BEN-GURION UNIVERSITY OF THE NEGEV

FACULTY OF ENGINEERING SCIENCES

DEPARTMENT OF INDUSTRIAL ENGINEERING AND MANAGEMENT

# Feedback modalities in a robot assistant for elder care

THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR THE M.Sc. DEGREE

By: Noa Markfeld

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By: Noa Markfeld

Supervised by: Prof. Yael Edan

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## Abstract

Life expectancy is rising, and together with this increase, the world's elderly population has grown rapidly. However, the population of caregivers does not increase at a similar rate, leading to an increased need in developing solutions that will assist the older adults. One solution is the use of Assistive Robots (ARs) to meet the needs of these older adults. The development of assistive robots for the elderly and their impact is the domain of the interrogee around the world, but many challenges remain and call for further research. It is important to understand in depth what makes the interaction between the robot and the elderly successful, to achieve a robot that offers a natural, ethical, safe and effective approach.

This research examined the interaction between assistive robots and the non-technological population, focusing on older adults and caregivers. Creating a successful interaction is a challenging task. To achieve this, robots must be able to communicate naturally with humans both verbally and nonverbally. One of the most important factors in human-robot interaction is feedback. In this thesis, the influence of feedback for different aspects that influence task performance was evaluated in user experiments: levels of automation, levels of transparency, levels of information and location of the secondary task. The experiments were performed in a series in which conclusions from one experiment served as inputs for the design of the subsequent experiment.

The first part of the research examined robot assistance to the elderly population in their home environment. This preliminary experiment served as a case study to explore different influencing factors with fourteen older participants (8 Females, 6 Males), aged 62- 86 (mean 69.8, std 4.48). A KUKA LBR iiwa 14 R820, 7 degrees of freedom robotic arm equipped with a pneumatic gripper was programmed in a table-setting task performed jointly by an older adult and the robot with two levels of automation (LOA) and two levels of transparency (LOT) conditions. This study explored how LOA and LOT influences the quality of interaction (QoI). The QoI is a construct which entails the fluency, understanding, engagement and comfortability during the interaction.

In the second part, we continued to examine robotic assistance to the elderly population in the home environment. For this purpose, we used the same system as in the case study experiment, while adding changes and upgrades depending on the feedback modalities employed. This study examined the effect of different feedback modalities in a table setting robot assistant for elder care. 21 older adults (13 males, 8 female) aged 70-86 (mean 74, std 4.12) participated in the study. Two different feedback modalities (visual and auditory) and their combination were evaluated for three levels of information (LOI). The visual feedback included the use of LEDs and a GUI screen. The auditory feedback included alerts (beeps) and verbal commands.

In the third part, the examination of feedback modalities on adults' daily environment was continued, while changing the robotic platform and the examined task. Originally, a mobile robot, Keylo[1] (WYCA robotics) was programmed to assist the adult in a shopping task in a supermarket environment. Due to the COVID-19 disease that entered the world and the need to preserve and isolate the elderly population the design of the experiment was changed. The experiment was

[1] WYCA robotics website: https://www.wyca-robotics.com/

focused to examine the interface for caregivers, another kind of non-technological users. Moreover, the experimental environment changed to a more challenging and relevant environment, hospital environment. This experiment simulated a hospital environment in which a caregiver (participant) delivers medication with other supplies to the patient and receives samples from the patient. Due to closures because of COVID experiments were performed with 40 students (27 females, 13 males) at Ben-Gurion University as participants for the role of the caregiver (mean age 26.5 years, std 1.11). This research investigated two of feedback modalities for the tele-operator to determine the most suitable for remote tele-robotic assistance in a telenursing task with secondary tasks. Additionally, we investigated if the location of the secondary task influences the collaboration between the robot and the operator. Two different feedback modalities (visual and auditory) and their combination were evaluated with two locations of the operator's secondary task. The interaction was measured in terms of objective performance (efficiency, effectiveness and understanding) and user perception (satisfaction, perceived workload and usability).

A main conclusion from all three experiments refers to the positive impact of audio feedback on the quality of the interaction between the user and the robot, regardless of the environment and the population being tested. Moreover, the combination of verbal commands with visual feedback was found to be most effective. The use of an intercensal combination of feedback integrated and intensified the benefits of each feedback modality. The use of this feedback contributed positively for using the robot in such a complex task and to a population whose capabilities are non-homogeneous. Moreover, the feedback should contain a low amount of information in order to avoid clutter and confusion among the participants, especially when it comes to the elderly population. Several more guidelines have been provided for interactive feedback as related to the specific investigated variables. The high LOA yielded best performance for the older population. Accordingly, the LOT is set at the low level in order to avoid clutter and confusion among the participants. Also, the recommended level of information (LOI) provided the information just at important points along the robot’s path to reduce the cognitive workload of the operator. The location of the secondary task did not result in significant differences, but it may be interesting to see if a more complex secondary task would make a difference in these different locations.

This study presents the importance of feedback designs in improving the interaction of older adults with assistive robots. Reliable use of feedback will increase confidence in the robotic system even in a population that is not used to the technology. Improving feedback design will lead to improved interaction and ensure that assistive robots will eventually become viable tools that add value to their everyday lives.

***Keywords:*** assistive robots, tele-robotic assistance, HRI, feedback, feedback modalities, tele-robotic assistance, secondary task, older adults, elder care, social assistive robots.

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The theoretical models are presented in the PhD thesis of Samuel Olatunji, *Socially Assistive Robots in Eldercare – Interaction Design for Varying Levels of Automation.*

This thesis was performed in parallel to the MSc thesis of Dana Gutman which focused on *Levels of Automation Design for Older Adults*. Some of the development work on the Kuka and experiments were performed in collaboration. Dana focused on the levels of automation while I focused on feedback design.

## This work has been reviewed and presented at:

C1. Olatunji, S., **N. Markfeld**, D. Gutman, S. Givati, V. Sarne-Fleischmann, T. Oron-Gilad, Y. Edan. 2019. Improving the interaction of older adults with a socially assistive table setting robot. *Proceedings of the International Conference on Social Robotics* (pp 568-577), 11876 LNAI Lecture Notes in Computer Science. Springer International Publishing. http://dx.doi.org/10.1007/978-3-030-35888-4_53.

C2. **Markfeld, N.**, Olatunji, S., Gutman, D., Givati, S., Sarne-Fleischmann, V., Edan, Y. 2019. Feedback modalities for a table setting robot assistant for elder care. In *Proceedings of Quality of Interaction in Socially Assistive Robots, Quality of Interaction in Socially Assistive Robots (QISAR) Workshop International Conference on Social Robotics (ICSR'19),* Madrid, Spain, November 26-29. Extended abstract.

C3. Gutman, D., **N. Markfeld**, S. Olatunji, V. Sarne-Fleischmann, T. Oron-Gilad, Y. Edan. 2019. Evaluating fluency in robot-assisted table setting for older adults, ICR 2019 – 6th Israeli Conference of Robotics, July 2019, Herzelia, Israel. Abstract, oral presentation.

## Submitted/in preparation journal publications

J1. Olatunji, S., T. Oron-Gilad, **N. Markfeld**, D. Gutman**,** V. Sarne-Fleischmann**,** Y. Edan. Levels of automation and transparency: interaction design considerations in socially assistive robots for older adults. *IEEE Transactions on Human-Machine Systems* (submitted, revision in process).

J2. Gutman, D., Olatunji, S., **N. Markfeld**, S. Givati, V. Sarne-Fleischmann, T. Oron-Gilad, Y. Edan. 2020a. Evaluating levels of automation and feedback in an assistive robotic table clearing task for eldercare. In preparation for MDPI Applied Sciences.**

J3. **N. Markfeld**, S. Olatunji, Y. Edan. 2020a. Exploring feedback modalities in a telecare robot. (in preparation or will be submitted as part of extended paper which will include an additional experiment).

**This publication is not part of the thesis, but complementary to a parallel experiment that was performed as part of the MSC thesis of Dana Gutman MSc. thesis (study 2) in which I led the feedback design and implementation.

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# 1. Introduction

Population aging is expected to be the most significant demographic change of the 21st century, with implications for almost all society sectors. According to the United Nations, the population of people aged over 60 will double by 2050, reaching a percentage high of 22% of the entire world population (2.1 billion, United Nations, 2017; Bolarinwa, 2019). Since the caregiver population does not increase at a similar rate, there is an increasing need to develop solutions to assist the older adults. A promising solution is the development of assistive robots (Broekens, 2009; Shishehgar, 2019).

This research focuses on the interaction between assistive robots developed for older adults and caregiver users who are not technologically oriented.

## 1.1 Problem description

Socially assistive robots

Assistive robots are robots that are intended to perform tasks normally done by humans in an environment in which humans work as well (van Osch et al., 2014). However, they are not required to accomplish these tasks in the same way as humans do and do not need to look like a human being (van Osch et al., 2014). Social robots are designed to interact with people naturally in order to achieve positive results in a variety of applications such as education, health, quality of life, entertainment, communication and tasks that require teamwork (Conti et al., 2020; Čaić et al., 2019; Shishehgar, 2019).

A socially assistive robot (SAR) blends the functions and characteristics of both assistive and social robots (Pfeil-Seifer & Mataric, 2005), helping humans (as assistive robots) through social intelligence (as social robots). A social assistive robot differs from a social robot and a robot for entertainment whose job is to provide simple interaction. In contrast, a social assistance robot is required to support the users' daily activities (Pu, 2019). Designing such a robot raises many challenges due to the many requirements that must be considered, depending on the person using the robot.

The long-term goal of developing social robots that will serve as partners for humans is quite challenging. To do this, robots must be able to communicate naturally with humans both verbally and nonverbally (Breazeal et al., 2016). 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., 2015). Socially assistive robots (SARs) are viewed as a possible solution to bridge the elder care gap and are expected to assist the older adults in three types of activities (Tang et al., 2015): activities of daily living (ADLs), instrumental activities of daily living (IADLs), and enhanced activities of daily living (EADLs). ADLs are basic self-maintenance tasks such as dressing, feeding and bathing. IADLs are tasks that are not mandatory for fundamental functioning but essential for independent living and interaction with the environment. They include activities like housekeeping, shopping and compliance with prescribed medication. EADLs are activities that facilitate participation in social and enriching activities such as leisure time activities, pursuing hobbies, and learning new skills (McColl et al., 2013; Smarr et al., 2012, 2014a). This thesis focuses on an assistive robot for a daily living activity (ADL).

Tele-operated robots

A tele-robot is a robot that is controlled by a human being (an operator) from a distance and performs tasks and/or services as if the operator was on the spot (Sheridan, 1992; van Osch et al., 2014). Tele-robots offer obvious benefits in terms of assisting the healthcare system (Tavakoli et al., 2020), and in performing many operations for a caregiver as pre-diagnosis, food delivery or monitoring. The ability to remotely perform a variety of tasks through robots contribute to workload reduction in hospitals supporting staff by performing various assistive functions (Aymerich-Franch, 2020).

For remote operators to effectively control the robot, they must be aware of a range of information about the local environment, including the position of the robot and objects to be manipulated in the task space, as well as the well-being of the person being assisted (Bolarinwa et al., 2019). Accordingly, this study focused on providing information via feedback.

Interaction for elderly population

Social robots have the potential to assist older adults and make them more independent leading to their improved lifestyle. Many studies have examined how a robot can provide for the social and emotional needs of the elderly, including depression and increasing social interaction with people (Shishehgar et al., 2018; Conti et al., 2020). To achieve a robot that offers a natural, ethical, safe and effective interaction, it is important to understand what makes the interaction between the robot and the elderly successful (Nimrod & Zafrani, 2018; Shishehgar, 2019).

The older person has perceptual abilities distinct from those of the younger population particularly evident in processing information (Beer et al., 2012). Moreover, what makes the older adult population such a unique group is that declines in abilities related to aging are not homogeneous (Nimrod & Zafrani, 2018). Therefore, the correct choice of interfaces between the assisting environment and the user is of high importance (Broekens et al., 2009; Conti et al., 2020). Older adults' interaction with robots requires effective feedback to keep them aware of the state of the interaction for optimum interaction quality (Beer et al., 2012; Olatunji, 2018). A reliable design should meet the needs and preferences of the older adults while keeping them informed of the robot's actions, capabilities and limitations (Mirning et al., 2011).

Levels of automation and transparency

The different levels at which a human operator can control an automatic process are defined and classified as levels of automation (LOA, González et al., 2012; Hart et al., 1988; Kaber et al., 2013). LOA is used to describe the functions the robot will perform and at what level of assistance to the user (Kaber, 2018). Designing LOA to fit the demands of the older adults in SAR operations is an important element of the interaction (Vagia et al., 2016). In order for such robots to be operated efficiently and effectively by non-technical users, it is important to examine if and how increasing the robotic system's level of automation (LOA) impacts their performance (Olatunji, et al., 2019). To ensure transparency of the robot's role at all times the LOA implementation is reflected in the ways through which the users interact with the robots.

The level of transparency (LOT), is defined as the degree of information provided to the user to aid the understanding of the state, reasoning process and future system plans (Feingold Polak et al., 2018). The information presented by the robot should conform with the perceptual and cognitive peculiarities of the older adults (Mitzner et al., 2015; Rogers et al., 2017; Eizicovits et al., 2018; Polak et al., 2018) and relate to the environment, task, and robot (Lyons, 2013). Too little information may not be sufficient to ensure reliable interaction with the robot (Doisy et al., 2014), whereas too much information could cause confusion and error (Lyons, 2013; En et al., 2011).

Robot feedback

Successful interaction requires communication between the human and the robot which generally involves sending and receiving of information to achieve specific goals (Doran et al., 2012). Communicative actions when presented in the most comprehensible form promote understanding which aids a successful interaction of the user with the robot (Balfe et al., 2018; Hellström, 2018; Olatunji et al., 2018). The communicative actions from the robot to the user, herein referred to as feedback, are the presentation of information by the robot to the user. actions. The content of the feedback information provided is an essential influencing factor for successful interaction between humans and robots (Mirnig, 2014). Feedback from the robot can help humans to evaluate the robot's internal state and its overall goals (Agrawal et al., 2018). Existing studies reveal that the information presented to the user significantly influences his / her comprehension of the robot's behavior, performance and limitations of the robot (Dubberly, 2009), influencing interaction quality (Nimrod & Zafrani, 2018). How the robot communicates is also a crucial component of the interaction in relation to what information is being communicated (Wortham et al.,2017; Fong et al., 2001; Eliav et al., 2011). The feedback can be provided in different modalities including visual feedback (Ferris, 2008; Céspedes et al., 2020), verbal feedback (Dzindolet et al., 2003; Shishehgar, 2019; Céspedes et al., 2020), and tactile devices (Dzindolet et al., 2003; Khoramshahi et al., 2020). Visual indicators may provide feedback and information in different ways (Baraka, 2018). The most common is using a screen to display information (Mirnig, 2014) and the use of lights (Baraka, 2018; Gombolay, 2017). Visual feedback is one of the most popular feedback modalities since it is considered a natural communication channel (Perrin et al., 2008). Auditory feedback concerns the use of sound to communicate information to the user about the state of the robot (Rosati et al., 2013). The sounds may include warning noises or verbal commands (Kuffner, 2018). The audial feedback has great potential, but in many cases, its potential is not fully utilized (Rosati et al., 2013). Combinations of these modalities, multimodal feedback, may enhance user interactions (Jacko et al., 2003; Bolarinwa et al., 2019). Multimodal interfaces can increase the quantity and quality of information conveyed (Mc Gee et al.,2000). Creating this combination is the main challenge in human-robot interaction (Sarter, 2006). It is important to find the balance point where the amount of information that the person receives contributes to and does not interfere.

