Empirical Investigation of Social Expression and Trust Repair in Human-Robot Interaction

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Abstract

In recent years, service robots have become increasingly common in various settings, requiring effective social expression capabilities for successful human-robot interaction. Recent advances in robotics technology are expanding the role of service robots in human environments, requiring effective social expression capabilities and trust repair mechanisms for successful human-robot interaction. This dissertation addresses fundamental challenges in social expression and trust repair through five empirical studies investigating both telepresence and manipulator robots.

To investigate factors influencing human presence and anthropomorphism in telepresence robots, two experimental studies were conducted comparing robotic embodiments with smartphone-based interactions. The results demonstrate that motion capabilities significantly affect presence perception regardless of facial appearance, while static robots with human faces enhance anthropomorphic perceptions. These findings provide insights into designing more effective telepresence systems for remote communication.

Three additional studies examine trust repair strategies in manipulator robots, particularly focusing on apologetic gestures after service errors. The first study reveals that synchronized multi-axis motions are perceived as more apologetic compared to single-axis movements. The second study demonstrates the effectiveness of combining verbal and non-verbal elements in robot apologies. The third study shows that joint human-robot apologies achieve superior trust repair outcomes compared to individual approaches.

The results of empirical evaluations indicate that motion-based social expressions significantly influence human perception and trust in both telepresence and manipulator systems. Despite several limitations, this research contributes to the development of more effective human-robot interaction by providing insights into social expression design and trust repair strategies for service robots. These findings can be applied to various robotic applications including service, healthcare, and industrial settings.

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Chapter 1

Introduction

Recent advances in robotics have led to increased integration of robots in various social contexts, from remote communication to service environments. This evolution raises important questions about how robots can effectively interact with humans in socially appropriate ways. As robots become more prevalent in our daily lives, understanding how social expression and its influence on anthropomorphism (the attribution of human characteristics to non-human entities) becomes crucial for successful human-robot interaction (HRI).

Social expression, a key aspect of human-robot interaction, encompasses both verbal and non-verbal communication elements, including facial expressions, gestures, and vocal patterns. These expressions play a vital role in enhancing relatability and fostering more natural interactions between humans and robots. The effectiveness of social expression in robotics varies significantly based on the robot's design and intended application, potentially influencing the degree of anthropomorphism perceived by users.

Our research specifically focuses on two distinct types of robots that are increasingly being implemented in society: telepresence robots and manipulator robots (robotic arms). This choice was deliberate, as these platforms represent contrasting levels of anthropomorphism. Telepresence robots, with their human-like features and communication capabilities, typically exhibit high anthropomorphism potential. In contrast, manipulator robots, designed primarily for functional tasks, generally display lower anthropomorphism, presenting unique challenges and opportunities for social expression and trust development.

Digital communication has evolved significantly, progressing from traditional telephone and email to sophisticated video conferencing systems and telepresence robots. Telepresence robots, also known as "mobile robotic presence systems," are physical robotic platforms equipped with video-conferencing capabilities mounted on mobile bases. These systems enable operators to control a physical embodiment from remote locations, enhancing video and audio communication opportunities. Beyond basic communication, these robots can create strong feelings of "being there" and "being together," making them valuable tools in business, education, medical fields, and particularly in providing employment opportunities for people with disabilities.

However, despite their growing adoption, questions remain about how to optimize telepresence robot design for effective social interaction. Key design elements such as facial display type (human vs. robot) and motion capabilities can significantly impact user perceptions and experiences, yet their combined effects on anthropomorphism and social presence are not well understood. This gap in knowledge limits our ability to design telepresence robots that effectively support remote communication and collaboration.

Similarly, in service robotics, the increasing deployment of manipulator robots in customer-facing roles introduces new challenges in maintaining positive human-robot relationships, particularly when errors occur. While robots offer efficiency and consistency, they are not infallible, and errors can lead to a loss of user trust. Understanding how different trust repair strategies affect anthropomorphism and user trust becomes essential for the broader adoption of robotic services.

This thesis investigates these challenges through two main studies:

1. Telepresence Robot Study: We examine how facial appearance (human vs. robot face) and motion capabilities (moving vs. static) affect perceived anthropomorphism and social presence. Through a novel 2×2 experimental design, we investigate which factors have the biggest effect on the sense of human presence and robot anthropomorphism.
2. Manipulator Robot Study: We explore trust repair strategies in service scenarios, investigating how different apology approaches (verbal, non-verbal, and combined) influence trust recovery after errors. We also examine how human-robot collaborative apologies and the perception of intentionality affect trust repair outcomes.

1.1 Contribution

Our research makes several novel contributions:

- Quantifies the combined effects of facial appearance and motion on user perceptions in telepresence robots
- Demonstrates that motion significantly influences presence regardless of facial type
- Identifies effective trust repair strategies for manipulator robots in service contexts
- Reveals the importance of human-robot collaboration in trust recovery

The findings from these studies have important implications for the design and implementation of socially aware robots across various applications. By understanding how different design elements and interaction strategies influence anthropomorphism and trust, we can better develop robots that effectively support human needs while maintaining positive social relationships.

1.2 Outline

This dissertation is organized as follows:

Chapter 2 Related Work: This chapter reviews existing literature in human-robot interaction and social robotics, mainly focusing on social expression and trust development in telepresence robots and robotic manipulators.

Chapter 3 Influence on Social Expression in Telepresence Robot: This chapter presents two empirical studies that examine the effectiveness of social expression in telepresence robots. We discuss the findings from investigating factors affecting human presence and robot anthropomorphism, and comparing different physical embodiments in telecommunication contexts.

Chapter 4 Influence on Social Expression and Trust Repair in Manipulator with End-Effectors : This chapter presents three empirical studies that examine social expression and trust repair in manipulator systems. We discuss the findings from investigating apologetic gestures, different apology strategies, and the effectiveness of human-robot collaborative apologies.

Chapter 5 General Disccusion This chapter includes discussions about social expression in telepresence robots, trust repair strategies in manipulator robots, the effectiveness of different apology approaches, and limitations of our experimental methods.

Chapter 6 Conclusion This chapter summarizes our research on social expression and trust repair in robotics and highlights the contributions of this dissertation in human-robot interaction.

Chapter 2

Related Work

This chapter presents related work on social expression and trust research to provide the background for this dissertation.

2.1 Telepresence Robot in Social Expression

In general, telepresence robots are being applied in a wide variety of fields such as business, education, and medical fields [1–6]. In particular, telepresence robots are commonly being used for higher education [7–9]. For telepresence robots used in schools, Ahumada-Newhart and Olson provide specific recommendations for improving telepresence robot design to better suit educational environments and the needs of young users [10]. In collaborative team settings, remote participants using telepresence robots spoke less, perceived the task difficulty to be greater, and were viewed as less trustworthy than collocated members, highlighting potential challenges for integrating remote students via robots in educational group activities [11].

Medical fields are now commonly using telepresence robots for general healthcare [12], elderly healthcare [13], healthcare for COVID-19 [14] and people with special needs [15]. Beyond institutional settings, there are use cases involving long distance relationships and families for facilitating and helping with communication [16, 17].

Among these applications, a particularly promising direction has emerged in employment accessibility. Through telepresence robots like OriHime-D [18], people with disabilities

Table 2.1: Comparative analysis of motion, face, anthropomorphism, and presence in telepresence robot literature and list of work. Overview of key aspects of factors mentioned in work (✓means mentioned or dealt with factor, blank means did not mention or did not deal with factor).

Work	Moving (arm motion)	Static motion	Human face	Robot face	Anthropo -morphism	Presence	Experiment
[3]		✓	✓			✓	In-person experiment
[23]				✓ (projected robot face)	✓	✓	In-person experiment
[18]	✓			✓		✓	In-person experiment
[24]	✓			✓			In-person experiment
[25]	✓		✓			✓	In-person experiment
[5]		✓	✓			✓	In-person experiment
[26]	✓ (one arm motion)		✓			✓	In-person experiment
[27]	✓			✓ (projected robot face)	✓	✓	In-person experiment
[28]	✓ (virtual environment)		✓ (virtual human agent)	✓ (virtual robot agent)	✓		In-online virtual environment experiment
[29]	✓	✓	✓		✓	✓	Online experiment
Ours	✓	✓	✓	✓	✓	✓	Online experiment

have been able to engage in employment opportunities in café settings [19–22]. Recent research has demonstrated how both robotic [21] and virtual avatars [22] can enable disabled workers to provide customer service and participate meaningfully in the workforce. These technologies have created new pathways for remote work and social inclusion in hospitality environments that were previously inaccessible [18–22].

Despite these diverse applications, there remain important questions about how to optimize telepresence robot design for effective interaction. As shown in Table 2.1, prior works have explored facial cues or motion capabilities as non-verbal cues for telepresence robots. In this section, we review the existing literature on telepresence robots, focusing on two key aspects that may influence user perceptions and experiences: the display of the operator's face and the robot's ability to perform non-verbal motions. We first discuss the different types of telepresence robots based on their facial display and how this may impact user interactions. Next, we examine the role of non-verbal motion capabilities in telepresence robot design and their potential effects on user outcomes. Finally, we highlight the gaps in current research regarding the specific impact of these factors on presence and anthropomorphism, motivating the need for the current study.

2.2 Facial Expression Cues in HRI

In human-robot interaction (HRI), one of various key points is facial cues in this study. McGinn conducted various studies on service robots in which the heads and facial cues were changed to determine the effect on social interaction between humans and robots [30]. To facilitate communication, it is significant for robots to have some kind of face for social feedback. Although not a real human's face and expressions, research has shown that relations between humans and robots can be enhanced when robots are equipped with human-like "robotic" faces that can express and show emotion like humans do [30]. OriHime[21, 31], created by Ory Laboratory Inc[1], is an avatar and telepresence robot that provides a bidirectional sense of presence even with its non-human facial appearance.

In addition, interactions with a robot get even better when the robot exhibits social behaviors with anthropomorphic characteristics [30, 32]. The projected face telepresence robot performs synchronous actions, and the facial expressions of the remote user increase agreement during conversation [23]. Regarding the effect of human facial cues on robots, it was found that eye gaze and certain facial expressions from a human can be used to further improve relations between humans and robots by physically displaying a human's face on a 2D screen using either telepresence or a virtual agent [33]. For example, Beam is a telepresence robotic system that utilizes this method by replacing the robot's head with an LED screen to display a human's face via video-conferencing. Several studies have indicated that people can really feel the presence of a human in such robots [3, 34].

2.3 Non-verbal Motion Cues in HRI

Non-verbal cues are important factors in the HRI research area. A telepresence robot that has the ability to display expressions used in social interaction by means of motion can make the user feel more engaged and the robot more likeable [25]. The spatial configuration and body orientation of telepresence robots affects the way people orient themselves toward the robots, and these robots tend to copy human-like actions and detect surrounding motion [24]. This greatly increases the quality of the interaction between humans and robots. In one study using a robot tele-operated by the "Wizard of Oz" method, the enjoyment of the participants was not affected by the knowledge of whether the robot was being controlled by a program or a human [35]. Yamada et al. proposed motion-based artificial subtle expressions (ASE) in which a robot slowly hesitates by turning to a human before giving advice with low confidence. They found that long- or short-wait expressions might be useful for expressing a robot's confidence, and that fast- or slow-motion ASE is more suitable for such expressions [36].

Another study demonstrated that synchronized on-screen and in-space gestures significantly improve viewers' (participants') interpretation of an action compared with on-screen or in-space gestures alone, and that the addition of proxy motion also improves the measure of perceived collaboration [37]. It was also found that in-space gestures positively influence perceptions of both local and remote participants [37]. Neustaedter et al. discussed using a telepresence robot called Beam to attend a conference, and as a result, they showed that the robot was able to attend the conference [3]. Fitter et al. did a comparison experiment between expressive arm motion, non-expressive arm motion, and light expression [26]. As a result, participants felt an advantage toward light expression, and the use of motion increased the perception of the robot being human-like [26].

Although OriHime[31, 38] and OriHime-D[18] do not have expressive facial cues, they have social expression embodiment and the ability to operate in a variety of social situations, which can help disabled people participate more actively in society and social events [18–22].

2.4 Anthropomorphism in HRI

An important key point in HRI is anthropomorphism, whose effects have been researched using telepresence robots. One researcher reviewed and explained anthropomorphism and its role in the design of interactive social robots and HRI [39]. Telepresence robots need anthropomorphism for social expression. There is one anthropomorphic telepresence robot that has expression display and gesturing for social expression [27]. The concept of robomorphism, which was introduced by Schouten et al., is based on anthropomorphism, and using this concept in telepresence robots for cooperation showed that it is an important concept to consider when studying the effect of human-mediated robot interaction [40]. When comparing telepresence robots (both with motion and without motion) with smartphones as two distinct types of video teleconference systems in terms of anthropomorphism, the results yielded an ironic outcome. Surprisingly, the anthropomorphism perception was higher for smartphones used as video teleconference systems than for telepresence robots, regardless of whether they had motion capabilities or not [29].

In HRI, researchers have discussed how anthropomorphism affects interaction. One team of researchers thought anthropomorphism might reduce psychological stress related to HRI and tested participant anticipation vs. no anticipation in interactions with human-like and machine-like robots [41]. As a result, anticipation increased psychological stress independent of the robot type [41]. Other researchers have discussed the development of social interaction between robots and people through anthropomorphism in terms of the robot's physical embodiment design and behavior [42]. The factor of anthropomorphism in social robot development, looking forward to considered to using mechanism that should be adopted in social robot research [42]. Furthermore, other researchers discussed the benefits of anthropomorphic robots from a philosophical point of view in HRI, and they believe that this human-like factor can help in implementing these robots in the real world [43]. In addition, anthropomorphism was researched with two dimensions, competence and warmth, as determinants of trust development, and the result showed that they are important for trust development and that anthropomorphism may increase user's trust in HRI [44]. Mandl et al. provide a nuanced view of anthropomorphism in HRI. While more human-like robots were generally perceived as more anthropomorphic, results were not always consistent. The authors emphasize that anthropomorphism is multiply determined, not just by physical design. Importantly, they found no clear relationship between anthropomorphic design and perceived competence or trustworthiness of robots [45]. A service robot with a high level of anthropomorphism positively influences the willingness of users to follow recommendations [28].

