



Ben-Gurion University of the Negev
The Faculty of Engineering Sciences
Department of Industrial Engineering and Management

**Human-Robot Interaction:
Interaction Modes and Levels of Explanation in
Mobile Robotic Telecare Tasks**

Thesis submitted in partial fulfillment of the requirements for the
M.Sc. degree

By: Omer Keidar

Supervised by: Prof. Yael Edan

November 2022



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Abstract

Life expectancy is rising resulting in a rapidly growing increase in the world's elderly population. In contrast, the population of caregivers is decreasing in relation to the number of older adults leading to an increased need in finding solutions that will make it possible to deal with the lack of caregivers in hospitals, care centers, and homes. A possible solution to overcome this problem is the development and use of assistive robots (AR) and more specifically, the development of mobile robotic telepresence (MRP) which enable robots to be controlled remotely. As robots become more and more capable and autonomous, the use of robots in daily tasks by nonprofessional users will increase. In order for such MRP systems to provide assistance in daily and healthcare tasks, additional research is needed to ensure smooth and efficient interaction. One aspect of the interaction is to make the MRP systems more understandable to their operator and to the environment.

This research examined the interaction and understanding between MRP systems and technological and non-technological operators. Creating a successful and understandable interaction is a challenging task. Some of the critical factors in human-robot interaction are the feedback and the way that the robot communicates with the user. To achieve this, robots must be able to convey information to the user in the right way and help the user understand their decisions, the thoughts that led to the decision, and their actions. In this thesis, we examined *how* feedback and explanations from the MRP system should be communicated to the user, *what* information should be communicated to the user and *when* it should be communicated.

The first part of the research examined an MRP system in a simulated healthcare setting to assist caregivers to perform their daily tasks, such as providing medication and food and taking measurements from patients while they perform a secondary task (e.g., filling out forms) and tried to answer the question of *how* feedback and explanations from the MRP system should be communicated to the user. We designed and evaluate two interaction modes that are different in the way that the users receive the information from the robot, denoted as proactive and reactive interaction modes. The effect of the two interaction modes on performance and user perception was evaluated with 50 participants that were divided into two groups - 40 engineering students (defined as the technological group) and 10 healthcare students (defined as the non-technological group). In this experiment, two different user interfaces for each of the interaction modes were implemented on a Keylo Wyca MRP to test their effect.

In the second part, the experimental setting was arranged to resemble a complex clinic that contained obstacles and patients and the task was to control the MRP system and by receiving explanations from it, to succeed in overcoming obstacles to reach the patients and provide them appropriate treatment. This part examined *what* information should be communicated to the user and *when* it should be communicated. We proposed two levels of clarity – high and low and two levels of explanation patterns – dynamic and static. Based on these, we designed three different levels of explanation (LOE) – high, medium, and low. The evaluation was conducted for two conditions related to time criticality, with and without a time limit. Two different groups of engineering students operated an MRP robot, the Keylo Wyca robot, in a healthcare simulated task in our labs. Each group which included 30 students (a total of 60 students in both groups) experimented with a different condition with an interface specially designed for the condition.

The main conclusion from the first study was that the proactive ('Push') interaction mode was the preferred way to communicate with the user and enhances performance, understanding, and reduced workload of the users compared to the reactive ('Pull') interaction mode. We also found that the users' understanding of the robot had a significant impact on all the other variables that were tested. It improves performance, satisfaction, and situation awareness and reduces the workload of the users. From the second study, we found that high LOE was preferred for the 'without time limit' condition for both completion time and adequacy of explanation. It was further found that both, high and medium LOEs were fluent and trusted in the case of the 'without time limit' condition. However, in the 'with time limit' condition, high and medium LOEs were similar and preferred in all measures compared to low LOE.

This research presents the importance of the way of interaction between humans and robots and emphasizes the need for the robot to be understandable and how this can be done by adjusting the correct LOE in different situations.

Keywords: mobile robotic telepresence (MRP), interaction modes, explanation, understandable, level of explanations (LOE), proactive, reactive, clarity, patterns.

Publications

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Chapter 1. Introduction

1.1 Overview

The elderly population rate is growing rapidly (United Nations, 2020) which causes an increased demand for healthcare services. The shortage of healthcare professionals and caregivers to cope with this increasing demand leads to an increased need in developing solutions to handle this problem (Murray, 2002; Nora, 2002). In addition, the Covid-19 pandemic emphasized the need for remote work and social distancing. The development of assistive robots has become a promising solution to deal with these problems (Broekens et al., 2009; Shishehgar et al., 2018). Assistive robots enable to support older adults and caregivers in homes, hospitals, and care centers (Aymerich-Franch & Ferrer, 2020; Broekens et al., 2009; Tavakoli et al., 2020). In this research, we focused on mobile robotic telepresence (MRP) which is a specific form of assistive robots that can be controlled remotely and can perform tasks automatically providing a possible solution to these problems. However, their use still has many challenges such as the way the robot communicates and interacts with the operator, and how to make the robot understandable to the user in different situations.

The feedback from the robot and the way it communicates is a critical factor for the success of interaction between the human and the robot during a task (Agrawal & Yanco, 2018a). In addition, the increase in robot autonomy enables robots to make decisions and execute them, but without explaining their reasons, they become not understood. The robot needs to help the user to understand its decision and why it takes them (Fong et al., 2002).

There has been a constant growth of studies regarding the way of communication and understanding between humans and robots due to the great importance of these issues to improve human-robot interaction.

This research examined the interaction and understanding between MRP systems and technological and non-technological operators. Creating a successful and understandable interaction is a challenging task. Some of the critical factors in human-robot interaction are the feedback and the way that the robot communicates with the user. To achieve this, robots must be able to convey information to the user in the right way and help the user understand their decisions, the thoughts that led to the decision, and their actions. In this thesis, we examined *how* feedback and explanations from the MRP system should be communicated to the user, *what* information should be communicated to the user and *when* it should be communicated. This research focuses on two main gaps that remain understudied and unanswered. In the first

part, which addresses the *how* aspects, we implemented two different interaction modes – proactive and reactive and compare them on interaction aspects. In the second part which focuses on *what* and *when* aspects, we focused on developing three levels of explanation to improve the operator's understanding of the robot.

1.2 Background and problem description

1.2.1 Assistive Robots

Assistive robots are defined as fully or partially automated technologies (Bartneck & Forlizzi, 2004; Naneva et al., 2020) that are developed to be socially intelligent and interact naturally with humans to help increase the quality of life in a variety of applications such as health, communication, and education (Naneva et al., 2020; Pieska et al., 2013).

Assistive Robotics (AR) has emerged as an important goal in the field of social robotics. Beyond the basic capabilities of moving and acting autonomously, the development of these robots focused on the use of the robot's physical embodiment to communicate and engagingly interact with users through social and emotional intelligence that could enable the robot to sense and interpret various human emotions, moods, and attitudes to guide its interaction and communication and to be guided by social norms, values and demands (Feil-Seifer & Mataric, 2011; Tapus et al., 2007). Examples of social robot applications include conversational robots (Sabelli et al., 2011), companionship robots (Breazeal & Scassellati, 2000), pets (Wada & Shibata, 2007), therapeutic aids (Dautenhahn, 2003), and toys (Fong et al., 2002). In AR, the robot's goal is different from that of a social robot in that its purpose is to create a close and effective interaction with the human user in order to assist and achieve measurable progress in specific applications such as convalescence, rehabilitation, and learning and not just for the sake of interaction itself (Feil-Seifer & Mataric, 2011). Designing such a robot raises many challenges due to the many requirements to consider, depending on the goal, the person using it, and the environment of the robot.

Evidence and research from the behavioral and neuroscience sciences demonstrate that people experience interactions with agents who are physically embodied, like robots, more fun and motivating than interactions with screens. In addition, people are more likely to be active, change their behavior and learn in such a context (Mataric, 2017). This gives a strong motivation for AR design and development, which have gained increased attention in applications such as health care, education, entertainment, and elder care (Tapus et al., 2007).

It is easy to imagine how such robots can monitor and develop physical, cognitive, and social development and help patients in hospitals, people in rehabilitation, and older adults (Mataria, 2017). But there are still a lot of challenges and issues that must be solved for assistive robots to be able to address the various needs in the best and the possible way such as levels of automation (LOA) (Vagia et al., 2016), acceptance of robots by users (Broadbent et al., 2009), the way of communicating with the robot and the interaction with it (Agrawal & Yanco, 2018), and making the robot more understandable (Fong et al., 2002).

1.2.2 Mobile Robotic Telepresence (Tele-Operated Robots)

Telepresence is about the sense of being in another environment. In particular, Mobile Robotic Telepresence (MRP) offers the ability to connect to a remote location with the added value of navigating and performing various operations (Kristoffersson et al., 2013). An MRP is a robot that is controlled by a remote operator and performs tasks and services as if the operator was on the spot (Van Osch et al., 2014).

MRP systems are becoming increasingly popular within certain application domains such as healthcare environments, independent living for the elderly, and office environments. They offer obvious benefits in terms of assisting the healthcare system (Tavakoli et al., 2020), and in performing operations for a caregiver as pre-diagnosis, food delivery, or monitoring. The ability to remotely perform a variety of tasks through robots contributes to workload reduction in hospitals supporting staff by performing assistive functions (Aymerich-Franch & Ferrer, 2020).

Usually, the operator controls the MRP system through a dedicated operator interface. The operator interface is one of the most important components in the MRP system and it influences many parameters such as effectiveness, security of operations, and workload. The functions, the design, and how the information is transmitted from the robot to the operator are critical to creating conditions for the system's success (Labonte et al., 2006).

Caregivers usually have multiple tasks to perform (e.g. monitoring patients while filling out reports and attending bystander inquiries). Hence, to ensure that the collaboration with the robot will improve their efficiency and performance they must perform tasks in parallel to the robot.

In order to effectively control the robot, remote operators must be aware of several types of interactions that occur simultaneously such as *human-robot interaction*, which is the interaction that occurs between the MRP and the persons in the environment of the MRP system, *human-computer interaction*, which is the interaction that occurs between the operator and interface of the MRP, and *human-human interaction* which occurs between the persons in the MRP

environment and the operator. All these interactions create a lot of information that the operator must absorb and respond to (Bolarinwa et al., 2019; Kristoffersson et al., 2013; Lee & Takayama, 2011). Therefore, it is important to convey the information to the operator in a correct way and in a form that is clear and understandable to him. Accordingly, this thesis focused on interaction modes (*how* the information is transmitted to the operator) and different levels of explanation (*what* and *when* information is conveyed).

1.2.3 Robot Feedback

The “Feedback loop” is an important feature of interactive systems. It represents the nature of the interaction between a person and a dynamic system. The user provides input to the system in order to achieve a goal, gets an output reply from the system (feedback), and interprets it (Dubberly & Pangaro, 2019).

In this manner, the robotic system may provide feedback about a task and its progress as well as about safety concerns associated with the task and/or the environment (Kuffner, 2018). Feedback is an important factor in human-robot interaction (Mirnig et al., 2020). Properly timed feedback encourages natural flow in the communication among the system elements and makes the robot more understandable (Tsui et al., 2011). In addition, feedback has been identified as a crucial factor in increasing trust in robots during human-robot collaboration missions. Feedback from the robot can help people assess the robot's internal state and overall goals. This importance is intensified when humans and robots cooperate in performing different tasks (Agrawal & Yanco, 2018).

The feedback can be provided in different modalities. Robots can provide information to humans through tactile devices (Dzindolet et al., 2003; Khoramshahi & Billard, 2020), verbal feedback (Céspedes et al., 2020; Shishehgar et al., 2019; Markfeld et al., 2019; Markfeld et al., 2020), and visual feedback (Céspedes et al., 2020; Ferris & Sarter, 2008) like screens and more. Similarly, humans can communicate with the robot in several modalities, including gestures, and voice, using a touch screen and interfaces (Berg & Lu, 2020, Gutman et al., 2023).

The type of feedback can impact system performance, especially in an environment in which conditions change over time (Doisy et al., 2014). Furthermore, feedback is critical for the usage of learning robotic systems by non-expert users (Rouanet et al., 2013). However, not every type of information is beneficial and it is necessary to find the right balance between increasing the system performance and not overloading the user (Doisy, 2014).

Two main factors that affect the interaction between a human and a robot are **how** the feedback is transmitted to the operator (defined as interaction modes) and the **timing** of the feedback (Mirnig et al., n.d.).

1.2.4 Timing of feedback

Timing of feedback is another critical feature for successful human-robot interaction (Mirnig et al., n.d.). Adequately timed feedback can maintain true understanding during communication between the person and the robot. Providing feedback too late may be confusing (Mirnig et al., n.d.). Alternatively, feedback given too soon will not be linked to the status of the robot or the mission performed. Moreover, the temporal proximity between user input and the robot's reaction is an important characteristic of natural interaction (Fischer et al., 2013). On the other hand, there is also a drawback between proximity feedback and action, since feedback given during tasks can interrupt the performance, interfere with the cognition of performing tasks, and prevent the user from learning.

The significant effects of cross-modal signals indicate the need to develop adaptive multimodal interfaces in which the location, modulation, and timing of the presentation of information are varied as a function of revolving stimuli and a consume (Ferris & Sarter, 2008a). Feedback scheduling can be considered in another context - the context of changes. That is, whether the timing of the feedback will be constant or only when there is a change in the environment of the robotic system. Research revealed that there is a definite advantage to providing feedback to the operator about changes in a common task (Doisy et al., 2014).

1.2.5 Interaction Modes

Interaction between a human and a robot encompasses activities that occur when a human is involved with a robot. These activities include interactivity, control, feedback, creativity, adaptation, and communication between the human and the robot (Rosales et al., 2018). It also includes the method through which the human accesses the information provided by the robot. This method of information access can define interaction modes commonly graded as reactive, proactive, and coactive (Sims, 1995) or mutual (Tianguang & James, 2003; Schwier & Misanchuk, 2003). It delimitates the degree of control the user has over the content and structure of the information being presented in the interaction (Rhodes, 1985).

Reactive interaction is an interaction mode in which information is given only when demanded (Tianguang & James, 2003). It describes a time dimension of feedback where information is given only on demand. In contexts such as HRI, it is referred to as the 'pulling' of information

to describe the process of requesting information which is the interaction pattern that dominates this interaction mode (McNeese et al., 2018). The robot provides information to the human only when the information is 'pulled'. It is considered the lowest interaction mode because it has the least potential for engagement in the interaction (Schwier & Misanchuk, 1993). The user has more control over the information being presented. This will be accompanied by some level of contextual awareness of the readiness of the robot to respond to information 'pull'.

Proactive interaction is an interaction mode in which information is continuously generated for the user even when it is not demanded (Tianguang & James, 2003). The feedback timing dimension is somewhat continuous since it does not depend on the user's impulse (Tianguang & James, 2003). In HRI contexts, information is 'pushed' to the human by the robot without the human requesting it (McNeese et al., 2018). It is considered a higher interaction mode than the reactive one because it potentially promotes more interactivity (Schwier & Misanchuk, 1993; Tianguang & James, 2003). The robot has more control over the presentation of information since it presents it without the consent of the user.

The coactive (mutual) interaction mode is characterized by a mutually adaptive pattern of interaction where the interaction could be reactive or proactive based on the situation, context, and environmental demand (Tianguang & James, 2003). Depending on the task/situation, information can either be 'pulled' by the human from the robot or 'pushed' to the human by the robot. It is the highest interaction mode where the interaction pattern between the robot and human adapts to changing situations (Schwier & Misanchuk, 1993; Tianguang & James, 2003).

Studies in various fields such as vehicle safety systems, robots, and activity tracking have dealt with comparing 'pushing' and 'pulling' feedback. They showed that 'push' feedbacks increase alertness, and awareness, encourages active actions and creates positive and encouraging thoughts during use compared to 'pull' feedback which made the task feel more difficult and boring (Cauchard et al., 2019). There have not been many studies on this topic related to robots. Accordingly, we examined two different interaction modes, proactive and reactive.

1.2.6 Understandable robots

As robots become more and more capable and autonomous, the use of robots in daily tasks by nonprofessional users and bystanders will increase. To improve the interaction and make it smoother and more efficient, robots need to be designed such that their behavior and states are understood by the interacting humans.

In the field of understandable robots, a theoretical model was proposed by (Hellström & Bensch, 2018) based on the requirement of generating communicative actions when there is a disparity between the robot's mind and the human model inside the robot's mind. The communicative action was based on *what* information needs to be communicated, *why* an action or plan has been decided, and *when* and *how* should the robot communicate its explanation. The challenges of generating explanations need to take into account the basic element of sensemaking (Papagni & Koeszegi, 2021). Furthermore, the authors suggest that explanations should include iterative communication, contextual explanations, and a combination of non-verbal and verbal cues. In both aforementioned studies, user studies were lacking; research was limited to presenting a theoretical framework for understandable robots.

This work is related to ongoing work in the explainable AI field (Sado et al., 2020). Previous review work in the field of GDXAI (an artificial intelligence framework, entirely written in Java, for game development, Iovino et al., 2022) categorized according to the behavioral aspects of the interaction between the agent and the human i.e., deliberative (where agents plans ahead to achieve a goal), reactive (agents respond to the environmental changes), and hybrid model (combination of reactive and deliberative actions, Sado et al., 2020). The goal-driven action plan generates explanations when an agent finds a mismatch between the expectation of a plan and the current status by tracking the agent's behavior (Jaidee et al., 2011; Molineaux et al., 2010; Nau, 2007b). The belief, desire, and intention (BDI) model explain based on underlying beliefs and desires (Georgeff et al., 1999; Harbers et al., 2010; Malle, 1999b; Van Camp, 2013). The main aspect is to explain human errors (Malle, 1999a). The situation awareness model is built on the BDI model which had built an interface communicating information not only about current status and reasoning but also about future projection (Boyce et al., 2015; Chen et al., 2018). In a proactive explanation model, the agent explains the surprise element of its action proactively such that participants are not flabbergasted (Gervasio et al., 2018).

The automated rationale generation model trains the encoder-decoder neural network to generate the explanation of the behavior of the agent as if a person explains it to another (Sequeira & Gervasio, 2020). The explainable reinforcement learning way to generate an explanation allows them to learn the policy to explain the behavior based on trial and error (Sequeira & Gervasio, 2020). The generation of explanations for robotics failures has been addressed by invoking explainable AI models such as action-based, context-based, and history-based explanations (Das et al., 2021; Diehl & Ramirez-Amaro, 2022). To explain robot action binary trees have been used to generate explanations (Han, Giger, et al., 2021). The progressive

explanation generation algorithm has proved to increase the performance of the task in a scavenger hunt and escape room task (Zakershahra et al., 2021b). This study considered the mental model of the human being as the state of reinforcement learning and reward function has been generated by the inverse reinforcement learning from retrieved human preference.

Another study on the comparison between non-verbal and verbal communication suggests that the non-verbal mode alone is not sufficient to explain the actions or plans of the robot (Han, Phillips, et al., 2021).

1.2.7 Levels of Explanation (LOEs)

The robot must help the user understand its decision, 'thinking', and actions (Fong et al., 2002). Not addressing this issue can hamper the user's perception of the robot (Bensch et al., 2017), safety during the interaction, efficiency in interaction as well as future usability of the system by the user (Baud-Bovy et al., 2014). A robot's inability to explain its 'thinking' or action could even lead to anxiety among the interacting human (Nomura & Kawakami, 2011) since the latter treats the prior as an agent similar to another human.

The generation of explanations for robotics failures has been addressed by invoking explainable artificial intelligent models including action-based, context-based, and history-based explanations (Das et al., 2021). In another study (Tabrez & Hayes, 2019), an explanation was generated based on two components the explanation of the robot and the justification of its 'thinking' along its operation.

Further, a theoretical model of levels of explanation (LOE) has been defined in previous work (Dazeley et al., 2021). This theory focuses only on mapping the psychological model of the human social process. Accordingly, in this research, we proposed and examined three different levels of explanation.

1.3 Research objectives

This thesis investigates two crucial issues in human-robot interaction (**the way of interaction** and **understanding**) and tries to answer three fundamental questions that arise as a result of these issues. **How** the information (feedback and explanations) should be conveyed to the operator when using MRP systems (defined as **Interaction mode** in this study), **What** information and **When** should it be transmitted to the operator (defined as **levels of explanation**). This research was divided into two studies with two systems designed and developed accordingly.

The specific objectives were to design and compare the effect of :

1. Proactive and reactive interaction modes, and
2. Different levels of explanation (High, Medium, and Low).

in a remote user interface of a telecare task on interaction aspects including performance, and user perception.

1.4 Thesis structure

The overall research methodology is depicted in Chapter 2. The research includes two separate studies corresponding to two experiments related to two main issues in human-robot interaction. The first study focused on interaction modes (study 1, Chapter 3), and the second study focused on levels of explanation (LOE) (study 2, Chapter 4). Each chapter is independent research but there is a strong connection between the issues. Findings from the first study led to the second study and emphasized its importance. The overall conclusion and future research are discussed in Chapter 5.

Chapter 2. Methodology

2.1 Overview

This research aims to evaluate the influence of different **interaction modes** (the way that the robot communicates with the user) on the interaction between the operator and the MRP system and examine how the user's understanding of the robot can be improved through different levels of explanation. Two studies were designed to examine these two issues (Table 1). In the first study, we examined **how** the information from the MRP system should be communicated to the user by designing and comparing two interaction modes. The findings from this study emphasized the importance of the user's understanding of the robot and led to the design of the second study. The second study focused on **levels of explanation** to answer two questions - **what** information and **when** the MRP system should be communicated to the user? Based on these we designed three levels of explanations and evaluated them in two different time-critical conditions (with and without a time limit). Both studies were performed in a simulated telenursing task with the Keylo Wyca MRP.

Table 1. Overview description of experiments

	Study 1	Study 2
Independent variable	Interaction modes (proactive, reactive)	Levels of explanation (High, Medium, Low)
Participants	Engineering students (technological group) Healthcare students (non-technological group)	Engineering students
Thesis chapter	Chapter 3	Chapter 4
Publications	C1, J1	J2

2.2 Study 1: Comparison of Proactive and Reactive Interaction Modes in a Mobile Robotic Telecare Study

This study explored *how* the information needs to be communicated to the user by examining two different interaction modes and evaluating their influence on performance and the user's perceptions. In an experiment carried out as part of this study, participants performed a primary task parallel to a secondary task. Details are provided in Chapter 3 and appear in publications C1¹, and J1².

Usually, operators control the MRP system through a dedicated operator interface. The operator interface is one of the most important components in the MRP system with an influence on several terms such as effectiveness, security of operations, navigation strategies, and workload. In order for such robots to be operated efficiently and effectively by the user, it is important to examine *how* the information needs to be communicated from the robot to the user (Labonte et al., 2006).

A Keylo Wyca teleoperated robot was programmed by the Robot Operation System (ROS) for a telenursing task performed by two different types of operators (technological and non-technological) in two different interaction modes, proactive and reactive. To increase workload, a secondary task was introduced via a secondary task screen.

The interaction modes were examined by building two different main user interfaces, one for each interaction mode. The main interface was used to control the robot and perform the main task. It contains information from three different cameras (front, bottom front, and rear), feedback from the robot at important points along the robot's path or warnings from obstacles, arrows for manual navigation, and boxes for filling in relevant information along the task.

In the proactive mode interface, the user received all the elements of the main interface and feedback from the robot continuously and constantly without being able to control it.