Secondary task

The caregivers usually have multiple tasks to perform in a short time (both in a hospital environment and in a home environment). Hence, to ensure the the collaboration with the robot improves their work, they must perform tasks in parallel with the robot work.

The definition of the task refers to many different factors such as task complexity, the distance between subtasks, and the time required to complete subtasks (Nagy et al., 2019). The location of the operator's additional (secondary) tasks is an important factor (Baumann et al., 2007). Many studies in the driving field have shown that the display position of the secondary task greatly affects the performance (Lee, 2019; Baumann et al., 2007). The location of both the secondary task and the main task has influence (Katsuyama, 1989). The right location of the task reduces the effort of the participant and even decreases the number of errors (Wittmann et al., 2006).

## 1.2 Research objectives

The objective of this research is to enhance human-robot interaction by evaluating influence of feedback for different aspects (Figure 1), focusing on older adults and non-technological populations. To this end, we examined several cases in which the task, the robotic platform and the users were different. Two systems were designed and developed according to the requirements of the task and the population. The specific objectives were to:

1. Develop two assistive robotics systems for non-technological users.
2. Design the content of the feedback and its timing to motivate the users.
3. Identify the mode of feedback that will improve user’s interaction with the system.

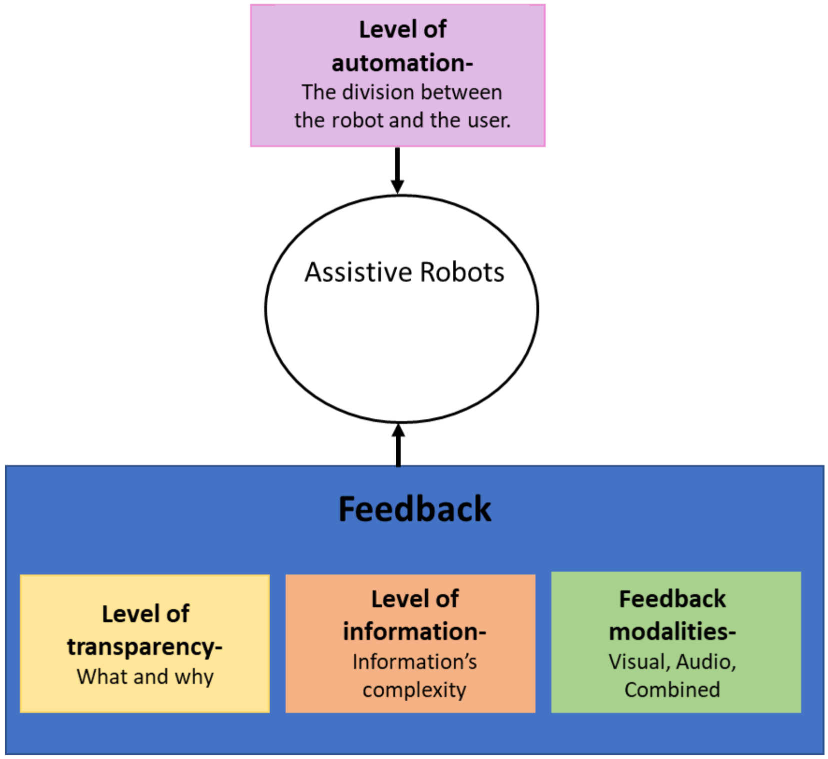


***Figure 1. Tested parameters influencing the human-robot interaction with assistive robots***

## 1.3 Thesis structure

This thesis begins with a general introduction on assistive robots and different interaction aspects focusing on older adults and non-technological users (chapter 1.1). The overall research methodology is depicted in chapter 2. The research includes three separate parts that correspond to the three experiments that evaluate influence of feedback for different aspects that influence task performance: levels of automation and transparency (case study, appendix A), levels of information (study 1, chapter 3) and levels of information and secondary task location (study 2, chapter 4). Each chapter includes a focused literature review and details the experimental and analysis methods and results. Overall conclusions and future research are discussed in chapter 5.

## 2. Methodology

### 2.1 Overview

Three experiments were performed to evaluate influence of feedback for different aspects that influence task performance (Figure 2): levels of automation and transparency (case study, appendix A), levels of information (study 1, chapter 3) and levels of information and secondary task location (study 2, chapter 4). The aim was to evaluate all influencing parameters for older adults however, due to limited access to older adults because of COVID-19 pandemic, study 2 was performed with simulated caregivers. The experiments were performed in a series in which conclusions from one experiment served as inputs for the design of the subsequent experiment. Details are provided below in the description of each experiment and in each chapter following.

| | *Case study* |
|---|---|
| *Independent variable* | Level of automation (LOA) |
| | Level of transparency (LOT) |
| *Robot platform* | A robotic arm, KUKA  |
| *Task type* | Table setting , direct control |
| *Population* | Older adults |
| *Thesis chapter* | Appendix A |
| *Publication* | C1,C3, J1 |

| | *Study 1* | *Study 2* |
|---|---|---|
| *Independent variable* | Feedback mode | Feedback mode |
| | Level of information (LOI) | Secondary task location |
| *Robot platform* | A robotic arm, KUKA  | Teleoperated robot, WYCA  |
| *Task type* | Table setting, direct control | Telenursing task, tele-operation |
| *Population* | Older adults | Caregivers |
| *Thesis chapter* | Chapter 3 | Chapter 4 |
| *Publication* | C2 | J3 |

***Figure 4. Overview description of experiments***

<u>Case study</u>

The first part of the research is a preliminary experiment designed to examine robot assistance to the elderly population in their home environment. This experiment served as a case study to explore different influencing factors.

In order for such robots to be operated efficiently and effectively by non-technical users, it is important to examine if and how increasing the robotic system's level of automation impacts their performance. (Olatunji, et al., 2019). Recall that the different levels at which a human operator can control an automatic process are defined and classified as levels of automation (LOA) (González et al., 2012)

The level of transparency (LOT), is defined as the degree of information provided to the user to aid the understanding of the state, reasoning process and future plans of the system (Feingold Polak et al., 2018).

*A KUKA LBR iiwa 14 R820,* 7 degrees of freedom robotic arm equipped with a pneumatic gripper was programmed in a table-setting task performed jointly by an older adult and the robot with two LOA and two LOT conditions. This study aimed to explore how LOA and LOT influences the quality of interaction (QoI). The QoI is a construct which entails the fluency, understanding, engagement and comfortability during the interaction.

Two LOA conditions were designed as follows:

> *Low LOA condition*. The robot minimally assists the human in acquiring information related to the task by presenting information through the applicable interface. The robot also assists in the information processing by providing options through which the task could be performed. The human must agree to the suggestions before the operation can continue. The human then solely makes the decision regarding what should be done while the robot assists in the execution of the actions.
>
> *High LOA condition*. The robot assists the human in acquiring information regarding details of the task. This information is fully processed by the robot. All decisions related to the task are taken only by the robot. The robot executes the decision but can be interrupted by the human.

The two conditions differed by the purpose of the information provided by the robot; LOT conditions were set as follows:

> *Low LOT condition.* The low level of information included text messages that specified the status of the robot by indicating **what** it was doing (e.g. bringing a plate, putting a fork, etc.)
>
> *High LOT condition.* The high level of information included also the **reason** for this status (i.e. I'm bringing the plate since you asked me, etc).

During the experiment, many participants noted the fact that the interaction with the robot is purely visual interferes with them, and the use of voice may improve the interaction. This point led us to the next stage in the experiment - where we focused on how feedback modalities affect the collaboration between the adult and the robot.

Based on the conclusions from this experiment, and given the nature of the population, it was decided to set the LOA at the high level where consistently higher performance was obtained. Accordingly, the LOT is set at the low level in order to avoid clutter and confusion among the participants.

Details of this research are presented in Appendix A and in publications C1, C3 and J1.

Study 1

In the second part, we continued to examine robotic assistance to the elderly population in the home environment. For this purpose, we used the *same system* as in the case study experiment, while adding changes and upgrades depending on the feedback modalities employed.

The correct choice of interfaces between the assisting environment and the user is of high importance (Broekens et al., 2009). Older adults' interaction with robots requires effective feedback to keep them aware of the state of the interaction for optimum interaction quality (Beer et al., 2012). The feedback is the information provided by the robot; the types of feedback were designed as follows:

> *Visual*. When providing visual feedback, both a graphical user interface (GUI) and LED lights were used. The GUI was presented on a PC screen, which was located on a desk to the left of the user, whereas the LED lights were embedded in the robot and were connected to the system using a Raspberry Pi computer.
>
> *Audio*. Audial feedback was transmitted to the user through a speaker system connected to the main computer and included using beep alert and verbal commands.
>
> *Combined*. Combined feedback was transmitted to the participant through both Visual and audio.

Another important factor is the level of information (LOI), we define the LOI according to its complexity. In contrast to LOT where the levels distinct in the purpose of information, the levels of LOI distinct in the complexity of the information. Each type of feedback was evaluated for three LOI. *The simple level* provided feedback through non-continuous alerts, using flashing lights and beeps. *The intermediate level* conveyed more information by using the screen and verbal commands and *the complicated level* combined the previous two levels together.

The dependent variable was the quality of the interaction which consisted of trust, engagement, understanding and comfortability measures.

This experiment revealed the preferred type of feedback. Details are provided in Chapter 3 and included in the C2 publication. The following experiment tested whether using a different kind of robot and a different task with a different population would lead to similar results and conclusions.

Study 2

In the third part, the examination of feedback modalities on adults' daily environment was continued, while changing the robotic platform and the examined task. Originally, a mobile robot, Keylo (WYCA) was programmed to assist the adult in a shopping task in a supermarket environment where an adult and a mobile robot will shop for the missing products in the adult's home. During the mission, the plan was that the robot will provide instructions on which items need to be collected and their locations. After the participant selects the item, he/she can place it on the robot and the robot will carry it for the rest of the task.

During this period, the COVID-19 disease entered the world which caused us to redesign the use case to avoid experiments with the elderly population, who had to be preserved and isolated. The interface design for assistive robots refers to two kinds of non-technological users - the elderly population and the caregiver population. Due to the situation, the experiment was focused to examine on the interface for the caregivers. Moreover, the experimental environment changed to a more challenging and relevant environment, hospital environment. Social assistive robots are developing a particularly outstanding role in hospitals supporting staff, where they contribute to reduce the workload by performing various assistive functions (Aymerich-Franch, 2020). One of these functions is the ability to perform remotely a variety of tasks.

This experiment simulated a hospital environment in which a caregiver (participant) delivers medication with other supplies to the patient and receives samples from the patient both with a teleoperated robot to avoid needing to get near the patient for several possible reasons (task load, risk of infection). The caregiver sends the robot towards the patient to accomplish the main task while carrying out a secondary task. The robot moves autonomously in space, with the exception of certain points that requires user involvement before continuing with its task (e.g., code for entering a room, elevator). In the secondary task the user answers the questions according to the relevant information.

Following the previous experiment, in this research, we also examined the type of feedback; the influence of different feedback types on the interaction between a caregiver and a tele-operated robot was investigated. The interaction was measured in terms of objective performance (efficiency, effectiveness and understanding) and user perception (satisfaction, perceived workload and usability). The caregiver receives feedback from the robot to the control station at important points along the robot's path to reduce the cognitive workload of the operator, according to the findings of Agrawal et al (Agrawal et al., 2018). When receiving the feedback, the participant must act according to it, so the robot can continue its task.

The types of feedback were designed to match the feedback provided in the previous experiment and the features of the current robot as follows:

> *Visual.* The visual feedback appeared on the central panel in the form of written messages. These messages were designed to convey the information clearly and immediately.
>
> *Auditory.* Auditory feedback appeared via voice commands. The content of these commands were the same as the content that appeared in the on-screen messages in the visual feedback. Voice commands and not alerts (beep) were used according to findings from a previous experiment (Markfeld et al., 2019) and since the task simulates a noisy work environment.

*Combined*. Feedback was transmitted to the participant through both on-screen messages and voice commands.

The caregivers usually have multiple tasks to perform in a short time (both in a hospital environment and in a home environment). Thus, they must perform tasks in parallel with the robot work. Hence, another factor we investigated was the influence of the location of the secondary task on the collaboration between the robot and the operator.

Two secondary task location designs were as follows:

*On the screen*. All the data is displayed on the right panel. This includes a table with the patient's medical information and some questions on these patients.

*Combination of screen and desk*. The data is divided between the screen and the desk below. The right panel contains only the questions on the patients and the table with their information is presented on the desk below on paper.

Details are provided in Chapter 4 and will be included in publication J3 which might be extended to include an additional experiment (with other users and in another environment).

## 3. Study 1

# Feedback modalities for a table setting robot assistant for elder care

This research is details of the QISAR extended abstract (publication C2).

# Feedback modalities for a table setting robot assistant for elder care

Noa Markfeld, Samuel Olatunji, Dana Gutman, Shay Givati,
Vardit Sarne-Fleischmann, Yael Edan
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**This research is details of the QISAR extended abstract (C2, Markfeld et al., 2019)**

**Abstract.** Older adults' interaction with robots requires effective feedback to keep them aware of the state of the interaction for optimum interaction quality. This study examines the effect of different feedback modalities in a table setting robot assistant for elder care. Two different feedback modalities (visual and auditory) and their combination were evaluated for three complexity levels corresponding to the level of information conveyed. The visual feedback compared the use of LEDs and a GUI screen. The auditory feed-back included alerts (beeps) and verbal commands. The results revealed that the quality of interaction was influenced mainly by the feedback modality, and complexity had less influence. The verbal feedback was significantly preferable and increased the participants' involvement during the experiment. The combination of LED lights and verbal commands increased participants' understanding contributing to the quality of interaction.

