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Enacting Human–Robot Encounters with Theater Professionals on a Mixed Reality Stage

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In this article, we report on methodological insights gained from a workshop in which we collaborated with theater professionals to enact situated encounters between humans and robots on a mixed reality stage combining VR with real-life interaction. We deployed the skills of theater professionals to investigate the behaviors of humans encountering robots to speculate about the kind of interactions that may result from encountering robots in supermarket settings. The mixed reality stage made it possible to adapt the robot's morphology quickly, as well as its movement and perceptual capacities, to investigate how this together co-determines possibilities for interaction. This setup allowed us to follow the interactions simultaneously from different perspectives, including the robot's, which provided the basis for a collective phenomenological analysis of the interactions. Our work contributes to approaches to HRI that do not work toward identifying communicative behaviors that can be universally applied but instead work toward insights that can be used to develop HRI that is emergent, and situation- and robot-specific. Furthermore, it supports a more-than-human-design approach that takes the fundamental differences between humans and robots as a starting point for the creative development of new kinds of communication and interaction.

CCS Concepts: • **Human-centered computing** → **Interaction design process and methods**;

Additional Key Words and Phrases: Enactments, Theater, Performativity, Situated Encounters, Mixed Reality Staging

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1 Introduction

While for the last two decades, robots have become commonplace in controlled industrial environments where they perform pre-scripted tasks within precisely structured work and production processes, more recently, robots are starting to enter everyday settings that are much less structured and require them to be more social and improvizational. Examples are robots cleaning your

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apartment, autonomous vehicles, and robots restocking products in a store. In everyday settings, robots need to be able to function in a more *ad hoc* manner and navigate situations that are not scripted and in which different people may relate to them in different ways, even within the same situation. This makes designing interactions with robots in everyday settings a complex endeavor.

What is needed to develop successful interactions with robots in everyday settings are new methods that take into account the range of possible responses that the presence and behavior of a robot within a specific everyday setting can bring about and how the behavior and looks of the robot can influence this range of possible behaviors. Consider scenarios where cleaning robots require human assistance, autonomous vehicles in traffic need to assert their right of way, and restocking robots need to communicate to customers to maintain a safe distance. How exactly people will respond to robots they may encounter in everyday life will, to a certain extent, remain unpredictable. However, explorations and analysis of *situated encounters* (that is, encounters between humans and robots within specific situations [Gemeinboeck, 2021] can help to identify the range of potential responses and contribute to further understanding of how design features invite particular responses and foreclose others. To this end, we developed a workshop in which we collaborated with theater professionals to enact situated encounters between humans and robots on a mixed reality stage that combines **Virtual Reality (VR)** with real-life interaction. We used this setup for speculations about the kind of interactions that may result from encounters between humans and robots in a supermarket setting. Supermarkets are a special kind of environment where the scripted meets the improvizational. On the one hand, they are spatially structured environments where products are arranged in aisles according to product categories, and work processes are well organized. On the other hand, supermarkets are dynamic physical and social settings inhabited by people who do not behave according to clearly defined scripts. The challenge, then, is how to engineer the behavior of robots—designed first and foremost to execute practical and pre-scripted tasks—to allow them to operate in often unpredictable real-world contexts with human beings.

This article describes how our mixed reality stage fostered a workshop that contributes to the development of human–robot interaction in at least four different ways. First, the setup provides tools to investigate the range of possible interactions that may unfold from human encounters with robots in supermarket situations. The mixed reality stage allowed a human puppeteer to manipulate the movement qualities (speed, acceleration) of a virtual robot model by means of a tailor-made interface (that we will refer to as the "straitjacket") that made the virtual robot's capabilities correspond with that of a PAL Tiago robot and also to expand the behavior of the robot to projected future possibilities. Second, the encounters that thus emerged (and that were recorded in various ways allowing for a diversity of perspectives on interactions unfolding) were then made the subject of collective phenomenological analysis. The aim of this analysis was to understand the role played by different aspects of robot looks and behavior in bringing about human–robot interactions: how do the presence and behavior of the robot invite responses, and how does this set the stage for interactions to unfold? Third, we deployed the skills of theater professionals to investigate the behaviors of humans encountering robots in such situated encounters. The actors performed explorations of human–robot encounters while a puppeteer controlled the robot. We used the creative, empathic, as well as analytical skills of the actors and the puppeteer to experiment with novel robot behaviors and speculate with us on how these may afford human–robot interactions. The mixed reality stage made it possible to quickly adapt the morphology and movement capacities of the robot to imaginary future possibilities, thus allowing the creative imagination of the puppeteer to inform new kinds of behavior. Fourth, our mixed reality stage made it possible to include in our investigations the robot's perceptual capacities and how these capacities for perceiving what it encounters co-determine its possibilities for interaction. To this end, the puppeteer manipulating the virtual robot was wearing a VR headset that reduced his perceptions in ways that approximated the robot's perception and thus required him to determine how the robot would respond on the basis of such restricted perception.

In the following, we first present related work in **Human-Robot Interaction (HRI)** by unpacking different threads of research to build up the rationale underpinning our work. We then describe the mixed reality stage and how we used it for a series of enactments during the workshop. We continue with describing methodological insights gained and conclude by discussing the practical and broader implications of the findings on speculative design methodologies in HRI.

2 Related Work

As robots are starting to move from controlled industrial sites of automatic production into the more spontaneous situations that make up everyday life, HRI researchers are focusing on what this shift demands from robot design and engineering. Threads of work have been developing in HRI focusing on varieties in robot morphologies [Oh and Park, 2014], expressiveness qualities [Hoffman and Ju, 2014], social interactions [Breazeal, 2004], and their embedding in daily practices [Forlizzi and DiSalvo, 2006]. Performative approaches to interaction direct attention to HRI as emerging from situated encounters [Gemeinboeck, 2021] in which robots and other kinds of technologies are "co-performers" [Kuijer and Giaccardi, 2018]. This brings about an inherent unpredictability in our dwellings with them, acknowledging that interactions cannot be fully scripted beforehand but instead involve a spontaneous "coming together" of human and nonhuman actors within situations as they unfold [Gemeinboeck, 2021]. Knowledge and skills from theater and the performing arts have been recognized as inspiration for novel approaches to get a grip on this phenomenon, being well suited to explore a robot's communicative qualities and presences [Bleeker and Rozendaal, 2021]. Speculative design techniques, including the use of VR, have been used to speculate about robotic futures [Auger, 2014; Simeone et al., 2022].

In this section, we position our approach in relation to these different research threads. A performative approach to HRI is at the core of our conceptual framework (Section 2.1). We align this with the emerging role of speculative design methodologies in HRI, particularly in speculative enactments. A range of HRI work has already been conducted on the intersection of performativity and speculation, drawing insights from theater to serve as either an interaction model or, more recently and more attuned with the framework of situated encounters as an interaction approach (Section 2.2). While a range of prior work on speculative enactments with such interaction approaches has effectively used VR—given the opportunities it provides for immersion in imaginaries—work within HRI to date has mostly used explorations in VR to develop or test interaction models (Section 2.3). Our work shows how VR can be used to support the development of situated encounters in HRI and to include the perceptual perspective of the robot in these explorations.

2.1 From Scripted to Performative

Performative approaches to HRI shift focus from "representation" toward "enactment" as the basis for developing a robot's behavior, communication, agency, and identity. A performative approach, Gemeinboeck [2021] observes, foregrounds materiality, embodiment, and relationality, and draws attention to how meaning, agency, and identity come about in encounters between human and robotic bodies, and within the enactment of relationships between them. A performative approach, therefore, explores how situated encounters between humans and robots set the stage for interactions to unfold, behaviors and communications to emerge, and identities to become defined as a result of how relationships are enacted within particular situations. Such a performative approach is most useful for developing HRI for robots that do not take "the human" as a model for interaction but instead starts from encounters between humans and robotic bodies, and the potential of their respective bodies for enacting interactions and relationships. Gemeinboeck's Machine Movement Lab [Gemeinboeck and Saunders, 2018; Gemeinboeck, 2021; Gemeinboeck and Saunders, 2022] is an example of how a performative approach allows for the creative invention of new forms of communication between humans and robots that is grounded in the morphology of their respective bodies, their expressive behavior, and build on human capacities for embodied meaning-making.

