, four (10%) favored a robot that was telepresent compared to a copresent and four (10%) were crossover interaction effects in which the direction of the effect varied based on participant gender, loneliness and the presence of robot gestures (as shown in Table 3). One study did not find any significant effects between conditions. Therefore, RQ1 was supported: the large majority of evidence suggested people respond more favorably to copresent vs. telepresent agents.

4.1.1. Participant behavior

RQ1 was supported when behavioral measures were considered separately: the majority of evidence suggested that physical presence improved participant behavior. Four studies included behavioral measures. Seven (70%) out of ten reported significant effects found stronger participant responses for a robot when it was copresent compared to telepresent, one (10%) favored a robot that was telepresent compared to copresent and two (20%) were crossover effects.

Physical presence had a significant effect on behavioral response. For performance, two (50%) of four results showed physical presence improved performance in a children's game, while the remaining two were interaction effects. For persuasion, three (100%) out of three significant effects indicated a copresent robot was more persuasive than a telepresent one, across an office task and health-related behavior change. One result showed physical presence improved respond speed and one showed it increased the amount of personal space given. Physiological arousal was the only measure to show a main effect favoring a telepresent robot: people felt significantly higher arousal with a robot that was telepresent compared to copresent.

4.1.2. Participant attitude

RQ1 was also supported for attitudinal measures: the majority of effects found indicated people viewed the robot more favorably when it was present in front of them rather than displayed on a screen. All 12 studies that compared copresent to telepresent robots measured participant attitudes. Out of 29 reported significant results, 24 (83%) indicated more favorable participant attitudes toward a robot that was copresent compared to telepresent, three (10%) found more favorable attitudes toward a robot that was telepresent and two (7%) found crossover interaction effects. One study did not find any significant effects between conditions.

Physical presence was found to have a beneficial impact on a variety of attitudinal measures: main effects favoring copresent over telepresent robots were found for measures of user enjoyment, attraction to the agent, trust toward the agent, agent utility, social presence and a variety of other measures.

4.2. Physical embodiment: comparing telepresent robots to virtual agents

RQ2 asked whether physical embodiment influenced participant response. To separate the influence of physical embodiment from physical presence, we looked at all studies that compared a telepresent (i.e., digitally displayed) robot (Category 2) to a virtual agent (Category 3). Thus, the agent (whether a robot or a virtual agent) was shown digitally in both conditions.

RQ2 was not supported: physical embodiment was not found to influence participant response. Four studies compared telepresent robot and virtual agent conditions. No studies reported significant effects between conditions for either behavioral or attitudinal measures. The behavioral measures used in works that compared telepresent robots and virtual agents included performance on a game task and on a robot gesture recognition task. The attitudinal measures included attraction to the agent and enjoyment of the interaction.

4.3. Physical embodiment and presence: comparing copresent robots to virtual agents

RQ3 asked whether the combined effect of physical embodiment and the presence influenced participant response. We looked at all studies that compared a robot that was copresent (Category 1) with a virtual agent (Category 3). In each of these studies, participants either interacted with a robot face-to-face or with an analogous virtual agent on a screen (or both). Twenty-eight studies included these conditions. Out of 62 reported significant effects, 45 (73%) favored a copresent robot compared to a virtual agent, 13 (21%) favored a virtual agent compared to a copresent robot and four (6%) were crossover interaction effects in which the direction of the effect varied depending on participant age, task type and presence of robot gestures (as shown in Table 3). Three studies did not find any significant effects between conditions. Therefore, RQ3 was supported: the majority of evidence suggested people respond more favorably to a copresent robot than a virtual agent.

4.3.1. Participant behavior

RQ3 was supported when behavioral measures were considered separately: the majority of evidence suggested that physical presence improved participant behavior. Thirteen studies included behavioral measures. Out of 27 reported significant effects, 19 (70%) found stronger participant responses for a copresent robot compared to a virtual agent, eight (30%) favored a virtual agent and none were crossover effects.

The combined effect of physical presence and embodiment was found to have a significant effect on five kinds of behavioral response. For performance, two (50%) of four results showed copresent robots improved performance over virtual agents in a negotiation task and a movement task, while the remaining two (50%) showed worse performance for the copresent robot in a movement task. For persuasion, five (83%) out of six significant effects indicated a copresent robot was more persuasive than a virtual agent for a game task, while one (17%) showed worse performance, also in a game task. Five (100%) out of five results showed that people paid more attention to copresent robots compared to virtual agents. Three (100%) out of three results showed improved response speed for a virtual agent over a copresent robot across game and educational task domains. Seven (88%) of eight results indicated people's linguistic behavior was significantly more engaged with a copresent robot than a virtual agent, while one (13%) supported better linguistic behavior for a virtual agent. Finally, one study revealed people used significantly fewer complementary gestures when speaking with a copresent robot compared to a virtual agent.