The reactive mode interface was designed in a way that the user only got the front camera, and if he/she wanted to use the other elements or get feedback from the robot, he/she had to 'pull' them by using four buttons that were added to this interface compared to the user interface in

¹ C1 includes preliminary results in which we compared 10 engineering students (technological group) to 10 healthcare students (non-technological group). The data analysis in this paper was relatively limited.

² J1 is an extension of C1, including additional experiments (additional engineering students) and analysis and presents new aspects.

the proactive mode. In this mode, the user had almost complete control over the elements in the interface and could open and close them during the task as much as he wanted.

The secondary interface was designed as an electronic sheet that contained questions regarding patients' information and simulated a daily task of medical teams that should be performed simultaneously with other tasks.

This study was designed as a within-design experiment with 40 engineering students that were defined as a technological group and 10 healthcare students that were defined as a non-technological group. The differences in the sample size between the groups were due to the difficulty in recruiting non-technological participants. Despite this, we did choose to examine a larger sample group in the technological group and showed that the power of the tests increased using the Cohen d test. Therefore, the different sample sizes are justified.

The results of the experiment showed that the users of both groups preferred the proactive interaction mode and it improved performance, the user's understanding of the robot, and reduced the workload. In addition, the experiment showed that there is a high correlation between understanding and all other dependent variables. This finding may indicate an influence of the understanding on the performance and the user's perception, although no clear causality can be claimed. led to the design of the second experiment that dealt with improving the user's understanding of the robot.

2.3 Study 2: Levels of Explanation – Implementation and Evaluation in a Mobile Robotic Telecare Task

This study aims to evaluate the potential of different levels of explanation to improve the user's understanding of the robot in different situations. We designed and implemented three different levels of explanation. Details are provided in Chapter 4 and appear in publication J2 which is an extension of this work and includes also a theoretical model that was developed as part of a parallel thesis (Kumar, 2022).

Robots should help users understand their decisions, actions, and 'thinking' (Fong et al., 2002). By failing to address this issue, we may adversely affect the user's perception of the robot (Bensch et al., 2017), the user's safety during the interaction, the efficiency of the interaction, and the user's future usability of the system (Baud-Bovy et al., 2014). In some cases, the inability of a robot to explain its 'thinking' or actions can even result in anxiety among the human interacting with the robot (Nomura & Kawakami, 2011). A theoretical model of levels

of explanation (LOEs) (Dazeley et al., 2021) focused only on mapping the psychological model of the human social process.

In this thesis, we define and evaluate different levels of explanation. The levels of explanation related to *what* information the robot needs to communicate to the user? and *when* should the robot need to communicate explanations? We defined clarity and explanation patterns and based on these we designed three levels of explanations (LOEs).

Clarity was defined as the amount of information that needs to be communicated to the user (*what*) and the explanation pattern is defined as the frequency of communication (*when*). It is divided into two levels – high and low. A high level of clarity is explaining all the smallest details in the action that the robot planned. A low level of clarity is explaining the broader sense plan without any details.

Two explanation patterns are defined – static and dynamic:

A static explanation pattern is an explanation that is given only once before the user started executing the robot's action plan. In the dynamic explanation pattern, the robot explains the actions of the plan in parallel to its execution by the user.

Based on these definitions, we designed three levels of explanation as follows:

- High LOE consists of a high level of clarity and dynamic explanation pattern.
- Medium LOE consists of a low level of clarity and dynamic explanation pattern.
- Medium LOE consists of a low level of clarity and static explanation pattern.

This study was designed as a within-between experiment with 60 engineering students that were randomly assigned into two groups to compare the effect of time criticality (a group with a time limit was compared to a group without a time limit).

Chapter 3. Comparison of Proactive and Reactive Interaction Modes in a Mobile Robotic Telecare Study

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Comparison of Proactive and Reactive Interaction Modes in a Mobile Robotic Telecare Study^{*}

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ABSTRACT

Mobile robotic telepresence systems require that information about the environment, the task, and the robot be presented to a remotely located user (operator) who controls the robot for a specific task. In this study, two interaction modes, proactive and reactive, that differ in the way the user receives information from the robot, were compared in an experimental system simulating a healthcare setting. The users controlled a mobile telepresence robot that delivered and received health-related items, while they performed a secondary healthcare-related task. The effect of the two interaction modes on overall performance and user perception was evaluated in a study conducted with 50 participants belonging to two different types of population (with and without a technological background). All users preferred the proactive interaction mode in which information is continuously generated for the user. This mode gave better performance and understanding of the robot and reduced the workload.

1. Introduction

The term 'telerobotics' generally refers to the remote operation of a robot, with a human operator in control or in the loop [7]. Such a telerobotic system aids the human to overcome barriers that prevent him/her from physically or directly interacting with the environment [37]. Over the years, telerobotic systems have gained popularity for a variety of reasons, e.g., ensuring human safety in hazardous (e.g., nuclear or chemical) or complex environments (e.g., home or public), lowering costs involved in reaching remote environments (e.g., in space or for surgery for a remote patient), reducing the risk of infection (e.g., during a pandemic), and enabling people to work in a large workspace or in several work environments in parallel (e.g., a professional healthcare worker's task spread over several healthcare facilities). Telerobotics applications include diverse tasks as search and rescue [21], space robotics [8], agriculture [2], medical systems [7], rehabilitation [17], surgical operations [41], and telecare [29]. This study focuses on a telecare application.

1.1. Telepresence with mobile robots

Telepresence, the basis of telerobotics in telecare [7], requires that information about the environment, the task, the robot, and the care recipient be presented to a remotely located robot operator (the user) [19]. Of particular relevance to this study, a mobile robotic telepresence (MRP) system involves remotely operating a robot moving through a local environment in such a way that its human operator

(also known as the remote user) can interact with other people (local users) within the same physical space via telecommunication networks [7]. To date, research on MRP systems for telecare has generated several important developments, such as the GiraffPlus research platform [13], and the ExCITE EU project [28], which offer a variety of functionalities, and the TERESA project [33], which focuses on social navigation capabilities. Most of the research to date has focused on the video stream that the users receive about the environment with the aim to improve situation awareness [32, 42]. In this context, it has been shown that users may become so absorbed in the video display that they ignore much of the information on the user interface [18, 42]. In contrast, very few studies, have been devoted to the issue of how the information should be transmitted and displayed to a user who operates the robot remotely and how this issue affects the overall performance of the system, user preferences, and system usability. Recent advances in computer networks have facilitated the relay to caregivers and healthcare professionals of huge amounts of data in a variety of information formats [7, 37], relating to the care recipient, the robot, the environment, and the task. It would thus appear that these advances would enable caregivers to interact with care recipients in a better manner and hence to provide improved remotely administered care [28], but this is not always the case in practice. Research has revealed that the remote operator may not always benefit from receiving a plethora of information at once, as too much information may cause information overload [22], leading to frustration or confusion and ultimately affecting overall performance [27, 22]. Therefore, it is important to understand how to present information to the user in a manner that would improve remote interactions. In this research, we designed and evaluated two interaction modes dealing with aspects related to how users access the information as detailed below.

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1.2. Interaction modes

The term 'interaction mode' is used in this study to describe how the remote user accesses the information provided by the MRP system. In previous studies, this term was sometimes referred to as the 'feedback mode' from the robot, which was commonly graded as proactive ('push'), reactive ('pull'), or coactive [38] / mutual [36, 11], as elaborated below. The interaction mode describes the degree of control over the content of the information displayed for the user-robot interaction [31]. The content of information includes all the activities that occur when a human is involved with a robot, such as control and feedback from the robot [34]. Hence, we use the term 'interaction mode' rather than 'feedback mode' to encompass all the activities involved in the interaction.

The proactive interaction mode is a mode in which information is continuously generated for the user, even when it is not demanded [11], i.e., it does not depend on the user [11]. In human-robot interaction (HRI) contexts, information is 'pushed' to the human by the robot, without the human requesting it [24]. In contrast, the reactive interaction mode is a mode in which information is provided only when demanded by the user [11]. In HRI contexts, it is referred to as the 'pulling' of information to describe the process of requesting information, which is the interaction pattern that dominates this interaction mode [24]. In this mode, the robot has minimal control over the interaction, since the information is 'pulled' by the user only when needed [36], whereas in the proactive mode the robot has higher control over the interaction [11, 36]. Finally, in the hybrid coactive/mutual interaction mode, the interaction is mutually adaptive and, depending on the situation, the context, or environmental demand, it can be reactive or proactive [11].

1.3. Interaction modes in different fields

The proactive and reactive interaction modes have been implemented in various fields, e.g., vehicle safety systems [25], activity tracking [4], virtual traffic light systems [10], and unmanned aerial systems [24]. Some studies on the subject have revealed that the proactive interaction mode increases alertness and awareness, encourages more engagement, and minimizes the potential for information loss during use. In a case study of activity tracking via wearables, the proactive mode was reported to create more positive and encouraging thoughts during use, compared to the reactive mode, which made the task feel more tedious and less stimulating [4]. Nonetheless, other studies have shown that there are also benefits to the reactive mode. For instance, in a virtual traffic light system, the reactive mode produced about the same performance outputs as the proactive mode without the risk of overloading the user [10]. In the context of an unmanned aerial system, users preferred the reactive mode for inquiries about different aspects of the information presented [24].

To the best of our knowledge, with the exception of our preliminary study [16], there has been no explicit exploration of the proactive and reactive interaction modes

for MRP systems in telecare. Our preliminary study [16] showed the feasibility of implementing these two interaction modes in an MRP system for a telecare task and it also investigated the influence of the interaction modes on a number of study variables. The current paper extends these findings as follows: i) experiments were conducted with a larger sample size; ii) the benefits of the reactive interaction mode and the influence of the items 'pulled' on overall user performance and user perception were explored; and iii) additional analyses of the information items that were 'pulled' during the experiment were conducted. In addition, we examined the influence of gender and sample size on the results and the correlations between the dependent variables and their effect on each other.

1.4. Study objectives

The study aimed to compare the proactive and reactive interaction modes for a remote operator of an MRP system in a telecare context. The specific objectives were to:

1. Implement the proactive and reactive modes in a remote user interface for a robotic telecare task.
2. Compare the effect of the interaction modes on performance and user perception measures.

2. Methods

2.1. Overview

The experimental setting was arranged to resemble a hospital-like environment with an MRP mission of delivering and receiving healthcare-related items to and from a patient (Fig. 1). Such a setting represents situations in which there is a heavy workload, a lack of manpower, a risk involved in approaching a patient, or other difficulties. So as to simulate the experiment as closely as possible to a real environment with a real combination of tasks of caregivers, the users were required to perform a secondary task in parallel to the main task. The two different interaction modes, proactive and reactive, were examined with two different types of user population: with and without technological backgrounds. The influence of the interaction modes on different aspects of performance and user perception was evaluated. In addition, the type of information and the number of times this information was 'pulled' by the users was analyzed.

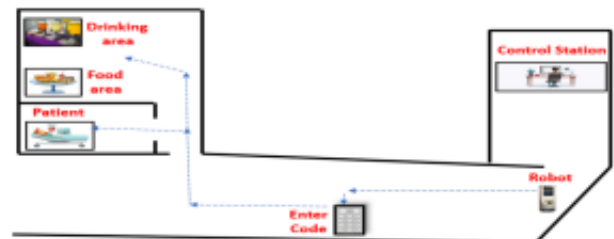


Figure 1: A cross-section of the lab, set up as a hospital-like environment

2.2. Task Description

The user was required to perform a main task (navigating the robot) and a secondary task (answering questions relating to the patient) in parallel. The user was required to perform the main task in the shortest possible time while answering correctly as many questions as possible in the secondary task.

Main task – The main task was to control, with an MRP system, a robot that was required to deliver medication (represented by empty medicine boxes) to a simulated patient, to obtain metrics (vital signs) from the patient (the metrics appeared on the screen of another robot that simulated the patient's monitor), and to carry food or drink to the patient, as required. In the main task, the robot moved autonomously in the environment but would require user involvement at certain points (e.g., entering a room that requires a code, manual navigation in a complex environment).

The interaction between the robot and the user through the user interface took place at three locations along the robot's path:

1. Start location – where the robot awaited instructions;
2. Midpoint location, i.e., a point along the way to the patient's room – where the user was required to provide a code to the robot, through the main interface, that would allow the robot to enter the patient's room);
3. Patient's room – where the user controlled the robot manually to obtain the relevant patient information (body temperature, blood pressure, pulse, and the patient's requirements for food or drink) and where, at the patient's request, the user was then required to navigate the robot to the appropriate position (for serving food/drink). The user was required to document the information from the patient in the appropriate place in the main interface.

Finally, the robot was allowed to return autonomously to the control station.

Secondary task - The user was required to fill out an electronic health record, which involved answering questions related to the information presented on the secondary task screen. This task started as soon as the robot commenced the main task and ended once the robot's main task had been completed.

2.3. Experimental system – hardware and software

The experimental system consisted of a mobile robot platform, a remote user interface, and a server-client communication architecture that provided the connection between the user (working on the remote interface) and the mobile robot platform (Fig. 2). The mobile robot platform was run on the robot operating system (ROS). The remote user interface was run on the user's computer through a standard web browser, which was programmed in HTML, JS, CSS, and PHP. The remote user interface was designed on a web browser to make it independent of the type of device or operating system of the device that the user would use.

The communication architecture was based on a Rosbridge server that provided the WebSocket layer for the ROS-based mobile robot. The WebSocket is a low-latency, bidirectional communication medium that provided the connection between the user working on the remote web-based interface and the mobile robot.

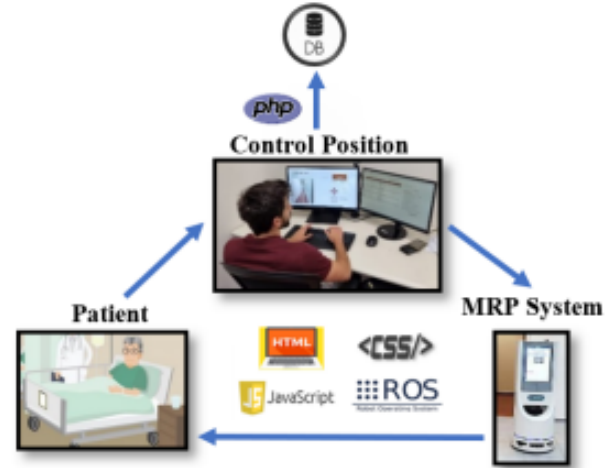


Figure 2: Schematic description of the system

2.3.1. Robot platform

The robot platform was a Keylo telepresence robot with a height of 1.64 m, a low center of gravity, and a circular footprint of 52 cm in diameter. The robot is equipped with a 24" multi-point FOV touch screen. It runs on Ubuntu 18.04 LTS and ROS Melodic with a standard ROS API for all its sensors and features. The navigation sensors include a LIDAR sensor (Hokuyo URG-04LX-UG01, range 5.6 m, FOV 240°), two sets of four front and rear ultrasonic range sensors (range 5 m), and two sets of two 2 IR edge detectors hard-wired to the motor's controller. Additionally, the robot is equipped with three 3D RGB-D camera Intel RealSense™ R200 cameras, two front, and one rear.

2.3.2. User interfaces

The user interface, for both the proactive and reactive modes, was divided into two screens – a main task screen and a secondary task screen (Fig. 3).

Main task screen - The main interaction with the robot took place through the main task screen, which showed: the display of three different camera views (front, front bottom, and rear); arrows that allowed manual navigation of the robot; boxes for filling in relevant information and feedback from the robot, which provided information only at important points along its path; and status information about the start of the mission, arrival at the destination (the patient's room), and conditions along the way (e.g., familiar position of the robot, facing a new corridor, any malfunction or anything unexpected on the robot's path). Combined visual and auditory feedback was provided, based on previous recommendations [23].



Figure 1: Screenshot of the patient information form. The form is titled "Patient Information" and contains fields for "Patient Name", "Patient Address", "Patient Phone Number", and "Patient Email Address". The "Patient Name" field is filled with "John Doe".

Patient's name	Cause of hospitalization	Recommended medical action	Treatment results
Brian Ben (J)	Joint issues	Best Practice: 10/10 Body temp: 37.3 Pain: 7/10	
David Hunt	Alzheimer's disease	Best Practice: 1/1/10 Body temp: 36.9 Pain: 7/10	Get used to the robot
Vera Bell	High fever and joint pain	Best Practice: 10/10 Body temp: 40.1 Pain: 10/10	Stable temperature
David Chen	Blind fracture	Best Practice: 14/10 Body temp: 36.7 Pain: 10	Stability no problem
Sally Taylor	Cerebral	Best Practice: 11/10 Body temp: 36.1 Pain: 10	Stable patient
Daniel King	Eye infection	Best Practice: 10/10 Body temp: 36.3 Pain: 10	
Jack Lu	Virus	Best Practice: 11/10 Body temp: 38.4 Pain: 7/10	

Questions

- How many patients are listed?
- How many patients have a temperature above 38.7 degrees?
- Which of the patients has a high fever?
- Who has the highest temperature?
- How many patients show the patients need?
- How many patients do not have patient requirement?
- How many patients have a pain tolerance 10/10?
- How many patients need hospitalization because of an eye infection?

[Show answer](#)

engineering students were given one-course credit, and the nursing students were paid 30 Israeli shekels.

Proactive mode interface (Fig. 5) - The user received all the existing elements on the main screen directly and permanently in each interaction mode, with the order of execution being randomly assigned. Accordingly, 20 participants be-

Reactive mode interface (Fig. 6) - The user received only the information from the main front camera but could

2.3.3. Participants The participants were 100 students (50 males and 50 females) from a large university in the United States. They were given a Technology Adoption Propensity (TAP) questionnaire [30] to assess the likelihood of the participants em-

User studies were performed with two types of partic-



Seed type	Statistical treatment	Seed Pressure: 1-3 (N) Seed type: 0-4 Date: 11	Seed count to the side	1. The heavy seeds have a temperature above 30.7 degrees
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2.3.4. *Experimental design and procedure*

The experiment was designed as a within-participants

only the information from the main front camera but could obtain, on demand, the rear and bottom camera views and

how the robot communicates with the participant through the interface, how the participant operates the robot and the details of the tasks. Each participant then performed the main task twice, once in each mode, in parallel to the secondary task. After each trial, the participant completed a post-trial questionnaire about his/her experience with the specific mode. Subjective measures were assessed via a post-trial questionnaire [15] using a 5-point Likert-type scale for all measures (details below), except for the situation awareness (SA) score for which a 7-point Likert-type scale was used. All scales ranged from 1 ("Strongly disagree") to 5/7 ("Strongly agree"). After completion of the two trials, the participants completed a final questionnaire, in which they provided their feedback regarding their general experience during the tasks. The questionnaire was designed to facilitate an understanding of whether the users felt a difference between the two different interaction modes and whether they preferred one of them. The experiment was video recorded with the permission of the participants.

2.3.5. Dependent Variables

The dependent variables included objective and subjective measures, as detailed below.

Efficiency – was evaluated objectively by the completion time of the task, i.e., the time (in seconds) between the robot's departure and return to the control position.

Effectiveness – was evaluated objectively by user performance in the secondary task, which involved the number of questions that were answered by the participants in the secondary task (completeness), the number of correct answers out of the total number of questions (accuracy), and the number of correct answers out of the total number of questions that were answered (precision).

Understanding – was evaluated subjectively by examining whether the feedback from the robot was comprehensible and clear to the user (comprehension, and clarity) and objectively by reaction time, i.e., the time (in seconds) that took for participants to respond to the robot's feedback.

Satisfaction – was evaluated subjectively in terms of communication (communication with the robot), confidence (confidence in using the robot), and comfortability (comfortability of use).

Workload, i.e., the perceived workload – was assessed subjectively using the NASA-Task Load Index (NASA-TLX) questionnaire [12], which measures mental demand, physical demand, temporal demand, effort, and frustration dimensions of a workload.

Situation awareness – was assessed subjectively using the 3D-SART version of the Situation Awareness Rating Tool [40]. In addition, this variable was evaluated objectively by the number of objects identified (the number of elements that were identified by the participants in the environment of the task).

2.3.6. Research hypotheses

Based on a previous study conducted on proactive and reactive feedback in various fields, the following hypotheses were put forward:

H1: The interaction mode will influence the interaction of the user with the MRP system.

Previously, in the context of feedback for wearable devices, proactive feedback seemed to produce more positive effects on users than reactive feedback [4]. We propose similarly:

H2: The proactive mode, as compared to the reactive mode, will increase the user's situation awareness and improve the user's performance.

We assume that, in some cases, users will require more information than the default information provided. We expect that the motivation to 'pull' that information will complement the users' understanding of the system and the environment, compared to situations in which all the information is provided a priori (as in the proactive mode) [24]. Hence, we propose:

H3: The use of the reactive mode, compared to the proactive mode, will improve the user's understanding of the robot's actions.

'The reactive mode ('pulling' information) is expected to provide the user with the information needed [14] when the user requests it (adapted from [24]). In contrast, the proactive mode ('pushing' information), without information overload would provide the user with all the information needed without the user actively requesting it (adapted from [22]). We posit that the multiplicity of tasks in our experiment could create some form of fatigue or cognitive overload, which would increase the workload, as established by [43]. In the reactive mode, the operation of the robot and the control of its interface, in addition to the existing task load, could lead to a higher workload. We therefore propose:

H4: The proactive mode, as compared to the reactive mode, will reduce the user's perceived workload.

In general, the more control options that users have over the system (e.g., in managing the content, and timing of the feedback from the robot), the more user-centered it appears to them and the higher the degree of satisfaction [20] they derive from the system (based on the explanation of satisfaction in the ISO 9241-151 guidelines [1, 3]). We, therefore, assume that the reactive mode ('pulling' information), which seemingly gives users options for controlling the information they receive in the different aspects of the interaction [24], would give a feeling of more control and would increase usability. We therefore propose:

H5: The reactive mode, as compared to the proactive mode, will increase satisfaction.

2.3.7. Analysis

The General Linear Mixed Model (GLMM) was applied to analyze the dependent variables and their sub-variables, with interaction modes, order, and gender as the fixed effects, and participants as the random effect. Dependent variables that consisted solely of subjective sub-variables were averaged, and variables that were composed of both subjective and objective sub-variables were first normalized and then averaged. Welch's T-test for independent samples was applied to compare the 'Tech' and 'Non-Tech' groups. The tests were designed as two-tailed with a significance level of 0.05.

Additionally, the effect of the sample sizes of the two groups of participants, 'Tech' and 'Non-Tech', on the results was assessed by using Cohen's d [5], which measures the standardized difference between the two means. Cohen's d was calculated as the mean difference divided by the SD:

$$\frac{\text{"Mean difference"}}{\text{"Standard deviation"}}$$

and in the two independent samples t-test as:

$$\frac{(\bar{X}_2 - \bar{X}_1)}{\text{"Pooled standard deviation"}}$$

where \bar{X} and s are the sample mean and standard deviation and

$$\text{the pooled standard deviation} = \sqrt{\frac{(n_1 - 1)S_1^2 + (n_2 - 1)S_2^2}{n_1 + n_2 - 2}}$$

where n_1 is the size of one group and n_2 of the other one.

