
Virtual-reality as a Simulation Tool for Non-humanoid Social Robots

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Abstract

Evaluating the interaction between people and non-humanoid robots requires advanced physical prototyping, and in many cases is limited to lab setting with Wizard-of-Oz control. Virtual Reality (VR) was suggested as a simulation tool, allowing for fast, flexible and iterative design processes. In this controlled study, we evaluated whether VR is a valid platform for testing social interaction between people and non-humanoid robots. Our quantitative findings indicate that social interpretations associated with two types of gestures of a robotic object are similar in virtual and physical interactions with the robot, suggesting that the core aspects of social interaction with non-humanoid robots are preserved in a VR simulation. The impact of this work to the CHI community is in indicating the potential of VR as a platform for initial evaluation of social experiences with non-humanoid robots, including interaction studies that involve different facets of the social experience.

Author Keywords

Virtual reality; robotic objects; non-humanoid robots; design process

CCS Concepts

•**Human-centered computing** → *Virtual reality; Systems and tools for interaction design;*

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Figure 1: Non-humanoid robot in the form of a small ball rolling on a larger dome. Taken from Anderson-Bashan et al. (2019) [1].

Introduction

Non-humanoid robots, also called robotic objects, give designers great freedom and flexibility in both form design and interaction design, as they are not limited to human-like features [10]. On the other hand, these robots also present a challenge due to their limited communication modalities, that cannot be designed to mimic human social cues. Robotic social features are perceived as the interface between robots and users, and should be, therefore, part of robotic objects' design considerations [5, 7, 9].

One of the most common approaches for addressing this challenge suggests to leverage robotic objects' gestures as non-verbal cues when designing social interaction with humans. Even minimal robotic gestures have been shown to successfully form a social experience [1, 10, 13, 21, 26]. Furthermore, non-verbal cues of robotic objects are automatically interpreted as indicating social intentions [8]. Hence, HCI (Human-computer Interaction) and HRI (Human-robot Interaction) designers can greatly leverage the design opportunity in both the form and the movement of non-humanoid robots, and explore the potential that gestures of non-humanoid robots may have on social experiences in a variety of social contexts.

Identifying the specific gestures leading for the desired social interaction with a non-humanoid robot is not trivial. Unlike humanoid robots, robotic objects cannot be designed to mimic human social cues, and various gestures should be explored and adjusted for reaching a consistent social experience. In addition, the freedom to design robots of different forms (as they are not constrained to a humanoid design) requires a specific interaction design process for every robot, and an evaluation of the social experience. Thus, implementing and studying interaction with non-humanoid robots present challenges limiting HCI designers contribu-

tion to this emerging field. A research platform for testing social interactions with non-humanoid robots should enable an iterative design process of various forms and movement properties. It should further allow for a rigorous evaluation of the design influence on users' social experience. The HCI and HRI communities already utilize 3D animation [10], third-person video [4, 6], and physical Wizard of Oz interaction [1, 30] as evaluation methods.

Virtual Reality (VR) is a strong simulation platform, that can be utilized to resolve some of the challenges when studying the interaction with non-humanoid robots. VR users are immersed in a computer-generated three-dimensional environment, that allows them to interact with the virtual environment by simulating the physical world [29]. By using VR it is possible to create realistic scenarios from a first person point of view, while manipulating and controlling a wide range of variables that influence the experience. Integrating a VR simulation in a controlled experimental design allows to evaluate the cognitive, emotional, and behavioral influences of human social interactions [3, 22]. The ability to manipulate different aspects of the environment makes VR a promising tool for studying social interactions with robotic objects. However, the validity of VR in the context of a social interaction with a non-humanoid robot is a methodological question that must be addressed before using VR for evaluating robotic objects' influence on social experience [18].

In this study, we test the validity of a VR-based social interaction with a robotic object. We compared the social interaction with a virtual robotic object to a similar interaction in a physical lab setting. The non-humanoid robot used in the study was an abstract robotic object designed as a small ball rolling on a larger dome (see Figure 1). The robotic object supports a variety of subtle movements, shown in previ-

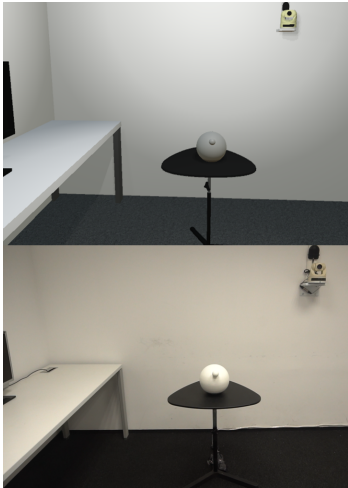


Figure 2: The Interaction-type conditions: a Virtual interaction condition (top) and a Physical interaction condition (bottom).

ous studies to be interpreted as both positive and negative social cues in the context of an opening-encounter [1].