2.5 Manipulator in Social Expression and Trust Repair

Previous work on trust involving manipulator or robotics arms can be found in [46–51]. Apologies play a crucial role in Human-Robot Interaction (HRI) for lessening the adverse effects of errors and preserving trust. Studies have highlighted that apologies are a vital strategy for trust repair in HRI. It has been demonstrated that robot apologies are effective in addressing trust breaches and enhancing views of robots following failures [52, 53].Studies have investigated various aspects of robot apologies, including verbal content, attribution, and perceived sincerity[54]. The perceived cost or effort of the apology has been identified as important, with more costly apologies seen as more sincere and effective[55]. Okada et al. explored multi-robot apology scenarios, finding that apologies from two robots can be more effective than just one in certain contexts [55]. Their study showed that participants significantly preferred and positively evaluated apologies from two robots over one robot in terms of forgiveness, negative word-of-mouth, trust, and intention to use. Other research has examined different roles for apologizing robots, such as cleaning up after a mistake in addition to verbal apologies[55]. Factors like the type of failure and repair strategy also influence apology effectiveness[53]. Effects of robot apologies, explanations, and trust disclosures on rebuilding trust after violations [56, 57]. Overall, while robot apologies have been shown to aid in trust repair, their effectiveness depends on various factors related to the apology design, failure context, and user perceptions.

2.6 Trust in HRI

Overview of Trust in human-robot interactions, is shaped by various factors such as robot errors, the nature of the tasks, and human personality traits. The study compares different methods of communicating uncertainty (graphical interface vs. embodied behavior), providing insights into how different modalities impact trust and decision-making[58]. Salem et al. [59] demonstrated that while robot errors can affect perceived trustworthiness, they do not necessarily influence compliance. Xie et al. [60] highlighted the importance of perceived robot capability and intent. Onnasch and Hildebrandt [46] discovered that anthropomorphic designs might reduce trust in industrial environments. Additionally, trust is dynamically affected by the timing and pattern of robot errors, with later errors having a more pronounced negative impact. It's also noted that subjective measures of trust do not always correlate with objective behavioral measures [61, 62]. Wang et al. [63] showed that automatically generated explanations about a robot's decision-making process and confidence levels can enhance transparency, trust, and team performance in human-robot collaboration, especially for robots with lower abilities. Sebo et al. [64] carried out a significant study exploring how frameworks for trust violation (competence vs. integrity) and repair strategies (apology vs. denial) influence human trust in robots. They found that the effectiveness of these repair strategies depends on the type of trust violation, aligning with results seen in human-human interactions and offering a basis for understanding trust repair dynamics in HRI. The researcher investigates the effects of errors made by a robot trainee while learning and performing a domestic task on the trust and perceptions of human teachers. Findings indicate that even minor errors drastically reduce trust, which complements work on trust repair in human-robot interactions by focusing specifically on the learning context [65].

2.7 Trust Repair in HRI

In prior work in human robot interaction, most researcher design trust repair strategy Explanation didnt lead to increase trust [51] Providing insights into trust recovery mechanisms examines different types of technical failures in HRI (logic, semantic, and syntax failures) and their impacts on human trust, and the study investigates multiple trust repair strategies (internal-attribution apology, external-attribution apology, denial, and no repair) and compares their effectiveness.[54] How unintended robot behaviors (perceived rejection) can negatively impact human trust in service robots, investigates non-verbal remediation strategies (favor rendering and apology) for repairing trust after perceived rejection[50]. So, we choose apology which used verbal, non-verbal, both(verbal and non-verbal) and human apologize for trust repair strategy. The timing of robot apologies affects trust repair[66]. how different apology strategies affect trust repair after robot errors, and how this interacts with individual differences like tendency to anthropomorphize. This relates to understanding how apology types and user traits influence trust recovery[47]. In addition, promises and apologies from automated systems affect trust repair over multiple interactions. This longitudinal perspective effects robot mistakes and repair strategies in human-robot interaction, including longitudinal effects and real-world context[67] and relevant for understanding trust dynamics over time[68]. Trust repair strategies after repeated deception by a robot in a high-stakes scenario. This relates to repairing trust after intentional violations, not just errors[53]. The effectiveness of different trust repair strategies, specifically explanations and expressions of regret, in human-agent teams using a first-person shooter task[69].

2.8 Intentional expression in HRI

Research on intention in human-robot interaction (HRI) has evolved through several key phases and approaches. Early work by Terada et al. [70] established that robots' behavioral patterns, particularly reactive movements, could trigger intention attribution in humans. Kim et al. [71] advanced this understanding by developing a multimodal approach combining joint attention, affordance modeling, and action-perception cycles to recognize human intentions through multiple channels. Building on multimodal approaches, Trick et al. [72] focused on reducing uncertainty in intention recognition through classifier fusion of different modalities like speech, gestures, gaze and scene objects. In parallel, Xie et al. [60] examined how humans' mental models of robots—specifically inferred capability and intention—influence trust and delegation decisions.

Futhermore, Bi et al. [73] introduced an interactive intention prediction model based on visual features like face orientation, social distance, and facial expressions, demonstrating how these could quantitatively predict interaction intention intensity. Aliasghari et al.[74] investigated how robots' verbal expressiveness when making errors impacts humans' intention to use them. Moving to audio aspects, Rafi et al. [75] examined how robots' voices and sounds shape perceived intentions. Recent work by Abe et al. [76]studied human understanding of unanticipated robot actions during physical interaction. Finally, Belardinelli[77] provided a comprehensive framework for gaze-based intention estimation in HRI, bridging cognitive science insights on visuomotor control with technical applications.

This progression shows how the field has moved from basic intention attribution mechanisms to increasingly sophisticated multimodal approaches incorporating visual, verbal, auditory, physical and gaze-based cues for more effective human-robot interaction.

Chapter 3

Influence on Social Expression in Telepresence Robot

This chapter presents two empirical studies done to examine how effective the proposed method would be in social expression conditions using telepresence robots. Section 3.1 describes the evaluation investigating factors that influence human presence and robot anthropomorphism in telepresence robots using facial and motion cues. Section 3.2 explains the evaluation comparing physical embodiments and smartphones in telecommunication contexts.

3.1 Study 1:Investigation of Factors that Influence Human Presence and Robot Anthropomorphism in Telepresence Robot

This section present the as study 1 to evalute the proposed method investigates factor human presence and robot anthropomorphism in telepresence robots. Comparing four different types of teleperesence robot with facial and motion cues are evaluated.

3.1.1 Introduction

There is a wide variety of choices when it comes to digital communication these days, with the telephone, email, SNS (Social Network Service), and video conferencing being the most common. In recent years, communication via telepresence robots has been attracting attention. In general, telepresence robots that enable robot-mediated interaction, also called “mobile robotic presence systems,” are physical robotic platforms with a video-conferencing system mounted on a robotic mobile platform [26, 40, 78]. Since remote operators can control this physical embodiment from a remote location, these systems increase opportunities for video-conference and audio-communication [78, 79]. Furthermore, they imbue communicators with a strong sense of presence, including feelings of “being there” [34, 80] and feelings of “being together” [81, 82]. Other researchers have mentioned that telepresence robots provide a new communication platform in various areas such as business, education, and medical fields [1–6]. These robots have also shown promise for people with disabilities in terms of helping them join in society more actively and perform labor [18].

With telepresence robots, the appearance of the face is an important factor that has one of the biggest effects on whether people feel the presence of a person [5, 34, 40]. Meanwhile, previous research on movement with telepresence robots has shown that robots that can express themselves socially through movement are more immersive and desirable than those that do not move [25]. In some cases, a robot that does not have a human face can make people feel the presence of a person through its movements[1]. In general, however, the effect of the face depends on whether the face is human-like or robot-like, and people may feel that one type gives a greater sense of anthropomorphism or presence. This also raises a related question: which makes people feel more anthropomorphism or presence in a robot, a robot that is moving or static or that has a face that is human-like or robot-like? Hence, in this paper, we try to give a solution to this research question in an experiment.

Despite the growing interest in telepresence robots, there is limited research on how the combination of facial appearance and motion affects user perceptions of anthropomorphism and social presence. While previous studies have investigated these factors individually, there is a lack of understanding regarding their interaction effects and how they can be optimized for different user outcomes. This gap in the literature limits our understanding of how to design telepresence robots that effectively support remote communication and collaboration across various applications.

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[1] https://orylab.com/en/#product

Our study aims to address this gap through experiments on the combined impact of facial appearance and motion on user perceptions using a novel experimental design. By providing insights into how these design factors work together to shape user experiences, we seek to contribute to the development of more effective telepresence robots that can better support remote communication and collaboration. The findings of this study have the potential to guide the design of telepresence robots in various applications, ultimately benefiting industries such as healthcare, education, and customer service.

In this study 1, we conduct a web-based experiment featuring videos of a telepresence robot using the Rapiro platform shown in Figure 3.1 (2 × 2 between-participant study; face factor: human face, robot face; motion: moving, static) to investigate which factors have the biggest effect on the sense of human presence and robot anthropomorphism.

Prior works have explored facial displays or motion capabilities for telepresence robots but largely in isolation. Table 1 summarizes and compares how our proposed work is a novel combination of both motion and face factors and relates to prior works that examined these design elements more individually for their impacts on perceived anthropomorphism and sense of presence in telepresence robots.

A key novel contribution of our research is the investigation combining both the robot's facial appearance (human vs. robot face) and motion (moving vs. static) as factors influencing user perceptions. Our 2 × 2 experimental design uniquely identifies that a static robot displaying a human face enhances anthropomorphic perceptions more than one that moves with a human face. Notably, we found that the robot's ability to move and make physical motions was the most important factor in creating a sense of human presence for local users, rather than the appearance of the robot's facial display. This novel finding contrasts potential assumptions that human-like facial representations would be most important for perceived presence. By quantifying the effects of combining these two design factors through experimentation, our work provides new insights overlooked by studies examining facial displays and motion in isolation.

Another of our approaches involves considering the implications when designing a telepresence robot in order to optimize their design for industrial applications. For example, when a telepresence robot needs to convey more humanness, the remote operator needs to show their face. Furthermore, when a telepresence robot only requires human presence, it should utilize non-verbal communication based on arm motion.

Table 3.1: Hardware specifications of robot.

Robot name	Rapiro	Modified Rapiro
Height	250 mm[H] × 200 mm[W] × 155 mm[L]	300 mm[H] × 200 mm[W] × 155 mm[L]
Weight	1 kg	1.5 kg
Degrees of freedom	12	
Input voltage	DC 6-12V 4A upper	
Computing unit	Rapiro mainboard (Atmega328P) Raspberry Pi 3B	
Electronics	Rapiro mainboard (ATmega328P) 5-inch monitor (for modified Rapiro only) Full color LED for eyes	
Material	PLA: modified Rapiro head	

3.1.2 Robot System

In this section, we describe the platform and system used in our experiment. We first introduce the Rapiro robot platform, including its technical specifications and the modifications made for our study. Then, we present the user interface developed to control the robot's motions and gestures.

From the comparative analysis in Table 2.1, our proposed work for two type of telepresence robots makes it possible to enable abilities such as arm motion in both hands and static motion, in addition to being able to show the operator's face or instead show a robot face.

3.1.3 Platform

In our experiment, we used a humanoid robot called Rapiro shown at Figure 3.1, which has been widely utilized for various applications related to education and hobbies [83, 84], among others. The Arduino and Raspberry Pi boards in the robot enable users (developers) to communicate with it simply by sending command signals from a PC, and they also allow for the system to be extended easily. These are the reasons we used this robot as the telepresence robot for our experiment. For the experiment, we fixed Rapiro's eye color to blue due to avoid color bias and modified the head so that it could show a remote user's face similar to a video teleconference system.

Rapiro has 12 degrees of freedom (DoF), a USB camera, a microphone in its forehead, and a speaker in its head. Figures 3.3 to 3.6 show an overview of Rapiro with and without our modifications, respectively. We modified the head of another Rapiro with a 5-inch portable monitor to show the face of a remote user; the head was made of PLA using a 3D printer. This Rapiro also had 12 DoF, a USB camera, a microphone, and a speaker. Hardware specifications are shown in Table 3.1

Figure 3.1: Rapiro.

3.1.4 User Interface and Robot Motion

To control Rapiro, we made a keyboard input interface in Processing 3. When the operator (from a geographically separate location) presses the number “2” on the keyboard, a local PC receives the signal from the operator’s location via Wi-Fi, and the robot makes that specific motion. The specifications of the system are shows in Figure 3.2

We generate robot motions according to the following principles. For both robots, we used preset motions and original motions that we developed for the experiment, such as “hands up” and “wave both hands.” In total, we used six motions in the video task, as listed in Table 3.2. The preset motions included actions like going forward or backward, but we did not use these at this time.

Table 3.2: List of robot motions.

	Motion
1	Both hands up
2	Wave both hands
3	Stretch right hand out
4	Grip both hands
5	Left hand up
6	Flutter both hands

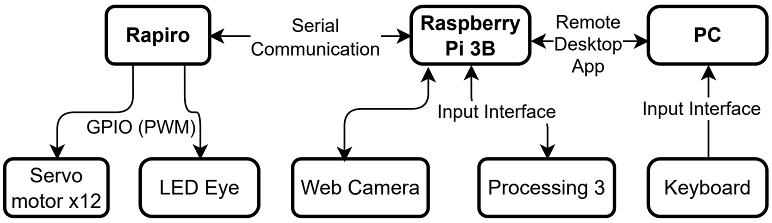

Figure 3.2: Specifications of robot system.

3.1.5 Method

This section outlines the methodology employed to investigate the impact of facial appearance and motion on user perceptions of anthropomorphism and social presence in telepresence robots. We first describe the study design and experimental conditions, followed by details on the participants and recruitment process. Next, we present the materials and apparatus used, including the telepresence robot platform, video stimuli, and questionnaires. Finally, we explain the procedure followed by participants and the data analysis approach.

3.1.6 Experimental Design

We conducted the experiment using a 2 × 2 (robot face: human face, robot face; arm motion: moving, static) between-participant design. To explore the different ways people could interact with our design, we used G*Power [85] sample size calculation (with effect size = 0.5) and ran our experiment using online questionnaire surveys after showing a video. Participants were recruited from Yahoo! Japan Crowdsourcing, and we used Google Forms for the survey. Most methods examined through online experiments use crowdsourcing services like Amazon Mechanical Turk and Yahoo! Japan Crowdsourcing, and we prepared video clips and questionnaires in Google form for a survey, referring to Sirkin et al. [37]. We wanted the remote operator's speech and gestures to have precise timings and the same interaction content. While online responses may differ from in-person experiments, Powers et al. demonstrated that remote robots could be used in experiments and be more sociable and engaging than co-located robots [86].