Values of d were selected for evaluation based on small, medium, and large values proposed by Cohen [5] (0.2, 0.5, 0.8) and extended to include values representing small, very large, and huge effect sizes (0.01, 1.2, 2) proposed by Sawilowsky [35]. These values were compared to the actual values in the different population sizes, $n_1=n_2=10$, and $n_1=10, n_2=40$.

In addition, correlations between the dependent variables were examined. The correlation between continuous variables was examined by Pearson's correlation, and the correlation between ordinal and ordinal or ordinal and continuous variables was examined using Spearman's correlation.

An additional analysis was performed to assess the utility of the reactive mode. The number of elements that were 'pulled' by each participant during the experiment, when the elements were 'pulled'? - at the start of the mission or along it, and the frequency at which these elements were 'pulled' were quantified by a visual analysis of the videos recorded during the experiment. The correlations between these measures and performance and user preferences were assessed.

The final analysis evaluated whether the order of execution of the two different modes influenced the participants' behavior, i.e., starting with the proactive mode vs. the reactive mode.

3. Results

A summary of the results for the proactive and reactive modes in each of the groups ('Tech' and 'Non-Tech') is presented in 1), and the results for the sub-variables are presented in Table 2. For both tables, results are presented as means \pm SD. Despite the relatively small sample size of the 'Non-Tech' group and the difference in sample sizes between the groups (section 3.10), we obtained significant results when examining the effect of the interaction modes on the dependent variables and also in the comparison between the groups. Note that in all the tables, a significant effect of the interaction modes on the variables is indicated in green, and a non-significant effect, in red.

3.1. Demographic analysis (TAP and NARS)

The technology adoption propensity between the 'Tech' and 'Non-Tech' groups was significantly different ($t = 3.87$, $p = 0.001$): 85% of the participants in the 'Tech' group and 70% in the 'Non-Tech' group had high confidence in their ability to quickly and easily learn to use innovative technologies. For the 'Tech' group, only 2.5% had low confidence (the remaining 12.5% were indifferent), while 30% of the 'Non-Tech' group had low confidence. Of the 'Tech' group, 70% identified themselves as technological individuals with no problems with technological devices; 5% believed themselves to be non-technological; and 25% were neutral. In contrast, only 30% of the 'Non-Tech' group identified themselves as technological, and 70% thought that they are not. Of the 'Tech' group, 85% said that they enjoyed learning new technologies, while only 40% of the 'Non-Tech' group noted that they enjoyed this type of learning.

In the NARS assessment, most of the participants did not have negative feelings about situations and interactions with robots. In the 'Tech' and 'Non-Tech' groups, respectively, 57.5% and 80% had a low negative attitude, 40% and 20% had a medium negative attitude, while only very few (2.5% and 0%) had a highly negative attitude towards situations and interactions with robots.

In the NARS assessment, most of the participants did not have negative feelings about situations and interactions with robots. 57.5% and 80% had low negative attitude in the 'Tech' and 'Non-Tech' groups respectively. 30% and 20% had medium negative attitude, while only very few (2.5% and 0%) had a highly negative attitude towards situations and interactions with robots.

3.2. Efficiency - completion time

The interaction mode had a significant influence on efficiency in both groups ('Tech': $F = 6.07$, $p = 0.016$; 'Non-Tech': $F = 21.74$, $p < 0.001$), with significantly higher efficiency for the proactive mode. There was a significant difference between the 'Tech' and 'Non-Tech' groups ($t = -2.06$, $p = 0.042$), with a significantly lower efficiency in the 'Tech' group for the reactive mode ($t = -2.51$, $p = 0.023$) in contrast to the proactive mode, for which there was no significant difference between the groups ($t = -0.92$, $p = 0.36$). The completion time was faster by 5.1% in the

Table 1
Summary of the results and comparisons for the different variables

Variable	GLMM						T-test		
	'Technological'			'Non-Technological'			Comparison		
	Proactive	Reactive	P-value	Proactive	Reactive	P-value	'Tech'	'Non-Tech'	P-value
Efficiency	390.88 ± 46.96	411.95 ± 55.32	0.016	404.1 ± 16.85	455 ± 16.85	<0.001	401.41 ± 57.64	429.55 ± 16.85	0.042
Effectiveness	0.826 ± 0.15	0.717 ± 0.17	0.001	0.761 ± 0.18	0.743 ± 0.16	0.722	0.77 ± 0.17	0.75 ± 0.16	0.643
Understanding	0.838 ± 0.09	0.79 ± 0.09	0.001	0.895 ± 0.05	0.728 ± 0.08	<0.001	0.814 ± 0.09	0.812 ± 0.1	0.931
Satisfaction	4 ± 0.8	3.81 ± 0.58	0.104	4.46 ± 0.41	4.06 ± 0.46	0.001	3.91 ± 0.7	4.26 ± 0.47	0.009
Workload	15.93 ± 2.2	18.73 ± 2.1	<0.001	17 ± 0.94	20.4 ± 0.84	<0.001	17.33 ± 2.15	18.7 ± 0.89	0.012
Situation awareness	0.657 ± 0.1	0.546 ± 0.1	<0.001	0.8 ± 0.06	0.77 ± 0.06	0.263	0.6 ± 0.1	0.785 ± 0.06	<0.001

Table 2
Summary of sub-variables results

Variable		'Technological'			'Non-Technological'		
		Proactive	Reactive	P-value	Proactive	Reactive	P-value
Efficiency	Completion time (sec)	390.88 ± 46.96	411.95 ± 55.32	0.016	404.1 ± 16.85	455 ± 16.85	<0.001
Effectiveness	Completeness (count)	6.63 ± 1.53	6.7 ± 1.65	0.18	6.9 ± 1.52	6.9 ± 1.37	0.896
	Accuracy (%)	0.75 ± 0.02	0.6 ± 0.02	0.001	0.63 ± 0.07	0.66 ± 0.07	0.62
	Precision (%)	0.84 ± 0.14	0.76 ± 0.19	0.026	0.75 ± 0.05	0.75 ± 0.05	0.55
Understanding	Comprehension	4.3 ± 0.68	4.25 ± 0.54	0.538	4.9 ± 0.31	4.6 ± 0.51	0.14
	Clarity	4.1 ± 0.81	4.25 ± 0.66	0.396	4.8 ± 0.42	4.2 ± 0.91	0.068
	Reaction time (sec)	4.65 ± 2.9	9.17 ± 3.4	<0.001	3.7 ± 0.4	8.35 ± 0.9	<0.001
Satisfaction	Communication	4.09 ± 0.91	3.7 ± 0.69	0.024	4.6 ± 0.51	4.2 ± 1.05	0.279
	Confidence	4.01 ± 0.86	3.95 ± 0.69	0.495	4.3 ± 0.63	4.5 ± 0.66	0.639
	Comfortability	3.82 ± 0.9	3.8 ± 0.88	0.306	4.5 ± 0.4	3.5 ± 0.23	0.007
Workload	Workload	15.93 ± 2.2	18.73 ± 2.1	<0.001	17 ± 0.94	20.4 ± 0.84	<0.001
Situation awareness	SA score	17.55 ± 2.8	14.73 ± 2.5	<0.001	18.6 ± 3.37	18.3 ± 2.75	0.76
	Number of objects identified (count)	6.68 ± 2.05	5.36 ± 1.96	0.033	5.6 ± 0.84	5.2 ± 1.39	0.12

'Tech' group and by 11.1% in the 'Non-Tech' group for the proactive mode.

3.3. Effectiveness - completeness, accuracy, and precision

The interaction mode had a significant influence on effectiveness in the 'Tech' group ($F = 11.5$, $p = 0.001$), with significantly higher effectiveness for the proactive mode. In the 'Non-Tech' group, the interaction mode did not significantly influence effectiveness ($F = 0.13$, $p = 0.722$). There was no significant difference in effectiveness between the groups ($t = 0.46$, $p = 0.643$).

Completeness was not significantly affected by the interaction mode in both groups. In the 'Non-Tech' group, accuracy and precision were also not significantly affected by the interaction mode. In the 'Tech' group, accuracy and precision were significantly influenced by the interaction mode, with better results – by 15% and 8%, respectively – for the proactive mode.

3.4. Understanding - comprehension, clarity, and reaction time

The interaction mode had a significant influence on the understanding of the robot by the user in both groups ('Tech': $F = 12.75$, $p = 0.001$; 'Non-Tech': $F = 37.57$, $p < 0.001$), with a significantly higher understanding for the proactive mode vs. the reactive mode. There was no significant difference in understanding between the groups ($t = 0.087$, $p = 0.931$). Comprehension and clarity were not significantly affected by the interaction mode in both groups. However, the reaction time was significantly affected by the interaction mode in

both groups, with better reaction times in the proactive mode ('Tech': better by 49%; 'Non-Tech': better by 55.6%)

3.5. Satisfaction - communication, confidence, and comfortability

Satisfaction was significantly influenced by interaction mode in the 'Non-Tech' group ($F = 17.05$, $p = 0.001$), with significantly higher satisfaction being reported for the proactive mode. In the 'Tech' group, the interaction mode did not have a significant influence on satisfaction ($F = 2.7$, $p = 0.104$). There was a significant difference between the 'Tech' and 'Non-Tech' groups for satisfaction ($t = -2.71$, $p = 0.009$), with significantly higher satisfaction in the 'Non-Tech' group for the proactive mode ($t = -2.55$, $p = 0.016$). For the reactive mode, there was no significant difference between the groups ($t = -1.27$, $p = 0.209$). In the 'Tech' group, communication was the only variable that was significantly affected by the interaction mode, with 10.54% better results in the proactive mode. In the 'Non-Tech' group, comfortability was the only variable that was significantly affected by interaction mode, with 28.57% better results in the proactive mode.

3.6. Perceived workload - NASA-TLX score

The perceived workload was significantly influenced by the interaction mode for both groups ('Tech': $F = 105.07$, $p < 0.001$; 'Non-Tech': $F = 40.93$, $p < 0.001$), with a significantly lower workload being reported for the proactive mode (by 15% and 16.6% in the 'Tech' and 'Non-Tech' groups respectively). There was a significant difference between the groups ($t = -2.62$, $p = 0.012$), with a significantly lower

Table 3

Effect of the order of the experiment and gender on the dependent variables.

Variable	Order						Gender					
	Technological			Non-Technological			Technological			Non-Technological		
	Started with Proactive	Started with Reactive	P-value	Started with Proactive	Started with Reactive	P-value	Male	Female	P-value	Male	Female	P-value
Efficiency	393.13 ± 47.2	416.85 ± 43.3	F=2.63 P=0.11	431.1 ± 53.9	437 ± 60.4	F=0.02 P=0.9	405.95 ± 54.2	404.03 ± 58.9	F=0.001 P=0.975	428.7 ± 60.7	439.6 ± 53.1	F=0.06 P=0.784
Effectiveness	0.76 ± 0.17	0.78 ± 0.17	F=0.11 P=0.745	0.78 ± 0.16	0.73 ± 0.17	F=0.19 P=0.665	0.78 ± 0.16	0.75 ± 0.18	F=0.57 P=0.454	0.77 ± 0.19	0.73 ± 0.14	F=0.14 P=0.718
Understanding	0.81 ± 0.09	0.81 ± 0.09	F=0.01 P=0.913	0.84 ± 0.09	0.79 ± 0.12	F=0.91 P=0.353	0.81 ± 0.1	0.81 ± 0.08	F=0.03 P=0.86	0.83 ± 0.1	0.8 ± 0.11	F=0.155 P=0.7
Satisfaction	3.8 ± 0.77	4 ± 0.63	F=0.6 P=0.438	4.43 ± 0.3	4.1 ± 0.56	F=1.3 P=0.28	3.96 ± 0.7	3.84 ± 0.71	F=0.24 P=0.627	4.26 ± 0.58	4.26 ± 0.37	F=0.03 P=0.873
Workload	17.7 ± 2.77	16.95 ± 2.36	F=0.93 P=0.34	18.4 ± 2.06	19 ± 1.88	F=0.5 P=0.491	17.05 ± 2.45	17.6 ± 2.72	F=0.5 P=0.48	18.8 ± 2.1	18.6 ± 1.9	F=0.36 P=0.562
Situation awareness	0.57 ± 0.11	0.63 ± 0.11	F=0.22 P=0.148	0.78 ± 0.09	0.78 ± 0.04	F=0.05 P=0.852	0.62 ± 0.11	0.58 ± 0.11	F=0.721 P=0.402	0.78 ± 0.07	0.79 ± 0.07	F=0.04 P=0.786

workload in the 'Tech' group for the reactive mode ($t = -2.42$, $p = 0.019$). For the proactive mode, there was no significant difference between the groups ($t = -1.48$, $p = 0.146$).

3.7. Situation awareness

The interaction mode had a significant influence on situation awareness in the 'Tech' group ($F = 48.67$, $p < 0.001$). The participants were more aware of the robot's activities and the environment for the proactive mode than for the reactive mode. In the 'Non-Tech' group, situation awareness was not significantly affected by the interaction mode ($F = 1.34$, $p = 0.263$). There was a significant difference in situation awareness between the groups ($t = -9.37$, $p < 0.001$), with a significantly higher situation awareness in the 'Non-Tech' group in both modes (proactive mode: $t = -4.23$, $p < 0.001$; reactive mode: $t = -6.61$, $p < 0.001$).

3.8. Order of interaction and gender

The order of interaction modes in which participants performed the experiment and the gender of the participants were not found to be statistically significant for any of the examined dependent variables (Table 3).

3.9. Correlations between dependent variables

The correlations between the dependent variables (Table 4) revealed that the users' understanding of the robot affected all the other variables. The higher the user's understanding of the robot, the less time it took to complete the main task and the better the performance in the secondary task. A better understanding also resulted in more satisfaction with the interaction, better situation awareness, and a reduced workload during the task.

3.10. Effect of sample size

Table 5 shows Cohen's d values calculated from the research data with two values estimated for each variable, one being, $n_1 = n_2 = 10$, and the other being $n_1 = 10$ and $n_2 = 40$. From Table 5 we see that when $n_1 = n_2 = 10$ (in each of the 'Non-Tech' and 'Tech' groups), the estimated d values ranged from 0 to 1.434; one of the values was "small" (< 0.2), and five were "large" (> 0.8). The d values that were estimated when $n_1 = 10$ (in the 'Non-Tech' group) and

Table 4

Correlations between dependent variables

Variable	Efficiency	Effectiveness	Understanding	Satisfaction	Workload	Situation awareness
Efficiency	1	-0.27*	-0.26*	-0.001	0.05	0.07
Effectiveness		1	0.219*	0.132	-0.23*	0.215*
Understanding			1	0.388*	-0.441*	0.361*
Satisfaction				1	-0.201*	-0.401*
Workload					1	-0.245*
Situation awareness						1

Table 5Estimated Cohen's d for the original data ($n_1 = n_2 = 10$) and for the extended data ($n_1 = 10$, $n_2 = 40$)

	$d(n_2 = 10)$	$d(n_2 = 40)$
Efficiency	1.379	0.536
Effectiveness	NA	0.119
Understanding	NA	0.022
Satisfaction	NA	0.528
Workload	NA	0.693
Situation awareness	NA	1.972
Completeness (count)	0.000	0.154
Accuracy (%)	1.090	0.851
Precision (%)	NA	0.323
Comprehension	1.328	0.813
Clarity	0.575	0.440
Reaction time(s)	0.531	0.312
Communication	0.626	0.609
Confidence	0.832	0.475
Comfortability	1.060	0.207
SA score	1.434	0.770
Number of objects identified (count)	0.297	0.303

$n_2 = 40$ (in the 'Tech' group) ranged from 0.022 to 1.972; three of these values were "small", and three were "large".

In Table 6 and Fig. 7 we demonstrate the influence of the effect size (d), the total number of observations ($N = n_1 + n_2$), and the number of observations of the first sample (n_1) on the power of the test, π , for a fixed level of α , namely, 0.05. The d values taken are the four values that Cohen mentioned, 0.2, 0.5, and 0.8, 1, the maximum and the minimum of the d values estimated for the original data [16], and the expanded data (from this research).

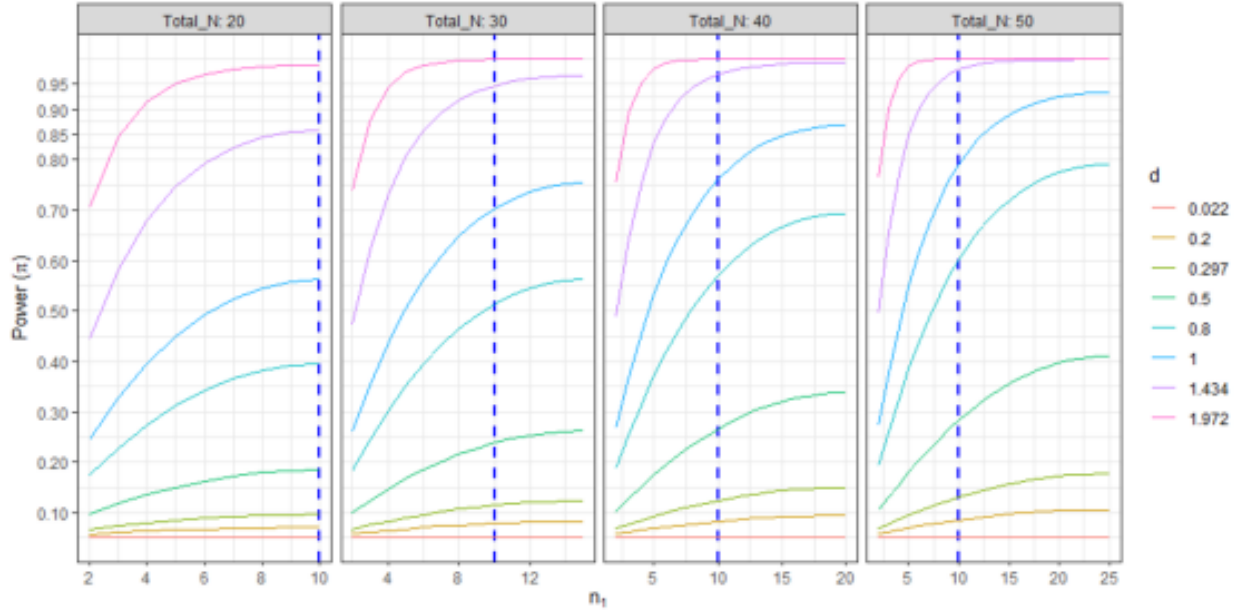


Figure 7: Power of the test as a function of Cohen's d . The different graphs present different N ; the x axis in each graph presents n_1 . The blue vertical line in each graph presents the result for $n_1=10$

Table 6

Power as a function of Cohen's d , the total number of observations ($N = n_1 + n_2$)

d	$n_1 = 10, n_2 = 10$	$n_1 = 10, n_2 = 20$	$n_1 = 10, n_2 = 30$	$n_1 = 10, n_2 = 40$	$n_1 = 25, n_2 = 25$
1	0.200	0.07082135	0.07896844	0.08325598	0.08589515
2	0.500	0.18509566	0.23859600	0.26642712	0.28339873
3	0.800	0.39509921	0.51382120	0.56962085	0.60155984
4	1.000	0.56200665	0.70287390	0.76079868	0.79145129
5	0.297	0.09648232	0.11485436	0.12455798	0.13053597
6	0.022	0.05024909	0.05034511	0.05039537	0.05042622
7	1.434	0.85827332	0.94861451	0.96899014	0.97797418
8	1.972	0.98623873	0.99841423	0.99951647	0.99977019

The results reveal that as d increases, the power of the test (π) increased, as expected for every combination of n_1 and n_2 . For each level of N , the maximum power of the test was obtained in a balanced experiment, as expected, i.e., $n_1 = n_2 = N/2$, meaning that if N observations can be conducted, the most efficient way to utilize the N observations is using a balanced experiment in which the sizes of the two groups are equal. For example, let us take the case of $N = 50$ and $d = 1$; in the balanced case where $n_1 = n_2 = 25$, the power of the test is equal to 0.93370765 compared to an unbalanced case in which, say $n_1 = 10$ and $n_2 = 40$, for which the power of the test is equal to 0.79145129. For each level of n_1 , as the total number of observations, N (or $n_2 = N - n_1$), increases, the power of the test increases; for example, for $d = 1$ and $n_1 = 10$ the powers obtained for $n_2 = 20, 30$ and 40 are 0.56200665, 0.70287390, 0.76079868 and 0.79145129 respectively. i.e., increasing the size of the second sample n_2 , and keeping the size of the first sample, n_1 , constant, increases the power of the test, as we also saw in our case when we increased the 'Tech' group to 40 participants and the 'Non-Tech' group remained smaller (10 participants).

3.11. Analysis of information and operation in the reactive interaction mode

3.11.1. Number of elements that were 'pulled' and number of interactions with the interface

The order of the interaction modes had a significant influence on the number of elements that were 'pulled' ($F = 9.88, p = 0.003$) and on the number of interactions with the interface ($F = 6.271, p = 0.016$). The participants 'pulled' significantly more elements when they started with the proactive mode (3.16 ± 0.85) than when they started with the reactive mode (2.16 ± 1.34), and the same trend was evident for the number of interactions with the interface (Start with proactive: 2.08 ± 1.18 ; Start with reactive: 1.36 ± 0.81).

3.11.2. When the elements were 'pulled' during the task

When participants started with the proactive mode, they 'pulled' more elements at the start of the mission compared to when they started with the reactive mode. A summary of these results is presented in Fig. 8.

3.11.3. Number of times elements were 'pulled' or closed

Forty-eight percent of the participants 'pulled' elements only once or not at all, and only 18% 'pulled' elements more than twice and less than five. Moreover, only 10 participants (20%) closed an element that had been 'pulled' during the task. The bottom camera was closed once, the rear camera was closed 5 times, and a warning about an obstacle was closed 4 times.

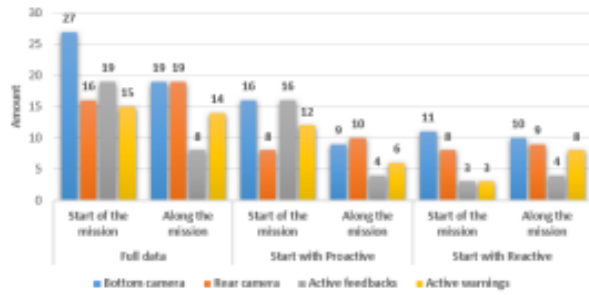


Figure 8: Number of times elements were 'pulled' relative to the time in the task

3.11.4. Correlation of 'pulled' elements with dependent variables

The number of elements that were 'pulled' showed a significant correlation with both effectiveness (correlation = 0.474, $p = 0.017$) and understanding (correlation = 0.468, $p = 0.018$). The number of different times that elements were 'pulled' showed a significant correlation with efficiency (correlation = 0.416, $p = 0.039$) and with situation awareness (correlation = -0.497, $p = 0.01$).

4. Discussion and conclusions

This study examined the influence of interaction modes – proactive vs. reactive – on overall performance and user perception in an MRP telecare task. In general, the study highlights the potential of improving the interaction between a remote operator and a robot by using the proactive interaction mode for the task and by fine-tuning the control that users have over the information presented through both modes of interaction with the MRP system.

The current study was conducted with students, some of whom had a technological background, and others did not. Although the groups were not balanced in terms of size, we obtained significant results, implying the importance of taking into account different types of population. The results showed that increasing the sample size of one or both groups would increase the power for a given level of "effect size."