In line with the above, our performative approach is iterative by nature, starting from experimental enactments of encounters, exploring what these bring about, and how they can be developed further to become the basis for HRI in actual real-world situations. This performativity is not a matter of what a person or a thing does per se, but of what ways of being present and doing things bring about within the given situation: how what is said and done affords interpretations, triggers associations, and brings about affects.

2.2 Speculative Design Methodologies and Theater

Our use of situated encounters to explore and speculate on human–robot interaction builds on and contributes to speculative design methodologies. Speculative approaches encompass imagination and the exploration of the possible. Elsden et al. [2017] use the notion of *speculative enactments* to describe how enactment can be used to examine possible futures together with participants. They discuss how speculative enactments allow genuine social interactions to unfold by setting a stage that invites participants to improvise on existing everyday routines as alternate lived realities in a personal and meaningful way, i.e., consequential to participants' experience outside of the speculation. Speculative enactments allow for the investigation of participants' experiences and behaviors in future situations, including social and ethical concerns. Furthermore, they point out how the future is not a neutral concept. Speculations are positioned from within specific contexts, bringing values, expectations, and cultures into the speculation.

During the past two decades, roboticists have begun to recognize the value of expertise from the theater for the development of robots and HRI and speculate about the opportunities as enactments. Knight [2011] refers to Breazeal's [2003] pioneering work and observes that "using the theater context and body of knowledge to bootstrap the development of effective social robots is important because non-verbal expression is key to understanding sociability." [Knight 2011, 43]. In Japan, theater maker Oriza Hirata and roboticist Hiroshi Ishiguro have collaborated since 2008 in the creation of plays with robots that also serve as experimental setups for the development of robot behavior as well as testbeds for the success of this behavior [see: Hirata and Ishiguro, 2010; Nishiguchi et al., 2017; Sone, 2017]. Jochum et al. [2016] have shown how theater can be used to study interaction with care robots and how the theater proves a useful site for exploring relevant factors in social robotics, such as social dynamics, interpersonal communication and conversation, and issues, such as timing and improvization. Similar improvizational approaches have been explored by Sirkin et al. [2016]. Hoffman and Ju [2014] identify movement as key to developing non-verbal HRI and look at the theater as a source of inspiration. They observe that theater acting and musical performance could serve as useful testbeds for the development and evaluation of action coordination in robotics, and point to the usefulness of insights from theater acting literature for HRI. Knight and Simmons [2014, 2016], for instance, look at Laban movement notation as a tool for developing HRI. Troughton et al. [2022] offer an overview of how approaches to movement improvization used in theater and dance have been used in the development of HRI and propose a new approach starting from rule-based improvization technologies.

Looking at the work of these and other authors, a distinction can be made between roughly two different approaches to theater in HRI. On the one hand, theater is taken as a model of human behavior and human-human interaction that can be applied to robots. On the other hand, skills, practices, and expertise from the theater are put to use to invent modes of behaving and communicating, and experiment with their possibilities. Whereas the first approach looks at the theater as a means to represent humans and their behavior and modes of interacting (taking the theater as a source of information about how to model human-like behavior and interaction that can then be implemented in robotics), the second builds on skills of makers to bring about worlds and identities and to engage audiences in relating to them. The second approach thus directs attention to the performativity of behavior, situations, and ways of addressing people in those situations, and to the skills of makers to recognize this performativity and put it to use. This performativity, as pointed out above, is not a matter of what a person or a thing does per se, but of what ways of being present and doing things bring about within the given situation: how what is said and done affords interpretations, triggers associations and affects, and brings about a sense of character, intention, and agency. Our approach, foregrounding performativity and using the skills of theater makers to analyze and speculate upon situated encounters, belongs to the second category.

Our use of the theater as part of a speculative approach to researching HRI through enactments bears some similarities to the work by Luria et al. [2020], who devised a theater performance to understand the social embedding of robots in home environments. Similar is that they, too, worked with actors to enact encounters with robots as well as for their capacities for embodied meaning-making, namely, to provide their embodied interpretation of what happens in these encounters. An important difference between their approach and ours is that they worked with pre-scripted scenarios that were shown to an audience, whereas the situated encounters we explore are not scripted. Furthermore, our workshop also involved a puppeteer to animate a virtual robot in VR (see Schulz et al. [2019] on animation techniques in HRI). Unique to our method is that the puppeteer is not only brought in to make the robot enact encounters with humans but also to enact the perception of the robot, i.e., to act based on visual information obtained from its sensors. This was made possible by our specific way of using VR as part of our mixed reality stage.

2.3 Staging Virtual and Physical Realities

One of the main arguments for relying on VR in HRI is that it is technically and economically more feasible to simulate HRI in VR than to actually build them while VR offers sufficient approximal correspondence with real-world situations. For example, Sadka et al. [2020] suggest that VR has the potential to be a valid prototyping tool for social interaction with non-humanoid robotic objects by comparing their physical and virtual experiences of a particular robot design. They conclude that “the similar social interpretations in the VR and physical interactions were consistent across all dependent measures, each representing a different facet of the interaction” [Sadka et al., 2020, p. 6]. Weistroffer et al. [2014] assess the acceptability of human–robot co-presence on assembly lines by comparing actual situations and their VR counterparts. Wadgaonkar et al. [2021] describe using VR to explore how people experience robot locomotion. They were particularly interested in finding out how collision detection worked, i.e., investigating the experience of colliding paths by using quantitative experience metrics, including the feeling of safety, friendliness, and so on, by varying a robot’s form, its material expression, and the spatial path it followed. Similarly, Herzog et al. [2022] use VR to investigate the experience of robots guiding passengers in a bus stop environment. These studies suggest that VR may be a good tool to assess the acceptability of human–robot collaboration when drawing on capturing people’s experiences based on variations of a robot’s appearance and behavior. Similar findings have been discussed by Mäkelä et al. [2020] who explored the use of VR in what they refer to as “virtual field studies” as well as by Mara et al. [2021] exploring HRI in a complex VR studio environment.

VR has also been used as a speculative design approach to provide access to a world that might not yet be possible in reality, thus allowing audiences to experience imaginary spaces. McVeigh-Schultz et al. [2018] describe the use of VR as providing rich embodied experiences that allow people to experience design fictions firsthand. Building on the work by Elsden et al. [2017], immersive speculative enactments (ISE) introduced by Simeone et al. [2022] describe how participants can become immersed in a speculative virtual world envisioned by designers. By describing different speculative design cases, their aim is to contrast the use of VR in enactments with other forms of speculation and provide a set of guidelines detailing how ISEs be designed and deployed. For them, the attractiveness of ISE lies in the potential to bring to life the world imagined by the creators of the speculation, and how this can result in actionable feedback that can help transfer insights from the speculation to the real world.

While VR transports one's actions and experiences into a virtual space, mixed reality brings together virtual and physical reality by blending physical and virtual prototypes and integrating VR in physical staging [Peters et al., 2018; Renner et al., 2018]. More recently, a taxonomy has been created by Walker et al. [2023] describing mixed reality as either merging virtual elements into realistic environments, or vice versa, merging real elements into virtual environments. Our notion of mixed reality, instead, is inspired by media theorist Mark Hansen (following artists Monika Fleischmann and Wolfgang Strauss, see Hansen [2012]) who describes how technologies like VR expand our possibilities for embodied enactment of our perception of real and imaginary situations. Our aim is not to completely immerse participants in imaginary situations made possible by VR but rather to support a "double consciousness" with regard to the situations being enacted. We introduce a mixed reality *stage* as an environment to support them to switch between the experience of the imaginary situation in VR and the real material setting to reflect on it from multiple perspectives, and thus bring about a double phenomenological consciousness with regard to the situation at hand. In the following section, we will elaborate on how the mixed reality stage made it possible for theater professionals to bring to bear their creative embodied expertise on a virtual representation of the robot's behavior (in the case of the participating actors) and on the robot's ability to act based on its perception of the environment (in the case of the puppeteer). Furthermore, the stage provided us with a combination of different perspectives (first-person and third-person ones), from inside the virtual simulation and from outside of it, from human actors and spectators and from the robot, that provided the basis for our collective phenomenological analysis of the interactions unfolding. In our experimental workshop, we investigated how such multiple perspective analysis of situated encounters between humans and robots can help to identify the range of potential responses and contribute to further understanding of the features and behaviors that invite or foreclose particular responses from occurring.