Furthermore, live and video-based HRI trials are known to be broadly equivalent in most cases [87]. However, in some cases, people may empathize less with video-based HRI trials compared with in-person experiments [88, 89]. Therefore, we chose to run the experiment online. Our dependent variables were presence and anthropomorphism. We designed the online experiment so that we could compare which condition affected the dependent values and perceptions of the remote operator who communicated with the participants via the telepresence robot across the following four robot conditions.

1. **Human face and moving** (Figure 3.3): The face of the robot is a video-conference style screen on which the remote operator is shown, and the robot's arm makes motions.
2. **Human face and static** (Figure 3.4): The face of the robot is a video-conference style screen on which the remote operator is shown, and the robot's arm is static.
3. **Robot face and moving** (Figure 3.5): The face of the robot is robot-like, and the robot's arm makes motions.
4. **Robot face and static** (Figure 3.6): The face of the robot is robot-like, and the robot's arm is static.

3.1.7 Hypotheses

As mentioned above, we conducted the experiment using a between-participant design (face: human face vs. robot face; motion: moving vs. static) to investigate which factors significantly affect presence and anthropomorphism. We wanted to independently see the effects of the motion and face factors, so we formulated four hypotheses for our experiment.

- **H1** The face factor positively affects anthropomorphism.
- **H2** The motion factor positively affects anthropomorphism.
- **H3** The face factor positively affects presence.
- **H4** The motion factor positively affects presence.

Recent telepresence robots can be broadly categorized into two types: monitor-type, similar to traditional telepresence robots [3, 78], and robot face-type, exemplified by robots like Orihime-D [18].

FIGURE 3.3: Human face and moving.

FIGURE 3.4: Human face and static.

FIGURE 3.5: Robot face and moving.

FIGURE 3.6: Robot face and static.

In **H1** and **H2**, in terms of motion factors, typical telepresence robots usually lack arm or manipulation functions, making it difficult to engage in non-verbal communication through gestures despite having mobility [78]. In contrast, Orihime-D [18] possesses arm or manipulation capabilities, allowing for the possibility of non-verbal communication through gestures. Furthermore, telepresence robots with arm-motion expression have been shown to increase the perception of being closer to local participants [26]. Therefore, we aim to investigate how motion factors affect presence and anthropomorphism as dependent variables in telepresence robots, whether they have motion capabilities or not.

In **H3** and **H4**, most telepresence robots show the remote user's face, but some, like Orihime-D [18–20], do not show faces and still evoke a sense of human presence. Usual telepresence robots have a monitor that shows the tele-operator's face [78], but Orihime-D [18] does not have a monitor and only displays the robot's face. Therefore, we aim to explore how the face factor affects presence and anthropomorphism as dependent variables in telepresence robots, whether they have a human face or a robot face.

3.1.8 Participants

A total of 216 participants took part in the experiment online (male: 147, female: 69). Their ages ranged from 18 to 76 (MEAN = 46.04, standard deviation (SD) = 10.61). We recruited the participants from Yahoo! Crowdsourcing, which is a service provided by Yahoo! Japan. All our experiments were approved by the ethics committee of the National Institute of Informatics.

3.1.9 Task

The participants watched one video from among the four different conditions shown in Figures 2–5. These videos showed a remote operator communicating via a telepresence robot and discussing moon survival and item ranking. We created this Moon Survival scenario from the Desert Survival Problem [90] and also a NASA exercise[3], as the Desert Survival Problem is used by many social scientists and robotics researchers [5, 23, 25, 79, 91].

The video was about an astronaut who had crash-landed on the moon and was discussing how to select 5 items that he needed from the 15 items left to return to his distant home planet. Due to the video length, we discussed ranking up to only 5 items because if we had gone up to 15, the video would have been too long. The ranking of the five items is shown in Table 3.3.

3.1.10 Procedure

The procedure of the whole experiment is shown in Figure 3.7. First, participants viewed the instructions and watched one video from the four conditions. The instructions stated, "In the experiment, you will watch a video of a human talking to a robot

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[3] https://www.psychologicalscience.org/observer/nasa-exercise

TABLE 3.3: Ranking of items.

	Experimenter	**Remote operator**
1	Oxygen cylinder	Oxygen cylinder
2	Stellar map	Water
3	Nylon rope	Food concentrate
4	Parachute	First aid kit
5	Life raft	Stellar map

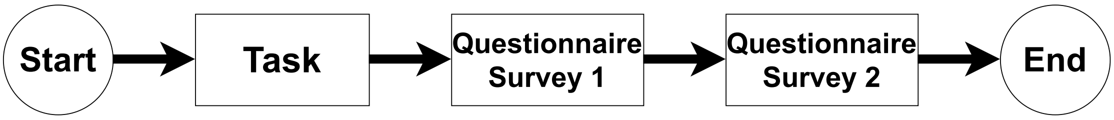

FIGURE 3.7: Flowchart of experiment.

controlled by a human via remote control" and "Watch as if you were talking to the robot." Afterward, we also told them that the task of the video was to have a discussion on moon survival. When participants finished watching the video, they were asked to rate their agreement on a seven-point Likert scale (1 = strongly disagree, 7 = strongly agree) in two questionnaire surveys. When they finished the experiment, there was an additional comment or question space. We paid 100 yen (about $1US), and the average time to complete the procedure was about 15 to 30 minutes.

In our experiment, we used two different questionnaires: the Godspeed series and one for social presence. Godspeed is a standardized measurement tool for HRI [92] that examines five key concepts: anthropomorphism, animacy, likeability, perceived intelligence, and perceived safety. We used only the anthropomorphism section for our study. For the second questionnaire, we used Networked Minds Measure of Social Presence, which is a measure of presence [91]. We modified it a little due to some of the statements not fitting into our experiment, and the questionnaires are listed in Tables 3.4 and 3.5.

3.1.11 Measurements

Before participants watched a video, they were asked to rate their agreement on a seven-point Likert scale (1 = not very familiar, 7 = very familiar) for two statements: "Are you familiar with video conferences?" and "Are you familiar with robots?" Most participants were not familiar with robots (mean = 2.46, SD = 1.57), but they were familiar with video conferences (mean = 3.39, SD = 1.84).

We used anthropomorphism from the Godspeed questionnaire series to measure anthropomorphis listed in Tables 3.4. To measure presence, we used the Networked Minds Measure of Social Presence questionnaire[91] listed in Tables 3.5. In both questionnaires, participants rate their agreement on a seven-point Likert scale.

Table 3.4: Godspeed questionnaire.

	Anthropomorphism	
1	Fake	Natural
2	Machine-like	Human-like
3	Unconscious	Conscious
4	Artificial	Lifelike
5	Moving rigidly	Moving elegantly

Table 3.5: Networked Minds Measure of Social Presence questionnaire.

	Social Presence
1	I often felt as if I was all alone.
2	I think the other individual often felt alone.
3	I was often aware of others in the environment.
4	Others were often aware of me in the room.
5	The other individual paid close attention to me.
6	I paid close attention to the other individual.
7	The other individual tended to ignore me.
8	My behavior was in direct response to the other's behavior.
9	The behavior of the other was in direct response to my behavior.
10	My partner did not help me very much.
11	The other's mood did NOT affect my mood/emotional state
12	My mood did NOT affect the other's mood/emotional state.
13	The other understood what I meant.
14	I understood what the other meant.
15	My actions were dependent on the other's actions.
16	The other's actions were dependent on my actions.

3.1.12 Result

To test our hypotheses, we used a two-way analysis of variance (ANOVA). This statistical method makes it possible to investigate the main effects of each independent variable, as well as their interaction effect. By using a two-way ANOVA, we can determine whether face and motion independently influence anthropomorphism and presence, and whether the effect of one factor depends on the level of the other factor. Before the data collection, we determined the sample size on the basis of power analysis. G*Power's parameters [85] had effect sizes of $f = 0.25$, α err prob = 0.05, and power = 0.8. The G*Power (version: 3.1.9.7) [85] analysis suggested that the sampling size was 128. For each condition, 32 participants were used for analysis. In total, 216 participants participated in this experiment. To ensure that the sample size matched the desired number, we randomly selected 32 participants using Excel.

The ANOVA results are shown in Tables 3.7(b) and 3.8(b), and the results of the simple main effect for anthropomorphism are shown in Table 3.8(c). The means and standard

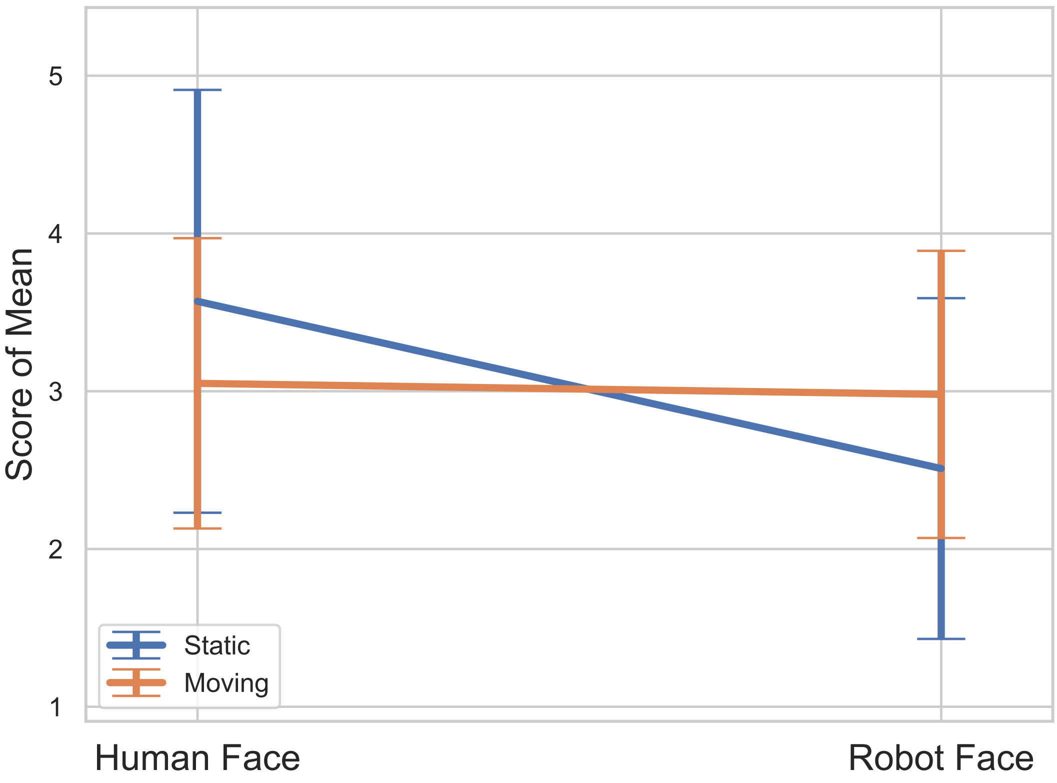

FIGURE 3.8: Average scores for motion perceived for each condition in experiment. Anthropomorphism is dependent value.

TABLE 3.6: Experiment conditions.

Condition	**Face**	**Motion**
Condition 1	Human face	Moving
Condition 2	Human face	Static
Condition 3	Robot face	Moving
Condition 4	Robot face	Static

deviations (SD) for all dependent variables are shown in Tables 3.8(a) and 3.7(a). Furthermore, interaction plots are shown in Figures 3.8 and 3.9, and the conditions are explained again in Table 3.6.

For anthropomorphism, we found that the interaction was significant (p <0.01, $\eta_p^2 = 0.0518$). In the static group, the simple main effect of face was significant (p <0.0001, $\eta_p^2 = 0.1110$). It was higher in the group with face. For presence, there was a significant interaction between the two factors. We found that the main effect was significant only for the motion factor (p <0.01, $\eta_p^2 = 0.0616$). Furthermore, the motion with moving was the highest.

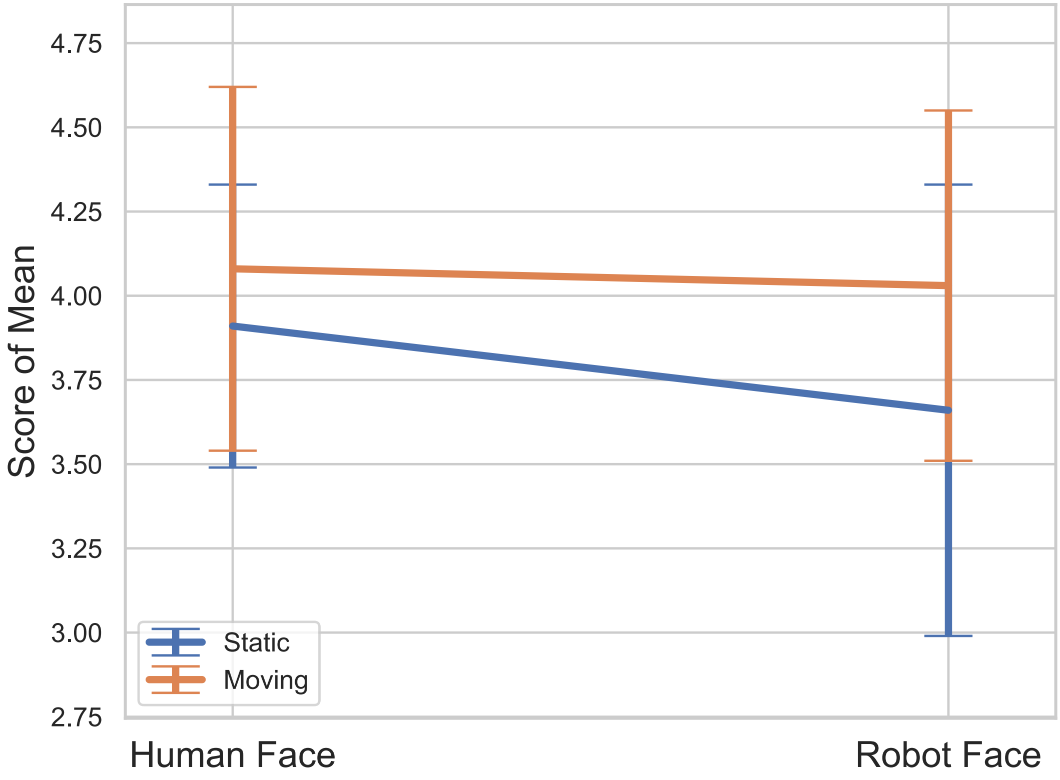

FIGURE 3.9: Average scores for motion perceived for each condition in experiment. Presence is dependent value.