4.1. Influence of the interaction modes

The implementation of the proactive and reactive interaction modes in the MRP system significantly influenced several of the variables assessed. The findings confirm hypothesis H1 (*the interaction mode will influence the interaction of the user with the MRP system*) and highlight the relevance of the way of transferring the information to the user of MRP systems. The proactive mode was the preferred mode compared to the reactive mode, validating hypotheses H2 and H4 (*the proactive mode will increase the user's situation awareness, improve the user's performance, and reduce the users' perceived workload*), but not H3 and H5 (*the reactive mode will improve the user's understanding and will increase satisfaction*), as expected. Although we did not find significant results for the preference for the reactive mode, several participants mentioned that they felt that the

ability to control some of the elements in the user interface was an advantage. The results correspond with the literature [24, 4] on the positive effect of the proactive mode on the overall response and performance of users, confirming the effectiveness of the proactive mode in an MRP scenario for a telecare task.

It appeared that the proactive mode provided the users with all the tools and information elements they required for the tasks. The users seemed to familiarize themselves easily with the system and the interfaces, such that there could have been a feeling that some elements had been 'withdrawn' from them when they were required to use the interface in the reactive mode. This notion was reflected in the results that revealed that participants who started with the proactive interface 'pulled' more information than those who started with the reactive interface. This notion that the order of starting the experiments influences the outcome is in keeping with the principles of user interface design, where the users of elements tend to adjust their use of the interface to the availability and position of the elements on the interface ([9]). Thus, any changes in the interface, such as those that we introduced in the reactive mode, may result in dissatisfaction, as reflected in the results where the satisfaction and usability variables were rated lower in the reactive mode vs. the proactive mode. In addition, the proactive mode had a greater effect on the 'Non-Tech' group than on the 'Tech' group; therefore greater attention should be paid to the interaction mode for non-technological user populations.

4.2. Usefulness of the reactive interaction mode

Examining the outcome of the effect of the reactive interaction mode alone on the dependent variables provided an indication of the desire of users to have some control over the information being presented to them, as seen in [24]. Several of the users mentioned this need for control in the subjective evaluation. The correlation results revealed that for users who 'pulled' more elements (i.e., obtained more information from the robot) both user effectiveness and user understanding of the MRP system improved. The results also showed that users who 'pulled' information from the interface multiple times exhibited reduced efficiency and situation awareness. Overall, for most of the performance variables assessed, the proactive interaction mode emerged as the preferred and more successful mode. This seemingly conflicting outcome could be explained in terms of the multiplicity of information being 'pushed', as previously reported in more general terms [6]. Most users are used to managing multiple levels of information elements being 'pushed' to them through various multimedia sources by unconsciously filtering out the information they require at specific points in time [6]. This process of information filtering is the added value that the reactive mode brings into the interaction.

4.3. Importance of understanding the robot by the user

Users' understanding of the robot had a significant impact on the experiment's outcome. It impacted completion

time, performance, satisfaction, situation awareness, and workload. Participants completed the assignments in less time with better performance in the secondary task when they understood the robot better. Similarly, when the level of understanding of the robot was higher, the participants' level of satisfaction with the interaction increased, as did situation awareness, and the perceived workload became smaller. This outcome indicates that improving the user's understanding of the robot can be a significant factor in improving the user's ability to perform remotely controlled tasks with robots and in enabling her/him to work with higher efficiency and greater overall satisfaction.

4.4. Future work

Future work should be aimed at extending evaluations of MRP systems to actual healthcare professionals and caregivers in other telecare applications and healthcare tasks. Implementing a proactive mode in other telehealth applications, such as monitoring or detecting abnormal conditions in patients, could aid in ensuring that the requisite healthcare information is provided through such MRPs in the best manner possible, even over a distance. Telerobots in telecare should be equipped with interfaces through which caregivers and healthcare professionals can control the information they require to care for patients with better efficiency, effectiveness, and situation awareness, and with a minimal workload. It is possible that in certain situations and in accordance with further research on this topic, the way forward will be to adapt such interfaces according to the work environment, the load on the operators, and the severity of the patient's condition. In such scenarios, it may be preferable to examine the use of the reactive mode.

The comments of the participants regarding the benefits of the reactive mode led us to consider the possible benefits of a hybrid mode in which some form of reactive mechanism is incorporated into a proactive interaction mode in the MRP. This could be considered as a 'Proactive-Reactive' option, where most of the basic information elements are 'Pushed' to the user, and provision is made for 'pulling' some additional information. Such a hybrid system could be developed in the form of intelligent sensing for different task-related, environment-related, robot-related, or human-related situations during telecare operations.

Since the current study revealed the importance of the user's understanding of the robot during remote control operation, further research should also examine different levels of explanation aimed to increase the user's understanding of the MRP system.

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Chapter 4. Levels of Explanation – Implementation and Evaluation in a Mobile Robotic Telecare Task

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(without theoretical model which is part of a parallel thesis, Kumar, 2022)

Levels of Explanation – Implementation and Evaluation in a Mobile Robotic Telecare Task

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As robots become more and more capable and autonomous, their usage in daily tasks by nonprofessional users and bystanders will increase. For smooth and efficient interaction, they should be designed such that their plans, decisions, and actions are understood by the interacting humans.

In this work, we examined **what** information should be communicated to the user by the robot? and **when** should the robot communicate this information? We defined clarity and patterns of explanation. Accordingly, we proposed two levels of clarity - high and low and two levels of explanation patterns - dynamic and static. Based on these, three different levels of explanation (LOEs) were designed and evaluated in a user study with a telepresence robot. The user study was conducted for a simulated health care task with two different conditions related to time criticality evaluated in two different user groups (with and without time limit). We found that the high LOE was preferred in case of completion time and adequacy of explanation in the 'without time limit' condition. It was further found that both high and medium LOEs were fluent and trusted. However, in the 'with time limit' condition, high and medium LOEs had similar performance and were preferred in all measures as compared to low LOE.

Additional Keywords and Phrases: levels of explanation, understandable, clarity, dynamic, static, time criticality

1 INTRODUCTION

Robotic systems are penetrating into many non-industrial environments with increasing interactions with humans [23]. The development of collaborative robots has ensured this shift. As robots become more and more capable and autonomous, their usage in daily tasks by nonprofessional users and bystanders will increase. The deployment of several robotic platforms during the COVID-19 pandemic further illustrates the paradigm shift in this field [29]. For smooth and efficient interaction, robots should be designed such that their plans, decisions, and actions are understood by the interacting humans [7]. Not addressing this issue can hamper the user's perception of the robot [2], efficiency and safety during the interaction, as well as future usability of the system by the user [1]. A robot's inability to explain its 'thinking' or action could even lead to anxiety amongst the interacting human [18].

A theoretical model of understandable robots claims that a communicative action should be generated when there is a disparity between the robot's state of mind and the theory of mind of a human inside the robot [10].

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A different model mapped the psychological model of the human to the social process proposing four levels of explanations [4] defined as:

- (1) interpreting a decision based on available information.
- (2) explaining the agent's internal functions interacting with other actors in the environment.
- (3) explaining based on other's agent's beliefs or mental state.
- (4) interpreting the systems based on the cultural expectations of the user.

The generation of explanations for bystanders has been studied in [15, 21, 25]. It was found that explanations help bystanders to understand the robot's action. Another study that deals with robot failures [3] generates explanations by invoking explainable artificial intelligent models including action-based, context-based, and history-based explanations. Results revealed that context-based explanations are helping with failure recovery. Another study used inverse reinforcement learning to predict its collaborator's action and tried to avoid the failure of the task by generating explanations in two modes[28]. The first mode involved explaining about particular action of the user that would cause a failures. The second mode involved justifying a particular user's action that would lead to failures of the task. It was found that justification of the explanations increased the performance.

This paper focuses on how should an explanation be designed such that it could easily be understood by the user. We devised three levels of explanation to and evaluated them in a user study with a telepresence robot. A telepresence robot is one that is controlled remotely by a human operator [6] and in this way, it can provide the user more opportunities to interact directly with the environment, even if there are barriers that prevent him or her from doing so physically [24]. Over the years, telepresence robots have developed to improve various factors such as human safety in dangerous and complex environments (e.g., hospitals, chemical factories) and saving manpower (working in large and remote environments or even in several environments at the same time).

An important aspect of human-robot interaction is task criticality [30]. Task criticality is defined as an error that would cause harm to human lives or to the environment. A critical task should be achieved at a specific time to avoid any negative effects [5]. A key component of the explanation would require time availability of the user to listen to it [20]. The amount of time the user would spend listening to the explanation from the robot depends upon the environment and task in which it is interacting. For example, in a library environment users have time for detailed explanations where the robot can suggest suitable material for the users based on iterative feedback [26]. However, in search and rescue operations where time is forcefully limited, a brief and precise explanation would be required [22] to accomplish the task successfully. To evaluate the influence of time criticality on the explanations we compared two conditions, one '*with time limit*' and the other '*without time limit*'. In this paper, we focused on explaining the planning or 'thinking' of the robot to the user for successful human-robot collaboration. To ensure safety in the dynamic environment, the plan was executed by the human instead of the robot. Hence, we hand over the control of the robot to the human when facing obstacles by teleoperation.

2 LEVELS OF EXPLANATION

The proposed LOEs aims to answer the following questions:

- (1) **What** information should be communicated to the user by the robot?
- (2) **When** should the robot communicate the information? (i.e., Should the robot explain its plan before the action or during the implementation of the plan?)

To address this we define two terms - clarity and explanation patterns. Clarity is defined as the amount of information that needs to be communicated for a better understanding of the robot. The explanation pattern is defined as the frequency of delivery of the communication actions.

We divided clarity into two levels, high and low. In the high level of clarity, the robot explains all the action details it has planned. For example in a telepresence robot facing an obstacle, the robot would explain to the user to turn 90 right, move forward etc. In the low level of clarity the robot explains only the broader sense of the

plan without any details. For example in the previous scenario the robot only explains to the user to turn right without detailing how to do this.

We defined two explanation patterns, static and dynamic. In static explanation pattern, the robot explains to the user only once before the execution of the plan. In the dynamic explanation pattern, the robot explains its actions of the plan in parallel to its execution.

Based on these, three LOEs (high, medium and low LOE) were devised as shown in Table 1.

Table 1. Defining of levels of explanation

Level of Explanation	Explanation pattern	Clarity
High	Dynamic	High level of clarity
Medium	Dynamic	Low level of clarity
Low	Static	Low level of clarity

3 METHODS

Three LOEs were implemented and evaluated in a teleoperated task. These LOEs were compared in two different conditions i.e., '*with time limit*' and '*without time limit*'. The users were divided into two equal groups. In the first condition, users performed the task without any time constraint. In the second condition we forced the user to accomplish the collaborative task with a time constraint.

3.1 The experimental system

The developed system consists of a mobile robot platform, remote user interfaces, and a server-client communication architecture that used a Rosbridge WebSocket to connect to the robot operating system (ROS) platform. The user interfaces were run on the operator's computer and were programmed using HTML, JS, CSS, and PHP.

The robot platform was a Keylo telepresence robot. The height of the robot is approximately 1.64 m with a low center of gravity and a circular footprint of 52 cm in diameter. Keylo is equipped with a 24" multi-point high FOV touch screen. It runs on Ubuntu 18.04 LTS and ROS Melodic with a standard ROS API for all its sensors and features. The navigation sensors include a Lidar (Hokuyo URG-04LX-UG01, range of 5.6 meters, FOV 240°), two sets of four front and rear ultrasonic range sensors (5 meters range), and two sets of two 2 IR edge detectors hard-wired to the motors controller. Additionally, the robot is equipped with three cameras, two front and one rear 3D RGB-D camera Intel RealSense™ R200.

3.2 Participants

Sixty participants, comprised of third-year undergraduate engineering studies were recruited for the study by announcing the experiment in the Department of Industrial Engineering and Management at Ben-Gurion University and offering a bonus point in a compulsory undergraduate course to commensurate for their time. The participants were randomly assigned into two groups - '*with time limit*' (15 male and 15 female; mean age = 26.1, SD = 1.32) and '*Without time limit*' (15 male and 15 female; mean age = 26, SD = 1.31).

All participants had experience programming robots but no previous experience with teleoperated robots.

3.3 Interfaces

Two interfaces were built – one for each group. The interfaces were designed to be user-centered following previous research recommendations [19]. According to the findings from [14], both interfaces were designed by

using the proactive interaction mode (in this mode, all the information is 'pushed' to the user). All the feedback were visual and auditory based on previous recommendations [16].

The interfaces of the different groups were completely identical and included a display of the front camera view, and feedback, explanations from the robot (e.g. explanations for passing obstacles, reaching important points, and warnings from obstacles), four buttons – one for sending the robot to perform the task automatically ("Go to patient room" button) and three for treating the patients along the task. Manual control of the robot was executed via the arrow keys (Fig. 2).

In the interface of the '*with time limit*' group, the time limit was simulated by a red marked timer placed at the top of the interface (Fig. 1). The specific time of one minute and ten seconds was empirically determined in several experiment pilots. The timer was initiated for each obstacle and reset after passing it.



Fig. 1. Interface of '*with time limit*' condition

3.4 Experimental setting

The experimental setting was arranged to resemble a complex clinic that contained three patients and three obstacles. The explanations were provided to help the robot to pass the obstacle. Further, during the movement of the robot toward the patient, the user received another explanation. For each patient and obstacle, the user received an explanation according to one of the LOEs. We tried to simulate the patient by a monitor (the monitor was a note on which the patient's measurements were written - blood pressure, body temperature, and pulse). The obstacles were simulated by poster stands (Fig. 3)

The three LOEs (High, Medium, and Low) were examined in two different conditions by comparing performance for two different groups – '*with time limit*' and '*without time limit*'. The influence of the LOEs on different aspects of performance and user perception was evaluated.

3.5 The Task

During the task, the remote operator (user) was in the control position and was asked to navigate a remote-control robot in an environment that simulates a complex clinic. This environment contained obstacles that the user



Fig. 2. Interface of 'without time limit' condition

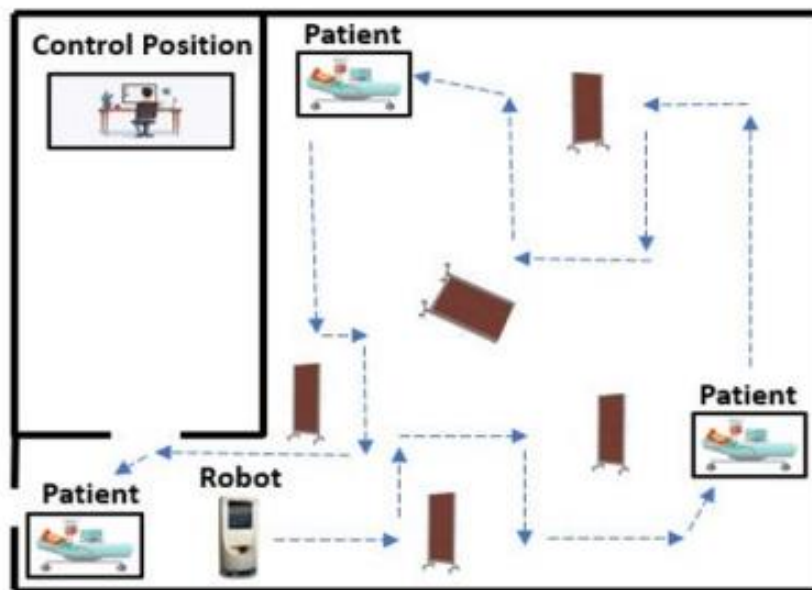


Fig. 3. A cross-section of the experimental environment

had to pass in order to reach the patients and give them appropriate treatment. The participants were instructed about the normal measures of any patient at beginning of the experiment (obviously standardised measures were taken into account.) If the user found out that any of the measures are beyond the normal range then the user has to treat it by clicking on the options provided in the interface. The path of the robot along the task included obstacles (poster stands that were scattered in the room) and patients for each LOE.

The robot advanced autonomously along a pre-defined path at the beginning of the task. It stopped when reaching an obstacle and informed about the obstacle and its inability to pass the obstacle. The robot gave instructions to the user to help it pass the obstacle through manual navigation of the robot. The instructions provided by the robot were according to each LOE for each patient and obstacle as demonstrated in Appendix B. Once the user managed to pass the obstacle, the robot informed him/her that it has passed the obstacle and automatically continued to the patient. When the robot reached patient, the user saw the patient's metrics and in addition, received or did not receive an explanation depending on LOEs (Appendix B). Accordingly, the user needed to give the patient appropriate treatment. Only after the user gave the correct treatment to the patient (different treatments were assigned for each LOE), the robot automatically moved toward the next patient.

The task included three obstacles and three patients (one for each LOE) so that each participant experienced each of the different LOEs in the same task (one obstacle and one patient were defined as a subtask).

The difficulty of the obstacles was identical for all three LOEs (same distance to navigate with the robot, same distance between obstacles and the same number of movements to be performed to pass the obstacle). The participants were free to ask for any help from the experimenter at any stage of the experiment.

3.6 Experimental design

The experiment was designed as a within-between experiment with the LOEs as the within independent variable and time limit as the between independent variable. Each participant was randomly assigned to one of the groups (taking into consideration that at the end gender in each group needed to be the same) and in addition, the order in which the participant experienced the different LOEs was also randomly determined. Accordingly, there were six different orders for the task and 5 participants from each group performed the task in each of these orders.

3.7 Procedure

At the beginning of the experiment, the participants received a consent form, read it, and signed it. Then they were asked to fill out a pre-experiment questionnaire (Section 3.9.1). Then they received a general explanation about the experimental area, the task (including an explanation about facing an obstacle and treating the patient) without going into great detail so as not to create deception. The participants proceeded with the experiment. After completion of the task, they were required to answer a final questionnaire (Section 3.9.2).

All experiments were approved by the department of industrial engineering and management ethics board.

3.8 Dependent Variables

The independent variables were evaluated using objective and subjective measures as detailed in Table 2.

Table 2. Dependent Variables

Dependent Variables		
Variable	Examined by	Explanation
Completion time	Completion time (objective)	the time (seconds) that it took from the moment that the user received the first explanation for passing an obstacle until he passed it, plus the time it took him to give the correct treatment to the patient from the moment that the robot arrived at him.
Fluency of interaction	Questionnaire (subjective)	Questions 1,5 in the final questionnaire
Adequacy of explanation	Number of collisions (objective)	how many times did a participant collide with an obstacle?
	Wrong movements (objective)	how many wrong movements participant did during the task? (movements contrary to the explanation of the robot)
	Questionnaire (subjective)	Questions 2,4,7 in the final questionnaire
Trust	Number of clarifications (objective)	how many times does the participant ask for clarification?
	Questionnaire (subjective)	Questions 3,6,8 in the final questionnaire

3.9 Questionnaires

3.9.1 Pre-experiment questionnaire. The pre-experiment questionnaire included demographic information questions (e.g., age, gender) and a Negative Attitude toward Robots Scale (NARS) questionnaire [27] to assess if the participants have a negative attitude toward situations of interaction with robots using a 5-point Likert-type scale ranging from 1 ("Strongly disagree") to 5 ("Strongly agree")

3.9.2 Final questionnaire. Subjective measures were assessed via the final questionnaire as shown in Appendix A using a 5-point Likert-type scale ranging from 1 ("Strongly disagree") to 5 ("Strongly agree") for all measures. Each question in the questionnaire was taken from previous works in the HRI community as illustrated in Appendix A. The final questionnaire included three subjective measures: Fluency of interaction [11], Adequacy of explanation [13], and Trust [13] which the participants rated for each of the different LOEs.

3.10 Analysis

Descriptive statistics (mean and standard deviation for normal distribution, median for not normal distribution and percentage for ordinal data) were computed for each of the dependent variables. Dependent variables that consisted only of subjective sub-variables were averaged and variables that were composed of both, subjective and objective sub-variables were first normalized between 0-1 and then averaged. Further, a Kolmogorov-Smirnov test was conducted on each dependent variable to check for normal distribution.

Results revealed that completion time ($D = 0.118$, $p = 0.013$) and fluency of interaction ($D = 0.239$, $p < 0.001$) were not normally distributed but adequacy of explanation ($D = 0.058$, $p = 0.762$) and Trust ($D = 0.086$, $p = 0.327$) were normally distributed. Therefore, a cumulative link mixed model (CLMM) regression analysis was conducted for fluency of interaction. To compute the ordinal regression, the response evaluated from this variable was rounded to the nearest integer resulting in 5 ordinal levels. For all the other dependent variables, a General Linear Mixed Model (GLMM) analysis was applied. Each analysis tested the following model with participant as random effect:

$$\text{Dependent Variable} \sim \text{LOEs} + \text{Gender} + \text{Order} + \text{LOEs} * \text{Gender} + \text{LOEs} * \text{Order} + \text{Gender} * \text{Order} + \text{LOEs} * \text{Gender} * \text{Order} + (1 | \text{Participant})$$

For each independent variable (LOEs, Gender, Order) whose effect on the dependent variable was significant, a post-hoc test was conducted using least square means. In the interaction variables, we examined whether the independent variables have an effect on each other. Welch's T-test for independent samples was applied to compare between 'with time limit' and 'without time limit' conditions in terms of adequacy of explanation and trust, and the Mann-Whitney U test was applied to compare them in terms of completion time and fluency of interaction.

In addition, we examined the correlations between the questions in the final questionnaire that belonged to the same variable to ensure that there were no contradictions in the participants' answers and that the questions did examine the same variable. The correlation between all the questions belonging to the same variable was significant (fluency of interaction (two questions): correlation = 0.357, $p = 0.048$; adequacy of explanation (three questions): correlations = 0.77, 0.64, 0.71, $p < 0.001$; trust (three questions): correlations = 0.33, 0.53, 0.5, $p = 0.01$, < 0.001 , < 0.001). All the tests were designed as two-tailed with a significance level of 0.05.

4 RESULTS

The statistical comparison between the LOE's (High, Medium and Low) for each dependent variable and condition ('with time limit' and 'without time limit') has been demonstrated in Table 3. The z. ratio (in case of not normal distribution), t.ration (in case of normal distribution) and p-value have been reported. Significant and non-significant variables were marked in green and red respectively.

Table 3. Summary of the significance of the results

LOEs	Completion time		Fluency of interaction		Adequacy of explanation		Trust	
	'With time limit'	'Without time limit'	'With time limit'	'Without time limit'	'With time limit'	'Without time limit'	'With time limit'	'Without time limit'
High								
Vs	z.ratio = 3.97	z.ratio = 5.78	z.ratio = 5.5	z.ratio = 4.86	t.ratio = 17.6	t.ratio = 15.06	t.ratio = 16.04	t.ratio = 9.89
Low	p < 0.001	p < 0.001	p < 0.001	p < 0.001	p < 0.001	p < 0.001	p < 0.001	p < 0.001
High								
Vs	z.ratio = 0.31	z.ratio = 2.42	z.ratio = 1.79	z.ratio = 1.89	t.ratio = 1.9	t.ratio = 3.47	t.ratio = 2.35	t.ratio = 2.18
Medium	p = 0.94	p = 0.04	p = 0.17	p = 0.139	p = 0.147	p = 0.002	p = 0.056	p = 0.082
Medium								
Vs	z.ratio = -3.62	z.ratio = -3.43	z.ratio = -4.34	z.ratio = -4.14	t.ratio = -15.7	t.ratio = -11.59	t.ratio = -7.68	t.ratio = -7.71
Low	p < 0.001	p < 0.001	p < 0.001	p < 0.001	p < 0.001	p < 0.001	p < 0.001	p < 0.001

4.1 Negative Attitude toward Robots Scale (NARS)

The NARS questionnaire is divided into three subcategories, negative attitudes toward situations of interaction with robots, negative attitudes toward the social influence of robots, and negative attitudes toward emotions in interaction with robots. The attitude of the participants in each of the groups were similar for all categories ($t(58) = 1.08$, $p = 0.282$; $t(58) = -1.12$, $p = 0.267$; $t(58) = -1.55$, $p = 0.126$; respectively).