4.3.2. Participant attitude

RQ3 was supported when attitudinal measures were considered separately: the majority of evidence suggested that physical presence improved participant attitudes. Thirteen studies included attitudinal measures. Out of 35 reported significant effects, 26 (74%) found people had significantly more positive attitudes toward a copresent robot compared to virtual agent, 5 (14%) found the opposite effect (more positive attitudes toward a virtual agent than a copresent robot) and four (11%) were crossover effects.

The combined effect of physical presence and embodiment was found to have a significant effect on a variety of attitudinal responses. These included measures of attraction, enjoyment, trust, utility, social presence and a variety of other user attitudes.

4.4. Moderators

As a post-hoc analysis, we looked at two moderators of the effects found in past work. Variables that moderated the effects found are shown on the right-most column of Table 3.

4.4.1. Gesturing

Evidence suggests that gesturing may moderate the effect of physical vs. virtual agency. Two studies included the presence or absence of gestures as an independent variable (Hasegawa et al., 2010; Kose-Bagci et al., 2009). Gesturing was a significant moderator for eight of twelve significant effects found by those studies. Crossover interaction effects were found for one measure of performance and three measures of user attitude: people responded more favorably to a copresent robot compared to either a telepresent (in RQ1) one or a virtual agent (in RQ2), but only when gestures were employed; the reverse effect was found when gestures were absent. Non-crossover interaction effects were found for enjoyment, familiarity and appearance: people enjoyed a copresent robot over a telepresent one when gestures were used, and found a copresent robot less familiar when gestures were absent. Only one result suggested that presence of gestures did not benefit a copresent robot: people rated a copresent robot as more attractive than a telepresent one when, which the authors attribute to poor gesture design (Kose-Bagci et al., 2009).

4.4.2. Task physicality

The physical or virtual nature of a task may also moderate experience with physical or virtual agents. Whether a participant had to perform a task in the “physical” (i.e., real) world or on a computer screen was found to moderate the effect of physical presence on an agent's persuasive ability. User acceptance of a recommendation was higher with a copresent robot than a virtual agent, but only when the selection task was performed on a physical box as opposed to a computer screen (Shinozawa et al., 2005).

5. Discussion

5.1. Summary of results

This work suggests that physical presence plays a greater role in psychological response to an agent than physical embodiment. A survey of experimental research comparing physical and virtual agents identified 38 unique studies among 33 published works. Simple qualitative assessment of the directionality of effects showed that 73% of reported significant results in 28 studies showed that a copresent, physical robot performed better than a virtual agent simulated using computer graphics. These studies found a copresent robot to be more persuasive, receive more attention and be perceived more positively than a virtual agent – even when the behavior of the robot was identical to the behavior of the virtual agent and when both agents had similar appearance.

Further, 79% of reported significant results across 12 studies showed that a physically present robot elicited more favorable responses than when the robot was displayed on a digital screen. People responded more positively to a copresent robot vs. a robot that was presented digitally – even when the robot itself was exactly the same. Robots were found to be more persuasive, more arousing, perceived more positively and result in better performance when copresent with people than when they were shown digitally using a screen or projector.

However, no studies comparing virtual characters and real-time video feeds of physical robots reported significant differences between the two conditions, suggesting that participants did not respond differently to a robot vs. a virtual agent when both were telepresent (i.e., presented digitally on a screen) – regardless of the fact that the robot was physically embodied and the virtual agent was not.

5.2. Implications for theory

Taken together, the results from this work suggest that it is a robot's physical presence, rather than its physical embodiment, that leads to more favorable psychological responses from people. In other words, physical or virtual embodiment only matters in the context of how that embodiment enables an agent to be present in a user's space. It appears that the factor of presence, which is directly related to how a user sees an agent, is more likely to influence a user's response than embodiment, a characteristic of the agent.

This lends support to the idea that people prefer speaking with agents “face-to-face.” Interpersonal communication theory has suggested that the physical collocation of a partner makes face-to-face interaction important; this collocation leads people to structure their representations concretely (Henderson et al., 2006) and differently from two-dimension experiences (Kawamichi et al., 2005). This survey suggests that this is true for agents as well and supports the general theory that people perceive agents as social actors (Reeves and Nass, 1996).

This work also suggests that efforts to improve the realism of some virtual agents, such that they appear to be real, physically-embodied entities, may not necessarily provide additional benefits over less realistic counterparts. Extant work indicated that there were no significant perceptual or behavioral differences between responses to virtual agents that looked like robots and actual telepresent robots. However, no work used agents that were very high in anthropomorphism (i.e., looked like real people) so the potential mediating effect of human appearance was not explored.