3 Experimental Workshop

The aim of our workshop was to investigate how our mixed reality stage, and the collaboration with theater professionals within it, could be used for investigating situated encounters between humans and robots and the interactions that emerge from these encounters. The aim was not to produce or test out specific interactions but to investigate how behavior and interactions emerge from situated encounters between humans and a robot in a supermarket. More precisely, our aim was to investigate how our mixed reality stage can be used to identify the range of possible interactions that may unfold from human encounters with robots in supermarket situations, and how the setup can be used to identify aspects of the robot's looks and behavior that play an important role in bringing about specific ways of responding to them. That is, the aim of our workshop was to explore the potential of our mixed reality stage to investigate behavior emerging from situated encounters methodically.

The workshop was part of a larger research program that works toward the further development of PAL Tiago robots for supermarket settings. Whereas other parts of this research program focused on technological developments, the focus of our contribution was on understanding how these

Table 1. List of Workshop Participants

#	Participants	Background/training	Role description
1	Theater professionals	Actor—Classically trained acting trainer	Played a customer
2		Actor—Acting trainer with mime background	Played a customer
3		Puppeteer—Acrobatics and Circus arts	Controlled the virtual robot
4	HRI researchers	HRI researcher—Interaction design	Principal investigator
5		HRI researcher—Emergent behavior	Principal investigator
6		HRI researcher—Theater studies and STS	Principal investigator
7		Theater studies intern	Process documenter
8	VR technicians	VR technician—Designer	Virtual robot designer/settings controller
9		VR technician—Producer	Assistive support
10		VR technician—Support	Assistive support
11	Roboticists	Roboticist—cognitive modeling	Informed virtual robot design
12		Roboticist—motion planning	Informed virtual robot design
13		Roboticist—gripper control	Informed virtual robot design

service robots could function as part of a social setting with customers. We were interested in how our mixed reality stage can be used to understand how interactions might emerge from encounters between this robot and customers in a supermarket setting, and how the behavior of the robot affords ways of responding and brings about ways of relating to it. We were interested in particular in the methodological potential and implications of our setup for new approaches to the development of HRI that are not based on making robots execute pregiven scenarios but instead build on possibilities for emergent behavior that is situated (i.e., specific to the situation and the robot's morphology).

To this end, we staged encounters between actors and a robot in a VR simulation of a supermarket. We worked with a puppeteer to control the virtual robot and worked with actors who played the customers encountering the robot. The mixed reality stage allowed us to follow the interactions simultaneously in real life and in VR and from different perspectives, including that of the robot. This combination of perspectives provided the basis for collective phenomenological analysis of the interactions in order to unpack the interactions and understand how they come about.

3.1 Participants

13 people in total participated in the workshop, bringing in skills and knowledge from the fields of Theater, HRI, VR, and Robotics. Each participant played a different role with varying levels of participation across the 4 days (Table 1).

Three *theater professionals* played a central role in performing the enactments. The puppeteer (Joris), controlling the robot, has a background in puppeteering, acrobatics, and circus arts. Two professional actors took on the role of supermarket customers. One of them (Jenne) is a classically trained actress whereas the other (Santino) has a background in movement theater. Both have extensive experience in using their acting skills in drama-based training situations. This proved to be most useful for our research because, as training actors, they were not only capable of analyzing and improvising real-world situations but also experienced in reflecting on these situations and their own roles as well as those of others within these situations.

Three *roboticists* participated in the preparatory phase. They provided input on how to model the virtual PAL Tiago robot so that it would reflect its capabilities for perception and action, as it is now, and what can be expected for the next 5–10 years. They gave input concerning the possibilities of machine vision, motion capabilities, and levels of responsiveness. Their input led to the design of the interface through which the puppeteer could control the robot avatar.

Three *VR technicians* supported the development of the mixed reality stage and the execution of the enactments. One technician created an abstracted virtual supermarket environment in the Unreal^{tm} platform and implemented the virtual robot in this environment based on the open-source **three-dimensional (3D)** model of the actual PAL Tiago (https://github.com/pal-robotics/tiago_robot). This model was also used to create the animation rig for the skeleton of the robot. This made it possible to apply inverse kinematics to the robot arms and be able to control it by using the VR controllers and trackers as input. This technician also created a visual display for the puppeteer to see as if "through the robot's eyes" as informed by the roboticists. During the enactments one of the technicians controlled the settings of the virtual robot and monitored data recordings by checking both the virtual and physical cameras, if they were well-positioned and recorded data. The two other technicians assisted in running the workshop by making sure the head-mounted displays were worn correctly during the enactments, the controllers and sensors worked, and prevented the actors on stage from tripping on the wires connecting the head-mounted displays with their base stations.

Four *HRI researchers* were involved in setting up, planning, and managing this study. One researcher has a background in Interaction Design (first author), the other in Emergent Behavior (second author), and the third has a background in theater, and Science and Technology Studies (third author). The fourth researcher (who was an intern in theater Studies at that time) was tasked with documenting the process and observing how the workshop was developing over time by making notes of observations and carrying out interviews with participants.

3.2 Setup

The workshop lasted 4 days, and each day was divided into a morning and an afternoon session. The mornings were used for performative explorations of situated encounters and collective reflection on what happened within them. In the afternoons, the HRI researchers reflected on the outcomes of the enactments and the ways of working explored in them and decided upon the next steps to be taken the following day. The researcher who acted as the documenter, initiated discussions about the workshop process by sharing her observations of the day and asking the other HRI researchers questions.

In the enactments, the puppeteer and one of the actors improvised encounters within the virtual environment of the supermarket. Each enactment started with simple instructions about the starting conditions of a scene, such as, "you enter the supermarket aisle and see this robot for the very first time." The theater professionals were then left free to improvise interactions emerging from this starting point. This was followed by collective reflection on the interactions together with the actors (contributing from the perspective of the supermarket customer) and the puppeteer (contributing from the perspective of the robot) in which relevant moments for further investigation were identified. These situated encounters were enacted multiple times to explore in detail how interactions emerged from them and to try out variations. This could also lead to making changes in the robot settings to explore what this would bring about. The HRI researchers and the second (off-stage) actor witnessed the enactments as an audience, observing the physical stage directly and the virtual environment via the available displays. Which one of the two actors performed the enactment first, varied across days to balance out their role as audience watching the enactment versus being the performer involved in the enactment.

An important part of our experimental setup was the collective phenomenological unpacking of what happened in the encounters and the interactions emerging from there. Phenomenology originated as a field of philosophical inquiry rooted in the work of Husserl [1999], Heidegger [2010], Merleau-Ponty [2013] and others, and is involved with how any understanding about reality is first and foremost disclosed in subjective experience. Phenomenology emphasizes the important role of experience, embodiment, and situatedness for how what we encounter comes to matter for us (see Moustakas [1994] and Giorgi [2009] for how phenomenology has been developed into practical research methods). A phenomenological analysis undertakes to rebuild from the beginning the conditions necessary for the formation of cultural units, which semiotics instead accepts as data because communication functions on the basis of them [O' States, 2007]. Likewise, our workshop set out to unpack the formation of the data on the basis of which communication functions and to trace the formation of communicative behavior. We looked for moments that seemed to be particularly meaningful for how relationships and interactions come about and develop from the encounters between humans and the robot, and how these could become the starting point for further investigation of this moment and its details and nuances.