**Keywords:** human-robot interaction, feedback modalities, collaborative robot, assistive robot, older adult

## 1. Introduction

The world's elderly population is rapidly growing due to the increase in life expectancy (United Nations, 2017). However, the population of caregivers does not increase at a similar rate, leading to an increased need in developing solutions that will assist the older adults. One solution is the use of Socially Assistive Robots (SARs) to meet the needs of these older adults (Broekens, 2009). The development of social robots for the elderly and their impact is the domain of the interrogee around the world (Zafrani et al., 2018; Kamali et al., 1982), but many challenges remain and call for further research. The older person has perceptual abilities distinct from those of the younger population particularly evident in processing information (Beer et al., 2012). Moreover, what makes the older adult population such a unique group is that declines in abilities related to aging are not homogeneous (Zafrani et al., 2018). Therefore, the correct choice of interfaces between the assisting environment and the user is of high importance (Broekens, 2009). Older adults' interaction with robots requires effective feedback to keep them aware of the state of the interaction for optimum interaction quality (Beer et al., 2012). The “feedback loop” is an important feature of interactive systems. It represents the nature of the interaction between a person and a dynamic system (Dubberly et al., 2009). Feedback from the robot can help humans to evaluate the robot's internal state and its overall goals (Agrawal et al., 2018). Existing studies reveal that the information presented to the user significantly influences his / her comprehension of the robot's behavior, performance and limitations of the robot (Dubberly et al., 2009), influencing interaction quality (Zafrani et al., 2018). Additionally, properly timed feedback encourages natural flow in the communication among the system elements (Mirnig et al., 2011). The feedback can be provided in different modalities (Stadler et al., 2012). Robots can provide information to the human by tactile devices (Sarter et al., 2006), verbal feedback (Kuffner, 2018), and visual feedback (Perrin et al., 2008). The feedback modality can strongly influence the interaction quality (Stadler et al., 2012). Visual indicators may provide feedback and information in different ways (Baraka et al., 2018). The most common is using a screen to display information (Mirnig et al., 2011) and the use of lights (Baraka et al., 2018; Gombolay et al., 2017). Visual feedback is one of the most popular feedback modalities since it is considered a natural communication channel (Perrin et al., 2008). Auditory feedback concerns the use of sound to communicate information to the user about the state of the robot (Rosati et al., 2013). The sounds may include warning noises or verbal commands (Kuffner, 2018). The audial feedback has great potential, but in many cases, its potential is not fully utilized (Rosati et al., 2013). Combinations of these modalities in multimodal feedback, may enhance user interactions (Sarter et al., 2006) by increasing the quantity and quality of information conveyed (Mirnig et al., 2011). Creating the most appropriate type of feedback is a main challenge in human-robot interaction (Dubberly et al., 2009).

Another important factor is the level of information (LOI), we define the LOI according to its complexity. The levels of LOI distinct in the complexity of the information. Existing studies recommend that feedback should be adequate and informative (Mirnig et al., 2014) to avoid overloading the user with information. In this research we examine different forms of information - discrete notifications (feedback that contains alerts about changes) or continuous information (feedback contains information about the state of the system). Studies show that notifications kept participants high alert and strengthen the trust in the automation (Dzindolet et al. 2003; Lee & See 2004). On the other hand, some claim that long-term notifications cause fatigue and thus feedback should be sent only at important points along the robot's path to reduce the cognitive workload (Agrawal et al, 2018; Doisy et al., 2014).

This study evaluates various feedback modalities that the robot provides to the person when performing a joint task, focusing on two main feedback types–visual and auditory. These feedback types and their combination are evaluated for different complexity levels (LOI) of the feedback. The overall goal is to ensure high interaction quality between the older adult and the robot in accomplishing the desired task while increasing the older adult's satisfaction along the collaboration.

# 2. Methods

## 2.1 Overview

This study examined older adults' preferences among the various types of feedback in collaboration with a robot in a simple daily task. The task examined in this study was a table-setting task to be performed jointly by the participant and the robotic arm. The task was carried out at a high level of automation meaning that the participant initiated the robot on the task start and stopped it when needed (when he/she feels a danger or when he/she thinks the robot is operating incorrectly) while the rest of the work is performed by the robot automatically. Each participant experienced one type of feedback while performing the task at three levels of complexity in a random order.

## 2.2 Experimental system

*The robot platform.*

A KUKA LBR iiwa 14 R820 7 degrees of freedom robotic arm equipped with a pneumatic gripper was programmed for a collaborative table setting task (see in figure 1). The tasks were programmed using the Python programming language and executed on the ROS platform (Schaefer, 2015). To instruct the user and to present the information received by the robot, different interfaces were used depending on the type of feedback being tested. When providing visual feedback, a graphical user interface (GUI) was used on a PC screen (Figure 1), which was located on a desk to the left of the user, and LED lights that were embedded in the robot and interfaced to the system using a Raspberry Pi computer (Figure 2). Audial feedback was transmitted to the user through a speaker system connected to the main computer.

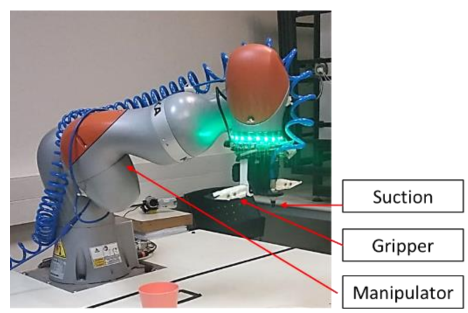



*Figure 1. Robot platform and setup*

*User Interfaces.*

A user interface was especially designed for the older adult user; the feedback was designed to provide minimal information while keeping informative (Mirnig et al., 2014) to avoid overloading the user with information (Lyons, 2013). We examined what level of information (LOI) enhances the interaction. The levels of LOI distinct in the complexity of the information. Different forms of information were examined- discrete notifications (feedback that contains alerts about changes only) or continuous information (feedback contains information about the state of the system). Each type of feedback was evaluated for three LOI:

*The simple level* provided feedback through non-continuous alerts, using flashing lights and beeps. There was a different notification for the different robot' actions (start, on the way toward the object, bring the object, stop)

*The intermediate level* conveyed more information by using both the screen and verbal commands. These commands include status information about- starting of the mission, stopping of the mission, bringing the object, malfunction/something unexpected on the way.

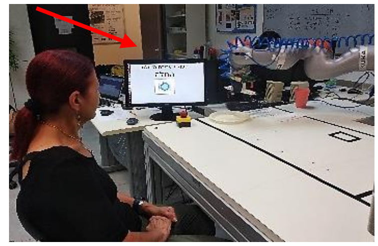
*The complicated level* combined the previous two levels together.

As aforementioned, the correct choice of interfaces between the robot and the user is of high importance (Beer et al., 2012; Broekens et al., 2009) hence, it is important to identify the most appropriate feedback the robot should give a person during a task. The feedback is the information provided by the robot; the types of feedback examined were visual, auditory and their combination:

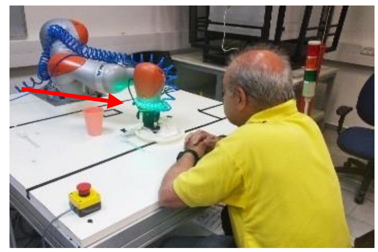
*Visual*. When providing visual feedback, a graphical user interface (GUI) and LED lights were used. The GUI was presented on a PC screen, which was located on a desk to the left of the user, whereas the LED lights were embedded in the robot and were connected to the system using a Raspberry Pi computer.

*Audio*. Audial feedback was transmitted to the user through a speaker system connected to the main computer and included using beep alert and verbal commands.

*Combination*. Combined feedback was transmitted to the participant using both visual and audio.



(a)



(b)

*Figure 2. GUI (a) and LED (b) feedback with arrow pointing on the feedback*

## 2.3 Procedures

Participants completed a preliminary questionnaire before each experiment. It included demographic information, the Technology Adoption Propensity (TAP) index (Ratchford et al., 2012) and the Negative Attitude towards Robots Scale (NARS) (Syrdal et al., 2009). Following this, they were briefed on the scenario, tasks and procedure. Each participant experienced one type of feedback while performing the task at three levels of complexity in a random order. Each trial was followed by a questionnaire enquiring about the experience with the condition (details on the measures are given below). After completion of all three trials, participants answered a final questionnaire in which they rated their overall experience with the robot and tasks. It further afforded the opportunity to provide free input, feedback or remarks.

## 2.4 Experimental design

A between-within experimental design was executed with types and complexity of feedback as the independent variables. Participants experienced one type of feedback while performing the task at three levels of complexity. Within each group, subjects performed the sequence of scenarios in a random order to eliminate the effect of the subject's familiarity with the task.

*Table 1. Experimental design*

| | | Type of feedback | | |
|---|---|---|---|---|
| | | **Visual** | **Audio** | **Combined** |
| **Level of Information (LOI)** | **Simple** | LED | Alert | LED-Alert |
| | **Medium** | GUI | Voice | GUI-Voice |
| | **Complex** | LED + GUI | Alert + Voice | LED-Alert + GUI-Voice |

## 2.5 Participants

Older adults were recruited at an older adult's local club in Beer Sheva, a local police pensioners club, BGU's older adults working force and previous older adults who performed experiments in our labs. 21 older adults (13 males, 8 female) aged 70-86 (mean 74, std 4.12) participated in the study. They were healthy individuals with no physical disability who came independently to the lab. Each participant completed the study separately at different timeslots, so there was no contact between participants.

## 2.6 Dependent measures

The dependent variable was the quality of the interaction which consisted of trust, engagement, understanding and comfortability measures. The measures were selected based on the relevance of these measures to the older adult population found in previous studies as detailed below. These variables were assessed subjectively through questionnaires used 5-point Likert scales with 5 representing "Strongly agree" and 1 representing "Strongly disagree", and objectively through recorded videos which were manually analyzed. The *trust* measure shows the level of reliance on the robot to enjoy successful interaction (Kachouie et al., 2014), evaluated by analysing the participant's sitting position and proximity to the robot (three positions were predefined and offered to participants before each session). The *engagement* measure describes the amount of time there was eye contact between humans and the robot implying the relationship between the older adult and the robot (Kamali et al., 1982). This measure is very significant for the elderly population who may lose attention and therefore must be kept consistently in the loop and as active as possible in the interaction (Kuffner, 2018). *Understanding* is required for the robot and human to be able to successfully interact with each other (Lyons, 2013). It's important to assess the degree of understanding that the user has in the interaction (Mc Gee, 2000) in order to ensure adequate situation awareness (Mirnig et al., 2011). This indicator examines whether the feedback was clear to the user evaluated by the amount of clarifications the person requested. The *comfortability* measure influences the level of satisfaction the user has while interacting with the system (Mirnig et al., 2014) and how much feedback was provided was convenient and accessible to the user. This measure was evaluated by the difference in the user's heart rate during the session and by the amount of physical gestures the user made.

## 2.7 Analysis

A two tailed General Linear Mixed Model (GLMM) analysis was performed to evaluate for a positive or negative effect of the independent variables. The user ID was included as a random effect to account for individual differences. Types of feedback and complexity level were utilized as fixed factors while all objective and subjective variables representing 'Quality of Interaction' (QoI) were used as dependent variables. This enable to assess the main effect, and/or interaction effect of feedback type and complexity level on the QoI as a whole and as the individual variables that constitute the construct. Additionally, several t-tests were performed to examine the relationship between dependent samples.

## 2. 8 Research hypotheses

The study model is depicted in Figure 3 with the three hypotheses detailed below.

We believe that visual feedback combined with audio will help the older adults to understand the system even if they have hearing limitations and as a result don't hear the audio feedback. This assumption aligned with the findings of another study (Mirnig et al., 2011) that stated that verbal feedback supported by another feedback modality provides more positive outcomes. Along with more studies that found out that a combination of visual feedback and speech can be efficient (Rosati et al., 2013; Lang et al., 2009) and lead to improved collaboration between the human and the robot (Baraka et al., 2018). This leads to the first hypothesis which is stated as follows:

$H_1$: **A combination of visual and audio feedback type increases the *quality of interaction* of users relative to the visual or audio feedback alone.**

Existing studies recommend that feedback should be adequate and informative (Mirnig et al., 2014), the information content should be minimal (Lyons, 2013) in order to avoid overloading the user with information. Furthermore, verbal feedback will increase the awareness and understanding of the participant regarding the task being performed (Lyons, 2013). This leads to the second hypothesis which is stated as follows:

$H_2$: **The intermediate level of information increases the *quality of interaction* of users relative to the other levels.**

The audial feedback has great potential, but in many cases, its potential is not fully utilized .If the sound is monotonous users will get used to it and at some points will stop referring to it (Rosati et al., 2013). According to the findings of Agrawal et al. (Agrawal et al., 2018) feedback should be received only at important points along the robot's path to reduce the cognitive workload of the operator**.** This leads to the third hypothesis which is stated as follows:

$H_3$: **The interaction between audio feedback and the intermediate level of information will increase the *quality of interaction* of users relative to other feedback type and the intermediate level of information combinations.**

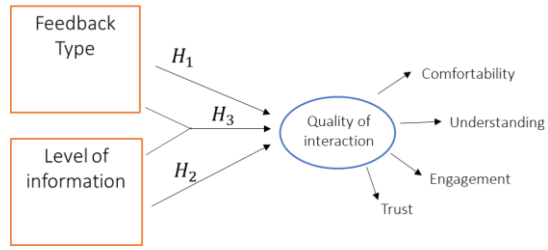



*Figure 3. The model for the study.*

## 3.Results

Most of the participants (78%) were comfortable interacting with a robot. The results revealed that the quality of interaction, as measured via trust, engagement, understanding and comfortability of the interaction was influenced mainly by the type of feedback (p = 0.05), and the level of information had less influence (p = 0.24). For each type of feedback, the participants indicated a specific preference for the different levels of information as detailed below (Figure 4).