5.3. Implications for methodological design

Three overall implications for methodology resulting from this work are presented. First, the categorization of experimental conditions in this work reveals a methodological error made by several past studies. Most research in the field compares collocated robots with virtual agents; however, this “object-centered” approach employs experimental conditions that differ along two different variables – agent embodiment and presence – and is therefore unsound theoretically (Nass and Mason, 1990). Instead, experimentalists interested in presence should isolate the variable in their methodology by comparing collocated robots with video feeds of the robots; similarly, those researchers interested in embodiment should evaluate physical agents against virtual agents while holding their presentation constant, by comparing digitally displayed robots with their virtual counterparts. Only a few notable studies made this distinction in comparing all three categories shown in Fig. 1 and considering similar research questions as those proposed here, in particular Wainer et al. (2006, 2007) and Kiesler et al. (2008). Some work has also grouped copresent and telepresent robot conditions into a single category for statistical analysis (e.g., Kiesler et al., 2008) or compared agents that have different morphologies (e.g., Heerink et al., 2009a; Jost et al., 2012a; Komatsu et al., 2011a), which presents a substantial confound for those reported results; instead, agents of similar morphology and appearance would better test hypotheses related to physicality and virtuality. At a minimum, these considerations can be acknowledged when generalizing from a given experiment to broader theoretical concepts.

Second, our review reveals several gaps in existing research that may aid researchers in setting future research agendas. The variable of embodiment has received less attention in experimental studies than presence. Future empirical work could target embodiment in isolation by comparing responses to video-presented robots and to virtual agents, which may suggest applications for video recordings of robots as an alternate form of interaction. Additionally, little research into embodiment and presence has been conducted in virtual reality. Looking at virtual reality could qualify the effect of presence in social interaction identified here. One possibility is that a shared substrate between a person and an agent is important, perhaps because the agent is perceived as being able to influence the environment. This could be tested by seeing whether people in virtual reality prefer interacting with a copresent virtual agent as opposed to a telepresent virtual agent or a telepresent robot. An alternate possibility is that people preferentially respond to physically present agents regardless of their environment, perhaps because of the potential for tactile interaction. This could be tested using the hypothesis that people in virtual reality are more influenced by a copresent robot than a virtual agent, when both agent types appear to share the same substrate as the user. A third possibility is that people prefer an agent's presence to match their own embodiment regardless of the substrate, which could be evaluated by comparing results in a CAVE VR environment (in which people are in a virtual world but are not virtually embodied) with those obtained using a head-mounted display.

Third, Table 3 provides a searchable directory that may aid designers of physical and virtual media. Interaction designers may attain a general feel for which agent type would work better under a given application. If response speed is critical to a cooperative task between a human and an agent, for instance, past work has found that people respond more quickly to a virtual agent than a copresent robot. A designer may therefore wish to employ a virtual agent rather than a copresent robot or account for an initial increase in response time with a robot by offering training to accommodate new users.

5.4. Limitations and future work

Statistical methods. In this work a simple counting method was used to assess the qualitative direction of effects found in the studies. This provided only a general indication of the existence and direction of the true effects of embodiment and presence. Our analyses focused on reported results and excluded statistical tests that were performed but not reported, as well as any statistical tests that authors could have performed but did not. These methods would have particularly aided RQ2 by increasing the number of studies in the sample. A formal meta-analysis based on original data that additionally considers effect size, sample size and null effects would provide a better estimation of the true effect of these variables and is intended as future work.

Morphology, gesturing and touch. This work focused on the effects of embodiment and presence as it pertained to the physical or virtual nature of an agent. Embodiment, however, is a concept with many different dimensions which may be relevant to psychological response. A robot's morphology may moderate the effects found here: for example, robots that appear to be human but not perfectly so may elicit less favorable psychological response when copresent as opposed to telepresent due to the "uncanny valley" effect (Mori, 1970; MacDorman and Ishiguro, 2006; Moore, 2012). Many other variables, including height, speed, appearance and so forth may be considered aspects of an agent's embodiment. The evaluation of the impact of such variables presents a methodological challenge for HRI (Dautenhahn, 2013). As this survey focuses on the physical nature of human–robot experiences, its results provide only a general sense of the influence of physical and virtual agency. Understanding how additional variables such as robot morphology, gestures and touch affect responses to human–agent interactions is important and is left as future work.

Virtual environments. Participants who were in a virtual substrate (i.e., in immersive virtual reality) and/or virtually embodied (i.e., as a virtual avatar) were not included in this analysis. Very few experimental studies comparing physical and virtual agents in a virtual substrate were found during the search phase of the survey and none met the inclusion criteria during the search phase. The effects found here may be moderated by participant substrate: in virtual reality, for example, a virtual agent may be preferable to either a copresent robot or a telepresent robot because it "matches" its environment. This topic is proposed as future work.

6. Conclusion

This survey aimed to clarify the unique benefits of physical and virtual agents. A review of past experimental research demonstrated that people had stronger behavioral and attitudinal responses to a physically present agent as opposed to a virtually present one, but that people did not respond differently to a physically embodied agent compared to a virtually embodied one when both were presented on a screen. Understanding how people respond to physical and virtual agents is important to successful agent design as physical bodies are introduced to the computer-controlled agents around us.

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