3.1.13 Hypotheses Summary

The first section in the Experiment section set four hypotheses for what we expected to be the outcome of the experiment. The results are as follows.

- **H1** Face affects anthropomorphism: In the static group, a simple main effect was found for the face factor (p <0.0001), which was partially supported.
- **H2** Motion affects anthropomorphism: This hypothesis did not hold since no simple main effect was found for the motion factor.
- **H3** Face affects presence: This hypothesis did not hold since there was no main effect of the face factor on presence.
- **H4** Motion affects presence: This hypothesis held since a main effect on presence was found for the motion factor (p <0.01).

When the telepresence robot had a human face and no arm motion, which is the static condition, the participants felt the robot to be human-like. Since a real human's face could be seen, they felt this robot to be the most human-like. Even when the human's

Table 3.7: Result of two-way ANOVA table for presence.

(a) Mean and SD of presence.

Condition	**Mean**	**SD**
Condition 1	4.08	0.54
Condition 2	3.91	0.42
Condition 3	4.03	0.52
Condition 4	3.66	0.67

(b) Results of two-way ANOVA for presence.

Source	**F(1,124)**	*p*	
Face	2.457	0.119	n.s.
Motion	8.144	0.005	**
Interaction	1.00	0.316	n.s.

$^{*}p < .05$, $^{**}p < 0.01$

Table 3.8: Results of two-way ANOVA table for anthropomorphism.

(a) Mean and SD of anthropomorphism.

Condition	**Mean**	**SD**
Condition 1	3.05	0.92
Condition 2	3.57	1.34
Condition 3	2.98	0.91
Condition 4	2.51	1.08

(b) Results of two-way ANOVA

Source	**F(1,124)**	*p*	
Face	8.776	0.003	**
Motion	0.021	0.883	n.s.
Interaction	6.772	0.010	*

$^{*}p < .05$, $^{**}p < 0.01$

(c) Results of simple main effect test for anthropomorphism.

Simple main effect	**F(1,124)**	*p*	
Face (Moving)	0.0648	0.7994	n.s.
Face (Static)	15.4846	0.0001	***
Motion (Human face)	3.7806	0.0541	n.s.
Motion (Robot face)	3.0139	0.0850	n.s.

$^{*}p < .05$, $^{**}p < 0.01$, $^{***}p < 0.001$

face appeared with motion, the participants did not feel the robot to be not human-like. Regarding the presence factor, participants felt presence when the robot was performing motions since there was a main effect on the presence factor ($p < 0.01$). In other words, it did not matter whether there was a human face or a robot-like face because there was no main effect on the face factor. For further information on this experiment, several participants pointed out that it was difficult to watch the video and answer questions because the motors of the robot were too loud. However, there was no problem with the motions.

3.1.14 CONCLUSION

In this work, we conducted a 2 × 2 between-participant experiment (face: human face, robot face; motion: moving, static) and found that people felt a presence with the motion factor regardless of whether the face was human-like or robot-like. Furthermore, what we also found in the condition where the face was a human face and motion was static was that anthropomorphism was highest, which means that people felt the human face to be more human-like than in the other conditions.

Our findings on presence in telepresence robots reveal a more complex picture than some previous studies have suggested. While we found motion to be a key factor influencing presence regardless of face type, this relationship is not straightforward. Our results, along with those from prior work, indicate that presence in telepresence interactions is a complex phenomenon influenced by multiple factors beyond just motion and facial appearance.

Enhancing telepresence robot design for presence and anthropomorphism, based on these insights, can improve the effectiveness of such robots in various fields, such as healthcare, education, and customer service. As telepresence robots see increasing adoption in industry, understanding the impact of core design attributes such as facial appearance and expressive motion is crucial for aligning design choices with the desired user experience. Our experimental approach using online video-based studies also offers an efficient way for companies to test different telepresence robot designs with target users before investing in physical prototypes, potentially accelerating development cycles.

This study contributes to human-robot interaction research by combining the investigation of a telepresence robots' facial appearance (human face vs. robot face) and motion capabilities (moving vs. static). Our novel approach explores how these factors together affect user perceptions of anthropomorphism and presence. Unlike previous studies that looked at these elements separately as shown in Table 2.1, our research shows that expressive motion can enhance presence, while a human face increases anthropomorphism. These innovative findings provide a new way to optimize telepresence robot design for different user experiences and applications across various industries.

Our findings on facial and motion cues should help support social interaction using a telepresence robot. By contributing insights that guide the design of telepresence robots optimized for their intended application, our work supports the effective deployment of this technology across industries.

3.2 Stduy 2: Comparing Physical embodiments and smartphone in telecommunication

This section presents Study 2, which compares the influence of physical embodiments and smartphones in telecommunication. The study examines how smartphone-based video conferencing compares to telepresence robots with and without motion capabilities in terms of social presence and user experience.

3.2.1 Introduction

These days, people are enjoying using teleconference systems like Zoom or Skype to communicate with people over long distances or to have drinks through the internet with others. Additionally, some people have started using embodied systems called telepresence robots, such as the Beam robot[3]. Nowadays, schools have started using telepresence robots for students attending school, and in other cases, like hospitals, doctors use robots to visit patients. However, in previous studies, systems have not been compared in terms of social presence and anthropomorphism, for example, robots compared with humans. Therefore, we wondered how the presence and anthropomorphism of such systems affect people. Therefore, we carried out a web-based experiment and conducted a one-way ANOVA (smartphone vs. telepresence robot with motion vs. without motion) and we used Rapiro platform shown at figure 3.1 and which we modified Rapiro shown at Figure 3.10 in our experiment. Modified Rapiro used as telepresence robot in this study.

3.2.2 Hypotheses

We formulated two hypotheses for our experiment. As mentioned above, we conducted the experiment using a between-participant design (smartphone vs. robot with or without motion) to investigate which factors significantly affect presence and anthropomorphism. In previous research robot ability with arm motion is more effective in communication[25]. So, we formulated two hypotheses below H1 and H2.

- **H1** Robot with motion provide positive effect to presence then other two conditions.

TABLE 3.9: Rank of Items

	experimenter	**Remote operator**
1	Tanks of oxygen	Tanks of oxygen
2	Map of the Moon's surface	Water
3	Nylon rope	Food concentrate
4	Parachute	First aid kit
5	Life raft	Map of the Moon's surface

- **H2** Robot with motion provide positive impact on anthropomorphism.

3.2.3 Experiment design

The experimental design encompasses sections 3.2.4 through 3.2.9, which detail the experimental flow from task design to user interface implementation.

3.2.4 Task

The participants watched one video from three different conditions as shown in Figs. 3.12, Figs. 3.13, Figs. 3.14. In motion condition, Modified Rapiro expressed arm motion and motions listed in Table3.13. In static motion, this condition did not play any motions. In smartphone condition, only shown remote user's face like ordinary teleconference system.

We created a set of discussion videos in which a remote operator communicated via a telepresence robot and a person discussed moon survival and item ranking. We used a modified version of the Desert Survival Problem [90] called the Moon Survival scenario, which is also known as the NASA exercise [93], since the Desert Survival Problem is used by many social scientists and robotics researchers [25][91][5][79][23]. The video scenario was about an astronaut who had crash-landed on the moon and was discussing how to select 5 items that he needed from the 15 items left to return to his distant home planet. Due to video length, we only discussed ranking up to 5 items because if we had gone up to 15 items, the video length would have been too long. The ranking of the five items is shown in Table 3.9.

3.2.5 Measurement

To measure presence and anthropomorphism in the three conditions, we used two different questionnaires, one from the Godspeed series and one for social presence to measure presence. Godspeed is a standardized measurement tool for HRI [92]. There are five key

Table 3.10: GODSPEED's Questionnaire

	ANTHROPOMORPHISM	
1	Fake	Natural
2	Machinelike	Humanlike
3	Unconscious	Conscious
4	Artificial	Lifelike

Table 3.11: Networked Minds Measure of Social Presence's Questionnaire

	Social Presence
1	I often felt as if I was all alone
2	I think the other individual often felt alone.
3	I was often aware of others in the environment.
4	Others were often aware of me in the room.
5	The other individual paid close attention to me
6	I paid close attention to the other individual.
7	The other individual tended to ignore me.
8	My behavior was in direct response to the other's behavior.
9	The behavior of the other was in direct response to my behavior.
10	My partner did not help me very much.
11	I did not help the other very much.

concepts for the measurement used: anthropomorphism, animacy, likeability, perceived intelligence, and perceived safety, but in this study, we only used anthropomorphism. For the second questionnaire, we used the Networked Minds measure of social presence, which is measure of presence [91]. In both questionnaires, participants rate their agreement on a seven-point Likert scale. We modified this questionnaire due to some of the statements not fitting into our experiment. The questions from the first and second questionnaires are listed in Tables 3.10 and 3.11.

3.2.6 Participants

A total of 216 participants took part in the experiment online (male: 130, female: 70). Their ages ranged from 18 to 63 (M = 44.2, SD = 10.6). We recruited the participants from Yahoo! Crowd-sourcing, which is a service provided by Yahoo! Japan. Regarding all conditions, there was no significant effect of gender in Sirkin et al. [37].

3.2.7 Platform

We used a humanoid robot, Rapiro [94], which is widely used for different applications, such as for education and hobbies[83][84]. The Arduino and Raspberry Pi boards in the robot enable users (developers) to communicate with the robot by only sending command signals from a PC, and they also allow for the system to be extended easily. Therefore,

FIGURE 3.10: Modified Rapiro

FIGURE 3.11: Smartphone.

we used this robot as a telepresence robot for our experiment. For the experiment, we fixed Rapiro's eye colour to blue due to colour bias. We modified Rapiro's head as a prototype for experimental study and Other condition, we used just simple ordinary about 5.2-inch smartphone(shown Fig.3.11) in generally used, so all condition show the remote user's face.

Table 3.12: Smartphone Specification

Model	5.2, ZE520KL 64GB
Brand	Asus
Screen size	5.2 inches
Size(width x height)	73.98 x 146.87 millimeters (2.91 x 5.78 in)
display resolution	1080x1920 pixels
System version	Android 6.0
CPU	Qualcomm Snapdragon 625 MSM8953

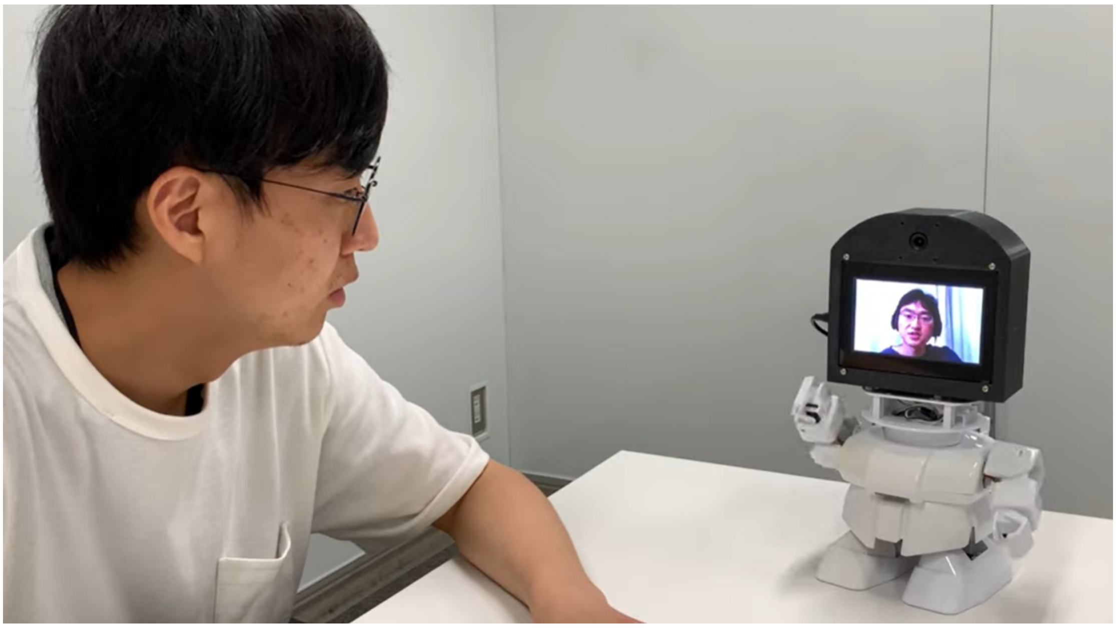

Figure 3.12: Motion condition

3.2.8 Hardware

Rapiro[94] has 12 degrees of freedom (DoF), a USB camera, a microphone in its forehead, and a speaker inside of its head. Fig.3.3 and 3.4 shows an overview of Rapiro. Modifications to Rapiro, we modified the head of another Rapiro to show the face of a remote user. We used a 5-inch portable monitor, and the head was made of PLA using a 3D printer. This Rapiro also had 12 DoF, a USB camera, microphone, and speaker inside of its head. Fig.3.5 and 3.6 shows an overview of the modified Rapiro. In order to match portable monitor size, we use almost same screen size smartphone which is 5.2-inch screen. Furthermore, smartphone's specification shown at table 3.12.

3.2.9 User Interface

To control Rapiro, we made a keyboard input interface. When the operator (from a geographically separate location) presses the number "2" on the keyboard, a local PC

FIGURE 3.13: Static condition.

FIGURE 3.14: smartphone condition.

receives the signal from the operator's location via Wi-Fi, and the robot makes that specific motion.