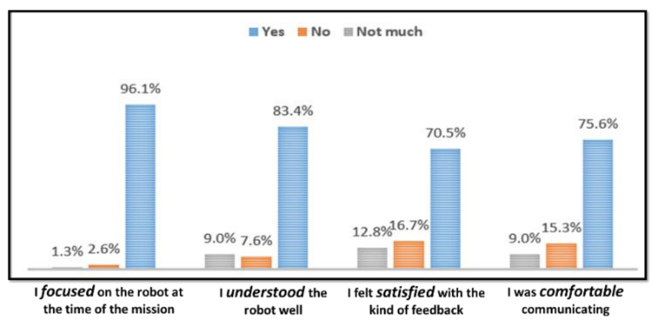



*Figure 4. Participants' experience*

### 3.1 Audial feedback

The preferred feedback for the audial type was the verbal feedback (implemented at the medium complexity level), a result which was reflected in all measures. Using this feedback increased the involvement of the participants during the experiment. i.e. the number of subjects' comments was higher (T=2.393, p = 0.049). Also, 86% of participants indicated that the verbal feedback helped them to understand the robot best. 13% preferred the combination of beep and verbal commands (the high complexity level), and only 1% preferred the use of beeping (the low complexity level). The comfortability measure showed similar results. The most comfortable feedback was the one that contained the verbal commands (med = 2.4).

The two levels that used the beeps were inconvenient to the users (med = 1.31). Also, heart rate during verbal commands was low (mean = 100.89, SD=5.79) whereas beep feedback resulted in a higher rate (mean = 112.28, SD= 6.76). Moreover, there was a large difference in the participants' sense of trust in the robot between complexity levels (p=0.049), with verbal feedback showing a higher trust (med = 3.43) vs. beep only (med = 2.43).

In the qualitative analyses (Figure 5) most of the participants testified that the voice feedback contributed to the understanding of the robot's action. There is little reference to the use of the beeps. Some of the participants claimed that they did not notice the whistling at all and some claimed that the beeps frightened them. On the other hand, the use of verbal commands caused many reactions among the participants: "Well done, I understood what you (the robot) were planning to do", "Great, now I want you to bring the spoon." A number of participants claimed that using verbal commands makes the system more useful because it allows for parallel tasks. "When the robot speaks, I can know what it is doing without looking at it and that will allow me to perform more tasks at the same time." Many users felt that communication was more natural when giving verbal feedback - "Now there is communication...", "I'm listening to you, now listen to me." And even thought that the robot could actually listen to their orders.

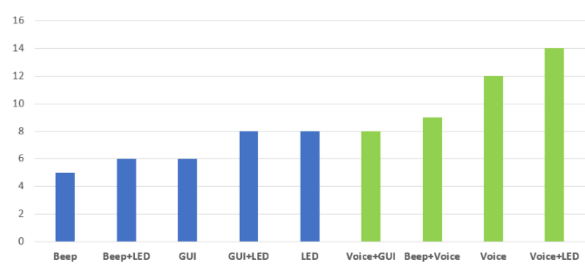



*Figure 5. User engagement comments- better with voice*

## 3.2 Visual feedback

The measures for this feedback type were also consistent with all measures. The preferred feedback was the use of LED lights as 96% of the participants were focused on the robot during the task and did not notice the information received from the screen. The simplest level of complexity involved in using LED lights resulted in the highest understanding (med = 3) compared to the two more complex levels that contained information displayed on a screen (med = 1.6). This preference was also noticeable in the comfortability measure. When using LED lights only, the overall sense of comfort was high (med = 2.3) and the heart rate measure was the lowest (mean = 98.96, SD=4.23) whilst using the screen resulted in a lower sense of comfortability (med = 1.5), and a higher heart rate (mean = 115.07, SD=5.87). When using LED lights, the lowest complexity level achieved the highest trust level (med = 3.03). This is probably due to the fact that using lights is similar to using other familiar devices.

In the qualitative analysis when the participants were asked about the information transmitted through the screen, the vast majority claimed that they did not even notice there was a screen. "I was so focused on the robot's movement that I did not even notice there was a screen." "I looked at the screen at first but once the robot started operating, I forgot to use the screen". Responses to feedback given by LED lights were ambivalent. Most of the users testified that the lights contributed very well to understanding and caused the unfamiliar cooperation with the robot to become similar to any other electric appliance - "the lights show me that the robot is starting to operate", "when the robot flickered it was like any other device I know and realized it works." However, a small part of the participants claimed that the lights dazzled them and were too strong.

## 3.3 Multimodal feedback

The multimodal feedback type provided the best understanding at all complexity levels (med = 3.8, p = 0.017). The levels containing verbal commands at the higher complexity levels, increased the understanding of the participants. The combination that contributed most to understanding was the combination of verbal commands and LED lights. The multimodal feedback contributed to the user's comfort and at all levels of complexity, mean heart rate was low (mean = 98). In both the comfortability measure and the trust measure, the most convenient (med = 3.1) and most reliable (med = 3.84) combination was the combination of LED lights and verbal commands (med = 3.1). A statistically significant result (p = 0.05) was obtained, showing a difference between the feedback types according to subjects' pleasure. Using multimodal feedback type showed greater pleasure, participants felt more natural with this type of feedback (med = 2.78). In addition, in-depth observation shows that the feedback that provided the greatest pleasure was the integration of LEDs into verbal commands (med = 3.14).

In the qualitative analysis the use of multimodal feedback resulted in conflicting comments. You can see that some of the participants thought that feedback given by two different senses contributes to understanding and can fill in the gaps. There were comments such as "It is excellent that there are lights, because when there are noises in the background I do not hear very well." Another part of the participants claimed that the combination was confusing and required attention to be divided between different factors and that was a bit difficult for them.

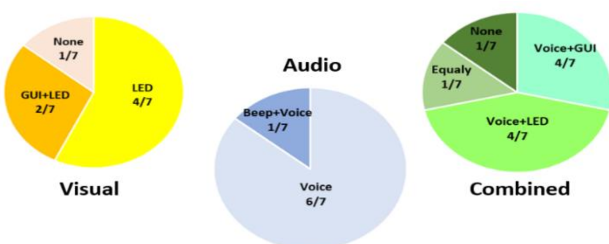



*Figure 6. LOI who contributed for best understanding*

## 4. Discussion

Most of the participants were comfortable interacting with a robot. The results revealed that the quality of interaction, as measured via trust, engagement, understanding and comfortability of the interaction was influenced mainly by the type of feedback, and the complexity level of the feedback (the level of information) had less influence.

### 4.1 Impact of verbal command

The preferred feedback for the audial type was the verbal feedback (implemented at the medium complexity level), a result that was reflected in all measures (in line with H2).

Most of the participants claimed that the use of verbal feedback contributed to their understanding of the robot's action. While they did not notice the beeps and even claimed that the beeps frightened them. The most important influence of verbal commands was on participants' involvement. The use of feedback that contained verbal commands increased the involvement of the participants during the experiment and raised their desire to communicate with the robot.

### 4.2 Impact of combined feedback

A combination of several components of feedback from the same sense did not contribute to the quality of interaction and even hampered the attention of the participants. When we look at the intercensal combination, we see opposite results indicating an increase in interaction quality (in line with H1), it contributes to participants' understanding and even if necessary, contributes to closing the gaps. The preferred combination was the combination of LED lights and verbal commands.

It is important to note that the various reactions of participants in this subject stem from the broad change in their physical and mental abilities. For these reasons, it is worthwhile to examine the suitability of the feedback type and its integration according to the subject's situation and condition and not only according to age.

### 4.3 Impact of feedback type and LOI interaction

It can be seen that for each type of feedback the participants indicated a clear preference for different levels of information. In visual feedback participants preferred the use of LED lights, that is, the simple level of information, while in the voice feedback the participants preferred the use of verbal commands, that is, a medium level of information (in line with H3). This is probably the reason the LOI alone did not have significant influence.

## 5. Conclusions and future work

Following the experiment, a number of key conclusions may be drawn. First, the preferred feedback should be given through verbal commands. This feedback significantly increased participants' involvement in the task, and it was evident that its use encouraged communication between the participant and the robot. Second, the LED lights provide a great contribution to understanding, since is a means familiar to older people from devices they use in their daily lives. The combination of the two types of feedback also had a positive effect. The incorporation of feedback from the robot was important since all the subjects concentrated on the robot's activity and did not notice the information received from the environment. However, as the users increase their familiarity with the robot's operation, we can expect that they may be able to share their visual attention with the robot's visual feedback mode. Another conclusion relates to the timing of the feedback. The feedback on the robot's operation should be given before the task is performed. In this way, it could provide information about the robot's intention. Information given after the task must relate to the quality of the performance.

For future work, it is recommended to apply the different feedback types in another robotic task. In this study, we used a stationary robotic arm for a table setting task. It would be interesting to see if using a different robot, for example, a mobile robot, performing a different task would lead to different results and conclusions or would reinforce the conclusions from this experiment.

**Acknowledgements**

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## 4. Study 2

Exploring Feedback Modalities in a Mobile Robot for Telecare

This work will be submitted as part of an independent journal publication (publication J3).

# Exploring Feedback Modalities in a Mobile Robot for Telecare

Noa Markfeld, Samuel Olatunji, Yael Edan

***Abstract.*** This study focused on evaluating different aspects of feedback in a telenursing task. The nurses are expected to teleoperate a robot to perform several tasks remotely, outside the immediate environment of the patient, in the hospital or in another location while they simultaneously manage other secondary tasks. The robot provides feedback related to status information on the robot's path and on tasks they perform. This feedback influences the performance of the telenursing tasks and the users' interaction.

This research investigated two feedback modalities (visual and audio) and their combination to determine the most suitable for a remote operator in a telenursing task with secondary tasks. Additionally, the influence of the secondary task location on interaction was evaluated. Experiments with 40 participants revealed that the interaction was influenced mainly by the feedback modality, while the secondary task location had less influence. In this type of scenario where time and accuracy are critical, a feedback mode that combined visual and audio feedback yielded the best results.

***Keywords:*** tele-operation, tele-robotic assistance, assistive robots, human-robot collaboration, feedback modalities, secondary task.

## 1. Introduction

There is increasing demand for health services as the aging population increases (United Nations, 2007). The shortage of healthcare professionals to cope with the increasing demands (Murray, 2002; Nora, 2002) of the rising proportion of older people (United Nations, 2007) leads to an increased need in developing solutions to assist the older adults. A promising solution to meet these needs is the use of assistive robots (Broekens, 2009). Assistive robots are being developed to fit into significant roles in hospitals supporting staff and to reduce the workload by performing various assistive functions (Aymerich-Franch, 2020). One of these functions is the ability to perform remotely a variety of tasks. A teleoperated robot is controlled by a human operator from a distance and performs tasks (services) as if the operator were on the spot (van Osch et al., 2014; Eliav et al., 2011). Tele-robots can provide assistance to the healthcare system (Tavakoli et al., 2020) by enabling caregivers to perform additional tasks while the robots are executing different tasks such as pre-diagnosis, food delivery, and monitoring.

This research investigates feedback modalities to determine the most suitable for remote tele-robotic assistance while performing a secondary task. Feedback from the robot can help inform the remote operator on different aspects: the robot's state of operation (e.g, moving towards goal or stopped due to an obstacle, Chen et al., 2014); details and constraints in the local environment (e.g., location of door to patient's room ahead, direction of passer-by in the corridor, Lyons, 2013); and on state of the task being performed (e.g., delivery of an item at the desired destination, vital sign check for a patient, Bolarinwa et al., 2019). The design of the feedback in our study relates to these aspects of the interaction. Existing studies reveal that the information presented to the user significantly influences his / her comprehension of the robot's behaviour, performance and limitations of the robot (Dubberly, 2009) which influences the interaction quality (Broekens, 2009; Stadler et al., 2012).

Robots can provide information to the human by visual feedback (Ferris, 2008), verbal feedback (Dzindolet et al., 2003), and tactile devices (Dzindolet et al., 2003). Combinations of these modalities (multimodal feedback) may enhance user interactions (Gombolay et al., 2017; Broz et al., 2012) and can increase the quantity and quality of information conveyed (Jacko et al., 2003; Markfeld et al., 2019). Creating the most appropriate type of feedback is a major challenge in human-robot interaction (Dubberly, 2009).

The caregivers usually have multiple tasks to perform in a short time (both in a hospital environment and in a home environment). Hence, to enable the collaboration with the robot to improve their work, they must perform tasks in parallel with the robot work. These kind of tasks involve many different factors such as task complexity, the distance between subtasks, and the time required to complete subtasks (Nagy et al., 2019).

In a telenursing task, which this study is focused on, nurses must carry out several tasks remotely, outside the immediate environment of the patient, in the hospital or in another location. The location of the operator's additional (secondary) tasks is an important factor that might influence performance (Baumann et al., 2007). Secondary tasks in telenursing can include completing health records, monitoring patients, preparing medicine. protocols, etc. Studies in other domains (e.g. in vehicle driving) have shown that the display position of the secondary task greatly affects performance (Lee, 2019; Baumann et al., 2007) in both secondary task and main tasks (Katsuyama, 1989). It was observed in those studies that locating the secondary task rightly, reduces the effort of the participant and even decreases the number of errors (Baumann et al., 2007). Results revealed that as the distance between the displays increases, in particular the vertical distance, the performance is impaired (Wittmann et al., 2006).

In this research we examine how the modality of feedback influences the interaction between a caregiver and a teleoperated robot for a telenursing task with a secondary task. The caregiver will attend to the secondary tasks while operating an autonomous robot that executes the main task. Feedback is provided on the robot's actions, details in the local environment and state of tasks the caregiver must perform. Additionally, we investigate if the location of the secondary task and the interaction with the feedback modalities influence the collaboration between the robot and the operator.

# 2. Materials and Methods

## 2.1 Overview

This experiment simulated a hospital environment (Figure 1) in which a caregiver (the user) delivers medication with other supplies to the patient and receives samples from the patient with a teleoperated robot. This is needed in situations where the nurse or caregiver cannot get near the patient for several possible reasons (task load, risk of infection, or other difficulties that may arise in getting to the same location with the patient). The caregiver sends the robot towards the patient to accomplish the main task while carrying out a secondary task. The robot moves autonomously in the environment but may require user involvement at certain points (e.g., code for entering a particular room, floor number for the elevator or access confirmation for a specific care unit) before continuing with its task. In the secondary task, the caregiver completes an electronic health record which involves answering some questions related to the patients. Feedback is provided during the process to indicate important points along the robot's path that require user involvement.