3.3 Mixed Reality Stage

The mixed reality stage involved a 3 m x 3 m physical stage on which the virtual supermarket environment could be mapped. The stage could facilitate two participants, each wearing a head-mounted display with two physical controllers, one in each hand. The head-mounted display tracked not only the actor playing the customer's position in space but also their head orientation, granting the actor the freedom to explore the virtual environment by moving and looking around. Additionally, two hand-held controllers tracked the position of the hands in relation to the body, allowing the actor to grasp products from the shelves and move them around. The puppeteer controlling the virtual robot sat down in an office chair to help him empathize with the rolling locomotion of the virtual robot while the actor playing the customer could freely walk around. The puppeteer also wore a head-mounted display and had access to various trackers, enabling control of the virtual robot through multiple means. Detailed descriptions of these trackers and controllers will be provided in the following sections. Other researchers who were seated or could stand next to the stage could observe the actions as they occurred live on stage as well as on various screens. One video livestream captured human–robot interactions in the virtual supermarket from a third-person perspective. This stream was presented on a large screen. To capture the enactment clearly, the VR technician re-adjusted the virtual camera depending on the changing positions of the robot and customer. Two other video livestreams showed the perspective of the customer and the robot from their first-person perspectives. These streams were presented on two smaller monitors next to the stage. All these streams, including video capturing the physical stage, were recorded for subsequent analysis. See Figure 1, which shows the floor plan of our workshop setup.

The virtual supermarket environment, created in an Unreal™ platform, consisted of a supermarket aisle of the same size as the physical stage. In general, the virtual supermarket was represented in a slightly abstract manner, leaving out visual detail and using basic colors. On both sides of the aisle, long cupboards were positioned 3 meters long and about 1.5 meters high. Both cupboards had four shelves. Three supermarket trolleys could be seen in the background as passive props adding to the store atmosphere. Virtual products shaped like cans were present for the robot and the visitor to interact with. These products could be picked up, repositioned, or thrown, following the rules of gravity. For instance, products could be placed on shelves, on the floor, and even on top of the robot. See Figure 2, showing an image of the physical stage juxtaposed with the virtual supermarket.

3.4 Virtual Robot Model

We used a virtual model of the PAL Tiago robot which included all different body parts (i.e., its base, arm, head, gripper, and so on). See Figure 3. We created an inversed kinematic model that could be moved around in VR according to the actual physical constraints of the robot. Next to this, we asked roboticists to give input on the level of *visual detail* in which the robot could see the environment, the *speed*, and *degrees of freedom* with which the robot could move, and levels of *responsiveness*. These inputs were used to set the control parameters as listed in Table 2. These limiting controls are what we came to call the *straitjacket*. The term straitjacket refers to being

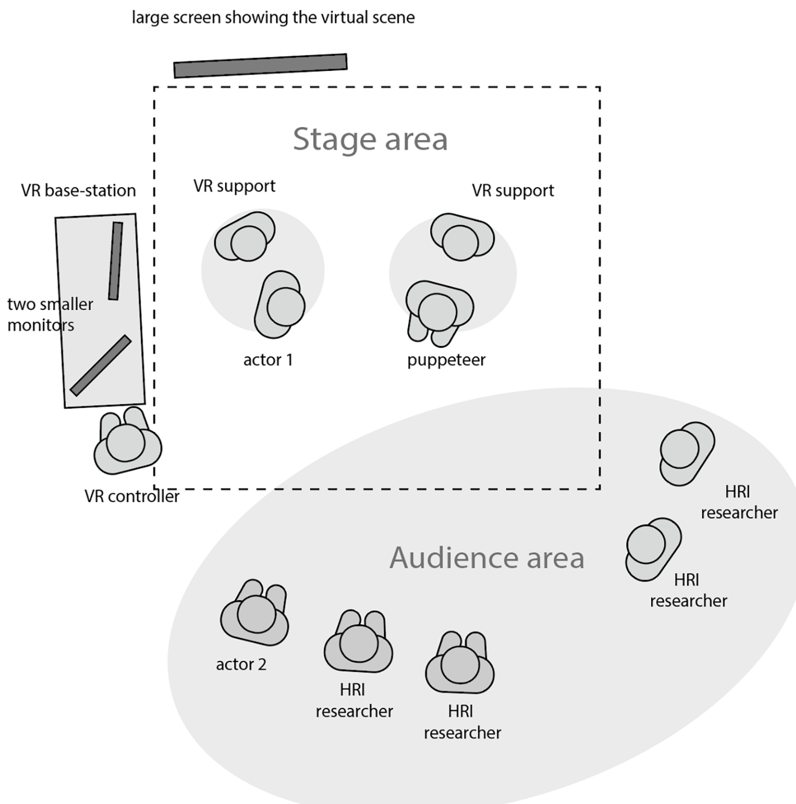

Fig. 1. Floorplan depicting the workshop setup.

locked in, to something that can be used to limit a person's capacities for movement, and that can be tightened or loosened. This is exactly what we did to the robot avatar the puppeteer controlled. The input given to us by the roboticists informed us about how tight or loose the straitjacket should be. This allowed us to explore the varieties in which the robot could respond to human actions while remaining realistic about the robotic technology we are simulating.

3.4.1 Body. The virtual robot consisted of a *base* that allowed the robot to move around in all directions with rotation. The puppeteer controlled this locomotion while sitting in an office chair to which a location tracker was attached, allowing the robot to move around in correspondence to the chair's movement and rotation. A robot arm could be moved with a hand-held controller (held in the same arm) and the gripper could be closed by pushing the button (by which the robot could also grasp products). Based on these standard elements, the robot body further allowed for two variations. One, the virtual robot could adjust its *body height* by sliding its upper section over a lower section of its base, allowing for variations in height. This movement could be controlled by the puppeteer raising or lowering a second position tracker in his left hand. Two, the robot could be equipped with or without a *head*, and in case it had one, this could be moveable or be fixed in position looking straight forward. If the head was moveable, its rotation and tilting could be controlled by rotating and tilting the same position tracker.

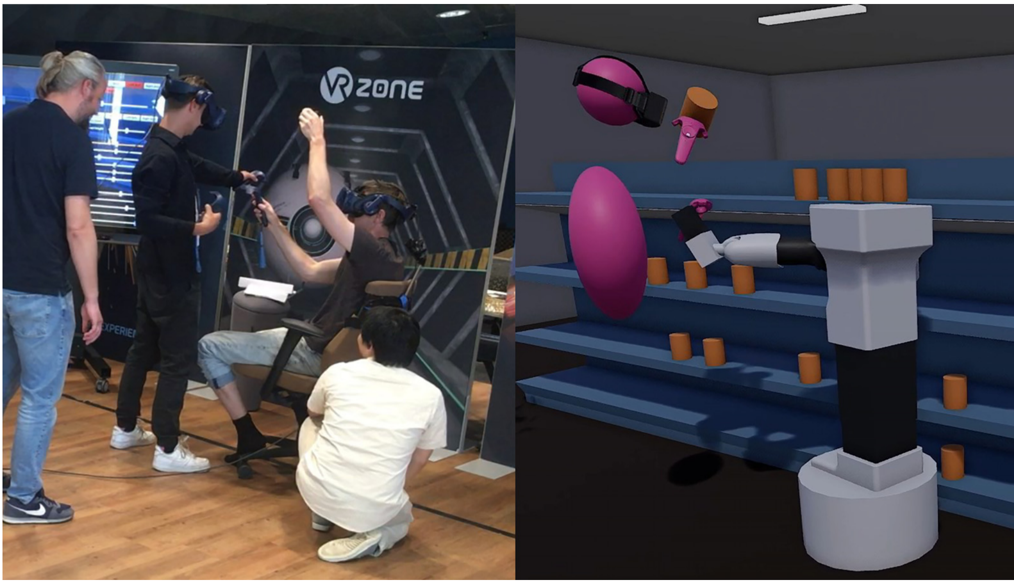

Fig. 2. Image of the physical stage (left) juxtaposed to its co-located presence in the virtual supermarket (left).