Related Work

VR is already used as a research platform for studying the interaction with different technologies such as autonomous cars [14, 23] and complex robotic systems [17]. Specifically, the validity of VR as a methodological tool for studying the interaction with robots was evaluated in several cases including, robotic arm in an industrial context [11, 28], children’s engagement with a humanoid robot [20], and participants’ discomfort in proxemics interaction with a humanoid robot [15].

In the industrial context, two studies compared the interaction between physical robotic arms and their virtual versions [11, 28]. These studies evaluated participants’ sense of security and the robots’ acceptance levels. In the first study, participants’ sense of security was evaluated when interacting with a physical and virtual versions of a mobile robotic arm. Participants in both conditions (Physical and VR) reported their sense of security when the robotic arm was approaching them while they were sitting, and when the robot was passing by them when they were standing. Sense of security ratings in the physical interaction were similar to those of the VR interaction [11]. In a second study, level of acceptance was evaluated after half a day of a human-robot collaboration with a robotic arm in an industrial assembly line. Acceptance levels in the physical interaction were similar to those reported in the VR interaction with the same robotic arm [28].

Studies with humanoid robots include children’s engagement and proxemics preferences. In the children’s engagement study, acceptance and feelings towards Arash, a humanoid mobile robot, were evaluated with the physical robot

and its virtual version after a social interaction in the context of storytelling. The social experience with the virtual robot was found to be similar to the social experience with the physical robot [20]. In the proxemics preferences study, the Pepper humanoid robot was used to evaluate differences in participants’ discomfort when interacting with a humanoid robot in different proxemics. The study tested participants’ discomfort in a physical interaction with Pepper, and with its virtual version. The proxemics preferences were not replicated in the VR interaction. Participants felt more discomfort and preferred a larger personal space when a physical robot was approaching them, in comparison to its virtual version [15].

Overall these studies indicate that some HRI aspects can be evaluated using VR while others are not well replicated. The interaction with non-humanoid robots is not similar to the interaction with humanoid robots. Non-humanoid robots are limited in their communication modalities, and commonly utilize non-verbal gestures as their main communication medium [10]. Due to these differences, VR-based HRI with non-humanoid robots should be validated by verifying that the virtual experience is similar to the physical experience [18]. In this study we evaluate physical vs. VR interactions with a non-humanoid robot, focusing specifically on the social aspect of the interaction.

Evaluation Study

The evaluation study focused on testing a social interaction with a non-humanoid robot, that was previously evaluated in Anderson-Bashan et al. (2019) [1]. We compared participants’ social experience in physical and virtual interactions with the non-humanoid robot, designed as a small ball rolling on a larger dome. The robotic object’s mechanism involves a custom gear and a lever that supports a variety of subtle movements. Anderson-Bashan et al. (2019) showed

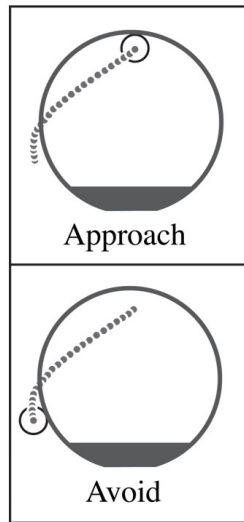


Figure 3: The Social-Experience conditions: Approach- a positive opening-encounter gesture (top). Avoid- a negative opening-encounter gesture (bottom). Taken from Anderson-Bashan et al. (2019) [1].

that the robot's minimal gestures can create a social experience in the context of an opening-encounter [1].

Method participants

38 participants, undergraduate students (28 females, 15 males, mean age= 21.92, SD= 2.17) participated in the study. All participants signed a consent form and received course credit for participation. Participants were randomly assigned to one of two conditions.

Experimental design

A 2X2 mixed experimental design was applied to evaluate the social interaction with the robot in physical and virtual interactions. The Interaction-Type conditions (between participants) involved a Physical interaction condition and a Virtual interaction condition (see Figure 2). The Social-Experience conditions (within participants) involved two Approach gestures and two Avoid gestures [1]. In the Approach interaction (back-to-front) the ball started from a position that is hidden from the participant's point of view. The ball moved from the back of the dome towards the participant and gradually revealed itself. In the Avoid interaction (front-to-back) the ball started from a position in front of the participant, and gradually moved away from the participant until it was hidden behind the dome (see Figure 3). Anderson-Bashan et al. (2019) showed that these approach and avoid gestures lead to opposite opening-encounter experiences. Approach gestures were associated with a range of emotions related to positive opening-encounters (e.g. greeting, welcoming). Avoid gestures were associated with a range of emotions related to negative opening-encounters (e.g. avoiding, ignoring) [1]. This experimental design allowed us to evaluate if different aspects of social interaction with the robot (positive and negative) are similar in physical and VR interactions.