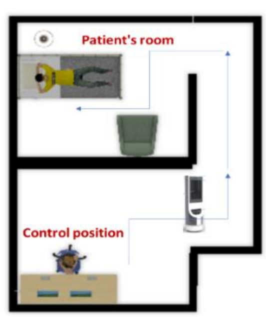


*Figure 1. A cross-section of the lab set up as a hospital-like environment for the study.*

## 2.2 Experimental system

The system (Figure 2) 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 (Quigley et al., 2009) of the robot. There are two user interfaces in the system - one runs on the robot while the other runs on the operator's computer. These interfaces run within a standard web browser making them independent of the operating system of the device or any specific software. This is particularly relevant for the user which would be the nurse who may need to access the robot via a standard computer desktop, laptop or tablet. This makes the robot more widely accessible via different devices. To enable the use of standard web browser we programmed our system on HTML, CSS, JS and PHP to store all the health records and user inputs. More details on the robot platform and user interfaces are provided in the following subsections:

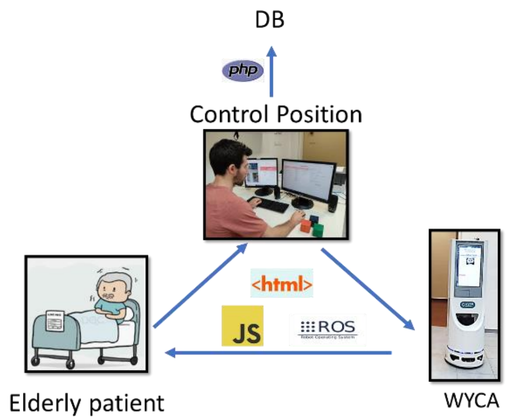


*Figure 2. The system*

*The robot platform.* The robot platform is a Keylo telepresence robot[2] (Figure 3). Its height is approximately 1.64m with a low centre of gravity and circular footprint 52cm of diameter. Keylo is equipped with a 24" multi-points high FOV touchscreen. It runs Ubuntu 18.04 LTS, ROS Melodic with a standard ROS API to all its sensors and features. The sensor specifications for navigation are: - Lidar: Hokuyo URG-04LX-UG01 (5.6 meters range, FOV 240°); 2 x 4 front and rear ultrasonic range sensors (5 meters range); 2 x 2 IR edge detectors hard-wired to the motors controller. Cameras include two front and one rear 3D RGB-D camera Intel® RealSense™ R200 that provide Point cloud, IR and RGB streams.


*Figure 3. Keylo robot description*

*User Interfaces.* The user interface running on the robot's browser was designed to welcome the user (Figure 4). The remote user interface through which the nurse teleoperates the robot is displayed on the computer through which the remote operator controls the robot. This interface was divided into three sections: a left, central and right panel (Figure 4). The video from the camera on the robot is broadcasted on the left panel. The right panel is the

[2] WYCA robotics website: https://www.wyca-robotics.com/

task window, on which the participant performs the secondary task. In the central panel, the feedback appears communicating to the caregiver the relevant information from the robot.

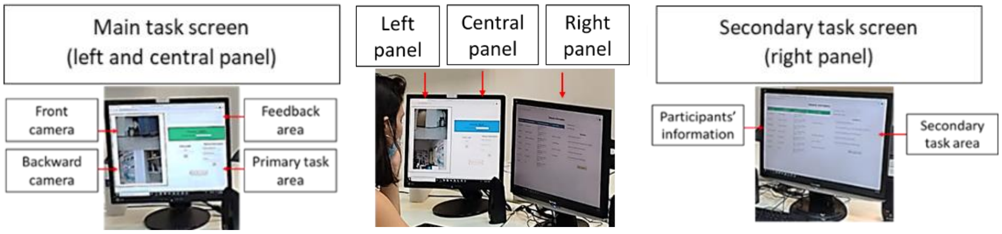


*Figure 4. User interface*

The right panel contains information related to the secondary task and was designed according to the two different scenarios which we termed secondary task locations in this paper. The secondary task locations are:

*On the screen only*- all information is displayed on the right panel. This includes a compilation of patients' health records and some questions on these patients.

*Combination of screen and desk*- the information is divided between the screen and papers containing health records on the desk below. The right panel contains only the questions on the patients while the compilation of patients' health records is in paper format on the desk.

In both scenarios the participant is expected to answer the questions according to the relevant information as best they can. Examples of the questions for the secondary task are given in Figure 5.

The main interaction with the robot takes place through the central panel which also displays the feedback from the robot. Throughout the task the caregiver receives feedback from the robot through this central panel. Feedback is only received only at important points along the robot's path to reduce the cognitive workload of the operator, according to the findings of Agrawal et al. (Agrawal et al, 2018). The feedback includes status information about: start of the mission, arrival at the destination (e.g. patient's bed), condition along the way (e.g. familiar position, facing a new corridor, malfunction/something unexpected on the way. When receiving the feedback, the participant is expected to attend to the information required by the robot so the robot can continue its task.

Two main types of feedback were examined based on previous findings (Markfeld et al., 2019; Olatunji, 2019) - visual, audio and their combination.

*Visual*- The visual feedback appeared on the central panel in the form of written messages. These messages were designed to convey the information clearly and immediately (Textual mode).

*Audio*- Audio feedback was given via voice commands as the robot navigates. The content of these commands was the same as the content that appeared in the on-screen messages in the visual feedback. Voice commands and not alerts (beeps) were used according to findings from a previous experiment (Markfeld et al., 2019) where it was stated that voice commands help the user understand the meaning of the information better in a noisy environment. This is also particularly relevant to the task since it simulates a noisy work environment.

*Visual and audio combination*- feedback was transmitted to the participant through both on-screen messages and voice commands.

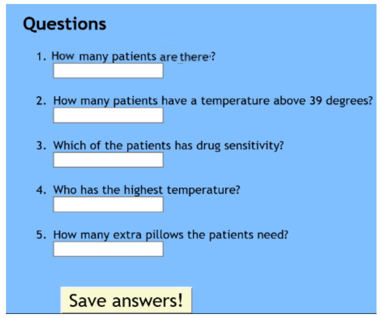


*Figure 5. Examples of the questions for the secondary task*

## 2. 3 Research hypotheses

The assumption is that user perception is influenced by objective performance that depends on feedback type and secondary task location as described in the study model (Figure 6) and explained below.

We assume that combined feedback will contribute to improved performance and shorten the response time. The audio feedback will draw the participant's attention at the appropriate time and the visual feedback will serve as a backup in case the user is focused on his tasks and misses the voice instructions. This hypothesis is based on our previous study where the results revealed that feedback coming from more than one source increases the quality of the interaction (Markfeld et al, 2019), similar to work by (Bolarinwa et al., 2019). This further revealed that different feedback modalities improved effectiveness of control and leads the first hypothesis:

$H_1$: **A combination of visual and audio feedback type increases the *objective performance* of users relative to the visual or audio feedback alone.**

Studies in a driving scenario show that the farther the display of the secondary task is from the main screen, the lower the performance (Wittmann et al, 2006). This is particularly relevant when the distance is a vertical distance, the response times increase and there are more errors (Katsuyama, 1989). This supports the second hypothesis:

$H_2$: **Executing the secondary task on-screen only will produce higher *objective performance* for users compared to executing the secondary task between desk and screen**.

The location of secondary task on the screen only, positioned in a horizontal line to the main task will reduce movement of the eyes and shorten response times (Sartre, 2006). Auditory displays, often reserved for alerting functions (Sartre, 2006), will draw participants' attention to their required task. When an immediate response from the participant is required while the visual media channel is overloaded, Michaelis and Wiggins, recommended the use of voice feedback (Michaelis & Wiggins, 1982). This backs up the third hypothesis:

$H_3$: **The interaction of audio feedback and on-screen secondary task location will increase the *objective performance* of users relative to other feedback type and secondary task location combinations.**

The better the participant's performance is (shorter response times, accurate and precise responses) the more positive his/her perception on the interaction with the robot will be (he/she will feel satisfied and will want to use the system more often (Avioz-Sarig et al., 2020). This agrees with the fourth hypothesis:

$H_4$: **An increase in the objective performance of users will lead to positive *user perception* of the interaction**.

Multi-modal interfaces have the potential to be extremely beneficial to both task performance and the interaction experience. (McGee, 1999). These interfaces can increase the potential realism of displays, and generally increase the quantity and quality of information we can convey through the interface. (McGee, 2001). In a robotic assistance study, it was found that the use of combined feedback augmented the user experience and caused the system to be more convenient and simpler to use (Bolarinwa et al., 2019). This supports the fifth hypothesis:

$H_5$: **Combination of visual and audio feedback type will lead to positive *user perception* of the interaction**.

When the secondary task is performed only on the screen, the participants' effort will be reduced, and the task performance will be easier (Wittmann et al, 2006). This proposition is based on studies of driving and the Click-through rate (CTR) field, and added that multiple and further eye movements cause discomfort (Katsuyama, 1989; Wittmann et al, 2006). This gives backing to the sixth hypothesis:

$H_6$: **Executing the secondary task on-screen only will improve *user perception* of the interaction compared to executing the secondary task between desk and screen.**

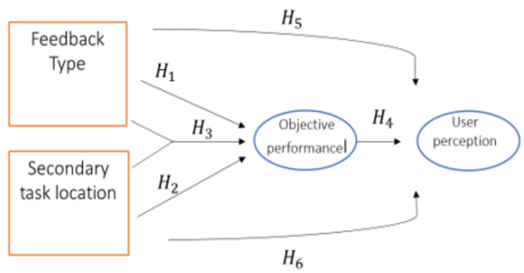


*Figure 6. The model for the study.*

## 2.4 Experimental design

The experiment is designed as a between-within experiment with the type of feedback and the location of secondary task defined as the independent variables (see Table 1). Each participant experienced one location of the secondary task while performing the task with three repetitions, with three types of feedback provided in a random order.

*Table 5. Experimental design*

| | | Secondary task location | |
|---|---|---|---|
| | | On the screen only | Combination of screen and desk |
| Type of feedback | Visual | Feedback about the main task will be provided to the user **in the center of the screen**. The secondary task will be performed **entirely on the screen on the right** | Feedback about the main task status will be provided to the user **in the center of the screen**. The secondary task will be done **alongside the screen and** only the answers will be recorded **on the screen in the right part**. |
| | Audio | Feedback about the main task will be provided to the user **via voice commands**. The secondary task will be performed **entirely on the screen on the right** | Feedback about the main task will be provided to the user **via voice commands**. The secondary task will be done **alongside the screen and** only the answers will be recorded **on the screen in the right part** |
| | Combination | Feedback about the main task will be provided to the user **in the center of the screen and via voice commands**. The secondary task will be performed **entirely on the screen on the right** | Feedback about the main task will be provided to the user **in the center of the screen via voice commands**. The secondary task will be done **alongside the screen and** only the answers will be recorded **on the screen in the right part** |

## 2.5 Dependent measures

*Objective Measures.* For each participant and trial, objective performance was measured in terms of efficiency, effectiveness and understanding.

The efficiency was evaluated as the completion time (seconds) of the task, the time between the robot's departure and return to the control point.
The effectiveness was evaluated as user performance in both primary and secondary tasks. This involves the number of subtasks in the secondary tasks completed, which was represented by the number of complete answers (completeness); the number of correct answers from total questions (accuracy) and the number of correct answers from total questions that answered (precision).
The understanding was evaluated by the reaction time. The reaction time is the time (seconds) that it took the participant to respond to the feedback the robot provided. Understanding was additionally evaluated by the number of clarifications the participant requested during the experiment after the initial explanation of the procedure at the beginning of the experiment.

The Objective Performance (OP) was calculated by an objective function (Equation 1) that combines these three measures.

$$OP = \sum_{n=1}^{\infty} \text{Effectiveness} - \text{Efficiency} + \text{Understanding} \quad (1)$$

*Subjective Measures.* The post-trial questionnaires included a total of 14 questions, used 5-point Likert scales, with 5 representing “Strongly agree” and 1 representing “Strongly disagree”. For these variables, the median results are presented.
The perceived workload was assessed using the NASA-Task Load Index (NASA-TLX) questionnaire (Sandra, 1988).
Subjective assessment concerning the system’s usability was collected using the System Usability Scale (SUS) questionnaire (Brooke et al. 1996).
Two additional dependent variables were evaluated based on their relevance to our work- understanding and satisfaction. Understanding examines whether the feedback was comprehensible and clear to the user. This indicator is required for the robot and human to successfully interact with each other (Hellström et al., 2018). Satisfaction was evaluated by four questions on communication, fluency, situation awareness and comfortability. It is important to assess the degree of satisfaction that the user has in the interaction (Frische, 2013).
The comfortability measures the influence of the level of ease the user has while interacting with the system (Czaja et al., 2019). Fluency measures if the feedback and operations of the robot was at the right timing (Hoffman, 2019). Situation awareness was assessed using a question on how much the information contributed to the participant’s awareness of the robot’s activities (Endsley, 1999). In the final questionnaire, participants provided their assessments regarding the ease of use, as well as possible recommendations for how to develop the system further.

## 2.6 Participants

40 third year undergraduate industrial engineering students (27 females, 13 males) at Ben-Gurion University were recruited as participants for the role of the caregiver (Mean age=26.5 years, SD=1.11). All of them had experience with computers and limited experience with robots. The students were compensated with a course credit, commensurate with their time of participation in the experiment.

## 2.7 Procedure

At the start of the experiment, after reading and signing the consent form, participants were asked to provide some background information regarding their age, gender and on their attitude toward robots. To assess their level of anxiety towards robots (Syrdal et al., 2009), we used a sub-set of the Negative Attitude toward Robots Scale (NARS). Following this, they were briefed on the scenario, tasks and procedure. Each participant performed the task three times - in each trial they experienced a different type of feedback. The order of feedbacks was randomly selected. Each trial was followed by a questionnaire enquiring about the experience with the condition (details on the measures are given below). After completion of all three trials, participants answered a final questionnaire in which they rated their overall experience with the robot and tasks. It afforded the opportunity to receive additional feedback or remarks from the participants.

### 2.8 Analysis

An ANOVA test was applied to ensure there was no significant effect between the trials. Then, a generalized linear mixed model (GLMM) was applied to analyse the data with the type of feedback and secondary task mode as fixed modes, whereas the random effect was selected as the variances from the participants. The tests were designed as two-tailed with a significance level of 0.05.

## 3. Results

### 3.1 Efficiency

The efficiency, measured as the completion time (seconds) of the task (mean=80.271, SD=1.806) was *significantly* affected by the type of feedback (F (2,114) =13.1, p=0.001). The completion time of those using only audio feedback was significantly lower (mean=70.61, SD=2.75) compared to participants that used both audio and visual feedback (mean=78.42, SD=2.75). The highest completion time was observed in trials with only visual feedback (mean=93.40, SD=3.64). The completion time *was not significantly* affected by the location of the secondary task (F (1,114) = 1.283, p=0.260). The completion time of participants that executed the task using the screen only (mean=78.25, SD=2.49) was shorter than participants who executed the task using both the desk and screen (mean=82.34, SD=2.62).

Moreover, the completion time was significantly affected by the order of feedback type provided (F(2,114)=2.058, p= 0.047). When the order started with only visual feedback the completion time of the task was the longest. It is noteworthy that the completion time reduced from trial 1 to trial 3 regardless of the type of feedback and the location of the secondary task. This indicates that it takes time to adjust to the system (although as noted earlier, training was performed a-priori and the order did not significantly influence performance).