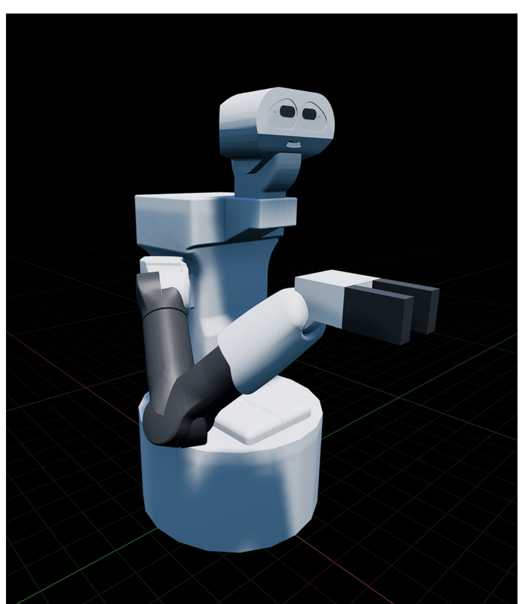

Fig. 3. Image of the virtual PAL Tiago robot model that could be equipped with or without its head.

3.4.2 Movement. Other variations involved the *speed*, *richness*, and *flow* of movement. These factors affected how the sensors tracked the motions made by the puppeteer, consequently influencing the movement of the virtual robot model. The *speed* of the robot's movements in VR (as distinct from the speed of the puppeteer manipulating the robot in actual space) could vary,

Table 2. Robot Capacity Variability across Its Body, Movement, and Vision during the Enactments

Body	**Options**	**Movement**	**Options**
Head	Yes/fixed/No	Speed	Slow/fast
Body height	Fixed or adjustable	Richness	Sequential/parallel
		Flow	Amount of delay between actions

Vision	*Options*
Depth	Whitening fog filter
Breadth	Narrow-/broadness
Detail	Level of pixelation
Product recognition	Volume/Point
Human recognition	Pillar/Facing direction/+Hands
Backside sensors	On/of

from the robot moving in VR at a much slower pace compared to the live actions of the puppeteer, toward the robot approximating the puppeteer's actual speed. Second, the *richness* of robot behavior could be varied by allowing for parallel actions versus requiring each action to be performed in a sequence. The latter required the puppeteer to toggle between a robot's different actions by pressing a button on the handheld controller. In sequential action mode, the experimenters could set the *flow* of movement from high to low, by varying the length of delays triggered when toggling between different action capabilities. When set to high, the puppeteer could toggle between action capabilities without delay and when set to low, there would be a delay of 5 seconds. These variations allowed us to experiment with the effects of technological advancements on interaction possibilities. Generally, lower settings across these parameters produce a robot that acts slowly, in a step-by-step, staccato-like manner, while higher settings make the robot appear to perform actions fast and fluidly, approximating the puppeteer's real-time physical motions.

3.4.3 Vision. A final set of variations concerned the perceptual capacities of the robot. The setup was designed to provide an approximation of how the robot "perceived" its environment, allowing the puppeteer (and others via one of the screens) to "see through the robot's eyes." These settings were informed by conversations with roboticists advising us on the visual sensing capabilities of robots in the preparation phase of the workshop. The "straitjacket" allowed us to vary the perceptual input from an extremely limited and pixelated field of vision toward a full high-resolution image, thus making it possible to investigate the effects of the robot's perceptual capacities on the unfolding of interactions with humans. The robot's *depth* of view was varied by applying a white fog filter that would blur the visual scene, and this could be set to start at a particular distance corresponding to the extent 3D cameras can see into the environment. Robot vision *breadth* could be changed by varying the field of view from only a small focus point (experienced as looking through a pinhole) to a broader field of view that, in its maximum capacity, could cover the full head-mounted display. This pertains to the angle at which robots can perceive the environment, whether through single or multiple camera setups. Robot vision *detail* was created by pixelating the screen from fine-grain to course-grain pixels, reflecting variations in robot vision granularity. See Figure 4 (left) for an overview of several options that could be part of a combined setting.

Robot vision could further vary in terms of seeing people and products in various levels of detail, reflecting variations in computer vision capabilities. This spectrum ranged from limited visual information to more elaborate data, enabling functions, such as object recognition and manipulation or facilitating social interaction. *Product recognition* consisted of either showing a 3D

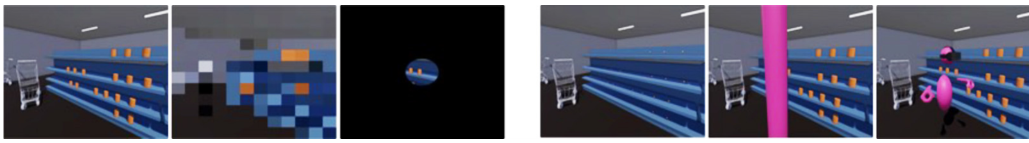

Fig. 4. Examples of some of the visual parameters. On the left, (1) a high-fidelity field of view, (2) pixelated field of view and (3) field of view with limited breadth (pinhole vision). On the right, (1) products represented as points rather than volumes, (2) limited human representation (column) and (3) detailed human representation (body, head, hands). Settings involved multiple parameters.

product representation (i.e., depicting a product's location and volume) or a product representation that used only one point (i.e., depicting a product's location only). *Human recognition* was simulated by depicting a person as a *pillar*, hereby only communicating a person's location and locomotion; as *two oval objects*, a larger oval representing the human torso and a smaller oval (above it) representing a human head with an indication of eyes. Together, they communicated location, locomotion, and (to some extent) gaze as well. In the most detailed representation, the human figure included *hands* that allowed the puppeteer to get a sense of what the person was doing. Additionally, *backside proximity sensors* were simulated by showing a red color filter in the field of vision periphery in case a person was standing behind the robot. See Figure 4 (right) for an overview of several settings on object recognition.

4 Outcomes and Insights

In the following we reflect on how our workshop contributed to the development of HRI in the four ways announced in the introduction, focusing on (1) how the mixed reality stage allowed us to investigate the range of possible interactions that may unfold from human encounters with robots in a supermarket setting; (2) how a collective phenomenological analysis can be used as a tool for unpacking what happened in these interactions to understand how emergent behavior is brought about in the encounters, and to identify aspects of the robot's appearance and behaviors that play an important role in bringing about specific ways of responding to them; (3) how skills and expertise from theater professionals contributed to the staging of situated encounters as well as analyzing them; and (4) how our mixed reality stage made it possible to include in our investigations the robot's perceptual capacities and to investigate how these capacities for perceiving what it encounters co-determines its possibilities for interaction.

4.1 Enacting Situated Encounters

Our mixed reality stage allowed us to investigate the potentials and possibilities of situated encounters between humans and robots and how encounters invite or foreclose interactions that emerge from them, as opposed to starting an investigation from a pre-conceptualization about how interactions might be scripted and modeled. Instead, we looked for how the robot's appearance, movement, and possibilities for responding afford ways of interacting with them, and investigated how these possibilities can be put to use to invite, guide, or end interactions. The mixed reality stage allowed us to methodically work through various aspects of these encounters while changing specific elements of them within successive iterations. The series of encounters initially had an open character, exploring various possibilities of what could happen, and it gradually shifted toward finding ways in which the robot could act appropriately within a given situation. To get a sense of the experience of these enactments, descriptive accounts for each day are briefly summarized below (see Table 3 for a summary). A full account of these workshop outcomes falls outside the scope of this article but will be published elsewhere.

Table 3. Overview of the 4 Days and Descriptions of Human Context and Robot Settings

Day	Theme	Familiarity with robot	Enactment Focus	Initiative	Robot settings
1	Making contact	Novel	On robot itself	Human takes initiative	Full body setup with limited sensorimotor capabilities
2	Sustaining engagement	Novel	On robot in task-situation	Robot takes initiative	Comparing rich and limited robot settings
3	Functional-social interaction	Familiar	Critical examination of social quality	Both human and robot take initiative	Robot body without a head with rich sensorimotor capabilities
4	Ideal situations	Familiar	Ideal situations from customer's perspective	Both human and robot take initiative	Robot body without a head, with rich sensorimotor capabilities

4.1.1 Day 1: Making Contact. The enactments on the first day were driven by curiosity about the initial impression elicited by a robot engaged in restocking tasks on actors playing customers. In these enactments, the robot was equipped with a single arm and a stationary head, while we varied its visual sensing and motion capabilities. During these enactments, we noticed how the actors experimented with various strategies to make contact and interact with the robot. A crucial factor within these interactions appeared to be puppeteer Joris' limited possibilities for sensing the presence and behavior of the individuals he encountered and his capacity to respond to them, both mediated by the "straitjacket" mimicking the perceptual and behavioral capacities of the robot. Additionally, the actors' perceptions of the robot (influenced by its appearance and movements) played an important role in shaping their interactions with it. We investigated the formation of these perceptions and the subsequent interactions by adjusting the robot's sensing and actuating capabilities and exploring how people's attributions triggered specific responses and affective experiences.