4.2 Order of LOEs and Gender

The order of LOEs in which the participants experimented had no significant effect on any of the dependent variables in both of the conditions as presented in Table 4.

Gender had no significant effect on any of the dependent variables except trust in the 'with time limit' condition as presented in Table 4. Males (Mean = 0.828, SD = 0.16) had higher trust in the robot than females (Mean = 0.688, SD = 0.23) when there was a time limit on the task.

Table 4. Order of LOEs and Gender effect on dependent variables

Variables	Gender		Order	
	'With time limit'	'Without time limit'	'With time limit'	'Without time limit'
Completion time	z = 1.821	z = 1.214	z = -0.294	z = 0.474
	p = 0.068	p = 0.225	p = 0.768	p = 0.635
Fluency of interaction	z = 0.362	z = 0.465	z = -1.153	z = -1.213
	p = 0.728	p = 0.642	p = 0.306	p = 0.225
Adequacy of Explanation	t = 1.128	t = 0.753	t = 0.541	t = -0.033
	p = 0.269	p = 0.458	p = 0.603	p = 0.782
Trust	t = 3.164	t = 1.864	t = -0.178	t = -1.483
	p = 0.0038	p = 0.07	p = 0.226	p = 0.122

4.3 Completion time

The LOEs had a significant influence on completion time in both conditions (Fig. 4). In the 'with time limit' condition, there was a significant difference between the high and low LOEs ($z.ratio = 3.97$, $p < 0.001$) and between medium and low LOEs ($z.ratio = -3.62$, $p < 0.001$) with a significantly shorter completion time in the high and medium LOEs compared to the low LOE. In the 'without time limit' condition, there was a significant difference

between all the LOEs (high vs low: z .ratio = 5.78, $p < 0.001$; high vs medium: z .ratio = 2.42, $p = 0.04$; medium vs low: z .ratio = -3.43, $p = 0.001$) with significantly shorter completion times in the high and medium LOEs compared to the low LOE and shorter completion time in the high LOE compared to the medium LOE.

There was a significant difference between the '*with time limit*' (Median = 71.98) and '*without time limit*' (Median = 79.72) conditions ($z = 3.712$, $p < 0.001$) with a significantly shorter completion time when there was a time limit.

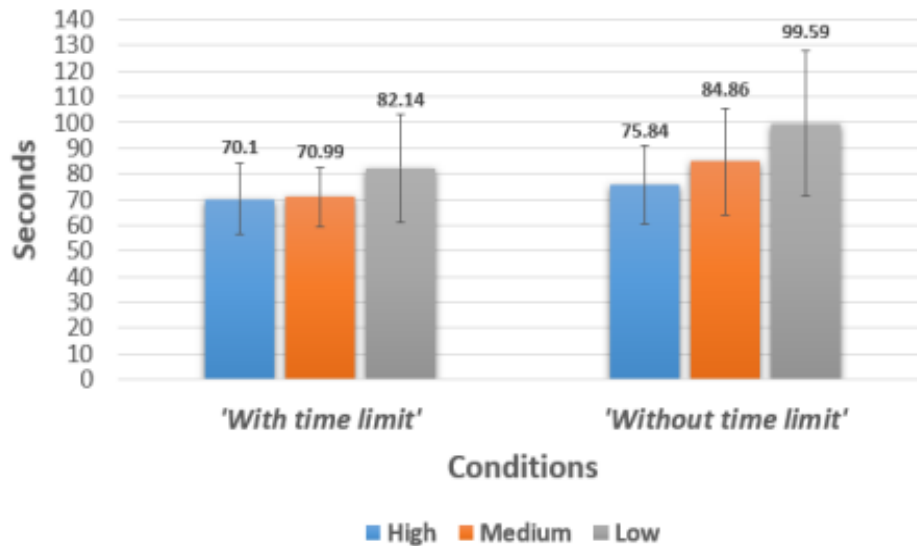


Fig. 4. Mean and SD of completion time for each level of explanation

4.4 Fluency of interaction

The fluency of interaction was significantly influenced by the LOEs for both conditions with significant difference between the high and low LOEs ('*with time limit*': z .ratio = 5.5, $p < 0.001$; '*without time limit*': z .ratio = 4.86, $p < 0.001$) and between medium and low LOEs ('*with time limit*': z .ratio = -4.34, $p < 0.001$; '*without time limit*': z .ratio = -4.14, $p < 0.001$).

In the '*with time limit*' condition, the participants were more satisfied with the fluency of interaction when received the high LOE (70% in strongly agree, 20% in agree, and 10% in neutral category) compare to the low LOE (6.66% in strongly agree, 30% in agree, 26.66% in neutral, and 36.66% in disagree category) and more satisfied when received the medium LOE (46.66% in strongly agree, 36.66% in agree, and 16.66% in neutral category) compare to the low LOE.

In the '*without time limit*' condition we saw the same trend, the participants were more satisfied from the fluency of interaction when received the high LOE (60% in strongly agree, 33.33% in agree, and 6.66% in neutral category) compare to the low LOE (20% in strongly agree, 20% in agree, 43.33% in neutral, and 16.66% in disagree category) and more satisfied when received the medium LOE (36.66% in strongly agree, 53.33% in agree, and 10% in neutral category) compare to the low LOE.

A summary in percentages of the fluency of interaction rating by the participants is shown in Fig. 5 and there was no significant difference between the conditions ($z = 0.308$, $p = 0.758$).

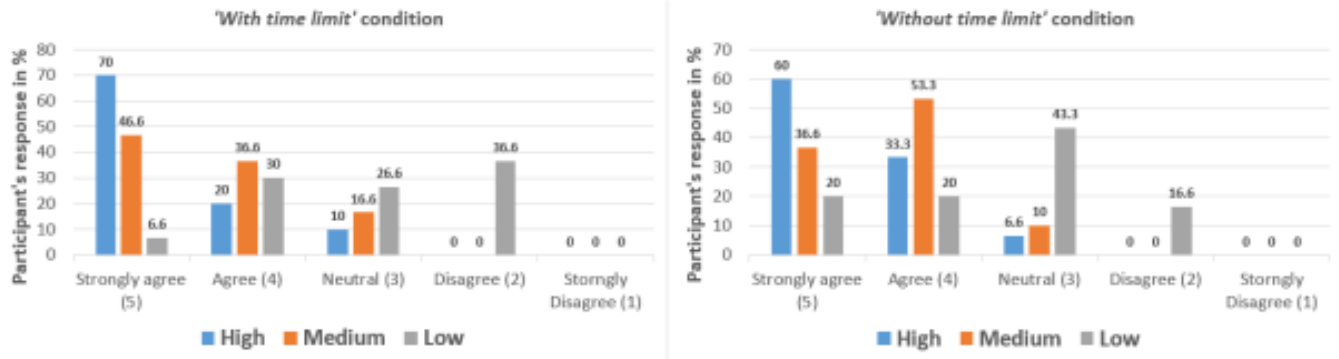


Fig. 5. The participant's responses to the fluency of interaction in different levels of explanation in percentage

4.5 Adequacy of explanation

The LOEs had a significant influence on the adequacy of explanation in both conditions. In the '*with time limit*' condition, there was a significant difference between the high and low LOEs ($t_{\text{ratio}} = 17.6$, $p < 0.001$) and between medium and low LOEs ($t_{\text{ratio}} = -15.7$, $p < 0.001$) with significantly better adequacy of explanation in the high and medium LOEs compared to the low LOE. In the '*without time limit*' condition, there was a significant difference between all the LOEs (high vs low: $t_{\text{ratio}} = 15.06$, $p < 0.001$; high vs medium: $t_{\text{ratio}} = 3.47$, $p = 0.002$; medium vs low: $t_{\text{ratio}} = -11.59$, $p < 0.001$) with significantly better adequacy of explanation in the high and medium LOEs compared to the low LOE and better adequacy of explanation in the high LOE compared to the medium LOE as presented in Fig. 6.

There was no significant difference between the conditions ($t(178) = -0.968$, $p = 0.334$).

4.6 Trust

The LOEs had a significant influence on trust in both conditions with significant difference between the high and low LOEs ('*with time limit*': $t_{\text{ratio}} = 10.04$, $p < 0.001$; '*without time limit*': $t_{\text{ratio}} = 9.89$, $p < 0.001$) and between medium and low LOEs ('*with time limit*': $t_{\text{ratio}} = -7.68$, $p < 0.001$; '*without time limit*': $t_{\text{ratio}} = -7.71$, $p < 0.001$). In both of the conditions, the trust in the robot was higher when the LOE was high or medium compared to the low LOE as presented in Fig. 6.

There was no significant difference between the conditions ($t(178) = 0.428$, $p = 0.669$).

5 DISCUSSION

Results revealed that LOEs had a significant effect on all dependent variables and participants found a difference among the three LOEs. With respect to all dependent variables, there was no difference between high LOE and medium LOE in the '*with time limit*' condition. However, there was a significant difference between high/medium (both were similar) and low LOE. In the '*without time limit*' condition, In the highest LOE its took lesser time to the participants to complete the task and the adequacy of explanation was higher. The medium and high LOEs were equally fluent and trusted by the user. However, the high or medium LOEs were significantly different from the low LOE. Irrespective of the time restrictive condition, we found that high LOE was preferred.

5.1 Completion Time

In a previous study [8], it was found that performance could increase with appropriate explanation in case of no time limit. In our work, we did find that the participants completed the task in a shorter time in the high LOE when there was no time limit. It confirms that the high LOE should be provided by the robot to improve the

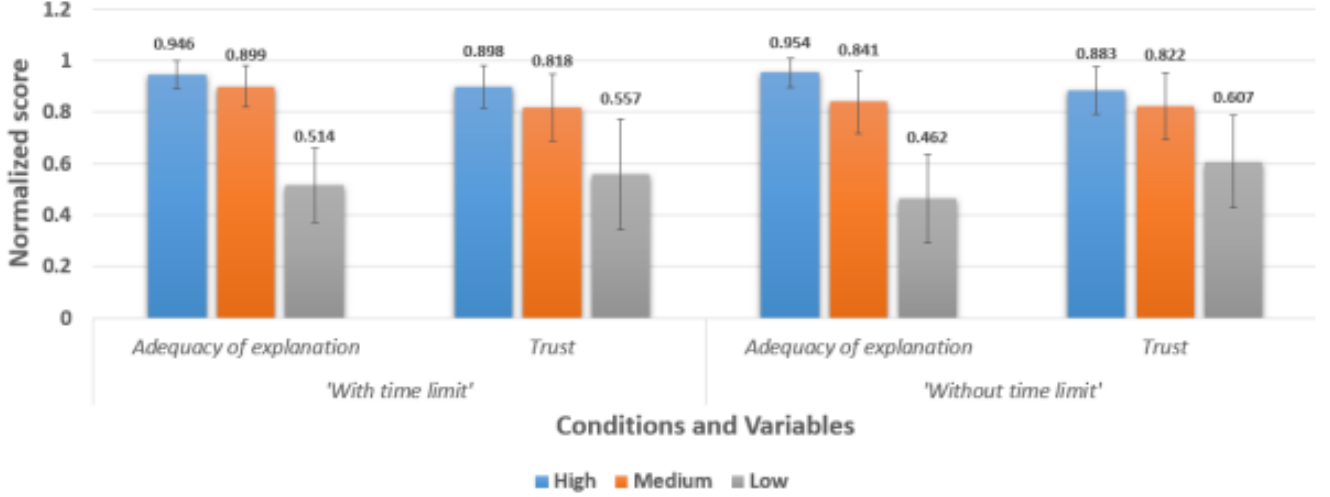


Fig. 6. Normalized Score of Adequacy of explanation and Trust

performance in case of '*without time limit*'. However, in case of '*with time limit*', high or medium LOE could be provided. This observation is opposite to previous research findings [22] where a brief explanation would be provided to complete the search rescue task (which is a time-critical task). However, we would like to stress that our study was conducted in a laboratory environment. Further, our experiment included only a time limitation for evaluating emergency situations. We found out that only completion time was shorter (statistically significant) in the case of '*with time limit*' condition compared to '*without time limit*' condition. However, other measures did not have any effect with the introduction of the time criticality aspect in the design.

5.2 Fluency of interaction

Irrespective of time restrictive cases, fluency of interaction was not impacted by the clarity of the information. Fluency of interaction increases when the collaborating agent can anticipate the action of the other [12]. In this work, we have proposed an explanation that would try to help users understand the plan of the robot. The pattern of explanation played an important role in deciding the fluency of interaction. The participants felt less fluent in interaction in case of a static pattern of explanation. Henceforth, the medium LOE and high LOE were equally preferred among the conditions.

5.3 Adequacy of explanation

The adequacy explanation is defined as the information provided by the robot should be clear and precise [13]. As aforementioned (section 5.1), the information provided in the '*without time limit*' condition can be long enough. This concurs with our result that a high level of clarity with dynamic pattern explanation was preferred. However, the high or low level of clarity did not play any role when there was a limit of time. This suggests that participants with a brief explanation in case of '*with time limit*' would be able to complete the task.

5.4 Trust

The trustor could only rely upon the trustee if its expectation is matched with the action performed by the trustee. [9, 17]. The explanation provided by the robot would increase the trust of the trustee in it [8]. Indeed high or medium LOEs have been trusted more compared to low LOE in both conditions. This reflects that users trusted the dynamic explanation pattern more compared to the static pattern. The high or low level of clarity does not

have any effect on the trust of the participants. This suggests that participants expect a more dynamic pattern of explanation in both time conditions from the robot.

6 CONCLUSION AND FUTURE WORK

We have proposed three LOEs to examine a communicative interaction between humans and robots. The LOEs was based on clarity and a pattern of explanations. We devised two levels for each of the parameters. We compare the LOEs in two conditions with two groups namely 'with time limit' and 'without time limit'.

It was illustrated that high LOE was preferred compared to the medium and low LOE in case of completion time and adequacy of explanation in the 'without time limit' condition. Further, fluency of interaction and trust was similar in the case of medium and high LOEs. In the case of the 'with time limit' condition, it was found that high and medium LOEs were similar and preferred more compared to the low LOE. It was found that the pattern of explanation played an important role in affecting the results. The clarity of explanation did affect some of the variables in the 'without time limit' condition. The need for justification of an explanation of robotic actions should also be taken into consideration for the LOEs. Time limitation is not the only factor to impose emergency situations. Therefore, different modalities like alarms need to be considered to simulate emergency situations.

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A QUESTIONS OF THE FINAL QUESTIONNAIRE

Table 5. Final Questionnaire - Questions by measures

Measure	Question	Reference
Human-oriented - Fluency of interaction	I felt the information provided by the robot was at the right time.	[11]
	I felt like the robot was committed to success.	
Adequacy of explanation	The robot's explanations were sufficient and sufficiently detailed for me to do my task.	[13]
	The robot's explanations were satisfactory.	
	The explanation is actionable, and I felt the robot and I were a good team.	
Trust	I felt stressed, worried or had doubts when the robot gave instructions.	[13]
	I was confident in the robot's instructions.	
	My trust in the robot and its abilities was high.	

B THE ROBOT'S EXPLANATIONS TO THE USER ALONG THE TASK IN EACH ONE OF THE LEVELS OF EXPLANATION

Table 6. The robot's explanations to the user in each of the levels of explanation

Level of Explanation	Explanations from the robot
High	<p>A very detailed explanation regarding the passage of the obstacle - each movement that the participant had to perform to pass the obstacle was detailed separately:</p> <ol style="list-style-type: none"> 1. "Turn left 90 degrees" 2. "Move forward" 3. "Stop and turn right 90 degrees" 4. "Move forward" 5. "Stop and turn right 90 degrees" 6. "Move forward" 7. "Stop and turn left 90 degrees" 8. "Move forward" <p>After passing the obstacle: "You passed the obstacle, I'm continue to patient" When reached the patient: "I'm in the patient's room, check patient's metrics" When the participant has finished giving appropriate treatment to the patient: "On the way to the next patient's room"</p>
Medium	<p>A partially detailed explanation regarding the passage of the obstacle - an explanation that combined between movements that need to be done:</p> <ol style="list-style-type: none"> 1. "Turn left and move forward" 2. "Stop, turn right and move forward" 3. "Stop, turn right and move forward" 4. "Stop, turn left and move forward" <p>After passing the obstacle: "You passed the obstacle, I'm continue to patient" When reached the patient: The robot gave no explanation. When the participant has finished giving appropriate treatment to the patient: "On the way to the next patient's room"</p>
Low	<p>A single explanation of all the movements that need to be done to pass the obstacle together:</p> <ol style="list-style-type: none"> 1. "Turn left, then turn right and then right again and finally turn left" <p>After passing the obstacle: "You passed the obstacle" When reached the patient: The robot gave no explanation. When the participant has finished giving appropriate treatment to the patient: "On the way to the next patient's room"</p>

Chapter 5. Summary and Conclusions

In recent years, we have witnessed an increase in the shortage of caregivers compared to the older population which is growing at a high rate. In parallel, robotic systems are penetrating into many non-industrial environments with increasing interaction with humans. The Covid-19 pandemic emphasized the need to use assistive robots and accelerated their entry into our lives. These robots are becoming more and more autonomous and their use as a solution to the healthcare system is increasing as well as their use by non-professionals and bystanders. This highlights the importance of improving human-robot interaction. Some of the critical factors in human-robot interaction are the feedback and the way that the robot communicates with the user. Creating a successful and understandable interaction is a challenging task.

In this thesis, we focused on two main aspects of human-robot interaction, the **way of interaction** and the **user's understanding of the robot**. The research was performed on a mobile robotic telepresence system.

In the first study, we examined *how* the feedback and explanations from the robot should be communicated to the user by designing two different interaction modes (proactive and reactive), and evaluating their influence on performance and the user's perception with two groups, technological and non-technological. The main result from this study was that *the proactive interaction mode was the preferred mode and enhanced performance, understanding of the robot by the users, and reduced workload*. Moreover, the results *emphasized the importance of understanding the robot by the user*. We found that the user's understanding of the robot affected all the other dependent variables that were examined in the experiment. Participants completed the task in a shorter time with better performance in the secondary task, were more satisfied with the interaction with the robot, were more aware of the situations in the environment, and the workload on them was lower when they understood the robot better. In addition, from the video analyses we conducted and the users' responses, an interesting finding emerged. It showed that there are also benefits to the reactive interaction mode. Participants did like in a certain way the ability to control the user interface while performing the task and the possibility to use certain elements only at appropriate moments. This finding should be examined in future work by applying a hybrid model that can be considered a proactive-reactive mode where most of the basic elements and feedback are 'pushed' to the user and some additional is allowed for 'pulling'.

On the whole, the first study highlights the potential of improving the interaction between a remote operator and robots by using the most appropriate interaction mode but it still has several limitations. This experiment examined a specific scenario of a telenursing task in which we tried to simulate a hospital environment but in practice was conducted under laboratory conditions and not with caregivers. In order to generalize these conclusions, additional experiments must be performed to examine more interaction modes (e.g. combination of proactive and reactive modes) in different tasks and environments and with different users. Caregivers can be divided into adults and young people when our hypothesis is that over time young caregivers will adapt to technology and their performance will be comparable to the technological population that was tested by us. In contrast, the older population of caregivers can have both resistance to accepting the new technology and difficulties in adapting to it, and these are things that need to be examined in the future.

The findings from the first experiment combined with the literature showed the importance of examining ways to improve the user's understanding of the robot. One aspect that may improve understanding is the **explanation that the robot gives to the user**. Accordingly, in the second study, we focused on *what* information should be communicated to the user? and *when* it should be communicated to him? in order to improve understanding. Based on these two questions we designed levels of explanation based on clarity and explanation patterns. We defined two levels of clarity (high and low) and two explanation patterns (static and dynamic). Accordingly, three levels of explanation were designed (high, medium, and low) and examined with two different groups, representing two conditions related to time criticality, with and without a time limit. We hypothesized that high LOE would be preferred in the 'without time limit' group and medium LOE in the 'with time limit' group. It was found from this study *that high LOE led to shorter completion time compared to the medium and low LOEs and was preferred in case of the adequacy of explanation in the 'without time limit' group. Further, fluency of interaction and trust was similar in the case of medium and high LOEs. In the 'with time limit' group, it was found that high and medium LOEs were similar and preferred more compared to the low LOE. It was found that the pattern of explanation played an important role in affecting the results. The clarity of explanation did affect some of the variables in the 'without time limit' group. Hence, our study concurs with previous research that a brief and precise explanation would be enough for time-limited conditions.*

Despite these findings, the need for justification of an explanation of robotic actions should also be taken into consideration. In addition, the time limit is not the only factor that is important

for time-critical tasks. Therefore, different modalities like alarms should be considered to simulate emergency situations.

It would also be interesting to examine aspects of usability in future studies in our research area and examine their contribution.

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Appendices

Appendix A – Study 1

A.1 BGU ethical committee



Ben-Gurion University of the Negev ~ Human Subjects Research Committee

Application for Approval to Use Humans as Subjects in Empirical Study

I. General

Name of Research Project: Level of Interaction in Mobile Robotic Telepresence for elderly care and medical needs .The experiment will take about an hour.

To which agency is the proposal being submitted (or has been submitted): None

Principal Investigator/s (or academic supervisor/s):

Name: Yael Edan	Name:
Department: IE&M	Department:
Academic position: Prof	Academic position:
University Telephone: 08-6472232	University Telephone:
Mobile Phone: 052-3683931	Mobile Phone:
University Email: yael@bgu.ac.il	University Email:
Other Email:	Other Email:

Name(s) of those conducting the research (if different from above):

Name: Omer Keidar	Name:
Department: IE&M	Department:
Academic position: BSc/MSc student	Academic position:
University Telephone:	University Telephone:
Mobile Phone: 050-8564583	Mobile Phone:
Email: omerkei@post.bgu.ac.il	Email:



Application for Approval to Use Humans as Subjects in Empirical Study

II. Consent to Participate

1. Are the subjects able to legally consent to participate in the research? ☒ Yes / ☐ No

If you answered 'No' to question 1, complete section IIb

2. Will the subjects be asked to sign a consent form? ☒ Yes / ☐ No

If you answered 'No' to question 2, explain here:

IIb: Subjects who cannot legally consent (minors, mentally incapacitated, etc.):

3. Will the subject's legal guardian be asked to sign a consent form? ☐ Yes / ☐ No

If you answered 'No', to question 3, please explain here:

4. Will the subject be asked to give oral consent? ☐ Yes / ☐ No

5. Are the instructions appropriate to the subjects' level of understanding? ☐ Yes / ☐ No

Comments: In the case of minors - they will be asked to give oral consent, whereas their parents will be asked to sign a consent form.

6. If informed consent forms will be signed, how will the informed consent forms be stored to ensure confidentiality? All signed forms will be saved in a locked cabinet.