### 3.2 Understanding

Understanding was measured both objectively and subjectively. Most of the participants (75.8%, med= 4, SD= 0.11) indicated in the questionnaire that they understood the system well and most indicated that the robot's feedback was received clearly (78.4%, med= 4, SD=1.05). The feedback type significantly affected comprehension (F (2,113) =10.254, p<0.001) and clarity (F (2,112) =12.015, p<0.001). Participants reported higher understanding while using the audio feedback mode (med=5, SD=0.5) compared to the using of visual feedback (med=3, SD=1.32). Using only the screen resulted in higher understanding (med=4.5, SD=0.96) compared to when using the combination of screen and desk (med=4, SD=0.966).

Objective measurement of understanding was with the reaction time and number of clarifications. The reaction time (seconds) of the participants in the first trial (mean=7.45, SD=0.52) was significantly affected by both the type of feedback (F (2,114) =49.905, p=0.000) and the location of secondary task (F (1,114) =4.94, p=0.028). The reaction time of participants that used visual feedback was significantly longer (mean=19.80, SD=2.37) than participants that used audio feedback. The reaction time using audio feedback only (mean=4.49, SD=0.54) was slightly shorter than the reaction time when they used combined feedback (mean=4.66, SD=0.56) (see Figure 7).

When the secondary task was executed on both - the screen and the desk, the reaction time was longer (mean=8.64, SD=0.85) than when the task was executed on the screen only (mean=6.39, SD=0.62). This result was significant (F (2,114) =3.40, p=0.04). The combination of visual feedback and a split location of the secondary task resulted in the longest response time (mean=27.36, SD=4.64). Also, when the feedback type was purely audio the shortest response time was obtained when the secondary task was split (mean=4.08, SD=0.69). The combination of visual and audio provided the shortest reaction time when there was only screen use and it also gave the shortest reaction time (mean=3.68, SD=0.62).

It was also observed that the reaction time in the first trial was significantly affected by the order of feedback type provided (F (2,114) =6.45, p= 0.004). When the order of experiment started with only visual feedback, the reaction time of participants was longer than trials with the other feedback modes. In the second trial, the second reaction time (mean=6.94, SD=0.48) was not significantly affected by the type of feedback (F (2,114) =2.25, p=0.11) and the location of secondary task (F (1,114) =2.87, p=0.09). The descriptive analysis of the variables corresponds to the results of the first reaction time. Reaction time of participants was shorter when only audio feedback was used (mean=6.23, SD=0.69) compared to using visual feedback (mean=8.34, SD=0.93). Similarly, the reaction time when performing the secondary task on the screen only (mean=6.17, SD=0.60) was shorter compared to when performed between the screen and the desk (mean=7.80, SD=0.76).

Participants that experienced audio feedback (mean=1.94, SD=0.71) asked more questions than participants that experienced the combined audio and visual feedback (mean=1.00, SD=0.57). All clarifications were inquired during the first trial only.

### 3.3 Effectiveness

All the participants completed the primary task in the right way and therefore we refer to the effectiveness of their performance in the secondary task only.

In terms of completeness, the type of feedback did not significantly affect the number of questions that was answered by the participants (mean=3.7, SD=0.18, F (2,114) =2.17, p=0.12). The participants' persistence to complete the task by participants who experienced visual feedback only (mean=4.18, SD=0.32) was higher than participants with audio feedback (mean=3.28, SD=0.29) and with combined feedback (mean=3.71, SD=0.30) (see Figure 7). The completeness was not significantly affected by the location of secondary task (F (1,114) = 0. 89, p=0.35). The completeness of answers when using the screen only (mean=3.54, SD=0.24) was slightly lower than the completeness when using desk and screen (mean=3.87, SD=0.25).

Regarding accuracy, the type of feedback did not significantly affect the number of correct answers given by participants from the total questions (mean=0.59, SD=0.04, F (2,114) = 2.07, p=0.13). The accuracy when using visual feedback only (mean=0.645, SD=0.042) was higher than when using with audio feedback (mean=0.54, SD=0.04) and with combined feedback (mean=0.57, SD=0.04). The accuracy measure was not significantly affected by the location of secondary task (F (1,114) = 0.455, p=0.501). The accuracy when using the screen only (mean=0.57, SD=0.04) was slightly lower than the completes when using desk and screen (mean=0.61, SD=0.04).

In terms of precision, the type of feedback (F(2,114)=0.005, p=0.95) and the location of secondary task (F(1,14)=0.342, p=0.560) did not affect the number of correct answers from total questions answered (mean=0.71 , SD=0.06). There is a correlation with the results of the previous indices (accuracy), but in this index (precision) the differences are very small: visual feedback (mean=0.71, SD=0.04), visual and audio feedback (mean=0.77, SD=0.04), audio feedback (mean=0.753, SD=0.04), screen only (mean=0.78, SD=0.03), screen and desk (mean=0.76, SD=0.03).

It was also observed that the performance of the participants improved along the trials regardless of the type of feedback and the location of the secondary task. Significant differences were obtained in the first trial and in which the best performance was obtained for visual feedback. When the secondary task location was divided between the screen and desk, the performance metrics were better.

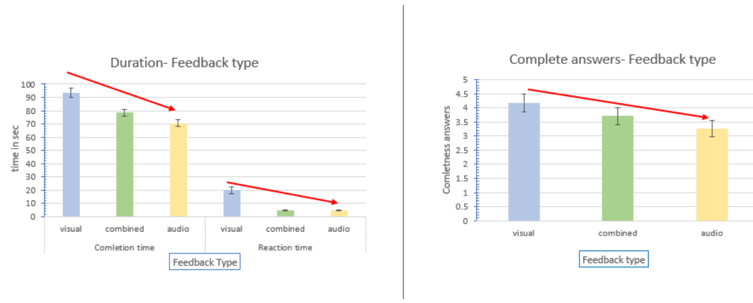


*Figure 7. Feedback trend-*
*the visual feedback had the longest duration time, but the highest number of answers*

### 3.4 Objective Performance (OP)

The OP (mean=0.67, SD=0.08) was significantly affected by the type of feedback (F (2,113) =3.95, p=0.02). The feedback which contained audio feedback resulted in a higher OP (audio only: mean=0.77, SD=0.13, visual only: mean= 0.34, SD= 0.13, combined: mean= 0.87, SD= 0.13).

The OP in the scenario with the screen only (mean= 0.74, SD= 0.15) was slightly lower than the scenario using desk and screen (mean= 0.61, SD= 0.15) but there was' not a significant effect of the secondary task location (F (1,113) = 0.65, p=0.44, Figure 8).

The OP was improved from trial 1 to trial 3 regardless of the type of feedback and the location of the secondary task. Although the results differ between trials, the OP increased when audio feedback was used – better performance was obtained when using audio feedback only and in feedback that combined audio and visual.

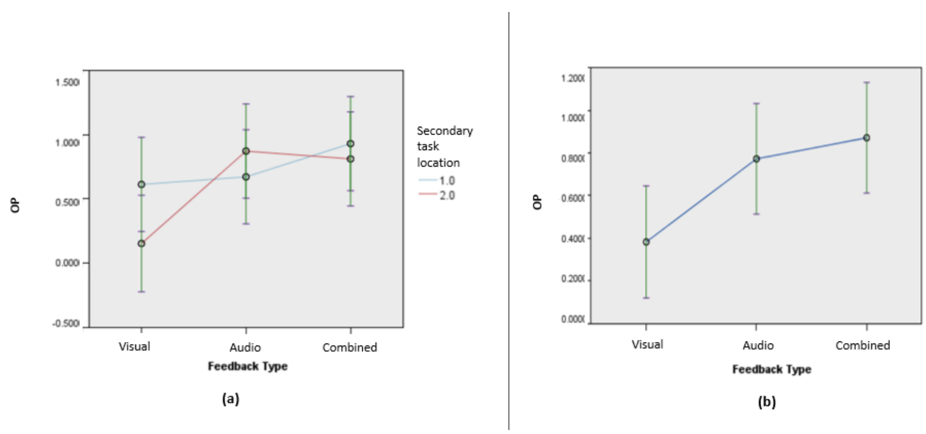


*Figure 8. The Objective Performance.* (a) The OP according the feedback type and the secondary task location. (b) The OP according the feedback type.

### 3.5 Satisfaction

In terms of communication, 66.7% of the participants indicated that they were satisfied with the way the robot communicated with them (med=3.75, SD=1.22). The communication was significant with respect to the feedback type (F (2,113) =10.25, p=0.001). Feedback that contained verbal commands in both audio feedback and combined feedback led to a higher communication score (med=4, SD=0.99) compared to when using feedback that contained only visual (med=3, SD=1.23).

The feedback type had a significant effect on fluency (F (2,112) = 10.04, p=0.001). 72.5% of the participants indicated that the feedback from the robot was received at the right timing. It was observed that the feedback that contained verbal commands in both audio feedback and combined feedback resulted in a very high score (med = 5, SD=0.93) while visual feedback had a reduced score (med = 3, SD=1.19). The secondary task location was not significant on fluency. Fluency score was similar for both secondary task locations (med=4, SD=0.94).

Regarding situation awareness (SA), 72.5% of the participants reported that through the feedback provided, they were aware of the robot's activity in the space. This assessment is relevant in a teleoperated task where the robot is not located near the operator. The situation awareness index (med=4, SD=1.13) was significantly affected by the type of feedback (F (2,112) =21.74, p=0.00). The audio feedback yielded higher SA score (med=4.5, SD=0.95) compared to combined feedback (med=4, SD=0.86) and to visual feedback (med=3, SD=1.244). The SA index was not significantly affected by the location of secondary task (F (1,112) =0.872, p=0.352); using the screen only (med=4, SD=1.05) was slightly higher than the SA when using desk and screen (mean=3.75, SD=1.23).

In terms of comfortability, 66.7% of the participants indicated that the robot's communication with them was comfortable. The type of feedback influenced significantly the comfortability (F (2,112) = 14.93, p=0.001) The lowest comfortability score was observed when participants used the visual feedback (med=2.5, SD=1.29). When participants used the audio feedback, the comfortability score was higher (med=4.37, SD=0.99) compared to when they used the combined feedback (med= 4.25, SD=1.14). The comfortability score was similar at both secondary task locations (med=4, SD=1.21).

### 3.6 Usability

64.2% of the participants reported that they would like to use this system frequently and 80.8% of them reported that the system was very easy to use. Only 19.1% of the participants claimed that they would have to learn new things before using the system. The frequency of use (F(2,112)=10.51, p=0.00) and ease of use (F(2,112)=4.26, p=0.02), were significantly affected by the feedback type but learnability was not (F(2,112)=0.35, p=0.71). The influence of the location of secondary task was not significant in all dimensions of usability. The usability scores were higher when using the audio feedback mode (med=4, SD=0.10) compared to the combined feedback (med=3.67, SD=0.11) and the use of visual feedback (med=3, SD=0.12). The usability scores when using the screen only (med=3.67, SD=0.04) was slightly higher than the usability when using screen and desk (mean=3.33, SD=0.14).

### 3.7 Perceived workload

The perceived workload was assessed through the aggregated raw NASA-TLX score. The perceived workload (mean= 56.26, SD=14) was not significantly influenced by the feedback type and the secondary task location (F (2,115) =0.11, p=0.90, (F(1,115)=0.63, p=0.43). The lowest perceived workload was obtained when providing the combined feedback (mean=55.8, SD=14) and the highest perceived workload was obtained when the feedback was only visual (mean=56.78, SD=11.2). In relation to the location of the secondary task, the lower perceived workload was obtained when the task was split between the screen and the desk (mean=54.66, SD=14).The perceived workload when the task was just on the screen was higher (mean=56.66, SD=13).

*Table 6. The significance of feedback type*

| Significance of feedback type | | | |
|---|---|---|---|
| Dependent Variables | Examined by | P-value | Best feedback type |
| Efficiency | Completion time | < 0.001 | Audio |
| Understanding | Comprehension | < 0.001 | Audio |
| | Clarity | < 0.001 | Combined |
| | Reaction time | < 0.001 | Audio |
| OP | Objective function | 0.022 | Combined |
| satisfaction | Communication | 0.001 | Audio, Combined |
| | SA | < 0.001 | Audio |
| | Comfortability | < 0.001 | Combined |
| Usability | Frequency of use | < 0.001 | Audio, Combined |
| | Easy of use | 0.017 | Audio, Combined |

## 4. Discussion

Improving the interaction of assistive robots is an important factor. This research examined how the type of feedback and secondary task location influence the interaction between a caregiver (for instance, a nurse) and a teleoperated robot. The results revealed that objective performance and user perception were influenced mainly by the type of feedback (confirming H1 and H5) and the secondary task location had less influence. The secondary task location influenced only some of the interaction parameters (confirming H2). More details are discussed in the succeeding subsections regarding the effect of each of these variables on the interaction.

### 4.1 Impact of feedback mode

88% of participants preferred voice feedback, of which 67% claimed that the combined feedback (the feedback that combined audio and visual) was most comfortable for them (in line with H5). Even though the audio feedback reduced both response times and completion times, it did not result in the highest objective performance in the study. This seems to point to some pitfalls of audio-only feedback which may have affected the quality of the performance. The audio feedback usually prompts a quick response, which may have caused some stress or additional workload as seen in the NASA-TLX scores, consequently lowering the quality of performance. This assumption is supported by the fact that the mental demand scores observed were higher while using purely audio feedback compared to when using the combined feedback (audio and visual). This is in line with previous research which showed that sound alone requires high attentional demand (Lee, 2001). Note that this was the preferred feedback regardless of the location of the secondary task (as opposed to H3).

When the task required of the participant is simple, the concentration required is low. In such cases, the transition between the tasks (primary and secondary) when giving a voice command is usually easier and does not often impair the performance of any of the tasks. The more complex the task, the more concentration the task requires, the more difficult the transition between tasks will be and the transitions will take longer. Thus, the combined feedback will be better than the voice-only feedback (in line with H1). We recommend voice feedback for attentive tasks and visual feedback as a backup communication mode.

Regarding visual-only feedback mode, the reaction time and the completion time were higher than other modes, specifically in the first trial. The participants were focused on the secondary task and the visual feedback did not attract their attention. They attended to the robot's instructions just after they had finished the secondary task. However, it is important to note that the trial order of the experiment influenced the results. When the visual feedback condition was in the first trial, the participants had no experience in performing the task and allocated their attention inappropriately. On the other hand, when the visual feedback condition was in the second trial or the third trial, the participants already knew what to expect and occasionally turned to the main task. Although visual feedback may be a significant feedback, which contains a lot of information (text, picture, and even video) (Sartre, 2006), but when the caregiver is busy and in high workload conditions, which require a quick and decisive response, it might not be sufficient alone. This further strengthens the recommendation for combined feedback mode in such tasks involving high workload as investigated in the current study.