4.1.2 Day 2: Sustaining Engagement. On the second day, we shifted our focus to examining how the robot's presence is experienced in scenarios where the attention is on the actors engaging in grocery shopping. Throughout the enactments, we varied the richness of motion (working with faster or slower movements) as well as the robot's embodiment (with or without head). We observed how the robot's presence affected the shopping experience, eliciting different responses—it could go unnoticed, make shopping more interesting, or obstruct it. The speed of movement proved crucial for adapting swiftly to shoppers' pace. We explored the differences between a headless robot and one with a movable or stationary head. Interestingly, the presence of a head significantly influenced customers' expectations regarding the robot's communicative abilities. They preferred the headless robot as it didn't raise social expectations, something they felt to be more appropriate for a restocking robot in a supermarket setting.

4.1.3 Day 3: Functional-Social Interaction. Building on the insights from the previous day, we continued working with the headless robot. We were curious to learn more about how customers could perceive a functional restocking robot as sociable, how the robot should behave to make this happen, and when this would be appropriate. Specifically, we examined situations where tensions might arise between the robot's need for space to perform its restocking task and the need to make room for the customer. We investigated how the robot's practical actions could also be interpreted as social and looked at how functional movements could be executed in manners that could be read as conveying politeness, disinterest, and dominance, among other expressions. Achieving this required equipping the robot with sufficiently rich sensorimotor capabilities to gauge human intent and respond with varying levels of speed and flexibility. Additionally, these enactments revealed how the robot could negotiate space assertively or subtly by adjusting its size through changes in its robotic body.

4.1.4 Day 4: Ideal Situations. On the fourth and last day, the actors were asked to enact their ideal use situation based on their experiences from the previous days. The robot's capabilities remained unchanged from the day before, with actors taking on the role of directors to stage and play out this situation. Actor Santino explored how the robot performing its task could respect his personal space during grocery shopping, while actor Jenne investigated how the robot could express its inability to respond to requests without encouraging further interaction or implying malfunction. In both cases, we noticed the importance for actors and puppeteers to understand the rules of engagement. This awareness enabled a deeper examination of the logic of action and response, as well as the movement qualities underlying these interactions. It also aided in identifying critical moments concerning the robot's readability and emotional tone, within more complex interaction sequences and when needing to convey being in an idle state.

4.2 Mixed Reality Staging

The mixed reality stage thus supported systematic experimentation with situated encounters and a methodological working through of the role played by various aspects of these encounters (like the robot's morphology, types of movements, speed, proxemics, position in space, as well as the robot's perceptual capacities). Our use of VR as part of the mixed reality stage made it easier to work through the effects of such variations. Easier, that is, than experimenting with an actual robot in a real supermarket would have been. Furthermore, the setup allowed us also to explore the effects of speed, motion fluidness and other features that robots currently do not possess but that they are expected to possess in the near future. Furthermore, having a physical stage with actors and the audience had other advantages. The audience could witness the enactments being performed on the physical stage while simultaneously seeing the different perspectives in VR i.e., the first-person perspectives of humans and robots, and the virtual scene, as being witnessed from a third-person perspective. This allowed the audience to empathize with multiple perspectives at once. We noticed that being able to witness the physical stage next to the virtual enactments proved particularly helpful in understanding how interactions in the virtual environment were experienced. Another advantage is that after enacting encounters with the actor and puppeteer in VR, taking off the head-mounted displays instantly created a more intimate social setting in which group conversations could unfold easily.

We also experienced some disadvantages of using VR on stage. The virtual setup created an immersive experience that felt comfortable to act in and did not lead to any feelings of vertigo or headaches. However, actor Santino pointed out that sometimes he noticed a mismatch between the virtual supermarket situation and what happened when he was physically moving around on the stage. This happened for example, when he accidentally bumped into parts of the chair on which the puppeteer was sitting (and that was not visualized in VR because it was not part of the supermarket reality represented there). This lack of correspondence between visual and tangible experience made him hold back on certain movements and thus limited the freedom of interaction with the robot. Furthermore, the VR environment did not allow the *peripheral vision* that people would normally experience. Santino mentioned how the robot might be doing things that, in an actual supermarket, he would be able to see from the corner of his eye, while in VR, he was unable to notice them. Also, the virtual environment showed a somewhat abstract interpretation of a supermarket rather than a realistic one, lacking the *contextual richness* of real-world supermarkets. Our experience of using VR aligns with that of Sadka et al. [2020], who conclude that VR simulates experiences that approximate real-world ones, however, while keeping in mind the limitations imposed by accidental mismatches between virtual and physical aspects of the experience, lack of peripheral vision, and limited richness of (social) context. Primarily motivated to lower the computation power required to render the virtual environment, this abstraction had its advantages as well as limitations. Both actors observed that the abstractness invited playful imagination, yet it also prevented them from taking into account complexities that might arise in actual supermarket environments.

4.3 Phenomenological Unpacking of Emergent Behavior

In our workshop, we used a phenomenological approach to unpack the interactions that emerged from the situated encounters between humans and robots. Central to phenomenology is the unraveling of relationships between the world as encountered and the experiencing subjectivity. Phenomenology shifts attention from measurement to meaning and, in particular, to how our sense of the world and of ourselves within it comes about in experience. Two practices from phenomenology that proved particularly useful are *phenomenological reduction* and *free imaginative variation* [Sokolowski, 2000]. Phenomenological reduction describes a particular attitude toward what we encounter, namely one that withholds interpretation and judgment, and instead directs attention to how our understanding of what we encounter is formed in the interplay between how the world gives itself to us and we give ourselves to the world. This attitude informed our focus on what kinds of behavior the situated encounters between humans and a robot might bring forth, rather than approaching encounters by means of *a priori* concepts or scripts. *Free imaginative variation* involves taking on different perspectives to get a clearer picture of the phenomenon of study. In the workshop, this literally translated to theater professionals replaying enactments to deepen and better understand what happens in the situated encounter and bring to light nuances or new aspects relevant to the experience. Actor Jenne described her performative investigations as informed by an "analytical way of looking" that made her closely examine the interaction in which she participated in minute detail. Through repeating the actions with slight variations, the reflexive process progressively deepened. Jenne observes that she experienced the beginning of such a series of repeated interactions to be more "intuitive" while later in the process, her understanding of the interaction seemed to become more "exact." This also reflects the transition from more open explorations initially to a desire to know more about ways of doing it right toward the conclusion. We noticed such phenomenological investigations to be intensive because of the continuous attention it takes to stay sensitive to nuances in experience, externalize them through verbalization, and reflect on them together with others.

The mixed reality stage proved to be very helpful in supporting our phenomenological investigations, as it allowed us to study the encounters collectively from a diversity of perspectives. These included the actors' first-person perspective of interacting with a robot in a supermarket and the puppeteer's first-person perspective on making the robot interact with them. Next to these first-person perspectives, the setup also allowed for third-person perspectives of the audience on the encounter in VR by means of video livestreams depicted on the screens, and in real life, on the physical stage. The actors and puppeteer thus functioned as a kind of phenomenological probe within the encounters that we investigated. As phenomenological informers from the inside, they provided first-person accounts of how their behavior came about within the encounter, and their interpretations of the dynamic enfolding of the encounters of which they were themselves part (i.e., the double consciousness referred to earlier). More than only enacting the situation, they provided us with descriptions of their embodied experiences and how these informed their ways of responding or prevented them from responding. The combination of these perspectives informed a collective phenomenological unpacking of what happened in the enactments.

4.4 Skills and Expertise from the Theater

The above description of our phenomenological approach shows that actors were not test persons brought in to see whether robot behavior triggered intended responses but collaborators investigating with us how interactions emerge from situated encounters. Their expertise proved relevant in various ways. First of all, their training provided them with the skills necessary to perform life-like interactions and to repeat these with variations. Furthermore, they were capable of inventing different ways of responding and interacting and imagining how they might respond in different ways and in different situations. This is not the same as an uninformed test person responding spontaneously to an unknown situation, but this was also not the aim of our investigation. Rather, our aim was to map possible responses and understand how these are brought about.