We generated robot motions in accordance with the following principle. For both of the robots, we used preset motions and the original motion which we developed for the experiments, such as “hands up” and “wave the both hands”and etc. In total, we used six motions in the video task and motions list showed in Table 3.13 . The preset motions

Table 3.13: List of Motions

	Motion
1	Both hands up
2	Wave the both hands
3	Stretch our right hand
4	Grip both hands
5	Left hand up
6	Fluttering both hands

Table 3.14: Presence of S.D. and Mean

Condition	**MEAN**	**S.D.**
motion	4.01	0.41
static	4.02	0.63
smartphone	4.04	0.56

included motion like going forward or backward, but we did not use these at this time. In smartphone condition, it shows remote user' face

3.2.10 Result

For the G*Power calculation [85], the sampling size was 159. For each condition, 53 participants were used for analysis. In total of 216 participants joined this experiments, we had some errors and in order to match sample size,so we delete some errors. We used anthropomorphism from the Godspeed questionnaire series to measure anthropomorphism [92]. To measure presence, we used the Networked Minds Measure of Social Presence questionnaire[91]. Furthermore, from both questionnaires, we took an average score.

The result the means and standard deviations(S.D.) for all of the dependent variables can be seen in Figs.3.15 and .3.16 as well as in Table 3.15 and Table3.14 To test our hypotheses, the data was analyzed by one-way analysis of variance(ANOVA) with the experimental conditions as the between-subjects factor. For presence as a result, A one-way ANOVA reveal that there was not a statistically significant difference in all conditions($F(2{,}156) = 0.04$, $p = 0.96$). Other condition for anthropomorphism, there was statistically significant difference between least two groups ($F(2{,}156) = 36.04$,$p = 0.00$). Shaffer's Sequentially Rejective Multiple Test Procedures for multiple comparisons found that the mean value of anthropomorphism was significantly different between motion and smartphone ($p = 0.00$). Furthermore, there was statistically significant difference in anthropomorphism between static and smartphone conditions ($p = 0.00$) and motion and static conditions ($p = 0.00$).

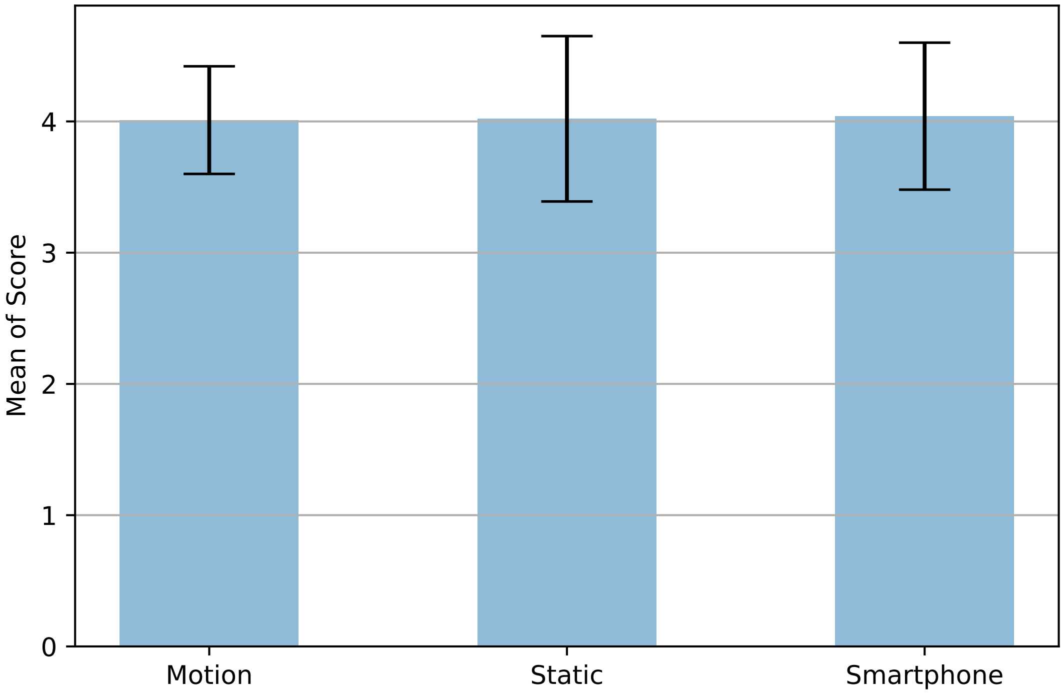

Figure 3.15: Mean scores of presence questionnaire under the three conditions.

Table 3.15: Anthropomorphism of S.D. and Mean

Condition	MEAN	S.D.
motion	3.10	1.12
static	4.17	1.39
smartphone	5.19	1.27

3.2.11 Hypothesis Summary

In the Experiment section set two hypotheses outcome of the experiment. Here are the results. H1, Robot with motion will affect to presence then other two conditions. Since, previous research robot ability with arm motion is more effective in communication[25].This hypothesis did not hold since a significant difference was not found for the motion factor($F(2,156) = 0.04$, $p = 0.96$). H2, We assume positive impact on anthropomorphism, since we mentioned again that ability with arm motion will active in communication[25]. This hypotheses did not hold since still anthropomorphism found that significant difference all conditions. However, when we look at MEAN value at Table3.14, motion condition was lowest value in anthropomorphism group. There are certain generalities among our results and the study presented here has limitations that may affect these generalities.

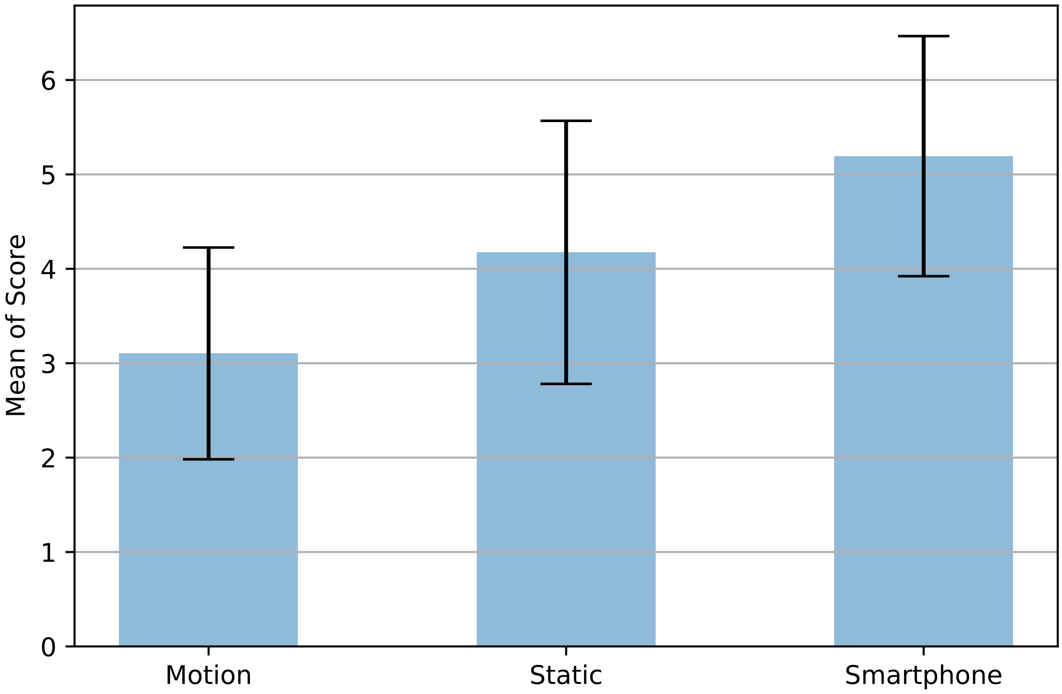

FIGURE 3.16: Mean scores of anthropomorphism questionnaire under the three conditions.

3.2.12 limitation

First, our use of Rapiro as the robot platform might affect generality since we only experimented with two particular robots. Naturally, each type of robot had its own limitations due to the number of actuators. Furthermore, Rapiro platform is low price robot platform for prototype and difficult to generate motion since actuators had poor dc motor with plastic gears and made some noise. However, the findings of our robot embodiment might not necessarily be generalizable to other types of robotic embodiment [33]. Second, there was a lack of support for our hypotheses on motion because we chose robot motion from in general movement from our human life. Moreover, when motions generate had to carefully because machine-like movement may effect and difficult to anthropomorphism since from our experiment anthropomorphism at motion condition was lowest MEAN value compare to two other conditions. In addition, the delay between the remote operator's speaking and the motion playback speed might also have affected the perceptions of presence and anthropomorphism. Third, the design of robot's head may have affected generality. We mentioned above that the finding of robot embodiment might not necessarily be generalizeable to other types of robotic embodiment [33], and we believe the same to be true for our conditions. Regarding online experiments in general, Crump et al. [95] showed that data collected online using a web browser seemed mostly in line with laboratory results, so long as the experimental methods were solid.

There were a few problems with the human-likeness and machine-likeness in the video task. When the head was robot-like, the robot appeared human-like even for those participants not used to robots, and the way the robot talked sounded human-like.

Since the face was that of a human, the participants felt the robot to be uncanny because it had a human face but a robot body. This may relate to the uncanny valley. Furthermore, most participants felt as if they were having a video chat in smartphone condition. In future work, we will conduct in-person experiments with the same conditions and method used in this study.

Finally, we found that no matter which robot we used, even simple motions could invoke a feeling of presence. The design of future telepresence robots will change depending on whether the emphasis is on human likeness or presence.

3.2.13 CONCLUSIONS

Therefore, people are commonly using teleconference systems to communicate with people over long distances. However, few people have started using telepresence robots, such as the Beam robot. We wondered how the presence and anthropomorphism of such systems affect people. Therefore, we conducted a web-based experiment and conducted a one-way ANOVA (smartphone vs. motion vs. static). Some people feel that telepresence robots bring a feeling of presence to remote places. However, from the results, a video teleconference system using a smartphone and a telepresence robot did not create a feeling of presence, but regarding anthropomorphism, participants felt more of a human-likeness in smartphone condition as the video teleconference system.

Chapter 4

Influence on Social Expression and Trust Repair in Manipulator with End-Effectors

This chapter presents three empirical studies in section 4.1, section 4.4 and section 4.5 done to examine how effective the proposed method would be in social expression conditions with Non-verbal motion and facial expression. In addition two levels with moving and static with task.

4.1 Study 3: Designing Apologetic Gestures for Multi-Joint Manipulators

4.1.1 Introduction

Service robots are now common in restaurant food delivery. However, machines aren't always stable and may encounter errors, causing a loss of trust. Typically, when people make an error, they apologize and are forgiven. We were curious about how people react when a service robot makes an error and apologizes. Before checking trust in a participant, we aimed to check for manipulative behavior and investigate which motions are suitable for apologetic gesture such as bowing, using non-anthropomorphic robot.

We conducted a web-based experiment with two-way ANOVA using a 2 x 5 (End-effector: Robot hand, Human hand; Motions: 5 different motions) within-participant design. Participants indicated a willingness to accept machine apologies, but we explored how trust could change. This study contributes insights into human-robot interactions, probing the acceptance of service robots in various roles and the impact of error and apology on trust.

4.1.2 Robot Platform

We used Mycobot280 M5Stack version by Elephant Robotic inc. as shown in Figure 4.1 and for end-effector we designed our own robotics end-effecotr for this study 4.1,4.4,and 4.5.

Figure 4.1: Mycobot280 M5Stack version

4.1.3 manipulation check for gesture

4.1.4 Experiment design

We conducted an experiment two-way ANOVA using a 2 x 5 (End-effector: Robot hand, Human hand; Motions:5 different motions) within-participant design. To explore the different ways people could interact with our design, we used G*Power sample size calculation ($n = 50$, with effect size = 0.5) and ran our experiment using online questionnaire surveys after showing videos. Participants were recruited from Yahoo! Japan Crowdsourcing. Furthermore, live and video-based HRI trials are known to be broadly equivalent in most cases[87]. However, in some cases, people may empathize less with video-based HRI trials compared to in-person experiments [88, 89].

4.1.5 Procedure

In our experiment, we used a robot called Mycobot 280 M54.1. The participants watched ten videos and in all conditions about robot bowing which apologetic gesture. The robot performed five different motions. Motion (a) involved the lowest axis at a 45-degree angle, while motion (b) used the middle axis at the same angle. Motion (c) utilized the highest axis, also at a 45-degree angle. In motion (d), all axes moved simultaneously. The final motion, (e), engaged all axes together but introduced a delay between each 45-degree angle movement. These motions were executed by the robot hand depicted in Figure 4.1 and correspond to the five motions shown in Figure 4.2.

TABLE 4.1: Estimated Marginal Means - Motion × End-Effector

End-Effector	Motion	Mean	SE	Lower	Upper
robot hand	motion1	3.84	0.230	3.38	4.30
	motion2	3.70	0.231	3.24	4.17
	motion3	3.34	0.285	2.77	3.92
	motion4	3.89	0.272	3.34	4.44
	motion5	3.82	0.252	3.31	4.33
human hand	motion1	3.59	0.248	3.09	4.09
	motion2	3.89	0.204	3.48	4.30
	motion3	2.73	0.214	2.30	3.16
	motion4	3.91	0.274	3.36	4.46
	motion5	3.43	0.267	2.89	3.97

4.1.6 Measurement

To measure the dependent variables, rating sorry motion, we asked participant to ”Please rate this robot motion look like apologizing”. All the answers ranged in seven-point Likert scale between (1) strongly disagree and (7) strongly agree.

4.1.7 Participants

A total of 45 participants took part in the experiment online (male: 38, female: 7). Their ages ranged from 26 to 65 (M =49.96, SD = 9.31). We recruited the participants from Yahoo! Crowd-sourcing, which is a service provided by Yahoo! Japan.

4.1.8 Result

To investigate apologetic gesture, we used a two-way analysis of variance (ANOVA) within-participant design. Before the data collection, we determined the sample size on the basis of power analysis. Our parameter for G*Power [85] used effect sizes of $f = 0.25$, $a = 0.05$, and $1 - b = 0.08$. For the G*Power calculation, the sampling size was 50. For each condition, 32 participants were used for analysis. In total of 45 participants joined and 5 drop out to this experiments, so we use 9 participants each in conditions.

Table 4.1 presents the estimated marginal means for each condition, while Table 4.2 shows the ANOVA results. The analysis revealed, no significant interaction between End-effector and Motions. No significant main effect of End-effector. A significant main effect of Motion (F(4, 176) = 5.17, $p <.001$, $\eta_p^2 = 0.105$) and motion 4 was highest shown at Figure 4.3.