### 4.3 Impact of secondary task location

It can be seen that the different locations of the secondary task did not have significant influence on results. Although, in most cases, better results were obtained when the secondary task was performed on the screen only and not when it divided between the screen and desk (in line with H2). An interesting point relates to the performance in the secondary task- the participants answered more questions when the task was divided between the screen and the desk, however the precision (number of correct answers out of the total answers) was higher when the task was performed on screen only. Namely, splitting the task and being at a vertical distance caused more errors. This agrees with a previous study in which multiple eye movements increased user's mistakes (Katsuyama, 1989).

### 4.4 Impact of user expectations

Some measures of performance improved from the first trial to the third trial regardless of the type of feedback and the location of the secondary task. We suspect that the expectation of participants could be influential. Users seemed to know better what to expect from the system after each trial, which may have resulted in improved performance. It seemed some of the participants observed that they felt pressure in the first trial, which then prevented them from paying attention to the information that the robot provided. Furthermore, they explained that after getting used to collaborating with the robot, they were more attentive to the feedback and it made a greater contribution. The fact that they were more acquainted with the system after each trial may have influenced their performance. Although, we cannot assert this claim because no statistical difference was found between the trials and the expectation factor was not specifically included in the experimental design. This highlights the value of a further study to explore the user expectations from the system. We therefore recommend that in future studies, more exposure and interaction of participants with the robot should be included in the experimental design to allow participants to work longer with the robot prior to the main experiment. This could help to better identify possible influences of user expectations. This recommendation may have a greater impact when tested with actual caregivers who have less experience with robots than engineering students, who participated in this experiment. Furthermore, it may provide some insights to the importance of expectations and perhaps ‘training’ of users for a variety of conditions.

## 5. Conclusions and Future work

This experiment simulated a hospital environment in which a simulated caregiver teleoperates a mobile robot while performing another task. In this type of scenario where the time and accuracy are critical, we found that the feedback that combined visual and audio feedback modes yielded best results. Note that, if the goal is to shorten the performance time, voice feedback is optimal. However, due to some of the shortcomings of audio-only feedback discussed, combined audio and visual feedback is recommended. It is also worth noting that haptic feedback was not tested in this experiment and it will be interesting to see how its use will affect the shared interaction.

The results of this experiment reinforce results obtained in a previous study, in which we examined the effect of feedback types on the interaction in another task and with a different population (Markfeld et al, 2019, a stationary robotics task with older adults). The use of audio feedback positively affects the interaction regardless of the environment and the users. Additionally, the benefits of using combined feedback have been intensified and it can be seen that using multiple types of feedback has contributed positively in the teleoperation of a robot in a complex task involving a noisy environment. The location of the secondary task did not result in significant differences, but it may be interesting to see if a more complex secondary task would make a difference in these different locations.

We expect these results to amplify when real caregiver users will use the system. However, it is important to note that these experiments examined specific scenarios. In order to generalize these conclusions, additional experiments examining different interfaces and different tasks must be performed.

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## 5. Summary and discussion

This research examined the influence of feedback in interaction between assistive robots and older adults and caregivers (non-technological users). Creating a successful interaction is a pretty challenging task. To achieve this, robots must be able to communicate naturally with humans both verbally and nonverbally (Breazeal et al., 2016). The feedback loop is an important feature of interactive systems; it provides the user with information improving the nature of the interaction between a person and a dynamic system.

Since older adults' perceptual capabilities and limitations differ from the younger population due to age-related perceptual declines, particularly evident in processing information (Mitzner et al., 2015). Thus, the correct choice of interaction between the assisting environment and the user is of high importance (Broekens et al., 2009). Older adults' interaction with robots requires effective feedback to keep them aware of the state of the interaction for optimum interaction quality (Beer et al., 2012).

In this research the influence of feedback for different aspects that influence task performance was evaluated: levels of automation, levels of transparency, levels of information and the location of the secondary task. The experiments were performed in a series in which conclusions from one experiment served as inputs for the design of the subsequent experiment.

Based on the research results we provide several guidelines for interactive feedback as related to the mode of feedback, the timing of the feedback and the amount of information provided. **The feedback on the robot's operation should be given before the task is performed**, so as to prepare the participant for the robots' action. **The feedback should contain a low amount of information** in order to avoid clutter and confusion among the participants, especially when it comes to the elderly population. This agrees with previous studies where feedback content, mode and timing suitable for the users and applicable for specific contexts was explored through user studies (Mirnig et al., 2011; Doisy et al., 2014; Olatunji et al., 2020). It was also recommended by (Lyons, 2013) that the user interface should provide information relevant to the task and environment (Lyons, 2013). Caution was raised that too much information or a non-intuitive display could create confusion or be frustrating for the user and particularly the older adult population (Olatunji et al., 2020).

A main conclusion refers to the **positive impact of audio feedback on the quality of the interaction between the user and the robot**, regardless of the environment and the population being tested. For direct control tasks, this feedback increased participants' involvement in the task significantly and encouraged robot-participant communication. For tele- operation task, with a noisy and stressful environment, this feedback has great importance in focusing attention and work efficiency.

Moreover, **the combination of verbal commands with visual feedback was found to be most effective**. The use of an intercensal combination of feedback integrated and intensified the benefits of each feedback modality. The use of this feedback contributed positively for use of the robots in a complex task such involving a noisy environment and to a population whose capabilities are non-homogeneous. This agrees with previous research that noted that multi-modal communication supported better user performance (Finomore et al., 2012).

This study yielded valuable insights into participants' preferences and characteristics of the operator interface related to feedback that are required to enhance the user experience and performance. This study reveals the importance of feedback designs in improving the interaction of older adults with assistive robots. Reliable use of feedback will increase confidence in the robotic system even in a population that is not used to it and will eventually become viable tools that add value to their everyday lives.

However, it is important to note that these experiments examined specific scenarios. In order to generalize these conclusions, additional experiments must be performed to examine different interfaces and different tasks at different complexity levels.

Another limitation aspect refers to the last experiment, this experiment simulated a hospital environment but in practice was conducted under laboratory conditions where the environment is known and not extremely noisy. Moreover, the participants were undergraduate industrial engineering students with technological backgrounds, a population different from real caregivers. We expect results to be amplified with a non-technical population. However, future research should consider extending this experiment and conducting it with real caregivers and even in a hospital or other treatment setting.

Another aspect for further research relates to the reason given in the feedback - in this study, the feedback was 'pushed' to the user, the information was provided to the human by the robot without the human asking for it. It will be interesting to examine the impact of 'pull' feedback, where information is provided only on demand by the user.

Another aspect that should be investigated is haptic feedback (also denoted as tactile). Since there are many types of tactile feedback research should investigate the design of such an interface and optimize to fit such a diverse population.

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## 7. Appendices

## 7.2 Appendix A- a case study on LOA-LOT

# Improving the Interaction of Older Adults with a Socially Assistive Table Setting Robot

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**Abstract.** This study provides user-studies aimed at exploring factors influencing the interaction between older adults and a robotic table setting assistant. The influence of level of automation (LOA) and level of transparency (LOT) on the quality of the interaction was considered. Results revealed that the interaction effect of LOA and LOT significantly influenced the interaction. A low LOA which required the user to control some of the actions of the robot influenced the older adults to participate more in the interaction when the LOT was high (more information) compared to situations with low LOT (less information) and high LOA (more robot autonomy). Even though, the higher LOA influenced more fluency in the interaction, the lower LOA encouraged a more collaborative form of interaction which is a priority in the design of robotic aids for older adult users. The results provide some insights into shared control designs which accommodates the preferences of the older adult users as they interact with robotic aids such as the table setting robot used in this study.

**Keywords:** Shared control · Levels of automation · Transparency · Collaborative robots · Human-robot interaction

## 1 Introduction

Robots with improved capabilities are advancing into prominent roles while assisting older adults in performing daily living tasks such as cleaning, dressing, feeding (Honig et al. 2018; Shishehgar et al. 2018). This has to be done with careful consideration for the strong desire of these older adults to maintain a certain level of autonomy while performing their daily living tasks, even if the robot provides the help they require (Wu et al. 2016). Furthermore, the robot's involvement should not drive the older adult to boredom, sedentariness or loss of skills relevant to daily living due to prolonged inactivity (Beer et al. 2014). A possible solution is shared control where the user preferences are adequately considered as the robot's role and actions are being defined during the interaction design. This ensures that the older adults are not deprived of the independence they desire (Zwijsen et al. 2011).

This study, proposes a shared control strategy using levels of automation (LOA) which refers to the degree to which the robot would perform particular functions in its defined role of assisting the user in a specific task (Parasuraman et al. 2008). The aim is to ensure high quality collaboration between the older adult and the robot in


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accomplishing desired tasks, without undermining the autonomy, preferences and satisfaction of the older adult.

To ensure transparency of the robot's role at all times, the LOA implementation is reflected in the ways through which the users interact with the robots. Transparency in this context is the degree of task-related information provided by the robot to the older adults to keep them aware of its state, actions and intentions of the robot (Chen et al. 2018). The content of this information provided by the robot can be graded according to the detail, quantity and type of information as mirrored in Endsley's situation awareness (SA) study (Endsley 1995) and Chen et al.'s SA-based Transparency model (Chen et al. 2014). It is essential that the level of transparency (LOT) of the information being presented to the older adults conforms with their perceptual and cognitive peculiarities such as the processing and interpretation of the information provided by the robot (Smarr et al. 2014; Mitzner et al. 2015; Feingold Polak et al. 2018). Existing studies reveal that the information presented to the users significantly influences their comprehension of the robot's behavior, performance and limitations (Dzindolet et al. 2003; Lyons 2013; Chen et al. 2014). This information facilitates the users' knowledge of the automation connected to the task (Endsley 2017). This affects the users' understanding of their role and that of the robot in any given interaction (Lyons 2013; Chen et al. 2014; Doran et al. 2017; Hellström and Bensch 2018).

Some studies explored the presentation of information through various technological aids such as digital mobile applications, webpages, rehabilitation equipment, and other facilities through which older adults would interact with their environment (Cen/Cenelec 2002; Fisk et al. 2009; Mitzner et al. 2015). These studies, provided recommendations which served as design guidelines for information presented in various modes such as visual, audial or haptic information. These recommendations are not specific to information presented by robots to the older adults. They are general guidelines recommended to aid usability as older adults interact with technological devices. It was therefore recommended in those studies that more user studies should be conducted in specific robot-assistance domains such physical support, social interaction, safety monitoring, cognitive stimulation and rehabilitation (Cen/Cenelec 2002; Fisk et al. 2009; Mitzner et al. 2015; Van Wynsberghe 2016). Through such studies, suitable design parameters could be identified that would meet the needs of the older adults in specific applications such as the table setting robot application on which this study is focused.

The aforementioned studies have explored individual effects of LOA or LOT separately in different domains. But this has not been examined in the use of socially assistive robots for older people. LOA, as a control strategy, tends to improve the collaboration between the user and the robot by sufficiently keeping the user in the loop. This is critical in older adults' interaction with robots in order to avoid inactiveness. LOT, as an information presentation strategy, also tends to improve the awareness of the user during the interaction. This is also critical for the older adults to ensure that they are constantly carried along in the interaction. We therefore hypothesize that exploring some LOA and LOT options in robot-assisted tasks could increase the engagement and satisfaction of the older adults as they interact with the robots. The current study aims to explore how LOA and LOT influences the quality of interaction (QoI) between the older adults and the assistive robot in a shared task of table setting.

The QoI is a construct in this paper which entails the fluency, understanding, engagement and comfortability during the interaction.

## 2 Methods

### 2.1 Overview

A table setting task performed by a robotic arm was used as the case study. The robot had to pick up a plate, a cup, a fork and a knife and to place them at preset positions on the table. The user operated the robot in two levels of automation. In the high LOA condition, the robot operated autonomously. The user could only start and stop the robot's operation by pressing a specific button. In the low LOA condition, the user could still start and stop the robot, but the robot required the user's consent before setting each item. The robot asked the user through a GUI which item to bring and the user was required to respond before the robot could continue its operation.

Two conditions utilizing different levels of transparency (LOT) were compared for two different levels of the robot's automation: high and low (Table 1). Information was given by the robot in visual form through a GUI on an adjacent screen where the LOT manipulated (Fig. 1). The two conditions differed by the amount of details provided by the robot. The low level of information included text messages that specified the status of the robot by indicating **what** it was doing (e.g. bringing a plate, putting a fork, etc.), while the high level of information included also the **reason** for this status (i.e. I'm bringing the plate since you asked me, etc.)

**Table 1.** Experimental conditions.

| LOT | LOA | |
|---|---|---|
| | Low | High |
| Low | Condition 1 – LL<br>User instructs the robot using the GUI and receives information about **what** the robot is doing in each stage | Condition 3 – LH<br>Robot operates automatically. In each stage user receives information about **what** the robot is doing |
| High | Condition 2 – HL<br>User instructs the robot using the GUI and receives information about what the robot is doing and the reason for it in each stage | Condition 4 – HH<br>Robot operates automatically. In each stage user receives information about **what** the robot is doing and the **reason** for it |

### 2.2 Apparatus

A KUKA LBR iiwa 14 R820 7 degrees of freedom robotic arm equipped with a pneumatic gripper was used (Fig. 1). The tasks were programmed using python and executed on the ROS (Schaefer 2015) platform.

In order to instruct the robot and to present the information received by the robot a graphical user interface (GUI) was used on a PC screen, which was located on a desk to the left of the user (see Fig. 1).

**Fig. 1.** A participant using the GUI to instruct the robot.

### 2.3 Participants

Fourteen older adults (8 Females, 6 Males) aged 62–82 (mean 69.8) participated in the study. Participants were recruited through an advertisement which was publicized electronically. They were healthy individuals with no physical disability who came independently to the lab. Each participant completed the study separately at different timeslots, so there was no contact between participants.

### 2.4 Experimental Design

The experiment was set with a mixed between and within subject design with the LOA modes as the between subject variable, and the LOT as the within subject variable.

Participants were assigned randomly to one of the two LOA conditions. All participants completed the same table setting task for both levels of transparency. The order of the two tasks was counterbalanced between participants, to accommodate for potential bias of learning effects, boredom or fatigue.