III. Discomfort:

7. Will the participants be subjected to physical discomfort? ☐ Yes / ☒ No

8. Will the participants be subjected to psychological discomfort?: ☐ Yes / ☒ No

If you answered 'Yes' to question 7 or 8, add here a detailed explanation of the circumstances:

IV. Deception

9. Does the research involve deceiving the subjects? ☐ Yes / ☒ No

10. Is the decision on the part of the subject to participate in the study based on deception?

(For example, if they are informed of their participation only after the event.) ☐ Yes / ☒ No



Application for Approval to Use Humans as Subjects in Empirical Study

If you answered 'Yes' to question 9 or 10, add here a detailed explanation why deception is necessary:

V. Feedback to the Subject

Note: Although feedback to the subject is recommended for *all* studies, it is required for studies that involve discomfort or deception. Feedback entails providing the subject, upon completion of the experiment, explanation of the experiment and its aims.

11. Will the subjects be provided with post-experiment oral feedback? ☒ Yes / ☐ No

12. Will the subjects be provided with post-experiment written feedback? ☐ Yes / ☒ No

If you answered 'No' to both questions 11 and 12, explain here:

VI. Compensation for Participation

13. Will the subjects receive compensation for participation? ☒ Yes / ☐ No

Detail here the type and amount of compensation: A bonus point in an automation course.

If you answered 'No' to question 13, explain the basis for participation:

VII. Privacy:

14. Will audio and/or visual recordings be made of the subjects? ☒ Yes / ☐ No

a. If yes, are they informed of this fact in the informed consent form? ☒ Yes / ☐ No

15. Will the data collected (apart from the informed consent form) contain identifying details about the subjects? ☒ Yes / ☐ No

a. If the data contains identifying details, please answer here: (1) What steps will you take to ensure the confidentiality of the information? (2) How will the data be stored? (3) What will be done with identifying information or recordings of the subjects at the end of the research? Video recordings of the participants will be stored on BGU computer systems. Data can be accessed only by authorized personnel who have personal passwords to the data.



Application for Approval to Use Humans as Subjects in Empirical Study

VIII. Withdrawal from the Study:

16. Will subjects be informed that they may withdraw from the study at any time? ☒ Yes / ☐ No
17. Will the subjects' compensation for participation be affected if they withdraw from the study before its completion? ☐ Yes / ☒ No
- a. If yes, are they informed of this fact in the informed consent form? ☐ Yes / ☒ No

IX. Research Equipment

18. Does the research entail the use of equipment other than standard equipment, such as computers, video recording equipment? ☒ Yes / ☐ No
19. If yes, does the equipment being used meet safety standard for use with human subjects? ☒ Yes / ☐ No

Please specify which standards (include documentation where appropriate): The mobile robot that we use, WYCA, has a built-in system that deals with this situation and prevents the possibility of collision with objects and with the user himself.

Signatories:

Name: Yael Edan Position: Professor

Signature: Yael Edan Date: _____

Name: _____ Position: _____

Signature: _____ Date: _____



Application for Approval to Use Humans as Subjects in Empirical Study

This section is to be filled out by a member of the Human Subjects Research Committee only

Decision of the Committee:

Note: The decision of this committee pertains only to ethical considerations involved in the conduct of the research.

Request Number:

Request Sub-Number:

Title of Research Project:

Principal Investigator/s:

Approval for research:

☒ Granted / ☐ Denied

Comments to the researcher in the event that application has been denied:

some small comments of typos and few that might be improved

Signature of committee:

Name: Raziel Riemer

Signature: Raziel

Date:

A.2 Explanation form for the subject

טופס הסבר לנבדק

נושא המחקר: השפעת רמות אינטראקציה שונות על רובוטים בשליטה מרחוק.

*גוף השאלון מנוסח בלשון זכר מטעמי נוחות אך מכוון לשני המינים.

מטרת העל של הפרויקט הינה לבחון את השפעת רמות האינטראקציה השונות על היבטיות שונים של האינטראקציה בין האדם לרובוט.

במסגרת המחקר תידרש לבצע משימות ניווט עם הרובוט באמצעות ממשק אינטרנטי שבעזרתו תשלוט ברובוט. במשימות אלו תידרש בין היתר להעביר תפוצים ממקום למקום בין שני חללי החדר השונים בהם מתבצע הניסוי ובנוסף תידרש להבחין בפרטים שונים אשר מופיעים בחלל החדר (במקום אליו תישלח על-פי בקשת המטופל), עליהם תשאל בסוף הניסוי.

פירוט מהלך הניסוי :

הינך נמצא בחדר השליטה ואתה מתבקש להעביר תרופה לחדר המטופל. שליחת הרובוט לחדר המטופל תהיה באופן אוטומטי, על-ידי כפתור המופיע בממשק המשתמש. לאחר מכן תתבקש להכניס קוד כדי שהרובוט יוכל להמשיך בדרכו ולהכנס לחדר המטופל. בחדר המטופל תשלוט ברובוט באופן ידני ותצטרך להגיע למטופל, לתת לו את התרופה, לקחת מדדים (אותם תזין בממשק המשתמש הראשי) ולבצע משימה נוספת על פי בקשת המטופל – המשימה הנוספת תהיה לנווט את הרובוט לאחד מהאיזורים בחלל החדר הנוסף ולאחר מכן החזרת הרובוט לחדר השליטה. במהלך המשימה תבצע גם משימה משנית, כלומר מענה על מספר שאלות על נתונים שיוצגו לך במסך מחשב נוסף.

המטרה היא לבצע את המשימות השונות בזמן הקצר ביותר, בהספק הטוב ביותר (מענה על כמה שיותר שאלות) ובדיוק הגבוה ביותר (מענה נכון על השאלות במשימה הראשית והמשנית) כל זאת תוך ערנות לסביבה.

בתחילת הניסוי תתבקש לענות על שאלון מקדים. לאחר מכן תבצע את הניסוי בפעם הראשונה ברמת אינטראקציה אחת, תמלא שאלון לאחר ניסוי ואז תחזור על ביצוע המשימה ברמת אינטראקציה נוספת ותמלא שוב שאלון. לאחר סיום שתי החזרות על הניסוי, תמלא שאלון מסכם קצר.

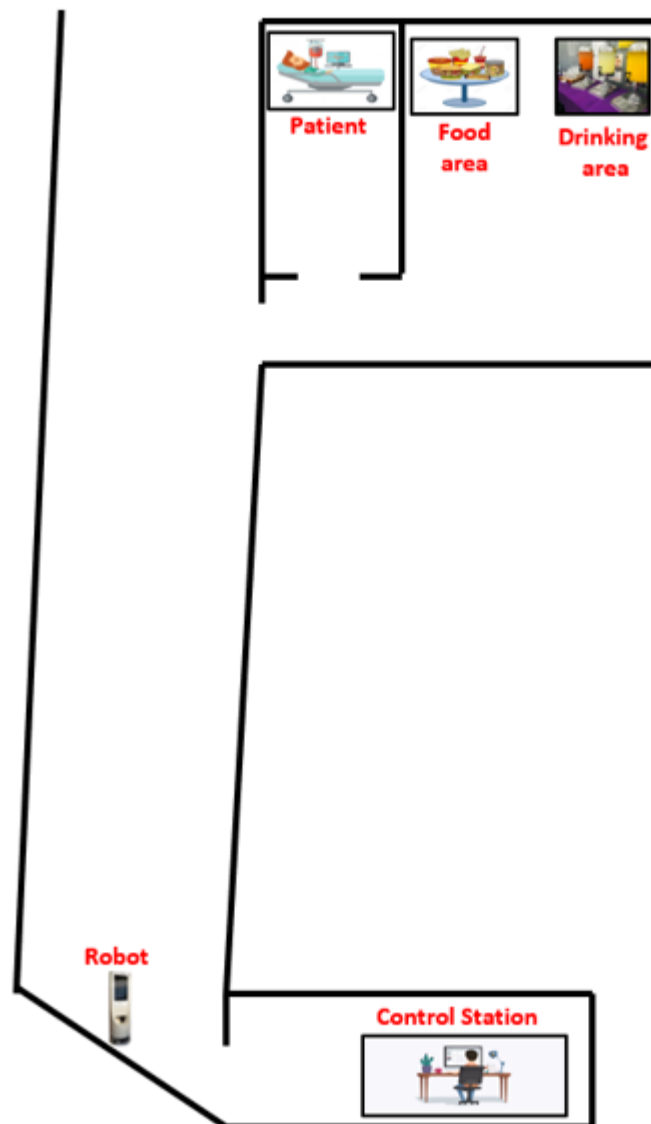
לא מתבצעת שמירה של הפרטים המזהים של הנבדקים. כל נבדק מקבל מספר נבדק אשר מופרד מפרטי הנבדק.

במהלך הניסוי תתבצע הקלטה של ממשק המשתמש בו תיעזר לשליטה ברובוט על מנת שנוכל לבצע ניתוחים סטטיסטיים בהמשך. הקלטות אלו ישמרו בתקיה מאובטחת עם סיסמא.

כל פרסום שיצא מהנתונים שייאספו בניסוי, יכללו אך ורק נתונים כוללים ולא ניתן יהיה לקשר את הנתונים לפרטים האישיים של הנבדק בשום צורה.

אם מכל סיבה שהיא הנך חש שלא בנוח, בבקשה עצור את הניסוי ועורך הניסויים ייגש אליך באופן מידי. בכל עת ובכל שלב תוכל, אם תרצה, להפסיק את השתתפותך במחקר. במידה ורצונך כי הניסוי ייפסק, תשוחרר מהניסוי ללא התחייבות.

תיאור מרחב הניסוי :



A.3 Consent form for the subject

טופס הסכמת נבדק

נושא המחקר: השפעת רמות אינטראקציה שונות על רובוטים בשליטה מרחוק.

נבדק יקר,

בבקשה קרא את דף ההסבר באשר לניסוי. במידה ויש שאלות, אשמח לענות.

בבקשה וודא כי הנך מבין היטב את שלבי המחקר.

להזכירך, המחקר עוסק ברמות אינטראקציה המשפיעות על האינטראקציה בין האדם לרובוט. במהלך הניסוי תידרש לנווט את הרובוט באמצעות ממשק אינטרנטי ולבצע משימת העברת תרופות, לקיחת מדדים וכיו. משך הניסוי כחצי שעה. אני החתום מטה:

- א. מצהיר/ה בזאת כי אני מסכים/ה להשתתף בניסוי, כמפורט במסמך המפרט את חלקי הניסוי.
ב. מצהיר שהוסבר לי בפירוט כל חלקי הניסוי והסכמתי ליטול בו חלק לאחר שנענו כל שאלותיי לגבי כל אחד מחלקי הניסוי.

ג. מצהיר בזאת כי הוסבר לי על-ידי החוקר/ת: עומר קינדר

- 1) כי אני חופשי לבחור שלא להשתתף בניסוי וכי אני חופשי להפסיק בכל עת את השתתפותי בניסוי מכל סיבה שהיא.
- 2) במידה ואשלים את הניסוי עד לסופו, אהיה זכאי לנקודת בונוס לציון הסופי בקורס אוטומציה.
- 3) במידה ואפסיק את הניסוי לפני סופו, לא אהיה זכאי לנקודת הבונוס לציון הסופי בקורס.
- 4) במידה ואני חש ברע או באי נוחות במהלך הניסוי חובה עלי לדווח לנסייך על מנת להפסיק את הניסוי.
- 5) מובטח שזהותי האישית תשמר סודית על-ידי כל העוסקים והמעורבים במחקר ולא תפורסם בכל פרסום כולל בפרסומים מדעיים.
- 6) מובטח כי גם אם אשתתף בניסוי - תהיה באפשרותי לבקש להפסיק השתתפותי במחקר עד 5 ימי עסקים מסיום הניסוי. במקרה זה, כל הנתונים אודותיי יימחקו.
- 7) מובטח כי באפשרותי לבקש, עד שבוע ימים לאחר תום הניסוי, לצפות בנתונים שנאספו לגביי בניסוי.
- 8) מובטחת לי נכונות לענות לשאלות שיועלו על-ידי.
- 9) **במהלך הניסוי החוקרים יצלמו תמונות וסרטונים לצורכי מחקר בלבד** (לא יצולמו תמונות של הנבדקים עצמם). במידה ואתה מאשרת זאת, חתום כאן: _____
- 10) במידה וייערך ניסוי המשך, האם תהיה מעוניין להשתתף בו? כן / לא (במידה ותאשר, יכול להיות שנפנה אליך בהמשך)

שם פרטי ומשפחה:	ת.ז.:
חתימה:	אימייל:

*הצהרה זו הינה סודית ואינה ניתנת להעברה או שימוש לצורך שום דבר או גורם אחר פרט לצורכי מחקר זה.

תאריך _____ חתימת מעביר הניסוי _____

A.4 Preliminary questionnaire

סעיף 1 מתוך 3

⋮ ✕ Pre questionnaire-Telenursing

*השאלון מנוסח בלשון זכר מטעמי נוחות אך פונה לשני המינים

* Participant's Number

טקסט של תשובה קצרה

* גיל (age)

טקסט של תשובה קצרה

* מגדר (gender)

זכר ☐

נקבה ☐

* האם יש לך ניסיון קודם עם הפעלת רובוטים ?

כן ☐

לא ☐



אנא ציין את מידת הסכמתך כלפי כל אחד מהמשפטים הבאים:
1-לא מסכים כלל, 2-לא מסכים, 3-נייטרלי, 4-מסכים, 5-מסכים מאוד

1. אני מצליח ללמוד להשתמש במוצרי ושירותי היי-טק חדשים ללא עזרה מאחרים *

	5	4	3	2	1	
מסכים מאוד	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	לא מסכים כלל

2. נדמה לי שאני נתקל בפחות בעיות בהפעלת טכנולוגיה מאשר אנשים אחרים. *

	5	4	3	2	1	
מסכים מאוד	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	לא מסכים בכלל

3. אנשים אחרים באים אליי לקבלת ייעוץ על טכנולוגיות חדשות *

	5	4	3	2	1	
מסכים מאוד	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	לא מסכים כלל

4. אני נהנה ללמוד להשתמש בטכנולוגיות חדשות *

	5	4	3	2	1	
לא מסכים בכלל	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	מסכים מאוד

⋮ ✕ NARS



אנא ציין את מידת הסכמתך כלפי כל אחד מהמשפטים הבאים:
1-לא מסכים כלל, 2-לא מסכים, 3-נייטרלי, 4-מסכים, 5-מסכים מאוד

5. הייתי מרגיש לא בנוח אם היה ניתן לי תפקיד בו הייתי צריך להשתמש ברובוטים *

	5	4	3	2	1	
מסכים מאוד	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	לא מסכים כלל

6. הפעלת רובוט בסביבה שיש בה אנשים הייתה גורמת לי לאי נוחות *

	5	4	3	2	1	
מסכים מאוד	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	לא מסכים כלל

7. הייתי שונא את הרעיון שרובוטים או אינטליגנציות מלאכותיות היו מפעילים שיקול דעת לגבי דברים. *

	5	4	3	2	1	
מסכים מאוד	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	לא מסכים כלל

8. עצם העמידה מול רובוט גורמת לי למתח *

	5	4	3	2	1	
מסכים מאוד	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	לא מסכים כלל

A.5 Post-trial questionnaire

סעיף 1 מתוך 4

⋮ ×

Post trial questionnaire - חום

*השאלון מנוסח בלשון זכר מטעמי נוחות אך מופנה לשני המינים

* Participant's Number

טקסט של תשובה קצרה

צבע הרצה(חום) *

טקסט של תשובה קצרה

אחרי סעיף 1 המשך לסעיף הבא

סעיף 2 מתוך 4

⋮ ×

אנא ציין את מידת הסכמתך עם האמירות הבאות:

1- לא מסכים כלל
2- לא מסכים
3- ניטרלי
4- מסכים
5- מסכים מאוד

1. הבנתי את הרובוט היטב *

5 4 3 2 1

מסכים מאוד ☐ ☐ ☐ ☐ ☐ לא מסכים כלל

2. הצורה בה עבר המידע מהרובוט הייתה מובנת לי *

	5	4	3	2	1	
לא מסכים כלל	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	מסכים מאוד

3. הייתי מרוצה מהאופן שבו הרובוט תיקשר איתי *

	5	4	3	2	1	
לא מסכים כלל	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	מסכים מאוד

4. כמות המידע שהועברה אלי מהרובוט הייתה מספקת *

	5	4	3	2	1	
לא מסכים כלל	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	מסכים מאוד

5. במהלך הניסוי, הרגשתי שאני יכול לסמוך על הרובוט *

	5	4	3	2	1	
לא מסכים כלל	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	מסכים מאוד

6. אני יכול לסמוך על המידע שמספק הרובוט *

	5	4	3	2	1	
לא מסכים כלל	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	מסכים מאוד

7. היה לי נוח להבין את המידע שקיבלתי מהרובוט בצורה בה הוא העביר לי את המידע *

	5	4	3	2	1	
לא מסכים כלל	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	מסכים מאוד

8. הרגשתי בנוח לתפעל את הרובוט *

	5	4	3	2	1	
מסכים מאוד	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	לא מסכים כלל

9. הייתי רוצה להשתמש במערכת זאת בתדירות גבוהה *

	5	4	3	2	1	
מסכים מאוד	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	לא מסכים כלל

10. המערכת הייתה קלה לשימוש *

	5	4	3	2	1	
מסכים מאוד	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	לא מסכים כלל

11. המערכת הייתה מסורבלת לשימוש *

	5	4	3	2	1	
מסכים מאוד	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	לא מסכים כלל

Assessment of Task load

תיאור (אופציונלי)

12. עומס מנטלי: עד כמה המשימה דרשה מאמץ מנטלי (מחשבה, ריכוז)? *

	5	4	3	2	1	
גבוה מאוד	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	נמוך מאוד

13. עומס פיזי: עד כמה המשימה דרשה מאמץ פיזי? *

	5	4	3	2	1	
גבוה מאוד	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	נמוך מאוד

14. עומס בזמן: עד כמה קצב המשימה דרש ממך לעבודה מהירה? *

	5	4	3	2	1	
דרש מאוד	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	לא דרש כלל

15. ביצועים: עד כמה מוצלח הצלחת לבצע את המשימה? *

	5	4	3	2	1	
הצלחה טוטאלית	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	כשלון מוחלט

16. מאמץ: עד כמה קשה היה עליך לעבוד בכדי לבצע את המשימה בצורה שבה השלמתה אותה? *

	5	4	3	2	1	
הרבה מאוד	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	מעט מאוד

17. עד כמה המשימה גרמה לך להיות מיואש ומתוסכל? *

	5	4	3	2	1	
הרבה מאוד	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	כלל לא

Environmental awareness

תיאור (אופציונלי)

18. מורכבות האינטראקציה: האם האינטראקציה עם הרובוט הייתה מורכבת (הכילה רכיבים רבים או הייתה פשוטה וישירה)? *

	7	6	5	4	3	2	1	
כלל לא	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	במידה רבה מאוד

19. מוקד תשומת הלב: האם התרכזת רק בהיבט אחד של האינטראקציה (למשל מצלמה אחת) - נמוך או שהתמקדת בהיבטים רבים של האינטראקציה עם הרובוט (גבוה)? *

	7	6	5	4	3	2	1	
נמוך מאוד	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	גבוה מאוד

20. כמות המידע שמעבר: כמה מידע הצלחת לצבור על הסביבה בה ניווט הרובוט? *

	7	6	5	4	3	2	1	
קצת מאוד	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	הרבה מאוד

21. בעת ביצוע המשימה, תשומת ליבי הייתה ממוקדת במצלמות הרובוט? *

	7	6	5	4	3	2	1	
כלל לא	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	במידה רבה מאוד

22. באמצעות המידע שקיבלתי הייתי מודע לפעולת הרובוט? *

	5	4	3	2	1	
לא מסכים כלל	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	מסכים מאוד

23. במהלך המשימה, כאשר שלטת ברובוט בצורה ידנית, אילו פרטים זיהית במרחב? *

- ☐ פלפל אדום
- ☐ קפה שחור
- ☐ גס קפה
- ☐ פלפל צהוב
- ☐ צלחת
- ☐ ארונית
- ☐ שעון
- ☐ וילון
- ☐ מזלגות
- ☐ מכונת קפה
- ☐ חסיף
- ☐ פלפל ירוק
- ☐ שולחן
- ☐ לוח
- ☐ מקרן
- ☐ כיסאות

A.6 Final questionnaire

Final questionnaire - Telenursing

תיאור טופס

תשובה קצרה

Participant's Number

טקסט של תשובה קצרה

✕

התאמה אישית של טקסט שגיאה

מספר

הוא מספר

חובה

1. חשתי בהבדל בין ההרצות השונות *

☐ כן

☐ לא

☐ לא יודע

2. במידה וחשתי בהבדל בין ההרצות השונות, מה לדעתך היו ההבדלים?

טקסט של תשובה ארוכה

3. איזו הרצה העדפת מבין השתיים? *

☐ חומה

☐ סגולה

☐ שניהם באותה מידה

Appendix B – Study 2

B.1 BGU ethical committee



Ben-Gurion University of the Negev ~ Human Subjects Research Committee

Application for Approval to Use Humans as Subjects in Empirical Study

I. General

Name of Research Project: Level of Explanation in Mobile Robotic Telepresence. The experiment will take about an hour.

To which agency is the proposal being submitted (or has been submitted): None

Principal Investigator/s (or academic supervisor/s):

Name: Yael Edan	Name:
Department: IE&M	Department:
Academic position: Prof	Academic position:
University Telephone: 08-6472232	University Telephone:
Mobile Phone: 052-3683931	Mobile Phone:
University Email: yael@bgu.ac.il	University Email:
Other Email:	Other Email:

Name(s) of those conducting the research (if different from above):

Name: Omer Keidar	Name:
Department: IE&M	Department:
Academic position: MSc student	Academic position:
University Telephone:	University Telephone:
Mobile Phone: 050-8564583	Mobile Phone:
Email: omerkei@post.bgu.ac.il	Email:



Application for Approval to Use Humans as Subjects in Empirical Study

II. Consent to Participate

1. Are the subjects able to legally consent to participate in the research? ☒ Yes / ☐ No

If you answered 'No' to question 1, complete section IIb

2. Will the subjects be asked to sign a consent form? ☒ Yes / ☐ No

If you answered 'No' to question 2, explain here:

IIb: Subjects who cannot legally consent (minors, mentally incapacitated, etc.):

3. Will the subject's legal guardian be asked to sign a consent form? ☐ Yes / ☐ No

If you answered 'No', to question 3, please explain here:

4. Will the subject be asked to give oral consent? ☐ Yes / ☐ No

5. Are the instructions appropriate to the subjects' level of understanding? ☐ Yes / ☐ No

Comments: In the case of minors - they will be asked to give oral consent, whereas their parents will be asked to sign a consent form.

6. If informed consent forms will be signed, how will the informed consent forms be stored to ensure confidentiality? All signed forms will be saved in a locked cabinet.