Table 4.2: ANOVA Results: Within Subjects Effects

Source	Sum of Squares	df	Mean Square	F	p	η_p^2
End-Effector	4.30	1	4.30	2.82	0.100	0.060
Residual	67.10	44	1.52			
Motion	45.05	4	11.26	5.17	$< .001$	0.105
Residual	383.75	176	2.18			
End-Effector × Motion	8.88	4	2.22	1.97	0.102	0.043
Residual	198.72	176	1.13			

Note: Type 3 Sums of Squares

4.1.9 Conclusion

This study provides valuable insights into the design of apologetic gestures for non-anthropomorphic service robots. Our findings suggest that certain robotic motions can effectively convey an apologetic intent and movement of all axes (Motion 4) was perceived as the most apologetic. This study offers valuable insights into human-robot interactions in service settings. Findings suggest that people are generally willing to accept apologies from service robots, though the impact on trust remains complex. The exploration of non-anthropomorphic apologetic gestures provides useful data for future robot design. Overall, this research contributes to our understanding of maintaining positive human-robot relationships in service contexts, even when errors occur, potentially facilitating broader acceptance of service robots in various roles.

4.2 Introduction for study 4 and 5

In recent years, food delivery by service robots in restaurants has become a common phenomenon. However, machines and robots are not always stable and errors can lead to a loss of trust. Although robots offer efficiency and consistency, they are not infallible. When errors occur, they can lead to a loss of user trust, potentially hindering the broader adoption of robotic services. It is questionable whether human apologies for machine errors can maintain trust in robotic services. In human interactions, apologies often serve to mitigate the negative impact of errors. However, it remains unclear whether similar mechanisms can be effective in human-robot interactions (HRI), especially with non-anthropomorphic robots.

Our trust repair strategies are apologies:verbal, non-verbal, both by robot self-apologies for study 4 and apologies with human or not for study 5. verbally try to trust repair [51], but when in human-human interaction genernally in asia culture bow and apologize together. So our motivation is to investigate verbal, non-verbal, both (verbal and non-verbal) for apologized will repair of trust. futhermore, if human apologized togher aslo will effect to trust repair.

By intentionally introducing errors (dropping items) and then implementing trust recovery strategies, we aim to simulate real-world scenarios where service robots might fail and need to regain user trust. This approach allows us to examine the resilience of human-robot trust and the effectiveness of different repair strategies in a controlled setting.

Through this research, we contribute to the development of socially aware robotics, potentially enhancing the acceptability and trust in service robots even in the face of errors. Our findings have implications for the design of robot behaviors and human-robot interaction protocols in service contexts, potentially facilitating smoother integration of robots into various service roles.

This study not only advances our understanding of trust dynamics in human-robot interactions but also provides practical insights for roboticists and service industry professionals. By exploring how robots can effectively recover from errors, we pave the way for more robust and socially acceptable service robot deployments, ultimately working towards a future where robots can seamlessly integrate into human-centric service environments.

4.3 Method for study 4 and 5

In study 4.4 and 4.5 used same meausurment as questionnaire but procedure last videos are diffrent use doffrenet trust repair strategy which study 4 is aplogies using verbal and non-verbal, and study 5 is human apologized.

To explore the different ways people could interact with our design, we used G*Power sample size calculation (study 4 for $n = 159$, study 5 for $n = 128$, study 4 and 5 with effect size = 0.5) and ran our experiment using online questionnaire surveys after showing videos. Participants were recruited from Yahoo! Japan Crowdsourcing. Furthermore, live and video-based HRI trials are known to be broadly equivalent in most cases[87]. However, in some cases, people may empathize less with video-based HRI trials compared to in-person experiments [88, 89].

4.3.1 Measurement

To measure trust, we use MDMT v2(Multi-Dimensional Measure of Trust version 2) scale by Malle et al. [96] featuring Performance Trust (Reliable, Competent) and Moral Trust (Ethical). Some of the other scales were not a fit for our study, so we did not use consistent, meticulous, has integrity. All the answers ranged in seven-point Likert scale between (1) strongly disagree and (7) strongly agree.

- Reliable subscale: reliable, predictable,dependable
- Vompetent subscale: competent, skilled, capable,
- Ethical subscale: ethical, moral, principled

4.3.2 Procedure

In our experiment, we used a robot called Mycobot 280 M5Stack version with end-effector. Futheremore, we used In Studies 4 and 5, participants watched three videos under different conditions. In the first video, they observed a manipulator with an end-effector picking and placing two bottles as shown in Figures 4.4, followed by a trust questionnaire. This phase established the initial value of trust.

In the second video, the manipulator intentionally dropped a bottle as shown in Figures 4.5, and participants again answered a trust questionnaire. This phase demonstrated the initial trust decline, as we aimed to observe a drop in trust.

In the third video, participants in Study 4 watched one of three different conditions, as shown in Figures 4.6 and 4.7, where trust repair strategies for apologized: verbal, non-verbal, or both. In Study 5, participants watched one of two conditions, as shown in Figures 4.8 and 4.9: either a human apologized, or human and a robot apologized together.

In this third phase (for both Study 4 and 5), we aimed to assess how the trust repair strategies affected participants and their trust levels.

When participants finished watching the video, they were asked to rate their agreement on a seven-point Likert scale (1 = strongly disagree, 7 = strongly agree) in two questionnaire surveys. When they finished the experiment, there was an additional comment or question space. We paid 100 yen (about \$1US), and the average time to complete the procedure was about 15 to 30 minutes.

4.4 Study 4: Trust Strategy by Apology: verbal, non-verbal and both

In our trust strategy using apology; verbal, non-verbal, and both (verbal and non-verbal), we chose the condition based on the lack of significant differences found between textual and auditory explanation modalities [51], and verbal content that included an apology [54] for the verbal condition. The non-verbal condition was based on [50], and for the combined condition, we explore how combining verbal and non-verbal elements affects trust repair. So we formulated hypotheses for our experiment.

- **H1** Trust repair is highest in both conditions.

4.4.1 Experiment design for study 4

We conducted an experiment one-way ANOVA (Trust Strategy by Apolgized: verbal and non-verbal, both) between-participant design. In the verbal condition, the robot does not move, and for voice generation, we used a web service to convert text to the robot's voice[1].

4.4.2 Participants for study 4

For the G*Power calculation [85], the sampling size was 159. For each condition, 53 participants were used for analysis. In total of 299 participants (male: 237, female: 61) joined in experiment online. To match the sample size, we used the top 53 participants. Their ages ranged from 21 to 81 (M = 49.25, SD = 10.44). We recruited the participants from Yahoo! Crowd-sourcing, which is a service provided by Yahoo! Japan. All our experiments were approved by the ethics committee of our institution.

4.4.3 Result for study 4

The ANOVA results indicated a significant effect of strategy on trust, $F(2, 156) = 7.35, p < .001, \eta_p^2 = 0.086$, suggesting that trust levels significantly vary across different strategies. The effect size η_p^2 of 0.086 points to a moderate influence of strategy on trust.

Post hoc comparisons showed that trust was significantly lower for verbal strategies compared to non-verbal strategies (mean difference = -0.7975, $p = .004$, $d = -0.6310$),

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[1] https://ondoku3.com/ja/

Table 4.3: Descriptives for Study 1 Mean and SD

	strategy	Mean	SD
Trust for initial value	verbal	3.98	0.860
	non-verbal	3.93	1.020
	both	3.90	0.947
Trust for 2nd value	verbal	2.00	0.758
	non-verbal	1.91	0.752
	both	1.99	0.818
Trust for strategy	verbal	3.18	1.060
	non-verbal	3.81	1.376
	both	3.90	1.103

Table 4.4: one-way ANOVA - Trust for strategy

	Sum of Squares	df	Mean Square	F	p	η^2p
strategy	16.3	2	8.15	5.78	0.004	0.069
Residuals	220.1	156	1.41			

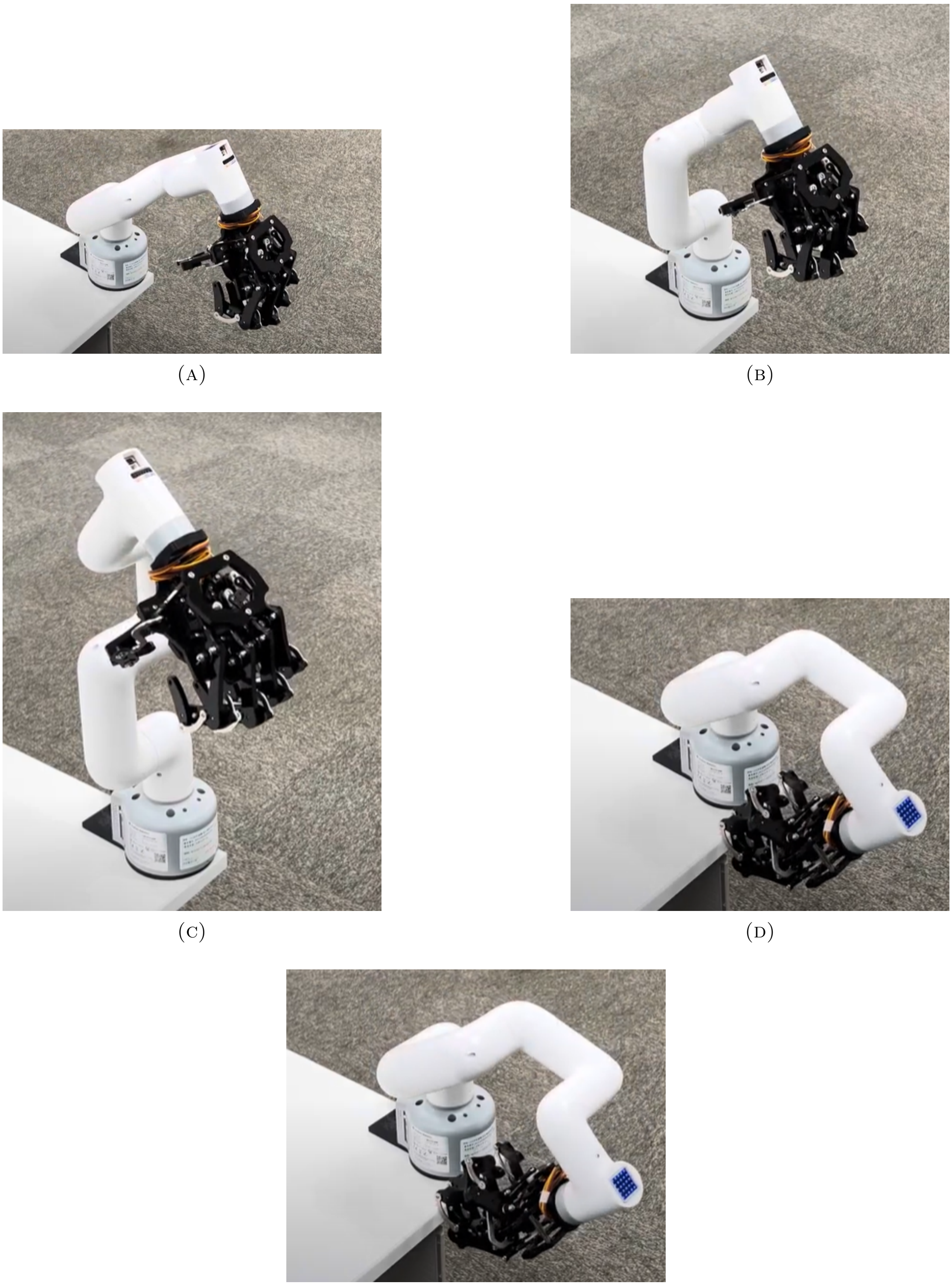
Table 4.5: Post Hoc Comparisons - strategy

Comparison								
strategy		strategy	Mean Difference	SE	df	t	p_{tukey}	Cohen's d
verbal	-	non-verbal	-0.6310	0.231	156	-2.735	0.019	-0.5313
	-	both	-0.7191	0.231	156	-3.116	0.006	-0.6054
non-verbal	-	both	-0.0881	0.231	156	-0.382	0.923	-0.0741

Note. ** p <0.05, *** p <0.001.

and compared to the combination of both strategies (mean difference = -0.8314, p = .003, $d = -0.6578$). However, no significant difference was found between non-verbal strategies and the combination of both strategies (mean difference = -0.0340, p = .990).

Descriptive statistics revealed that the mean trust for the strategy condition was highest for the combination of both strategies $M = 3.56$, followed by non-verbal strategies $M = 3.53$, and lowest for verbal strategies $M = 2.73$. These findings are consistent with the ANOVA and post hoc results, indicating that strategies combining both verbal and non-verbal elements result in higher trust compared to verbal strategies alone.



(A)

(B)

(C)

(D)

(E)

FIGURE 4.2: Five motions in human hand version. Please see Appendix A, these motions have video links on YouTube.

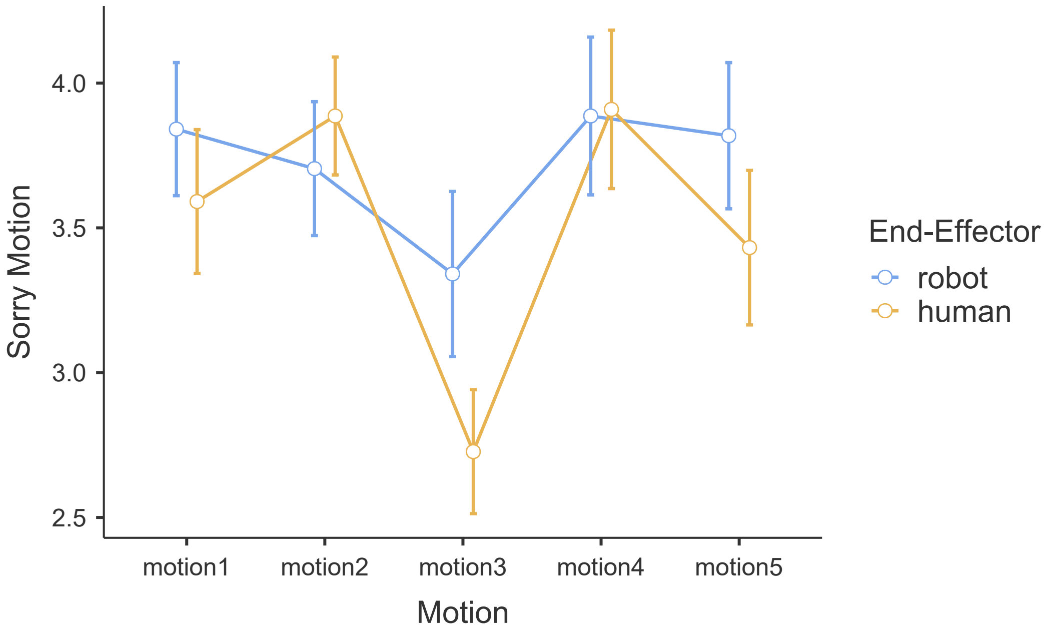


FIGURE 4.3: Average scores for motions perceived for each condition in experiment for rating sorry motion.