Dependent Measures

- Opening-encounter scale: The scale is based on the 20 most frequent social descriptions associated with the robotic object's gestures suggested by the participants in Anderson-Bashan et al. (2019) [1]. In a preliminary study with 33 students, the descriptions were categorized into two sub-scales: Negative opening-encounter (e.g. Avoiding, Ignoring, Hiding) and Positive opening-encounter (e.g. Greeting, Welcoming, Acknowledging). This categorization was further validated with 25 additional participants who rated the relevance of each description to the categories on a 5 level scale ranging from "not at all" to "extremely" [27].
- Godspeed questionnaire [2]: the Animacy (Cronbach's alpha, 0.93) and Likeability (Cronbach's alpha, 0.96) sub-scales were selected due to their relevance to the interaction with the robotic object in this study.

Procedure:

Physical Interaction condition: The Physical Interaction was conducted in a quiet room at the research lab. The room was designed to evaluate participants' experience with no association to a specific environmental context (i.e. home or work). To create an opening-encounter experience, participants were instructed to enter the experiential room through a door that was opened by a research assistant, walk alongside a partition, stop at a specific position (marked by three blue dots on the floor) and then turn to the right and face the center of the room, where the robotic object was visible. When participants turned to face the robotic object, one of the gestures (Approach/Avoid) was triggered. No other instructions or descriptions of the robotic object were given. The robot was placed on a small desk (75cm high) at a distance of 1.5m in-front of the three

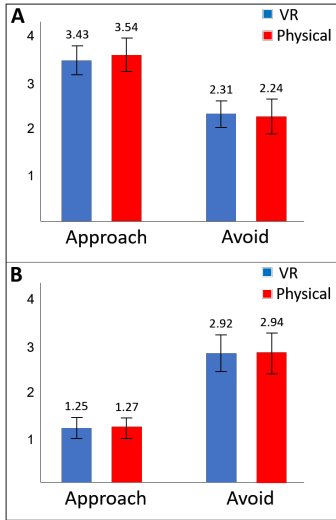


Figure 4: Statistical interaction between the Interaction-Type conditions and the Social-Experience conditions for Opening-encounter scale: (A) Positive opening-encounter and (B) Negative opening-encounter.

blue dots. The researchers used a Wizard-of-Oz [19] desktop application to trigger the desired gesture. When the gesture ended, a short sound was played indicating that the interaction was over. The participants were instructed to leave the room and sit on a couch at the waiting room. After each interaction participants rated their experience using a tablet.

Virtual Interaction condition: The Virtual Interaction took place in a designated VR lab. The room used for the Physical Interaction was virtually modeled, including the waiting room, the door, the partition, the three blue dots on the floor, and the robotic object. The real partition was placed in the VR lab and served as a passive haptic feedback to help immerse users into the virtual environment [25]. The waiting room was separated by a virtual wall and virtual door that was automatically controlled by the research assistant once the participant approached it. The experiment began with a VR familiarization phase without the robotic object. Participants were encouraged to explore the VR environment by walking between the virtual rooms through the virtual door until they felt comfortable. The purpose of the VR familiarization phase was to reduce the novelty effect of the experience in the virtual environment. After the familiarization phase, participants received instructions that were similar to those given in the Physical Interaction condition. They entered the virtual room through the virtual door, walked along the partition and turned to face the robotic object that performed one of the gestures. After each interaction with the virtual robotic object, the same short sound was played, indicating that the interaction ended and that the participant should exit the virtual room and sit on the couch in the waiting room. Participants were then asked to remove the head-mounted device and rate their experience. To support participants' immersion in the virtual experience, the physical waiting room was similar to the waiting room

modeled in the VR environment.

Findings

We conducted a 2-way-ANOVA analysis with the following independent variables: Interaction-Type (Physical vs. Virtual), and Social-Experience (Approach vs. Avoid). The interaction and main effects were evaluated for the two opening-encounters sub-scales and the two sub-scales of the god-speed questionnaire.