III. Discomfort:

7. Will the participants be subjected to physical discomfort? ☐ Yes / ☒ No

8. Will the participants be subjected to psychological discomfort?: ☐ Yes / ☒ No

If you answered 'Yes' to question 7 or 8, add here a detailed explanation of the circumstances:

IV. Deception

9. Does the research involve deceiving the subjects? ☐ Yes / ☒ No

10. Is the decision on the part of the subject to participate in the study based on deception?

(For example, if they are informed of their participation only after the event.) ☐ Yes / ☒ No



Application for Approval to Use Humans as Subjects in Empirical Study

If you answered 'Yes' to question 9 or 10, add here a detailed explanation why deception is necessary:

V. Feedback to the Subject

Note: Although feedback to the subject is recommended for *all* studies, it is required for studies that involve discomfort or deception. Feedback entails providing the subject, upon completion of the experiment, explanation of the experiment and its aims.

11. Will the subjects be provided with post-experiment oral feedback? ☒ Yes / ☐ No

12. Will the subjects be provided with post-experiment written feedback? ☒ Yes / ☐ No

If you answered 'No' to both questions 11 and 12, explain here:

VI. Compensation for Participation

13. Will the subjects receive compensation for participation? ☒ Yes / ☐ No

Detail here the type and amount of compensation: A bonus point in automation course.

If you answered 'No' to question 13, explain the basis for participation:

VII. Privacy:

14. Will audio and/or visual recordings be made of the subjects? ☐ Yes / ☒ No

a. If yes, are they informed of this fact in the informed consent form? ☐ Yes / ☐ No

15. Will the data collected (apart from the informed consent form) contain identifying details about the subjects? ☐ Yes / ☒ No

a. If the data contains identifying details, please answer here: (1) What steps will you take to ensure the confidentiality of the information? (2) How will the data be stored? (3) What will be done with identifying information or recordings of the subjects at the end of the research?



Application for Approval to Use Humans as Subjects in Empirical Study

VIII. Withdrawal from the Study:

16. Will subjects be informed that they may withdraw from the study at any time? ☒ Yes / ☐ No
17. Will the subjects' compensation for participation be affected if they withdraw from the study before its completion? ☒ Yes / ☐ No
- a. If yes, are they informed of this fact in the informed consent form? ☒ Yes / ☐ No

IX. Research Equipment

18. Does the research entail the use of equipment other than standard equipment, such as computers, video recording equipment? ☒ Yes / ☐ No
19. If yes, does the equipment being used meet safety standard for use with human subjects? ☒ Yes / ☐ No

Please specify which standards (include documentation where appropriate): The mobile robot that we use, WYCA, has a built-in system that deals with this situation and prevents the possibility of collision with objects and with the user himself.

Signatories:

Name: Yael Edan Position: Professor

Signature: Yael Edan Date: _____

Name: _____ Position: _____

Signature: _____ Date: _____



Application for Approval to Use Humans as Subjects in Empirical Study

This section is to be filled out by a member of the Human Subjects Research Committee only

Decision of the Committee:

Note: The decision of this committee pertains only to ethical considerations involved in the conduct of the research.

Request Number:

Request Sub-Number:

Title of Research Project:

Principal Investigator/s:

Approval for research:

☒ Granted / ☐ Denied

Comments to the researcher in the event that application has been denied:

Signature of committee:

Gilad Ravid

Name: _____

Signature: _____

גילד ראביד

Date: _____

17/7/2022

B.2 Explanation form for subject

טופס הסבר לנבדק

נושא המחקר: בחינת השפעת רמות הסבר שונות על הבנת רובוט הנשלט מרחוק במשימת ניווט במרחב מורכב.

*גוף השאלון מנוסח בלשון זכר מטעמי נוחות אך מכון לשני המינים.

מטרת העל של הפרויקט הינה לבחון את השפעת רמות הסבר שונות על ההבנה של המשתמש השולט ברובוט מרחוק.

**הניסוי מדמה מצב אמיתי, אך זהו ניסוי ואין שום משמעות אמיתית לנתונים והפעולות שתבצע במלך הניסוי (הכל מסומלץ).

במסגרת הניסוי תידרש לבצע משימות ניווט עם רובוט אשר נשלט מרחוק באמצעות ממשיק ייעודי שנבנה ובה תצטרך לעבור מכשולים המפוזרים בחדר מרוחק, להגיע למוניטורים שמפוזרים בחדר ולדווח על מדד חריג בכל אחד מהם באמצעות מקרא מדדים תקינים אשר מופיע מולך. המוניטורים אליהם תגיע במהלך הניסוי הם דפים אשר עליהם מודפסים מדדים – לחץ דם, חום גוף ודופק ותצטרך לדווח על מדד אחד חריג בהם על-ידי לחיצה על הכפתור המתאים בממשק המשתמש אשר מופיע מולך. ניווט הרובוט בין המכשולים ייעשה על-ידי חצי המקלות ובהתאם להוראות אשר תקבל מהרובוט במהלך הניסוי.

פירוט מהלך הניסוי :

הינך נמצא בחדר השליטה (מרוחק מהרובוט בו תשלוט) ואתה מתבקש לבצע סיור שגרתי בחדר מורכב המכיל מכשולים (פרגודים) 31 מוניטורים (מדומים על-ידי דפים שעליהם כתובים מדדים) באמצעות רובוט הנשלט מרחוק. במהלך ניווט הרובוט תיתקל במכשולים אותם תצטרך לעבור באמצעות הוראות שתקבל מהרובוט. בכל מכשול ומוניטור אלו תגיע, תקבל רמה אחרת של הסבר לצורך מעבר המכשול ודיווח על מדד חריג במוניטור. לכל מוניטור אלו תגיע יהיו מדדים, כאשר אחד מהם יהיה חריג. בהתאם למקרא אותו תקבל בתחילת הניסוי ובעזרת הסברי הרובוט תצטרך להבין מהו המדד החריג ולדווח עליו באמצעות ממשיק המשתמש. בכל שלב במשימה במידה ולא ברור לך כיצד להתקדם, תוכל לפנות לאחראי הניסוי ולקבל הסבר שיעזור לך. (בכל מקרה לא קורה דבר במידה ולא הצלחת / דיווחת על מדד שגוי ואין פגיעה אמיתית שיכולה לקרות בכל שלב בניסוי).

לצורך הניסוי המטרה היא לבצע את המשימה, בצורה הטובה ביותר (זמן קצר ככל הניתן למעבר המכשולים, דיווח מהיר ונכון על מדד חריג בכל מוניטור, לבצע כמה שפחות תנועות שגויות שלא תואמות את ההוראות ולהיזהר כמה שאפשר מהתקלות במכשולים). לביצועים שלך כמוזן לא תהיה השפעה אמיתית על אף אדם / גורם כלשהו והכל נבדק בהקשרי הניסוי בלבד.

בתחילת הניסוי תתבקש לענות על שאלון מקדים. לאחר מכן תבצע את הניסוי ולאחריו תמלא שאלון לאחר ניסוי. לבסוף, יערך ראיון קצר שיכיל מספר שאלות.

לא מתבצעת שמירה של הפרטים המזהים של הנבדקים. כל נבדק מקבל מספר נבדק אשר מופרד מפרטי הנבדק שלו!

במהלך הניסוי תתבצע הקלטה של ממשיק המשתמש (מסך המחשב בלבד והשימוש בו על-ידי המשתתף. המשתתף לא יצולם בשום שלב בניסוי!) – אין תיעוד של פרטים מזהים של הנבדק) בו תיעזר לשליטה ברובוט על מנת שיוכל לבצע ניתוחים בהמשך. הקלטות אלו ישמרו בתקיה מאובטחת עם סיסמא במחשבי האוניברסיטה.

כל פרסום שיצא מהנתונים שייאספו בניסוי, יכללו אך ורק נתונים כוללים ולא ניתן יהיה לקשר את הנתונים לפרטים האישיים של הנבדק בשום צורה.

אם מכל סיבה שהיא הנך חש שלא בנוח, בבקשה עצור את הניסוי ועזרך הניסויים ייגש אליך באופן מידי. בכל עת ובכל שלב שיוכל, אם תרצה, להפסיק את השתתפותך במחקר. במידה ורצונך כי הניסוי ייפסק, תשוחרר מהניסוי ללא התחייבות. במידה ולא תשלים את הניסוי במלואו, לא תהיה זכאי לקבלת נקודת בוגוס בקורס אוטומציה (נקודת בוגוס תינתן רק במידה והניסוי יושלם במלואו).

פרטים ליצירת קשר :

אחראי הניסוי: עומר קידר, omerkei@post.bgu.ac.il, 0508564583

B.3 Consent form for the subject

נושא המחקר: בחינת השפעת רמות הסבר שונות על הבנת רובוט הנשלט מרחוק וכיצד זה משפר את השליטה בו.

נבדק יקר,

בבקשה קרא את דף ההסבר באשר לניסוי. במידה ויש שאלות, אשמח לענות.

בבקשה וודא כי הנך מבין היטב את שלבי המחקר.

להזכירך, המחקר עוסק ברמות הסבר שונות והשפעתן על הבנת הרובוט הנשלט מרחוק.

משך הניסוי כשעה.

אני החתום מטה:

- א. מצהיר/ה בזאת כי אני מסכים/ה להשתתף בניסוי, כמפורט במסמך המפרט את חלקי הניסוי.
ב. מצהיר שהוסברו לי בפירוט כל חלקי הניסוי והסכמתי ליטול בו חלק לאחר שנענו כל שאלותיי לגבי כל אחד מחלקי הניסוי.

ג. מצהיר בזאת כי הוסבר לי על-ידי החוקר/ת: עומר קידר

- (1) כי אני חופשי לבחור שלא להשתתף בניסוי וכי אני חופשי להפסיק בכל עת את השתתפותי בניסוי מכל סיבה שהיא.
(2) **במידה ואשלים את הניסוי עד לסופו**, אהיה זכאי לנקודת בונוס לציון הסופי בקורס אוטומציה.
(3) במידה ואפסיק את הניסוי לפני סופו, לא אהיה זכאי לנקודת הבונוס לציון הסופי בקורס.
(4) במידה ואני חש ברע או באי נוחות במהלך הניסוי חובה עלי לדווח לנסייך על מנת להפסיק את הניסוי.
(5) מובטח שזהותי האישית תשמר סודית על-ידי כל העוסקים והמעורבים במחקר ולא תפורסם בכל פרסום כולל בפרסומים מדעיים.
(6) מובטח כי גם אם אשתתף בניסוי - תהיה באפשרותי לבקש להפסיק השתתפותי במחקר עד 5 ימי עסקים מסיום הניסוי. במקרה זה, כל הנתונים אודותיי יימחקו.
(7) מובטח כי באפשרותי לבקש, עד שבוע ימים לאחר תום הניסוי, לצפות בנתונים שנאספו לגביי בניסוי.
(8) מובטחת לי נכונות לענות לשאלות שיועלו על-ידי.
(9) במהלך הניסוי החוקרים יצלמו סרטונים לצורכי מחקר בלבד **(לא יצולמו תמונות של הנבדקים עצמם, אלא אך ורק של ממשק המשתמש במהלך המשימה - צילום מסך)**. במידה ואתה מאשר/ת זאת, חתום כאן: _____
(10) במידה וייערך ניסוי המשך, האם תהיה מעוניין להשתתף בו? כן / לא
(במידה ותאשר, יכול להיות שנפנה אליך בהמשך)

שם פרטי ומשפחה:	ת.ז.:
חתימה:	אימייל:

*הצהרה זו הינה סודית ואינה ניתנת להעברה או שימוש לצורך שום דבר או גורם אחר פרט לצורכי מחקר זה.

תאריך _____ חתימת מעביר הניסוי _____

B.4 Pre-questionnaire

סעיף 1 מתוך 3

⋮ ×

Pre questionnaire - LOE

השאלון מנוסח בלשון זכר מטעמי נוחות אך פונה לשני המינים

* Participant's Number

טקסט של תשובה קצרה

* Age

טקסט של תשובה קצרה

* Gender

Male ☐

Female ☐

האם יש לך ניסיון קודם עם הפעלת רובוטים הנשלטים מרחוק? *

כן ☐

לא ☐

⋮ ✕ TAP

אנא ציין את מידת הסכמתך כלפי כל אחד מהמשפטים הבאים:
1-לא מסכים כלל, 2-לא מסכים, 3-נייטרלי, 4-מסכים, 5-מסכים מאוד

1. אני מצליח ללמוד להשתמש במוצרי ושירותי היי-טק חדשים ללא עזרה מאחרים *

	5	4	3	2	1	
מסכים מאוד	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	לא מסכים כלל

2. נדמה לי שאני נתקל בפחות בעיות בהפעלת טכנולוגיה מאשר אנשים אחרים. *

	5	4	3	2	1	
מסכים מאוד	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	לא מסכים בכלל

3. אנשים אחרים באים אליי לקבלת ייעוץ על טכנולוגיות חדשות *

	5	4	3	2	1	
מסכים מאוד	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	לא מסכים כלל

4. אני נהנה ללמוד להשתמש בטכנולוגיות חדשות *

	5	4	3	2	1	
לא מסכים בכלל	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	מסכים מאוד

אנא ציין את מידת הסכמתך כלפי כל אחד מהמשפטים הבאים:
1-לא מסכים כלל, 2-לא מסכים, 3-נייטרלי, 4-מסכים, 5-מסכים מאוד

5. הייתי מרגיש לא בנוח אם היה ניתן לי תפקיד בו הייתי צריך להשתמש ברובוטים *

	5	4	3	2	1	
מסכים מאוד	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	לא מסכים כלל

6. הפעלת רובוט בסביבה שיש בה אנשים הייתה גורמת לי לאי נוחות *

	5	4	3	2	1	
מסכים מאוד	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	לא מסכים כלל

7. הייתי שונא את הרעיון שרובוטים או אינטליגנציות מלאכותיות היו מפעילים שיקול דעת לגבי דברים. *

	5	4	3	2	1	
מסכים מאוד	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	לא מסכים כלל

8. עצם העמידה מול רובוט גורמת לי למתח *

	5	4	3	2	1	
מסכים מאוד	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	לא מסכים כלל

B.5 Post-questionnaire

Post questionnaire - LOE

*השאלון מנוסח בלשון זכר מטעמי נוחות אך פונה לשני המינים
אנא ציין את מידת הסכמתך כלפי כל אחד מהמשפטים הבאים:

* Participant's Number

טקסט של תשובה קצרה

* Order number

1	<input type="radio"/>
2	<input type="radio"/>
3	<input type="radio"/>
4	<input type="radio"/>
5	<input type="radio"/>
6	<input type="radio"/>

1. הרגשתי שההסברים שניתנו לי ע"י הרובוט ניתנו בזמן הנכון *

מסכים מאוד	מסכים	ניטרלי	לא מסכים	לא מסכים כלל	
<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	מכשול 1
<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	מכשול 2
<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	מכשול 3

2. ההסברים של הרובוט היו מספיק מפורטים כדי שאוכל לבצע את המשימה *

מסכים כלל	לא מסכים	ניטרלי	מסכים	מסכים מאוד	
<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	מכשול 1
<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	מכשול 2
<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	מכשול 3

3. הרגשתי לחוץ, מודאג או היו לי ספקות כשהרובוט נתן הוראות *

מסכים כלל	לא מסכים	ניטרלי	מסכים	מסכים מאוד	
<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	מכשול 1
<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	מכשול 2
<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	מכשול 3

4. ההסברים של הרובוט היו מספקים *

מסכים כלל	לא מסכים	ניטרלי	מסכים	מסכים מאוד	
<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	מכשול 1
<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	מכשול 2
<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	מכשול 3

5. הרגשתי שהרובוט מחויב להצלחת המשימה *

מסכים מאוד	מסכים	ניטרלי	לא מסכים	לא מסכים כלל	
<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	מכשול 1
<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	מכשול 2
<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	מכשול 3

6. האמון שלי ברובוט וביכולותיו היה גבוה. *

מסכים מאוד	מסכים	ניטרלי	לא מסכים	לא מסכים כלל	
<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	מכשול 1
<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	מכשול 2
<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	מכשול 3

7. ההסברים של הרובוט היו ניתנים לביצוע והרגשתי שהרובוט ואני צוות טוב *

מסכים מאוד	מסכים	ניטרלי	לא מסכים	לא מסכים כלל	
<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	מכשול 1
<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	מכשול 2
<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	מכשול 3

8. הרגשתי בטוח בהנחיות של הרובוט *

מסכים מאוד	מסכים	ניטרלי	לא מסכים	לא מסכים כלל	
<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	מכשול 1
<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	מכשול 2
<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	מכשול 3

Appendix C - Push and Pull Feedback in Mobile Robotic Telepresence - A Telecare Case Study

C1. **O. Keidar**, S. Olatunji and Y. Edan, Push and Pull Feedback in Mobile Robotic Telepresence - A Telecare Case Study, 2022 31st IEEE International Conference on Robot and Human Interactive Communication (RO-MAN), 2022, pp. 693-698, doi: [10.1109/RO-MAN53752.2022.9900596](https://doi.org/10.1109/RO-MAN53752.2022.9900596).

Push and Pull Feedback in Mobile Robotic Telepresence - A Telecare Case Study

Omer Keidar, Samuel Olatunji, Yael Edan

Abstract— Mobile robotic telepresence (MRP) has emerged as a possible solution for supporting health caregivers in a multitude of tasks such as monitoring, pre-diagnosis, and delivery of items. Improved interaction with the system is an important part of using such MRP systems. The current study compared two feedback types ('push' and 'pull') for controlling mobile robots via telepresence. An experimental system that represented a hospital environment was developed. A remote operator (defined as a user) teleoperated a mobile robot to deliver medication supplies to a patient and receive samples from the patient while attending to a secondary task involving medical records. The influence of the feedback types on different aspects of performance and user perception was investigated. User studies were performed with 20 participants coming from two different types of groups – users with and without technological backgrounds. Results revealed that for both user types, the 'push' feedback enhances performance, situation awareness, and satisfaction compared to the 'pull' feedback. The study highlights the potential of improving the telecare experience with MRPs through different feedback types.

I. INTRODUCTION

There is an increasing demand for health services as the aging population increases [1]. The shortage of healthcare professionals to cope with the increasing demands [2], [3] of the rising proportion of older people [1] leads to an increased need in developing solutions to assist the older adults. Assistive robots are being developed as a solution enabling to support older adults and caregivers in homes, hospitals, and care centers [4], [5], [6]. These robots can reduce workload from the caregivers by executing autonomously different tasks such as pre-diagnosis, food delivery, and monitoring while the caregivers perform other tasks [7]. A teleoperated robot can be controlled by a human operator from a distance and can perform tasks (services) as if the operator were on the spot [6]. In parallel, it can operate autonomously (e.g. navigate in known environments) and release the operator to execute other tasks.

In this study, we focused on a mobile telepresence robot which is a specific form of a teleoperated robot, commonly termed mobile robotic telepresence (MRP) [8]. MRP enables a remote user to move around and carry out tasks in a distant environment while interacting with other people in the environment through the teleoperated robot [8]. The robotic hardware for MRPs has been evolving over the years leading to improved actuators and sensors that enable users to accomplish more tasks remotely. Telecare is an example that has benefitted from the use of MRPs for home care [9], for assisting those with special needs [10], to support older adults

for activities of daily living [11], for situations when social distancing is required [12], for clinical and telemedicine applications [13] particularly when health centers were overcrowded during the COVID-19 pandemic [14]. Research in MRPs for telecare includes the development of the GiraffPlus research platform [10], the ExCITE EU project [15] which worked on several functionalities and the TERESA project [16] which focused on social navigation capabilities.

However, in all previous projects, a challenge that has lingered is the need to improve the information presented to the users. Most research focused on the video stream the users receive about the environment in order to improve situation awareness [15], [17], [18]. An observation that came to the fore was that the users became so absorbed in the video display that they ignored a lot of information on the user interface [19]. This brings several thoughts regarding the ability to control the information needed to ensure important information is not missed. We, therefore, evaluate in this study if it is beneficial for the user to have control over the information being presented.

To address this challenge, we compared two feedback types to control the information that is transmitted to the user, information that is 'pushed' to the user (proactively provided) and information that is 'pulled' (reactively provided) by the user based on demand. Finding the right feedback type holds the potential to improve human-robot communication for remotely controlled tasks.

Interaction captures control, feedback, adaptation, and communication between the human and the robot [20]. It also includes the method through which the human accesses the information provided by the robot. This method of information access can define feedback types commonly graded as 'push' (proactive), 'pull' (reactive), and coactive [21] or mutual [22], [23] (combined proactive and reactive). It delimitates the degree of control the user has over the content and structure of the information being presented in the interaction [24]. In the 'push' feedback information is continuously generated to the user even when it is not demanded [26]. The 'pull' feedback describes a time dimension of feedback where information is given only on demand [25]. The robot provides information to the human only when the information is 'pulled'. These feedbacks can be also combined in a mutual mode [27].

Studies in various fields (e.g., vehicle safety systems [27], activity tracking [28], virtual traffic light systems [29], and unmanned aerial systems [30]) have compared between 'push'

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and 'pull' feedback types. They showed that 'push' feedback increases alertness, awareness, encourages active actions, and minimizes the potential of losing information during use. In some cases, such as in activity tracking in wearables, the 'push' feedback was reported to create more positive and encouraging thoughts during use, compared to the 'pull' feedback that made the task feel more difficult and boring [28]. However, some benefits of the 'pull' feedback were also reported in these studies, for instance, the virtual light system, provided similar performance outputs to the 'push' feedback [29]. In the unmanned aerial system context, users preferred the 'pull' feedback for inquiring about certain information or expressing concerns [30]. These contributions are relevant to the specific context and cannot be generalized. There has been no explicit evaluation of 'push' and 'pull' feedback types in robotic telecare and for different types of users. The current study, therefore, sets out to examine the influence of the feedback types in this domain of telecare and identify possible insights to improve the interaction of the remote caregiver with the care recipient.

This study focuses on implementing MRP in a telecare task and comparing two different feedback types – 'push' and 'pull'. The specific objectives were to:

- Develop 'push' and 'pull' feedback types in a remote user interface of an MRP for a telecare task.
- Compare these feedback types in a telecare task with a secondary care-related task and evaluate the influence of these feedbacks on performance and user perception.
- Evaluate if the user's background influences overall performance and usability.

II. METHODS

A. Overview

The experimental setting was arranged to resemble a hospital-like environment with a MRP mission of delivering and receiving healthcare related items to and from a patient. Along with this task, the users performed a secondary task. Two different feedback types, 'push' and 'pull' were examined with two groups: one with a technological background and one without a technological background.

B. The experimental system

The system consists of a WYCA mobile robot platform, remote user interfaces, and a server-client communication architecture that used a Rosbridge WebSocket to connect to the robot operating system (ROS) platform of the robot (Figure 1). The user interfaces were programmed using HTML, JS, CSS and PHP and ran on the operator's computer.

C. User interfaces

The user interface was divided into two screens – a main task screen and a secondary task screen. The interfaces were built according to conclusions regarding workload, convenience, and desires of the users as detailed in [32]. For each feedback type ('push', 'pull'), different main and secondary task interfaces were designed.

Main task screen - the main interaction with the robot takes place through the main task screen which contains a display of three different cameras views (front, front bottom

and rear), arrows that allow manual navigation of the robot and feedback from the robot that received information only at important points along the robot's path, and status information about the start of the mission, arrival at the destination e.g. patient's room, condition along the way e.g. familiar position, facing a new corridor, malfunction, something unexpected on the way or obstacle. Combined visual and auditory feedback was included based on previous experiments [32], [33].