Actors are trained not only to convincingly perform ways of behaving but also to invent behavior that feels right in a particular situation and in interaction with others. They are experienced in making their empathic and emotional responses part of their "reading" of the situation, including their own position and possibilities for action within it. These skills proved to be most useful for investigating how situated encounters with robots may trigger responses and bring about interaction. Furthermore, as pointed out above, we worked with actors who had worked in drama-based training situations in which they had learned to verbalize detailed observations and reflections about the interactions that they were part of. These skills helped our phenomenological unpacking of what happened in the situated encounters. Relevant for our iterative approach was precisely repetition in variation (rather than one time spontaneously testing out). Useful here were the skills of the actors to perform scenes multiple times and use this to deepen the understanding of what happens in the interactions. This requires not ignorance about what will happen, or being a "blank slate," but skills that actors acquire by training and that Jenne described as "entering the situation from the here and now" and that Santino described as going back to "zero point."

The puppeteer brought in a different set of theater skills. Unlike the actors, he was not shaping his own performance but animating another entity from the outside. As he put it: "In puppeteering, I am supportive of what I need to control. I am not the actor; rather, I support a story by *bringing something to life*." His experience as puppeteer informed an approach to animating the robot from a creative exploration of the morphology of the robot and its possibilities for movement, rather than imposing human-like motions on it. This proved most useful for understanding how robotic bodies and their behavior can generate new modes of interacting that do not follow existing human models but instead follow from their own morphology and modes of expression.

With regard to working through repetition in variation, we noticed a certain resemblance to the rehearsal process of a theater performance in which theater makers feel comfortable repeating scenes multiple times to explore the potential of a scene collaboratively. Our primary aim was not to find the ideal way of performing a particular encounter, but rather to deepen our understanding of how an encounter may generate interaction. Playing and replaying encounters allowed the actors to investigate what triggered their ways of responding and what matters to how this happened. During the workshop, thematic content was developed based on our collective experience. These themes helped Jenne frame her investigations and provided clarity in her experimentation. Joris added how he felt like the developing themes provided, "new roads, interactions and moments" that they would not have found when having defined these themes beforehand.

4.5 The Robot's Perspective

The VR setup allowed us to methodically manipulate the morphology and capabilities of the virtual robot via the "'straitjacket" that was carefully crafted based on input given by roboticist. This crafting appeared to be critical for the technical realism required for the learnings of the speculation to be transferred back to the robot's engineering, and also led to the constrained puppeteering environment that challenged us to be creative. Our experiences confirm Riek's [2012] observation that imposing behavioral and sensorial limitations of robots being enacted by humans is an important methodological possibility of Wizard of Oz (WoZ) techniques in HRI. During the enactments, the straitjacket triggered puppeteer Joris to think like a robot, "I felt like I was lending out my brain like an inversed cyborg: the robot is using my brains to do things it cannot do yet." Joris mentioned how "each setting of the straitjacket brought something new to the table" and challenged him to find ways to work with it (instead of against it or in spite of it) in inventing modes of behaving for the robot and modes of interacting with customers.

As pointed out above, the restrictions of the straitjacket did not only involve the robot's possibilities for movement but also its perceptual capacities. This required Joris to develop strategies for moving the robot around within the virtual supermarket and interacting with customers on the basis of very limited perceptual input and restricted movement capacities. This involved a particular kind of double consciousness concerned with continuously shifting "being" and "playing" the robot. He managed to cope with these limitations by inventing what he referred to as *machinic strategies*: strategies of responsive behavior that do not require a detailed understanding of customers and their intentions or complex decision-making about how to respond. These could, for example, be: if a customer is detected to move close, the robot moves out of the way sideways and pauses its activities. This proved to work well in giving the customers the sense that the robot makes room for them and is politely giving them space to do what they need to do. We also noticed that this could be further improved when the robot reduced its size (by lowering its head and keeping its arm down and close to its body) when it noticed the actor playing the customer approaching.

With regard to developing HRI, this means that the starting point for designing the way in which the robot responds to a customer is not its understanding of the behavior and intentions of the customer but an automatic response to a customer approaching that is designed in such a way as to leave space for the customer to project their interpretation of the behavior on the robot. The relevance of this shift in focus was confirmed by the actors who experienced the behavior of the robot as a positive and respectful acknowledgment of their presence. Actually, they were quite surprised when we told and showed them how little the robot could perceive (we did so only afterward). In their experience, the robot had genuinely responded to them, and not merely semi-automatically reacted to a sensor indicating something was approaching.

Our experiences demonstrate the importance of taking into account not only the kind of expressive behavior a robot is capable of performing but also its perceptual capacities and how these inform its potential for responding to its environment, including humans. Our mixed reality stage provided a useful tool to experiment with the creative use of both, as well as with minimizing the necessary processing and response time. To this end, Joris developed what we came to refer to as an *algorithmic way of thinking*. Building on his skills and experience as a juggler, he somehow compartmentalized his behavior into separate elements, in order to reduce complexity and focus on key elements and his semi-automated responses to them. Like, for example, in the situation of encountering a customer described above where his focus was only on detecting that something approached him, and in case this happened, he applied his machinic response of executing a sidewise move, away from what was approaching and reducing his height.

5 Discussion

Our mixed reality stage and setup foreground the experiential aspects of interaction and communication, and shifts focus from an understanding of robots as senders of codified messages that need to be correctly interpreted toward how meaning and interaction come about in the interaction between robots and humans, appealing to a performative understanding of HRI. The setup thus supports approaches to HRI that do not work toward identifying communicative behaviors that can be universally applied but work toward insights that can be used to develop HRI that is emergent and situation- and robot-specific. Designing for emergence is exploratory by nature and works toward understanding how to set the stage for interaction to happen and how design choices may influence what behavior emerges. Our mixed reality stage supports the first steps toward such an approach in how it provides a means to investigate the emergence of human–robot interactions from situated encounters, and to identify aspects of a robot's looks and behavior that play an important role in bringing about specific ways of responding to them. However, sound has been missing as an important modality in our study. While the PAL Tiago robot does have sound capabilities, we prioritized embodiment and motion. A recent special issue within this journal highlights the significance of sound [Robinson et al., 2023]. Topics covered include taxonomies of nonverbal robot sounds [Zhang and Fitter, 2023] as well as considerations regarding sound design and evaluation [Orthmann et al., 2023]. An important question concerns how sound is also performative, i.e., [Searle, 1979], and how it can be effectively explored on a mixed reality stage.

Using these insights for designing HRI that is emergent, relational, and situational will require additional steps that are not covered by our current research. These include how to make robots capable of shifting between multiple (partial) scripts. How to make them capable of choosing between possible actions, prioritizing, or integrating them? Also: how may probabilistic models provide general behavioral trajectories that are actualized depending on local conditions and that, therefore, can take on different expressions? This requires further research. Here we would like to share some observations from our current research that may contribute to these next steps. First, designing for emergent HRI requires a different methodological rigor than the teleological logic of developing HRI according to fixed scripts. In the research described in this article, we experimented with an alternative approach based on collective reflection and step-by-step decision-making. Collective reflection also provided the basis for transdisciplinary collaboration. Such collaboration holds great potential for engaging with the complexity of developing HRI for robots intended to perform in (unpredictable) social settings and may impact society. Finally, it seems that much is to be gained from a more-than-human approach that includes the perspective of robots and takes the fundamental differences between humans and robots as a starting point for the creative development of new kinds of interaction (rather than as something that needs to be glossed over).

5.1 Reflexive Research Process

Not working toward projected outcomes, our research required openness and flexibility, yet we also needed a rigor that would prevent us from drifting. In line with our phenomenological approach, such *reflexivity* can be understood as "thoughtful, self-aware evaluation of the intersubjective dynamics between the researcher and researched." [Finlay, 2008, p. 3). We decided on a step-by-step process in which collective reflection informed choices about the next step to be taken.