FIGURE 4.4: Study 1 and 2 for first video that is pick and place bottle to other place and initial trust value.

Figure 4.5: Study 1 and 2 for second vidoe that is drop bottle on intentionally.

Figure 4.6: Study 1 for Trust Repair Strategy: verbal that saying sorry.

Figure 4.7: Study 1 for Trust Repair Strategy: non-verbal and both that saying sorry with motion.

Figure 4.8: Study 2 for Trust Repair Strategy: Human apologized.

FIGURE 4.9: Study 2 for Trust Repair Strategy: human and a robot apologized together.

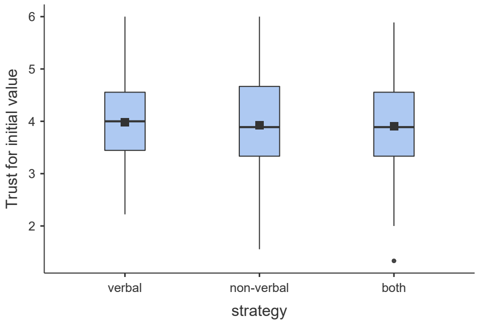


FIGURE 4.10: Average scores for trust in the first video and the initial value for trust for study 1

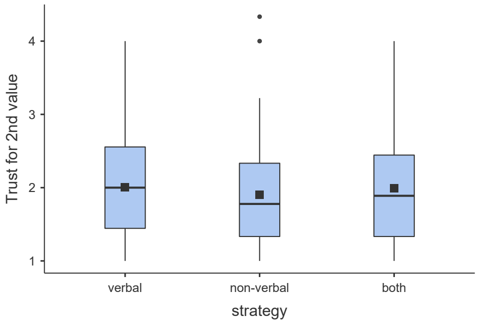


FIGURE 4.11: Average scores for trust in the second video and the second value for trust in the drop-down for study 1.

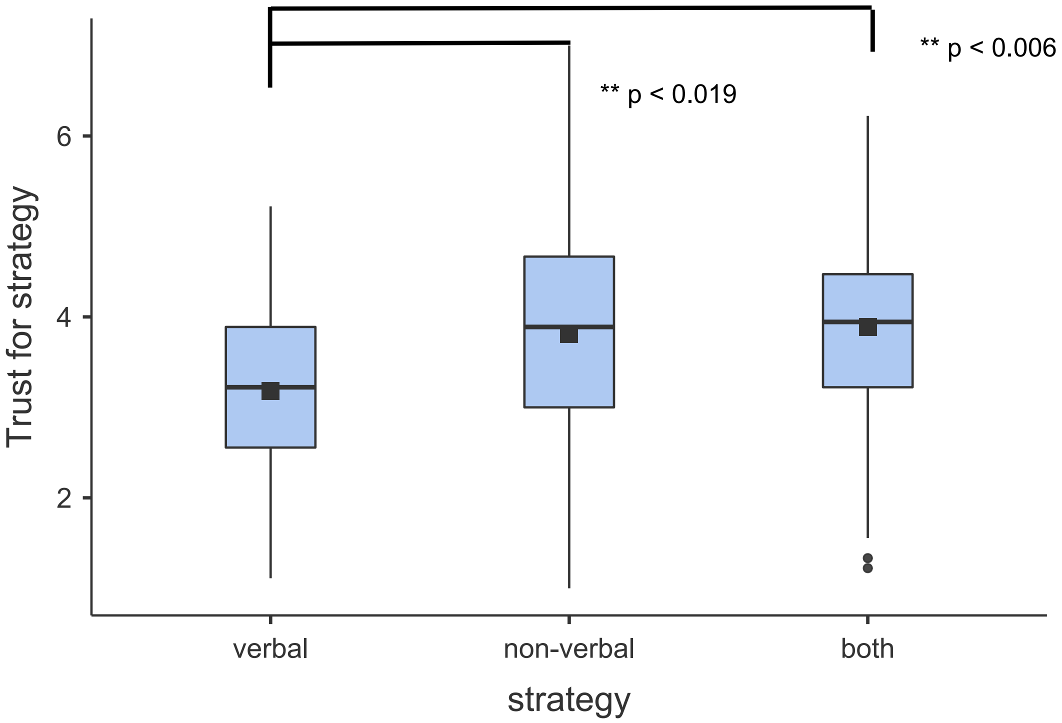


FIGURE 4.12: Average scores for trust in the third video and the corresponding trust repair for study 1.

4.5 Study 5: Trust Strategy by Apology: Apolozied Human and Robot or Only Human

In prior work, research havent seen robot and human apologized together. So we wonder how only human or human and robot apologies together repair of trust. So we formulated hypotheses for our experiment.

- **H2** Trust repair is highest in human and robot apologies together.

Table 4.6: Descriptives for Study 2 Mean and SD

	Strategy	Mean	SD
Trust for initial value	only human apologies	3.46	1.047
	human and robot apologies	3.73	1.067
Trust for 2nd value	only human apologies	1.88	0.723
	human and robot apologies	2.01	0.962
Trust for strategy	only human apologies	2.87	1.133
	human and robot apologies	3.79	1.351

4.5.1 Experiment design for study 5

We conducted an experiment independent sampet T-test which include only human apologized and robot not move vs. human and robot apologized together.

4.5.2 Participants for study 5

For the G*Power calculation [85], the sampling size was 128. For each condition, 64 participants were used for analysis. In total of 199 participants (male: 138, female: 61) joined in experiment online, in order to match sample size,so we used top 64. Their ages ranged from 22 to 75 (MEAN =50.18, SD = 11.40). We recruited the participants from Yahoo! Crowd-sourcing, which is a service provided by Yahoo! Japan. All our experiments were approved by the ethics committee of our institution.

4.5.3 Result for study 5

The Independent Samples T-Test revealed a significant difference in trust levels between the ”only human apologies” group and the ”human and robot apologies” group, $t(126) = -4.17, p < .001$. The negative t-value indicates that trust was lower in the ”only human apologies” condition compared to the ”human and robot apologies” condition. The effect size, $d = -0.736$, represents a medium to large effect, suggesting a substantial practical difference between the two groups. These results support the hypothesis H_3, which posits that trust is higher when both human and robot apologies are present compared to when only humans apologize.

TABLE 4.7: Results of the independent samples t-test for the third video, focusing on the two trust repair strategies.

		Statistic	df	p		Effect Size
Trust	Student's t	-4.17	126	< 0.001	Cohen's d	-0.736

Note. H_2: $\mu_{\text{only human apologies}} < \mu_{\text{human and robot apologies}}$.

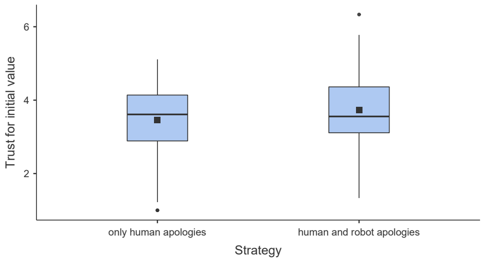


FIGURE 4.13: Average scores for trust in the first video and the initial value for trust for study 2.

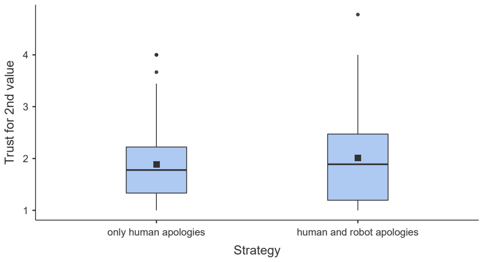


FIGURE 4.14: Average scores for trust in the second video and the second value for trust in the drop-down for study 2.

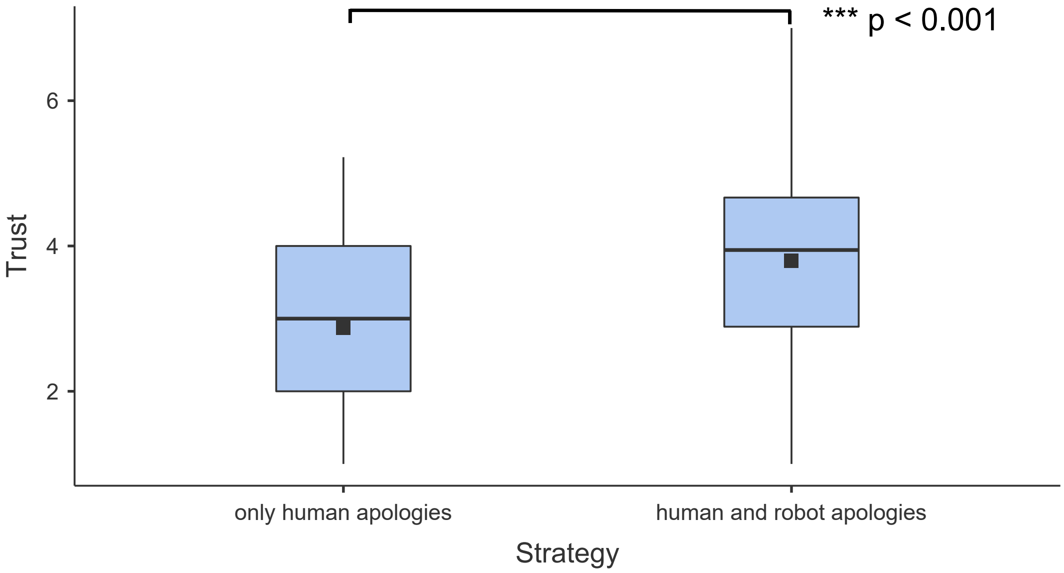


FIGURE 4.15: Average scores for trust in the third video and the corresponding trust repair for study 2.

4.6 CONCLUSIONS for study 4 and 5

This study offers significant insights into the design of apology strategies for non-anthropomorphic service robots and their impact on trust repair in human-robot interactions. Our findings reveal the complex dynamics of trust in these interactions and provide valuable guidance for future robotic system design.

In conclusion, this research takes a significant step towards creating more socially aware and trustworthy robotic systems. By demonstrating the effectiveness of non-verbal and collaborative apology strategies, it opens up new avenues for designing robots that can maintain positive relationships with humans, even in the face of errors or misunderstandings. As we continue to explore the intricacies of human-robot interaction, studies like this will be crucial in shaping a future where robots can seamlessly integrate into human social contexts.

Chapter 5

General Discussion

This research has investigated social expression and trust repair across two distinct robotic platforms: telepresence robots and manipulators. Through multiple empirical studies, we have gained valuable insights into how different design elements and interaction strategies influence human perception and trust in human-robot interactions.

In telepresence robots, our research revealed that motion was a key factor influencing presence, regardless of facial display type. The finding that motion consistently affects presence regardless of face type (human or robot face) challenges common assumptions about the primacy of facial displays in telepresence systems. Interestingly, for anthropomorphism, we found that a static telepresence robot with a human face was perceived as more anthropomorphic compared to other conditions, suggesting that the uncanny valley effect may influence perceptions when human faces are combined with robot motion.

For manipulator robots, despite their typically lower anthropomorphism, we found that social expression through combined verbal and non-verbal approaches was highly effective for trust repair. The studies revealed that trust was significantly higher in both non-verbal and combined (verbal and non-verbal) conditions compared to verbal-only approaches. Furthermore, when both humans and robots apologized together, trust repair was more effective than human-only apologies , suggesting the importance of collaborative approaches in service contexts.

These findings across both platforms reveal several important insights about social expression and trust in human-robot interaction:

1. The role of motion differs across platforms: In telepresence robots, motion primarily influences presence, while in manipulators, specific motion patterns can effectively convey social cues like apologies.
2. Anthropomorphism is not always necessary for effective social interaction: While human-like features enhanced anthropomorphism in static telepresence robots, even non-anthropomorphic manipulators could effectively engage in social repair through well-designed motion patterns.
3. Human Robot communication enhances effectiveness: Both studies showed that combining different communication modes (verbal, non-verbal, or human-robot collaboration) led to better outcomes.

However, our research faced several limitations. The use of video-based studies, while allowing for controlled comparisons, may not fully capture real-world interactions. Technical constraints of our robot platforms, including limited degrees of freedom and motor noise issues, may have influenced participant perceptions. Additionally, our studies were conducted primarily with Japanese participants, and cultural factors may influence how different social expressions and trust repair strategies are perceived.

Our findings contribute to the broader field of human-robot interaction by demonstrating that effective social interaction depends less on replicating human-like features and more on implementing appropriate and well-designed social expression strategies that align with each platform's capabilities and context of use. Future work should explore these effects in real-world settings, across different cultures, and over longer periods of interaction.

5.1 Discussion in telepresence robot

In this section, we discuss the findings of our study investigating the impact of facial appearance and motion on users' perceptions of anthropomorphism and social presence in interactions with a telepresence robot. We begin by summarizing the main results and their significance in relation to our research questions and hypotheses. Next, we situate our findings within the broader context of human-robot interaction literature, comparing them with those of prior studies. We then consider the implications of our work for the design and development of telepresence robots, offering practical recommendations for optimizing user experiences based on our findings. Finally, we address the limitations of our study and propose directions for future research to further advance our understanding of the factors that shape user perceptions and experiences in human-robot interaction.

The present study investigated the impact of facial type and motion on users' perceptions of anthropomorphism and social presence in a telepresence robot. Our findings revealed a significant interaction effect between face type and motion on anthropomorphism, with a human-like face leading to higher ratings only when the robot was static. Additionally, motion was found to be a key driver of social presence, regardless of the robot's face type. These results make several novel contributions to the field of human-robot interaction (HRI). First, our study systematically investigates the interaction effects of a telepresence robot's face type and motion on users' perceptions of anthropomorphism and social presence, providing new insights into how these design factors work together to shape user experiences. Second, our findings reveal that the impact of face type on anthropomorphism is more pronounced when the robot is static, highlighting the importance of considering the robot's intended use and mobility when designing its facial features. Third, our results demonstrate the crucial role of motion in conveying social presence, regardless of the robot's face type, underscoring the need for telepresence robots to have expressive movement capabilities to foster user engagement. These contributions advance our understanding of the factors influencing human-robot interactions and provide valuable guidance for designing effective telepresence robots that can support remote communication and collaboration.