Statistical interactions analysis

The main analysis involved the (statistical) interaction between the Interaction-Type conditions and the Social-Experience conditions (See Figures 4 and 5). This analysis evaluated if the social interpretation of the robot's gestures was similar (or different) in the Physical Interaction condition and Virtual Interaction condition. The analysis revealed lack of (statistical) interaction between the Interaction-Type conditions and Social-Experience conditions in all dependent measures, indicating that the Social-Experience ratings were similar in both Interaction-Type conditions (Physical and VR). To vali-

Dependent variable	2-way- ANOVA	Bayes factor
Positive opening-encounter	$F(1,36)=0.39$, $p=0.53$	0.35
Negative opening-encounter	$F(1,36)=0.0002$, $p=0.99$	0.27
Animacy	$F(1,36)=0.42$, $p=0.51$	0.55
Likeability	$F(1,36)=1.59$, $p=0.22$	0.69

Table 1: The NULL (statistical) interactions between Interaction-Type and Social-Experience, in all dependent measures (2-way-ANOVA and Bayesian analyses).

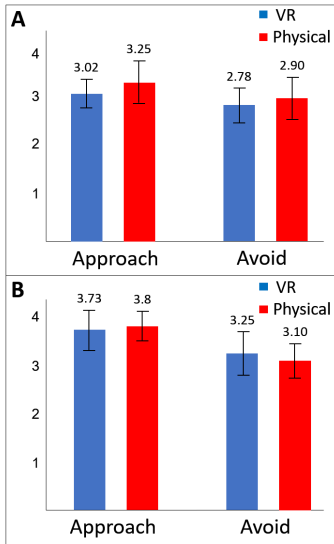


Figure 5: Statistical interaction between the Interaction-Type conditions and the Social-Experience conditions for the Godspeed questionnaire: (A) Animacy and (B) Likeability.

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date the null interactions, we further conducted a Bayesian effects analysis (using JASP [16]). The effects analysis revealed that *none* of the (statistical) interactions reached a Bayes factor equal or larger than 3 (viewed as compelling support for the interaction model [12, 24]). See Table 1 for both analyses.

Main effects analysis

The analysis also revealed a main effect for Social-Experience in all dependent measures, indicating a significant difference between the interpretations of Approach and Avoid gestures. Positive opening-encounter $F(1, 36) = 75.50$, $p < 0.001$; Negative opening-encounter $F(1, 36) = 120.53$, $p < 0.001$; Animacy $F(1, 36) = 14.45$, $p < 0.001$; and Likability $F(1, 36) = 47.93$, $p < 0.001$.

The Interaction-Type main effect did not reach significance in any of the dependent variables: Positive opening-encounter $F(1, 36) = 0.01$, $p = 0.91$; Negative opening-encounter $F(1, 36) = 0.02$, $p = 0.89$; Animacy $F(1, 36) = 0.49$, $p = 0.48$; Likability $F(1, 36) = 0.03$, $p = 0.86$.

Discussion

Previous studies indicate that in some cases, human interaction with a humanoid robot or with an industrial robotic arm can be replicated in a VR environment, suggesting that VR can be used as a platform for evaluating different aspects of human interaction with such robots [11, 20, 28]. In this study, we validated VR as a relevant simulation tool for evaluating social interaction between humans and a non-humanoid robot. The social interpretations participants associated with two types of gestures performed by the robotic object in a physical interaction were similar to those associated with the gestures of its virtual version (See Table 1). Specifically, participants in both the physical and the VR interactions interpreted the social cues as indicating the

robotic object's willingness for interaction. Approach gestures were interpreted as an invitation for an interaction, while avoid gestures were interpreted as unwillingness for interaction. This pattern was similar in both Interaction-Type conditions (physical interaction and virtual interaction).

The similar social interpretations in the VR and physical interactions were consistent across all dependent measures, each representing a different facet of the interaction. This indicates that various aspects of the experience with the robotic object were replicated in the VR interaction, suggesting that VR has the potential to be a valid prototyping tool for social interaction with non-humanoid robotic objects. The validation of VR as a platform for studying social interaction with non-humanoid robots may suggest new opportunities for studying various contexts-of-use that are too challenging to study in physical settings, as they involve sensitive populations (e.g. children, elderly) or hard-to-reach locations for in-situ studies (e.g. hospitals, schools, elderly homes). It is, however, important to consider that this study evaluated one robot which performed two types of gestures, and that the potential of VR as a research platform for testing social interactions with non-humanoid robots should be further evaluated with various robots and various social interactions.

Conclusion

Our findings suggest that VR can be a valid tool for researchers that design and evaluate social interactions with non-humanoid robots. VR provides an opportunity for inexpensive, iterative, and flexible prototyping process, which is required when designing interactions with robots that cannot mimic human behavior. This study indicates that core aspects of the interaction with a non-humanoid robot are preserved in a VR simulation.

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