One of the principal investigators (the first author) took a chairing role in socially managing people to share their observations, insights, and feedback. Suggestions could be made by all about what would be interesting to focus on as a next step in the research (leading to the daily themes described earlier). Then, three principal investigators (i.e., the three authors of this article) consulted in a subcommittee to decide upon the next steps. General rules of thumb guiding our decision-making were that (1) new steps should build on insights gained from previous steps; (2) should not be a repetition of previous steps; and (3), should align with the overall research objective. Such a step-by-step approach demands a different kind of trust from those involved in the project. Trust not in known and formalized procedures that, in clearly identifiable steps, work toward projected outcomes, but rather trust in what shared insights and collaboration will bring. We noticed how this requires transparency with regard to how decisions are taken, and a safe space in which participants feel free to experiment creatively and speak openly.

5.2 Transdisciplinarity

Such safe spaces are also necessary for the kind of transdisciplinarity collaborations that were important to our workshop and that are most relevant for the further development of HRI. We understand transdisciplinarity to describe research that involves multiple stakeholders who are affected by a "wicked" real-world problem and/or both can be part of a solution. Transdisciplinary research embraces multiple kinds of knowing (academic, experiential, and so on) in an emergent research process that produces academic and societal change. In our workshop, the mixed reality stage established what Wallis et al. [2010] after Soja [2000] describe as "third space": a conceptual space in-between disciplines and as a site of crossings between theory and practice. The stage not only mediated in bringing together various first- and third-person perspectives on the encounters (see above) but also in bringing together skills and knowledge from the fields of Theater, HRI, VR, and Robotics. Additionally, it supported fluid interactions in the collective unpacking of, and reflection about, what emerged from the situated encounters.

This "third space" for experiencing and discussing HRI from multiple perspectives and disciplines is also in line with Takayama and Scassellati's call for interdisciplinary work in HRI [Takayama and Scassellati, 2012] as well as the steadily growing interest in transdisciplinarity [Hannibal and Lindner, 2018; Jørgensen, 2023; Seibt et al., 2018; Thellman et al., 2022; Zaga et al., 2023]. As discussed by Zaga et al. [2023], transdisciplinary futuring tools, like our workshop, can generate open and inclusive societal conversations toward fair and inclusive futures with robots. They define transdisciplinarity as "a socially responsible way to practice research on an equal footing between academics, stakeholders, practitioners, and citizens" (p. 2). The latter group, citizens, was not explicitly represented in the current version of the workshop as described in this article, yet they can easily be included. An interesting point of departure in this regard, with crossovers from the theater, is Rimini Protokoll [Malzacher, 2010], known for making theater with non-actors who contribute with their everyday skills and expertise. This is something we deem worthwhile to explore in future iterations, including, for instance, the perspectives of store managers and restockers.

5.3 Development as a Speculative Design Methodology

Speculative design methodologies are gaining traction and are part of the broader adoption of *designerly approaches* in HRI [Cila et al., 2024; Lupetti et al., 2021]. As a speculation, our mixed reality stage created a space that informed us about people's experience of robots by enacting future robotic technology in a technical and economically feasible way in an immersive interactive fictional storyworld, in which actions and relations emerged as part of open-ended improvization rather than experiencing scripted narratives. By relying on theater professionals as participating researchers, we could capitalize on their creative, empathic, as well as analytical skills to reveal the interaction tendencies, interaction trajectories, and experiences that particular robots may trigger in specific situations. Furthermore, the careful crafting of the virtual robot body with input given by roboticists grounded the speculation technologically while at the same time opening up an interesting interaction space created in the coming together of human and machine agencies.

In developing this speculative technique, we see an opportunity to strengthen the consequentiality and actionability of the speculation [Elsden et al., 2017]. We noticed how the current speculation affected participants personally and made them reflect on what their experiences with the robot would imply for visiting supermarkets in real life. By involving more stakeholders, we could use these speculations to explore the impact of robotics on real-world settings more broadly. For instance, supermarket employees can shed light on how a particular robot could become part of their work practices while store managers can reflect on the impact on customer concerns (i.e., see the reference to Rimini Protokoll made earlier). Furthermore, adding a data perspective to the speculation collected through VR controllers and other sensors, as suggested by Simeone [2022], could help to strengthen the actionability of the speculation on technology development. The robot's motion trajectories, the onset of robot actions based on the locations and actions of a customer, and the interaction sequences that follow from them, can then be measured and modeled.

5.4 Towards More-than-Human-Design

The insights obtained from this study inform "More than Human design" (MTHD), which is influenced by new materialism [Bennett, 2010] and post-humanism [Barad, 2003], further elaborated on by Frauenberger [2020] as "entanglement theories" in the context of **Human-Computer Interaction (HCI)**. MTHD aims to "design for and design with non-human stakeholders, such as objects, animals, or robots" [Coskun et al., 2022, p. 1] and has gained traction in HCI and HRI research [Coskun et al., 2022; Coulton and Lindley, 2019; Gemeinboeck and Saunders, 2022; Giaccardi and Redström, 2020]. Dörrenbächer et al. [2020] propose the notion of "techno-mimesis," pointing out that interactions with robots involve moving beyond anthropocentrism in perception and communication in HRI. They suggest using low-fidelity prostheses made from cardboard and other simple materials to explore how to "move and sense in a presumably technological and robotic way" (p. 3). Similarly, the straitjacket used by Joris (as a high-fidelity virtual prosthesis rather than a low-tech one) enabled empathizing with the virtual robot in their experiments. Beyond low-fidelity mockups, the straitjacket offers insights that can directly inform future developments in robot technology. This experiential approach allows designers to empathize with technology by embodying it, fostering a deeper understanding of the differences between humans and robots, thereby aiding the design process.

Our mixed reality stage works toward such more-than-human perspective by making it possible to include the robot's perspective in our phenomenological unpacking of situated encounters between humans and robots. The setup confronted us as researchers with the fundamental differences between how the world is available from a human perspective and from that of a robot. We might say that our setup mediates an expansion of our phenomenological unpacking beyond the human and is in line with Bogost's *Alien Phenomenology* [2012]. Our explorations also demonstrate the productivity of taking the specificities of the robot's morphology, possibilities for movement, and perceptual capacities as inspiration for new approaches to developing HRI, rather than as problems to be solved in ways that obscure the differences. Creatively building on these specificities may result in new, more-than-human modes of communicating that acknowledge that, far from being something naturally given, human forms of communication are themselves profoundly affected by histories of interacting with technology, HRI being the latest step in the human co-evolution with technology.

6 Conclusion

Making robots capable of navigating everyday environments requires new approaches to HRI that acknowledge that interaction and communication are relational and emergent phenomena. Our mixed reality stage contributes to the development of such approaches by providing a tool for investigating how HRI emerges from situated encounters between humans and robots. The set-up proved useful for experimentation with situated encounters and a methodological working through of the role played by various aspects of these encounters (like the robot's morphology, types of movements, speed, proxemics, position in space, as well as the robot's perceptual capacities). Our use of VR as part of the mixed reality stage made it easier to work through the effects of such variations. Furthermore, the setup allowed theater professionals to bring to bear their creative embodied expertise on a virtual representation of the robot's behavior (in the case of the participating actors) and on the robot's perception of its environment (in the case of the puppeteer). Providing a combination of different perspectives (first-person and third-person, from inside the virtual simulation and from outside of it, from human actors and spectators, and from the robot), the setup also proved most useful to support a collective phenomenological analysis of the interactions unfolding. Our performative explorations of situated encounters on a mixed reality stage show how this approach can be used to investigate how interactions between humans and robots come about. These insights, in turn, can be used to identify relevant parameters for HRI that is emergent and situation- and robot-specific. Our mixed reality stage, therefore, is not a means to test out predesigned behavior to see whether it has the effect intended, and the actors are not replacing test persons. Rather, our mixed reality stage (including the theater professionals) offers a starting point for designing HRI from the potential of situated encounters to generate interaction, rather than from implementing fixed and predetermined scenarios. It also contributes to a more-than-human approach to HRI in how it makes it possible to include the robot's perspective in the phenomenological unpacking of situated encounters between humans and robots.

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