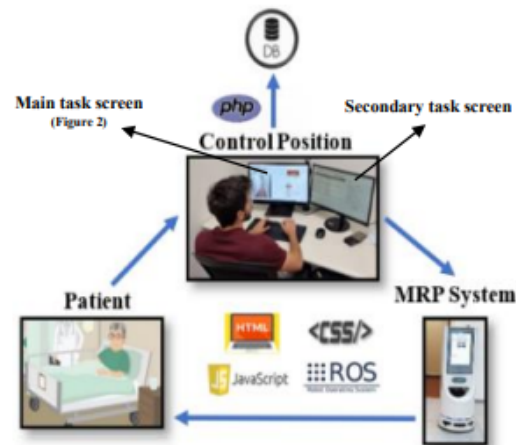


Figure 1. Schematic description of the system

Secondary task screen - the secondary task screen contains a compilation of patients' health records and some questions about them. The difference between the 'push' and 'pull' feedbacks is in the information about the patients presented to the user.

D. Implementation of the feedback types

The remote user interface indicating the various information items that can be 'pushed' or 'pulled' is presented in Figure 2. The difference between the user interfaces was the level of information and control afforded to the user.

In the main 'Push' interface, the user receives all the existing elements on the main screen directly and permanently. This means that he/she does not need to demand the various elements in the interface and he/she cannot turn them off, they are working all the time.

In the main 'Pull' interface, the user receives the main front camera only but can demand the rear camera, bottom camera, and the various feedbacks that are available in the main interface. In this interface, the user can control the various elements on the screen (turn off and on) as needed.

E. Task

The main task is to use a MRP to deliver medication with other supplies to the patient and receive samples from the patient. The user must perform in parallel a secondary task of answering questions related to information about patients he/she retrieves from online data records. This secondary task was introduced to simulate an increased workload. The robot moves autonomously in the environment but may require user involvement at a certain point (e.g., entering a room that

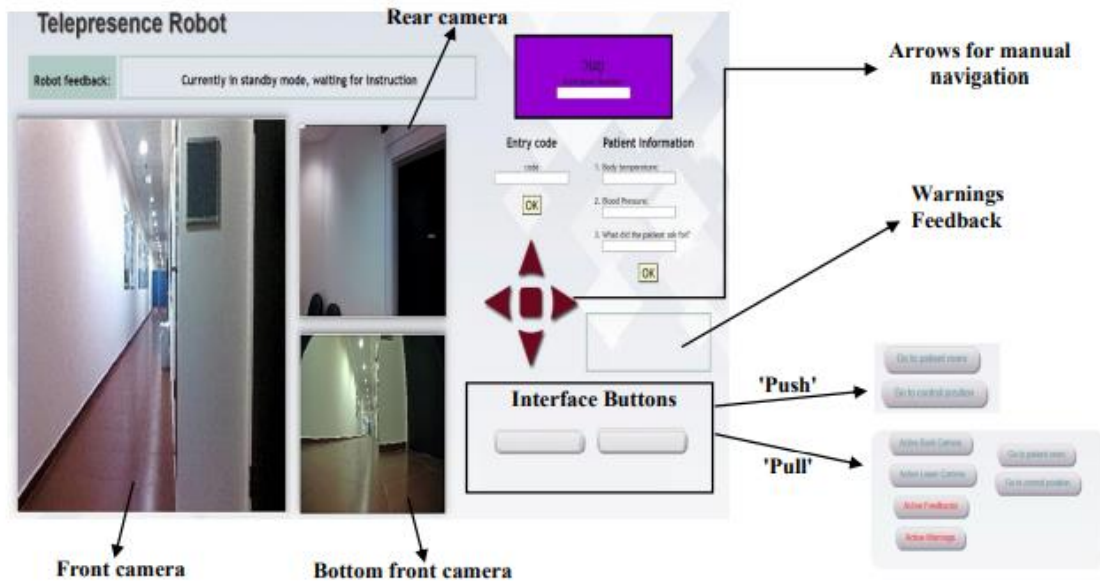


Figure 2. The remote user interface containing information elements that can be 'pushed' to the user (top) or 'pulled' by the user (bottom) depending on the experimental feedback type

requires a code, manual navigation in a complex environment). The user sends the robot automatically towards the patient's room to accomplish the main task. Along the way, a code is required to be entered by the user before continuing the task (to simulate similar scenarios in which the robot should enter a room with a code or enter an elevator, etc.). When the robot reached the patient's room, the robot switched to manual navigation mode and the user had to control it using the arrows in the interface to reach the patient (which is required when the environment is dynamic and constantly changing). Upon completion of the mission in the patient room, the robot is automatically sent back to the control position. The user is required to perform the main task in the shortest time while trying to answer as many questions as possible correctly in the secondary task.

F. Research hypotheses

Based on a previous study conducted on 'push' and 'pull' feedbacks in wearable devices [28], where the 'push' feedback seemed to produce more positive effects on users compared to the 'pull' feedback, we propose similarly:

H1: 'Push' feedback, as compared to 'pull' feedback will increase the user's situation awareness and improve user's performance.

We assume that in some cases, users require more information than the default they have been provided with. We expect that the motivation to 'pull' that information will complement their understanding of the system and environment more as they receive the information, compared to situations when all information has been provided a priori (as in the 'push' feedback) [30]. Hence, we propose:

H2: 'Pulling' information as needed compared to all information 'pushed' to the users will improve the user's understanding.

G. Participants

User studies were performed with 20 participants coming from two types of groups – users with technological background (denoted as 'Tech') and without technological background (denoted as 'Non-Tech'). The participants completed a preliminary questionnaire before starting the experiment. This preliminary questionnaire included questions on demographic information such as age, gender, etc. It also included the Technology Adoption Propensity (TAP) [34] questionnaire to assess their likelihood to embrace new technologies. They also filled out a Negative Attitude toward Robots Scale (NARS) questionnaire [35] to assess if the participants had any negative bias in their evaluation of the interaction with robots.

Gender was equally balanced in each group. All had no previous experience with robots. The 'Tech' group included 10 third-year undergraduate industrial engineering students (mean age=25.3 years, SD=1.49). The students were compensated with course credit, to commensurate with their time of participation in the experiment. The 'Non-Tech' group included 10 undergraduate nursing students (mean age=23.8 years, SD=1.68). These students were compensated with a payment of 30 Israeli shekels, to commensurate with their time of participation in the experiment. The TAP questionnaire analysis revealed a significant difference between the groups ($t=3.87$, $p=0.001$) confirming the technological difference between the groups. According to the NARS questionnaire, most of the participants did not have

negative feelings about situations and interactions with robots with similar results for both groups.

H. Experimental design

The experiment was designed as a within experiment with the feedback types as the independent variable. Each user repeated the task twice, in each of the two feedbacks. The order of execution was assigned randomly so that we had 5 who started with 'push' and 5 who started with 'pull' in each group.

I. Procedure

At the start of the experiment, after reading and signing the consent form, participants were asked to fill out the preliminary questionnaire. Following this, they were briefed on the feedback types and task. Each participant performed the task twice - in each trial they experienced a different feedback type. The order of feedback type was randomly selected. Each trial was followed by a questionnaire enquiring about the experience with the specific feedback (details on the measures are given below). After completion of the two trials, participants answered a final questionnaire in which they rated their overall experience with the robot and task.

J. Measures

The evaluation was carried out using objective and subjective measures (detailed in Table I) which were taken as the dependent variables. Subjective measures were assessed via a post-trial questionnaire [23] using a 5-point Likert-type scale for all measures except the SA score where we used a 7-point Likert-type scale, all of them ranging from 1 ("Strongly disagree") to 5/7 ("Strongly agree"). We used a 7 Likert-type scale in the SA score according to [31] and other articles that examined situation awareness and used it as well.

TABLE I. DEPENDENT VARIABLES

Variable	Dependent Variables	
	Examined by	Explanation
Efficiency	Completion time (obj)	Duration of the task (seconds)
Effectiveness	Completeness (obj)	Number of complete answers in the secondary task
	Accuracy (obj)	Number of correct answers from total questions in the secondary task
Understanding	Comprehension (sub)	How comprehensible and clear the robot was
	Clarity (sub)	
	Reaction time (obj)	Time (seconds) that took to participants to respond to the robot feedback
Satisfaction	Communication (sub)	Communication with the robot
	Confidence (sub)	Confidence while using the robot
	Comfortability (sub)	Comfortability of use
Workload	NASA TLX score (sub)	-
	Aggregate raw SA score (sub)	-
Situation awareness	Number of objects identified (obj)	Number of elements that were identified by the participants in the environment of the task

obj. objective measure; sub. subjective measure

K. Analysis

General Linear Mixed Model (GLMM) analysis was applied to analyze the data with the feedback type and order as fixed effects, whereas the random effect was selected as the participants' variances. The tests were designed as two-tailed with a significance level of 0.05.

III. RESULTS

Summary of the results is presented by mean \pm SD (standard deviation) with the significant variables highlighted in green in Table II. The order of feedback type did not affect any of the variables (completion time: $F=1.41$, $p=0.23$; completeness: $F=0.017$, $p=0.896$; reaction time: $F=0.017$, $p=0.99$).

A. Efficiency

The task completion time was significantly affected by the feedback type for both groups ('Tech': $F=5.05$, $p=0.037$; 'Non-Tech': $F=21.7$, $p<0.001$) with a significantly lower completion time when using the 'push' feedback.

B. Effectiveness

The feedback type did not significantly affect the number of questions that were answered by the participants ('Tech': $F=0.718$, $p=0.4$; 'Non-Tech': $F=0$, $p=0.99$).

In the 'Tech' group, the feedback type significantly affect accuracy ($F=9.76$, $p=0.006$) with significantly higher accuracy when using the 'push' feedback than when using the 'pull' feedback. In the 'Non-Tech' group, the feedback type did not significantly affect the accuracy ($F=0.241$, $p=0.62$).

C. Understanding

The feedback type did not significantly affect comprehension ($F=0.2$, $p=0.66$; $F=2.38$, $p=0.14$) and clarity ($F=0.643$, $p=0.433$; $F=3.81$, $p=0.068$) for 'Tech' and 'Non-Tech' groups respectively.

Reaction time was significantly affected by the feedback type in both groups ('Tech': $F=18.13$, $p<0.001$; 'Non-Tech': $F=54.96$, $p<0.001$) with a significantly lower reaction time when using the 'push' feedback.

D. Satisfaction

Communication was significantly influenced by feedback type ($F=8.7$, $p=0.01$) in the 'Tech' group with significantly higher perceived communication when using the 'push' feedback. In the 'Non-Tech' group, the feedback type did not significantly affect the perceived communication ($F=1.26$, $p=0.279$).

In both groups, the feedback type did not significantly influence the users' confidence ('Tech': $F=2.82$, $p=0.117$; 'Non-Tech': $F=0.22$, $p=0.639$).

In the 'Tech' group, the feedback type did not significantly influence comfortability ($F=1.335$, $p=0.267$). In contrast, in the 'Non-Tech' group, the comfortability was significantly affected by feedback type ($F=9.54$, $p=0.007$), and the score while using the 'push' feedback was higher than when using the 'pull' feedback.

TABLE II. SUMMARY OF RESULTS

Variable	Technological			Non-Technological		
	Push	Pull	P-value	Push	Pull	P-value
Completion time (sec)	379.6 ± 16.51	431.83 ± 18.79	0.037	404.1 ± 16.85	455 ± 16.85	<0.001
Completeness (count)	7.4 ± 0.8	6.4 ± 0.86	0.4	6.9 ± 1.52	6.9 ± 1.37	0.896
Accuracy (%)	0.82 ± 0.047	0.61 ± 0.047	0.006	0.63 ± 0.07	0.66 ± 0.066	0.62
Comprehension	4.1 ± 0.56	4.2 ± 0.42	0.66	4.9 ± 0.31	4.6 ± 0.51	0.14
Clarity	4.2 ± 0.78	4 ± 0.66	0.433	4.8 ± 0.42	4.2 ± 0.91	0.068
Reaction time (sec)	3.8 ± 0.62	7.4 ± 1.2	<0.001	3.7 ± 0.4	8.35 ± 0.9	<0.001
Communication	4.55 ± 0.13	3.55 ± 0.13	0.01	4.6 ± 0.51	4.2 ± 1.05	0.279
Confidence	3.85 ± 0.27	3.4 ± 0.27	0.117	4.3 ± 0.63	4.5 ± 0.66	0.639
Comfortability	3.65 ± 0.74	3.25 ± 0.58	0.267	4.5 ± 0.4	3.5 ± 0.23	0.007
Workload	15.4 ± 0.68	19.1 ± 0.69	<0.001	17 ± 0.94	20.4 ± 0.84	<0.001
SA score	16.6 ± 0.82	14.6 ± 0.8	0.013	18.6 ± 0.97	18.3 ± 0.97	0.76
Number of objects identified (count)	6.63 ± 2.05	5.43 ± 1.96	0.015	5.6 ± 0.84	5.2 ± 1.39	0.12

Green indicates significantly statistical results; 'Push' was the preferred feedback in all cases.

E. Perceived Workload

The perceived workload was significantly influenced by the feedback type for both groups ('Tech': $F=87.38$, $p<0.001$; 'Non-Tech': $F=40.93$, $p<0.001$) and significantly lower when using the 'push' feedback.

F. Situation awareness (SA)

The SA score was significantly influenced by the feedback type ($F=7.5$, $p=0.013$) in the 'Tech' group. When using the 'push' feedback, the participants were more aware of the robot's activities and the environment than when using the 'pull' feedback. In addition, the number of objects identified was significantly affected by the feedback type and a correlation can be seen between the SA score and the number of objects that were identified. Results revealed that when participants used the 'push' feedback, they identified more objects in the environment. In the 'Non-Tech' group, the SA was not significantly affected by the feedback type ($F=0.096$, $p=0.76$) and the score was almost the same for both feedbacks. The number of objects identified was not significantly affected by the feedback type ($F=2.63$, $p=0.12$).

IV. DISCUSSION

A. Users' perspectives on the 'push' and 'pull' feedback type in the MRP

Users were able to successfully utilize both the 'push' and 'pull' feedback types and were satisfied with these feedbacks. All the participants completed the tasks successfully. The users noted the ease of use in each of these feedbacks. In both feedbacks, the participants were able to attend to the secondary task. There were no comments regarding information overload, hindrance or barrier that either the 'push' or 'pull' feedback feedbacks caused which could have prevented them from carrying out any aspect of the task corresponding to [30]. Results revealed that information available to them facilitated the successful completion of the main task alongside attendance to the secondary task.

B. Influence of the feedback type

The feedback type has a significant influence across several of the assessment variables. The 'push' feedback was rated as best across all the significant variables compared to the 'pull' feedback confirming H1 but not H2. This

corresponds with the literature [28], [30] on the positive effect of the 'push' feedback on the overall response and performance of users, confirming the effectiveness of the 'push' feedback in a MRP scenario for a telecare task. We also note in our results that some of the users indicated that the 'pull' feedback gave them more control over the information provided compared to the 'push' feedback. Even though they still rated the 'push' feedback eventually higher in terms of comfortability, this subtly reflects the desire of users for some control of the information where possible without being deprived of performance [30]. It, therefore, calls for more improved designs where the 'pull' feedback can be interwoven with the 'push' feedback option in a hybrid design as recommended in [30]. This will permit the performance of the 'push' feedback without depriving the users of the option to 'push back' some of the information provided if not required and even 'pulling' back information as needed. This can provide the users with a greater sense of control over the information provided and can also further build trust [36].

C. User interface design

Different populations may have different requirements regarding user interface design. Based on the results of our experiment, which were quite similar between the two populations examined ('Tech' and 'Non-Tech'), it seems that there was no difference in needs in the context of the interface. Despite this, the topic of user interface design can be very interesting and it may be worth examining it in further experiments between more populations, such as older and younger populations, etc.

V. CONCLUSION

This research reveals that 'push' feedback enhances performance, situation awareness, and satisfaction of the users compared to 'pull' feedback.

The current study was conducted with a limited number of participants with both, technological and non-technological backgrounds. Future work should aim at extended evaluation to be conducted in larger and different types of groups and include qualitative feedback to capture missed details via subjective rating. The study highlights the potential of improving the telecare experience with MRP through these feedback types.

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תקציר

תוחלת החיים בעולם עולה ויחד עם העלייה הזו, אוכלוסיית הקשישים בעולם גדלה במהירות. לעומת זאת, אוכלוסיית המטפלים הולכת וקטנה ביחס למספר המבוגרים, דבר שמוביל לעלייה בצורך למצוא פתרונות שיאפשרו להתמודד עם המחסור במטפלים בבתי חולים, בבתים וכו'. אחד הפתרונות הוא פיתוח ושימוש ברובוטים מסייעים (AR) וליתר דיוק, פיתוח של טלנוכחות רובוטית ניידת (MRP), שהם רובוטים הניתנים לשליטה מרחוק ומסוגלים גם לבצע משימות באופן אוטונומי. ככל שיכולות הרובוטים מתפתחות והם הופכים ליותר ויותר אוטונומיים, השימוש ברובוטים במשימות יומיומיות על ידי משתמשים לא מקצועיים יגדל. על מנת שמערכות MRP כאלה יוכלו להיכנס לחיינו ולספק סיוע במשימות היומיומיות ולסייע בהתמודדות עם הבעיות במערכות הבריאות, יש צורך במחקר רב נוסף בכדי להפוך את האינטראקציה איתן לחלקה, יעילה ומובנת הן למפעיל שלהם והן וכלפי הסביבה.

מחקר זה בחן את האינטראקציה וההבנה בין מערכות MRP לבין מפעילים טכנולוגיים ולא טכנולוגיים. יצירת אינטראקציה מוצלחת ומובנת היא משימה מאתגרת. חלק מהגורמים הקריטיים באינטראקציה בין אדם לרובוט הם המשוב והאופן שבו הרובוט מתקשר עם המשתמש. כדי להשיג זאת, רובוטים חייבים להיות מסוגלים להעביר מידע למשתמש בצורה נכונה ולעזור למשתמש להבין את החלטותיהם, את 'המחשבות' שהובילו להחלטות אלו ואת מעשיהם. בתזה זו בדקנו **כיצד** יש להעביר למשתמש משוב והסברים ממערכת ה-MRP, **איזה** מידע יש להעביר למשתמש **ומתי** יש להעביר אותו אליו.

החלק הראשון של המחקר בדק את מערכת ה-MRP במסגרת רפואית מדומה כדי לסייע למטפלים לבצע את המשימות היומיומיות שלהם, כגון אספקת תרופות ומזון ולקחת מדדים ממטופלים תוך כדי שהם מבצעים משימה משנית (כגון מילוי טפסים) וניסינו לענות על השאלה, כיצד מערכת ה-MRP צריכה לתקשר עם המשתמש. ניסוי זה שימש כמקרה לבחינת שני אופני אינטראקציה שונים. תכננו והערכנו שני מצבי אינטראקציה שונים באופן שבו המשתמשים מקבלים את המידע מהרובוט, הוגדרו כמצבי אינטראקציה פרואקטיביים ותגובתיים. ההשפעה של שני מצבי האינטראקציה על הביצועים ותפיסת המשתמש הוערכה עם 50 משתתפים שחולקו לשתי קבוצות - 40 סטודנטים להנדסה (הוגדרו כקבוצה טכנולוגית) ו-10 סטודנטים לרפואה (הוגדרו כקבוצה לא טכנולוגית). בניסוי זה, השתמשנו ברובוט Keylo Wyca ובנינו שני ממשקי משתמש שונים עבור כל אחד ממצבי האינטראקציה כדי לבדוק את השפעתם.

בחלק השני דימינו מרפאה מורכבת המכילה מכשולים וחולים והמשימה הייתה לשלוט במערכת ה-MRP ובאמצעות קבלת הסברים ממנה, להצליח להתגבר על המכשולים, להגיע לחולים ולהעניק להם טיפול מתאים. חלק זה בדק איזה מידע יש להעביר למשתמש ומתי יש להעבירו ועל סמך זה תכננו מודל הסבר. כדי לעצב מודל זה, הצענו שתי רמות של ברירות - גבוה ונמוך ושתי רמות של דפוסי הסבר - דינמי וסטטי. על סמך אלה, עיצבנו שלוש רמות שונות של הסבר (LOEs) - גבוה, בינוני ונמוך. הערכנו את המודל המוצע בשתי קבוצות שונות, עם הגבלת זמן וללא הגבלת זמן עם 60 סטודנטים להנדסה. השתמשנו שוב ברובוט Keylo Wyca ובנינו שני ממשקים חדשים, אחד לכל קבוצה.

המסקנה העיקרית מהמחקר הראשון הייתה שמצב האינטראקציה הפרואקטיבי ('דחיפה') היה הדרך המועדפת לתקשורת עם המשתמש והוא שיפר את הביצועים, את ההבנה והוריד את עומס העבודה על המשתמשים בהשוואה

למצב האינטראקציה הריאקטיבית ('משיכה'). מצאנו גם שלהבנת המשתמשים את הרובוט הייתה השפעה משמעותית על כל שאר המשתנים שנבדקו. זה שיפר את הביצועים, שביעות הרצון ומודעות לסביבה והפחית את עומס העבודה על המשתמשים. מהמחקר השני, מצאנו שרמת הסבר גבוהה הועדף במקרה של משך הזמן שלוקח לבצע את המשימה והתאמת ההסבר בקבוצה שהייתה ללא הגבלת זמן. עוד נמצא שגם רמת ההסבר הגבוהה וגם הבינוניות יצרו שטף במהלך המשימה וגרמו לאמון ברובוט בקבוצה ללא הגבלת זמן. עם זאת, בקבוצת עם הגבלת הזמן, רמת הסבר גבוהה ובינונית היו דומים ומועדפים בכל המדדים בהשוואה לרמת הסבר נמוכה.

מחקר זה מציג את החשיבות של דרך האינטראקציה בין בני אדם לרובוטים ומדגיש את הצורך שהרובוט יהיה מובן ומציג את הדרך כיצד ניתן לעשות זאת על ידי התאמת רמות הסבר שונות בהתאם למצבים שונים.

מילות מפתח: נוכחות רובוטית ניידת (MRP), מצבי אינטראקציה, הסבר, הבנה, רמת הסברים (LOE), פרואקטיבית, תגובתית, ברירות, דפוסים.



אוניברסיטת בן-גוריון בנגב

הפקולטה למדעי ההנדסה

המחלקה להנדסת תעשייה וניהול

אינטראקציה בין אדם לרובוט:

**מצבי אינטראקציה ורמות הסבר שונות ברובוטים ניידים במשימות
עזרה רפואיות**

חיבור זה מהווה חלק מהדרישות לקבלת תואר מגיסטר במדעי ההנדסה

מאת: עומר קידר
בהנחיית: פרופ' יעל אידן

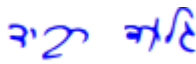
תאריך: 30.11.2022

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חתימת המחבר: 

תאריך: 30.11.2022

.....
אישור המנחה: 

תאריך: 2/12/2022

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אישור יו"ר ועדת תואר שני מחלקתי: 

כסלו, תשפ"ג
נובמבר, 2022



אוניברסיטת בן-גוריון בנגב
הפקולטה למדעי ההנדסה
המחלקה להנדסת תעשייה וניהול

אינטראקציה בין אדם לרובוט:
מצבי אינטראקציה ורמות הסבר שונות ברובוטים ניידים במשימות
עזרה רפואיות

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מאת: עומר קידר
בהנחיית: פרופ' יעל אידן

כסלו, תשפ"ג
נובמבר, 2022