5.1.1 Anthropomorphism in Telepresence robots

Regarding anthropomorphism, our findings demonstrate that a static telepresence robot with a human face was perceived as more anthropomorphic compared to other conditions. This suggests that the presence of a human face, even without motion, can significantly impact perceptions of a telepresence robot's human-likeness. These results align with previous work on telepresence robots that display either a remote operator's face or a robot face. Our previous study [29] found lower anthropomorphism in motion conditions, which is consistent with our current results, possibly because the embodiment as a moving robot while showing a human face may have felt uncanny [97].

Interestingly, robots like OriHime [31, 38] and OriHime-D [18] can evoke a sense of presence in both directions even with a robot face. While Fitter et al. [26] found mixed preferences among local participants between basic and arm conditions for telepresence robots, they did not directly measure anthropomorphism.

Similarly, while mobile telepresence robots like Beam [3, 78] potentially provide human-likeness, anthropomorphism was not directly measured in these studies. Our results suggest that using a robot face, as seen in OriHime-D [18], might not provide high levels of human-likeness to local participants.

5.1.2 Presence in Telepresence Robots

Our study found that motion was a key factor influencing presence in telepresence robots, regardless of face type. However, measuring presence in human-robot interaction is challenging, and prior work found both similar and different results.

Several studies, including ours, have found consistent results regarding presence in telepresence interactions. Adalgeirsson and Breazeal [25] found no significant differences in co-presence between static and expressive conditions in their MeBot[25] experiment, although they did find differences in other measures. Our previous work [29] found no differences in presence between smartphone conditions and telepresence robot conditions with and without motion. Similarly, Fitter et al. [26] did not find significant differences in presence measures across their experimental conditions, although they noted some trends favoring the expressive arm condition. These studies suggest two important implications: First, the effect of expressiveness or motion on presence might not be as strong or significant as generally expected in the field of telepresence robotics. Second, there may be other factors that have a greater influence on how present someone feels during a telepresence interaction.

Previous studies [3, 78, 79, 98] suggest that using mobile telepresence robots like Beam [3, 78] may influence presence without necessarily requiring motion or expressive arms. This indicates that the relationship between expressiveness, motion, and presence is not as straightforward as initially expected, suggesting the need to consider a wider range of factors when trying to understand what creates a feeling of presence in telepresence systems.

However, some studies have found positive effects of embodiment and motion on presence. Schouten et al. [40] found that the use of a telepresence robot increased social presence compared to videoconferencing, highlighting the importance of physical embodiment. Furthermore, studies by Kristoffersson et al. [78] on spatial formations in telepresence interactions hint at the importance of positioning and orientation in creating a sense of presence. A prior study [5] found that mobility significantly increased the remote user's feelings of presence, especially in tasks requiring more movement. Choi et al. [34] found that movement conditions (both mimicry and random) led to more positive outcomes compared to the static condition. Supporting these findings, the Orihime-D [18–22] telepresence robot, which features a robot face without showing the operator's face but can express arm motions, demonstrates how motion capabilities can effectively convey presence even without facial displays.

While our results align with studies showing the positive effect of motion on presence, the broader complexity of presence was not our main research focus. Rather, our contribution comes from the systematic comparison across our four experimental conditions, which revealed that motion consistently influences presence regardless of facial type (human or robot face). This novel finding advances our understanding of how different design elements impact presence in telepresence robots. Based on these research outcomes, we can provide concrete recommendations for the field: incorporating motion capabilities should be prioritized when developing telepresence robots aimed at enhancing presence. These insights offer valuable practical guidance for designers developing telepresence robots, researchers studying human-robot interaction, and users selecting or implementing telepresence systems in various applications.

5.1.3 Generality and Limitations

There are certain generalities among our results, and the study presented here has limitations that may affect these generalities. First, our use of Rapiro as the robot platform might affect generality since we only experimented with two particular robots. Naturally, each type of robot had its own limitations due to the number of actuators. However, the findings for our robot embodiment might not necessarily be generalizable to other types of robotic embodiments [33]. Second, there was a lack of support for our hypotheses on motion because we chose robot motion from the general movements in our human life. In addition, the delay between the remote operator's speaking and the motion playback speed might also have affected the perceptions of presence and anthropomorphism. Third, the robot face may have affected the generality. We mentioned above that the findings for robot embodiment might not necessarily be generalizable to other types of robotic embodiments [33], and we believe the same to be true for facial cues. In addition, Japanese people often imagine humanoid robots as friendly [35], and since we only used Japanese participants, it is uncertain whether our results would apply to people of other cultures.

Regarding online experiments in general, Crump et al. [95] showed that data collected online using a web browser seemed mostly in line with laboratory results, so long as the experimental methods were solid.

There were a few problems with the human-likeness and machine-likeness in the video task. When the face was robot-like, the robot appeared human-like even for those participants not used to robots, and the way the robot talked sounded human-like. When the face was that of a human, the participants felt the robot to be uncanny because it had a human face but a robot body. This may relate to the uncanny valley.

Furthermore, most participants felt as if they were having a video chat in the condition using a human face without arm motion (static condition). /colorred In future work, we will conduct in-person experiments with the same conditions and method used in this study. We will also compare video chat and this condition of using a human face and no motion. Furthermore, we need to consider a wider range of factors when trying to understand what creates a feeling of presence in telepresence systems. /colorblack

Finally, we found that no matter which robot we used, even simple motions could invoke a feeling of presence. Regarding human-face conditions, there was no significant effect of gender in the study by Sirkin et al. [37]. The design of future telepresence robots will change depending on whether the emphasis is on human likeness or presence.

5.2 Discussion in manipulator

H1: Trust repair is highest in both conditions (verbal and non-verbal combined). Result: Partially supported. The study found that trust was significantly higher in both the non-verbal and combined (verbal and non-verbal) conditions compared to the verbal-only condition. However, there was no significant difference between the non-verbal and combined conditions. The mean trust scores were highest for the combined condition (M = 3.90), followed closely by the non-verbal condition (M = 3.81), and lowest for the verbal condition (M = 3.18). H2: Trust repair is highest when human and robot apologize together. Result: Supported. The study found a significant difference in trust levels between the "only human apologies" group and the "human and robot apologies" group. Trust was significantly higher when both human and robot apologized together (M = 3.79) compared to when only humans apologized (M = 2.87). The effect size (Cohen's d = -0.736) suggests a medium to large practical difference between the two groups. These results indicate that non-verbal and combined apology strategies from robots are more effective in repairing trust than verbal-only strategies, and that collaborative apologies involving both humans and robots are more effective than human-only apologies in service robot contexts.

The results from Study 1 demonstrate that when it comes to robotic apologies, actions speak louder than words. Non-verbal and combined verbal and non-verbal apology strategies proved significantly more effective in repairing trust compared to verbal strategies alone. This suggests that incorporating physical gestures or movements into robotic apologies can enhance their effectiveness, even in non-anthropomorphic robots. This finding challenges the notion that humanoid features are necessary for effective social interaction and opens up new possibilities for designing socially aware behaviors in a wide range of robotic forms.

Study 2 further expanded our understanding by exploring the interplay between human and robot apologies. The discovery that combined human and robot apologies led to higher trust repair compared to human-only apologies is particularly intriguing. It suggests that in service contexts where both humans and robots are involved, a collaborative approach to addressing errors or mishaps could be most effective. This finding has potential implications for the design of human-robot teams in various service industries.

Both studies highlighted the fragile nature of trust in human-robot interactions. While initial trust levels were relatively high, they dropped significantly after an error occurred. However, the partial recovery of trust through appropriate apology strategies offers hope for maintaining positive human-robot relationships even in the face of mistakes.

These findings contribute to the growing body of knowledge on designing social behaviors for non-anthropomorphic robots. They suggest that even robots without human-like features can engage in effective social repair strategies, challenging preconceptions about the necessity of anthropomorphism in social robotics.

The implications of this research extend beyond the immediate context of service robots. As robots become increasingly integrated into various aspects of daily life, understanding how to maintain positive human-robot relationships, even when errors occur, becomes crucial. This study provides valuable insights that could inform the design of robotic systems across multiple domains, from healthcare and education to manufacturing and home assistance.

5.2.1 Generality

The generality of this study's findings is constrained by several factors. While the use of a non-anthropomorphic robot (Mycobot280 M5Stack) enhances applicability to various robotic forms, the specific context of a food delivery scenario may limit direct generalization to all service robot applications. The online video-based methodology, while allowing for a larger sample size, may not fully capture the nuances of human-robot interactions in person. Additionally, the study's participants were recruited from a Japanese crowdsourcing platform, which may introduce cultural biases in perceptions of apologies and trust. Despite these limitations, the consistent patterns observed across different apology strategies and the human-robot collaboration scenario suggest that the core findings, the effectiveness of non-verbal and combined apology strategies, and the benefits of human-robot collaborative apologies, may have broader applicability in the field of human-robot interaction.

5.2.2 Limitation

Limitation in our study arose from the voice used in the verbal condition. We utilized a web service (https://ondoku3.com/ja/) to generate a robotic voice from text, which may have influenced participants' perceptions. The artificial nature of this voice could have affected the results, as a more natural or differently modulated voice might elicit different responses. Furthermore, the verbal content was limited to a simple ”I am sorry” statement, which may not fully represent the range of possible verbal apologies. This minimalistic approach, while allowing for controlled comparison, might not capture the nuances of more elaborate or contextually tailored apologies. Future studies could benefit from exploring a wider range of vocal characteristics and verbal content to provide a more comprehensive understanding of verbal apology effectiveness in human-robot interactions.

Chapter 6

Conclusion

This dissertation has investigated social expression and trust repair in human-robot interaction through a series of empirical studies spanning telepresence robots and robotic manipulators. Through these investigations, we have gained valuable insights into how robots can effectively engage in social interactions and maintain trust with humans, even in challenging situations such as after errors or misunderstandings occur.

Our research on telepresence robots has revealed several important findings about the relationship between motion, facial appearance, and user perceptions. Most significantly, we found that motion serves as a critical factor in creating a sense of presence, regardless of whether the robot displays a human or robot-like face. This finding challenges traditional assumptions about the primacy of facial displays in telepresence systems. Interestingly, our studies showed that static telepresence robots with human faces were perceived as more anthropomorphic than other configurations, suggesting that the combination of human faces with robot motion may trigger uncanny valley effects. These results indicate that the relationship between motion and presence is more nuanced than previously theorized, with different types of motion contributing uniquely to the overall user experience.

In our investigation of manipulator robots, we uncovered crucial insights about trust repair strategies in service contexts. The research demonstrated that combined verbal and non-verbal approaches prove most effective for trust repair, with non-verbal gestures playing an especially important role. Notably, we found that collaborative human-robot apologies outperform human-only apologies in service contexts, highlighting the value of including both human and robotic elements in trust repair strategies. Perhaps most surprisingly, our studies showed that even non-anthropomorphic robots can effectively convey social cues through motion patterns, challenging the assumption that sophisticated social expression requires human-like features.

These findings contribute significantly to our theoretical understanding of human-robot interaction. They demonstrate that effective social interaction depends more heavily on appropriate behavioral design than on anthropomorphic features, prompting a reconsideration of the necessity of human-like attributes in social robotics. Our work suggests a new framework for understanding presence in telepresence systems, where motion capabilities play a central role independent of facial display type. Furthermore, we have expanded trust repair theory in human-robot interaction by demonstrating the effectiveness of multi-modal and collaborative approaches in service contexts.

The practical implications of our research extend to both telepresence and manipulator robot design. For telepresence robots, our findings suggest prioritizing motion capabilities in design while carefully considering the trade-offs between human-like features and motion in facial displays. The focus should be on developing natural and meaningful movements rather than pursuing anthropomorphic appearance. In the context of manipulator robots, our research supports implementing multi-modal trust repair strategies that combine verbal and non-verbal elements, designing collaborative trust repair protocols that involve both humans and robots, and developing expressive motion patterns even for non-anthropomorphic robots.

Looking toward the future, several promising research directions emerge from this work. Long-term studies will be crucial to understanding how social expression and trust repair strategies perform over extended periods of interaction. Cross-cultural investigations could reveal how different populations respond to various social expression and trust repair approaches. Additional research could explore how these findings might apply to other types of robots and interaction contexts, while technical work could focus on developing more sophisticated motion patterns and gesture libraries for social expression. Furthermore, investigating how different types of errors and contexts influence the effectiveness of trust repair strategies will be essential for developing more robust interaction systems.

We acknowledge several limitations in our current research. The use of video-based studies, while allowing for controlled comparisons, may not fully capture the complexity of real-world interactions. Technical constraints of our robot platforms, including limited degrees of freedom and motor noise issues, may have influenced our results. Additionally, our participant pool was primarily Japanese, which may limit the cultural generalizability of our findings. The focus on specific types of interactions and errors may also restrict the broader applicability of our conclusions.

Despite these limitations, this dissertation makes substantial progress in understanding how robots can effectively engage in social interaction and maintain trust with humans. Our findings suggest that the future of social robotics lies not in creating perfect human analogues, but in developing robots that can effectively communicate and interact in ways appropriate to their form and function. This perspective opens new possibilities for robot design and implementation across various applications, from service and healthcare to education and industrial collaboration.

As we move forward, the central challenge will be building upon these findings to create robots capable of increasingly sophisticated social interactions while maintaining trust and acceptance among human users. This will require continued research into both the theoretical foundations of human-robot interaction and practical implementations of social expression and trust repair strategies. Through such ongoing work, we can advance toward a future where robots seamlessly integrate into human social contexts while maintaining positive and trustworthy relationships with their users.

The implications of this research extend beyond the immediate context of telepresence and manipulator robots. As autonomous systems become increasingly integrated into various aspects of human society, understanding how to maintain positive human-robot relationships, even when errors occur, becomes crucial. Our findings provide valuable insights for designing robotic systems that can effectively engage in social interaction and maintain trust across multiple domains, ultimately contributing to the broader goal of creating robots that can successfully operate alongside humans in diverse social contexts.

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