### 2.5 Performance Measures

Initially, participants completed a pre-test questionnaire which included the following: demographic information, and a subset of questions from the Technology Adoption Propensity (TAP) index (Ratchford and Barnhart 2012) to assess their level of experience with technology and from the Negative Attitude toward Robots Scale (NARS) (Syrdal et al. 2009) to assess their level of anxiety towards robots.

Objective measures that were collected during each session are interaction-related variables such as fluency, engagement, understanding and comfortability. Subjective measures were assessed via questionnaires. Participants completed a short post-session questionnaire after each session and a final questionnaire at the end of the two sessions to evaluate subjective measures. The post-session questionnaire used 5-point Likert scales with 5 representing "Strongly agree" and 1 representing "Strongly disagree". The final questionnaire related to the difference between both sessions.

### 2.6 Analysis

A two-tailed General Linear Mixed Model (GLMM) analysis was performed to evaluate for a positive or negative effect of the independent variables. The user ID was included as a random effect to account for individual differences. LOA and LOT were utilized as fixed factors while all objective and subjective variables representing 'Quality of Interaction' (QoC) were used as dependent variables.

## 3 Results

### 3.1 Demographics and Attitude Towards Technology

There was an equal distribution of participants within the two groups. On a scale of 1 (strongly disagree) to 5 (strongly agree), the TAP index reveals that most of the participants are optimistic about technology providing more control and flexibility in life (*mean = 3.86, SD = 1.17*). It was also observed that over 75% of the participants like to learn the use of new technology (*mean = 3.93, SD = 1.07*) and feel comfortable communicating with robots (*mean = 3.43, SD = 1.50*). The majority (80%) did not have negative feelings about situations in which they have to interact with a robot (*mean = 4.14, SD = 0.86*).

### 3.2 Quality of Interaction

A two-way ANOVA was run to find out if there was a significant difference between the LOA-LOT manipulation as conditions ($F(3, 22) = 2.35$, $p = 0.033$). The effect of the manipulation was significant on the robot's idle time ($F(3, 22) = 4.91$, $p = 0.009$), functional delay ($F(3, 22) = 21.22$, $p < 0.001$), human idle time ($F(3, 22) = 3.03$, $p = 0.005$), the gaze on the robot ($F(3, 22) = 3.97$, $p = 0.021$), perception of safety ($F(3, 22) = 3.22$, $p = 0.042$) and overall interaction time ($F(3, 22) = 5.31$, $p = 0.007$). The effect of the manipulation was not significant on the gaze on the GUI where the robot provided feedback ($F(3, 22) = 2.01$, $p = 0.142$). More details of the components of the quality of interaction are presented below.

### 3.3 Fluency

Fluency was represented by the idle time of the robot, functional delay and overall time spent on the task. The LOA was significant on the robot's idle time (*mean = 122.54, SD = 59.70*, $F(1, 24) = 9.97$, $p = 0.004$) with the high LOA (*mean = 88.85, SD = 2.48*) having a lower robot idle time compared to low LOA (*mean 156.21, SD = 70.38*). The LOT was not significant as a main effect but there was a significant effect in the interaction between the LOA and LOT ($F(4, 24) = 44.2$, $p < 0.001$) as depicted in Fig. 2. In terms of delay (*mean = 12.86, SD = 13.87*), the LOA was significant ($F(1, 24) = 14.48$, $p = 0.001$). The low LOA had more delays (*mean = 20.85, SD = 15.99*) than high LOA ($mean = 4.87$, $SD = 13.87$). The LOT was not significant ($F(1, 24) = 2.04$, $p = 0.17$). There was also no interaction effect of the LOA and LOT on the delays ($F(1, 24) = 1.49$, $p = 0.23$). The duration of the experiment with low LOA ($mean = 239.21$, $SD = 74.41$) were longer than that with high LOA ($mean = 158.53$, $SD = 66.17$). This was also statistically significant ($mean = 198.53$, $SD = 66.17$, $F(1, 24) = 15.42$, $p = 0.001$). The results therefore suggest that high LOA influenced more fluency in the interaction than low LOA.

### 3.4 Engagement

The duration of the gaze on the robot was significantly affected by LOA ($mean = 155.64$, $SD = 34.51$, $p = 0.006$). Participants in low LOA ($mean = 175.57$, $SD = 34.77$) gazed on the robot more than participants in high LOA ($mean = 135.71$, $SD = 20.22$). The interaction between LOA and LOT on the time participants gazed on the robot was significant ($F(1,24) = 7.83$, $p = 0.01$). Participants in low LOA ($mean = 35.50$, $SD = 17.81$) were also more significantly focused on the GUI ($mean = 27.01$, $SD = 19.60$, $p = 0.037$) than participants in high LOA ($mean = 18.643$, $SD = 18.10$). The interaction between LOA and LOT was significant regarding the focus on GUI ($F(1, 24) = 4.48$, $p = 0.045$). The effect of LOA on the human's active time was also significant ($mean = 16.39$, $SD = 16.62$, $p < 0.001$) with low LOA ($mean = 31.07$, $SD = 10.47$) keeping the human more active than the high LOA ($mean = 1.71$, $SD = 0.82$). There was an interaction effect between the LOA and LOT ($F(1, 24) = 47.28$, $p < 0.001$).

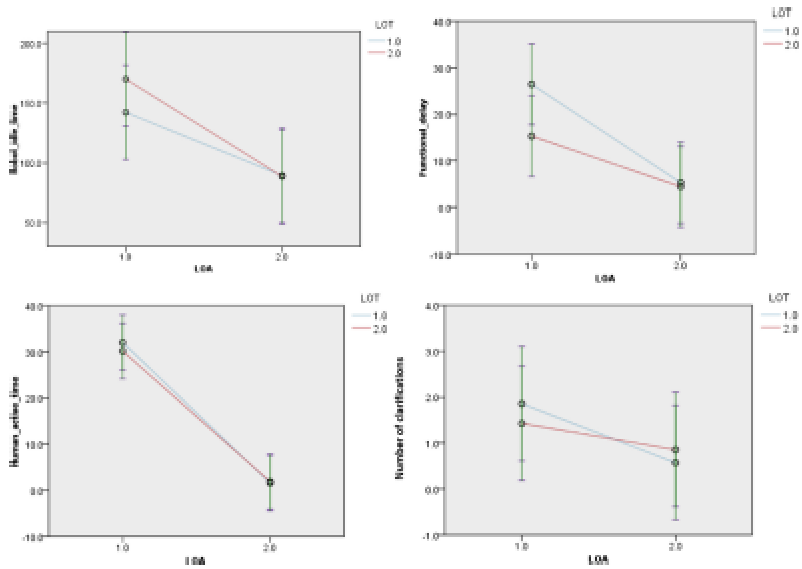


**Fig. 2.** Interaction effect of LOA and LOT on various some QoI variables

### 3.5 Understanding

There was no significant difference in the number of clarifications made by the participants during the interaction (*mean* = *1.18*, *SD* = *1.59*, *p* = *0.124*) as a result of the LOA manipulation. The participants seemed to understand the status of the interaction and actions of the robot in both LOA and LOT modes ($F(1, 24) = 2.27$, $p = 0.15$). Only a few participants asked for clarification at the low LOA (*mean* = *1.64*, *SD* = *1.95*) and high LOA modes (*mean* = *0.71*, *SD* = *0.99*). However, in terms of reaction time of the participants as the robot interacted with them, the LOA was significant (*mean* = *12.86*, *SD* = *13.87*, *p* = *0.001*). The participants spent more time observing and processing the information the robot was presenting to them as consent in the low LOA (*mean* = *20.85*, *SD* = *15.99*) compared to the high LOA (*mean* = *4.87*, *SD* = *13.87*).

### 3.6 Comfortability

The effect of the LOA and LOT did not influence the heart rate of the participants. But it was also not significant on the comfortability of the participants with regards to their perception of safety of the robot (*mean* = *2.54*, *SD* = *0.58*, *p* = *0.48*). However, it was observed that participants in low LOA moved much closer to the robot which represented more comfortability with it than participants in high LOA which sat further away from the robot.

## 4 Discussion and Conclusion

Most of the participants were comfortable interacting with a robot. The results revealed that the quality of interaction, as measured via fluency, engagement, understanding and comfortability of the interaction was influenced mainly by the interaction of LOA and LOT. The main effect of LOT had less influence compared to that of the main effect of LOA but the interaction of LOA and LOT was significant across most of the variables. Participants seem to prefer less information (low LOT) when the robot was operating more autonomously (high LOA). They also seem to prefer more information (high LOT) when they were more active with the robot such as the case in low LOA mode. This agrees with the findings in (Chen et al. 2018) where differences were not found in the transparency level that included only status information and reason without LOA involved. In current study where the level of involvement of the participant varies with the LOA, it is noteworthy that the LOT preferred is influenced by the LOA the robot is operating in.

This corroborates the characteristics of the visuospatial sketchpad (VSSP) working principle as modelled by Baddeley (1975, 1986, 1997). It suggests a dissociation within the VSSP, between active operations such as the movement of the robot and a passive store of information as the information displayed on the GUI (Bruyer and Scailquin 1998). Even though, there is a high cognitive demand on the participants when actively involved with the robot in a low LOA mode, the participants still handle more information (high LOT) since the information display was passive. This is in contrast to the scenario where the robot was more autonomous (high LOA), with less cognitive demand on the participant.

Future research should advance a longitudinal study, to increase familiarity with the robot operation and overcome the suspected naivety effect (Shah and Wiken 2011; Kirchner and Alempijevic 2012) of the older adults with the robot. We expect that the more the older adults get familiar with the operation of the robot, their level of trust in the robot may change and thus cause a change in their LOT demands as well.

According to the participants' recommendations more awareness might be improved through voice feedback. This possibility is also supported by the suggestion of (Sobczak-Edmans *et al.* 2016) indicating that some form of verbal representation of information supports visual representations. This should be explored in future work to improve the shared control of the older adult with the table setting robot.

Previous research in human robot collaboration discovered the effectiveness of coordination in team performance as presented in (Shah and Wiken 2011). Our work further presents the potential of LOA in improving quality of interaction. This is reflected in the various objective measures taken for engagement, fluency, degree of involvement and comfortability with the robot where the LOA effect was significant. The low LOA enabled the participant to interact more with the robot by selecting the specific item that the robot should pick up and the order of arrangement. This inspired greater collaboration with the robot. It enhanced the concept of shared control where the user is more involved in the decisions and control of the robot's operations. This is very critical to ensure that the older adult keeps active so as not to lose skills or functionality of the muscles (Wu et al. 2014). This corresponds with the "use it or lose it" logic presented by (Katzman 1995) in their study of older adult lifestyle.

Most studies which included some form of adaptive coordination to improve the collaboration between the robot and the user (Huang et al. 2015; Someshwar and Edan 2017) tried to reduce the completion time of the task. There was a trade off in this current study regarding degree of involvement and time to complete task i.e., at a higher degree of user involvement, more time was spent to complete the task. It is noteworthy that the focus for the target population is to ensure user involvement to avoid idleness and other negative outcomes of sedentariness and not speed. Moreover, most participants expressed enjoyment, and pleasure as they interacted with the robot, which suggests other reasons for the longer interactive time. This can therefore be considered as a positive outcome of the interaction and a favorable contribution to improve shared control in human-robot interaction scenarios such as this.

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## 7.2 Appendix B- study 1

### 7.2.1 BGU ethical committee

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

**<u>Application for Approval to Use Humans as Subjects in Empirical Study</u>**

I. General

**Name of Research Project: Different types of feedback in the system combine human-robot**

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

**<u>Principal Investigator/s (or academic supervisor/s):</u>**

| | |
|---|---|
| **Name**: **Vardit Sarne-Fleischmann Name**:<br>**Department:** IE&M **Department:** IE&M<br>**Academic position: Phd Academic position:**<br>**Telephone**:<br>**Mobile Phone: Mobile Phone:**<br>**University Email:** varditf@gmail.com<br>**Other Email:**<br>**Other Email:** | **Yael Edan**<br><br>**Prof University Telephone**: **University**<br><br><br>**University Email:** yael@bgu.ac.il |

**<u>Name(s) of those conducting the research (if different from above):</u>**

| | |
|---|---|
| **Name**: Noa Markfeld **Name**:<br>**Department:** IE&M **Department:**<br>**Academic position:** BSc Student **Academic**<br>**University Telephone**: **University**<br>**Mobile Phone:** 0522778341 **Mobile Phone:**<br>**Email:** noamark@gmail.com **Email:** | <br><br>**position:**<br>**Telephone**: |

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

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:

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

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?

These measures will be analyzed using a video camera that documents the experiment and will allow for accurate examination of the parameters after the end of the experiment. And the data will be encoded and will be deleted after the research

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):

During the experiment, hands can be placed in the robot's work area. In order to deal with this situation, we defined clear and defined areas for the individual where he is allowed to work. Morover, the robot which will be used in the study is programmed to avoid collision and to slow down when approaching any obstacle. It meets the ISO 10218-1:2011 safety standard.

**Signatories:**

**Name:** noa markfeld **Position**: Student

**Signature:** ______________ **Date**: 18/4/2019

**Name:** Yael Edan **Position**: Professor

**Signature:** ______________ **Date**: 19/4/2019

Yael Edan

טופס הסבר לנבדק

**<u>נושא המחקר: סוגי משוב במערכת משלבת אדם -רובוט</u>**

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

מטרת העל בפרויקט הינה בחינת השפעת סוגי משובים שונים במשימה משותפת בין אוכלוסייה מבוגרת לזרוע רובוטית.

השלב הנוכחי של המחקר והניסוי שיתבצע נערך בבניין 16 במתחם אוניברסיטת בן גוריון בבאר שבע. המחקר עוסק **<u>באפיון המשוב במערכת משלבת אדם -רובוט</u>**. משך המחקר כ-שעה.

במסגרת המחקר תידרש לבצע אינטראקציה עם זרוע רובוטית במשימת עריכת שולחן.

הזרוע הרובוטית אמורה לסייע לך במשימה ולכן נסה להתנהג בצורה טבעית ורגילה כפי שאתה נוהג לתקשר עם אדם אחר בחיי היומיום. בנוסף, חשוב לנו להדגיש כי הזרוע מגיבה למגע ותוכנתה כך שתספיק לפעול אם היא מזהה סכנה ולכן אין צורך לחשוש מהפעולה המשותפת

הניסוי הנוכחי מתחלק לשלושה חלקים. החלק הראשון מורכב ממספר שאלונים אישיותיים, החלק השני מורכב מביצוע משימת עריכת השולחן. חלק זה יתבצע שלוש פעמים כך שבכל פעם תקבל משוב שונה מהרובוט על פעולתו . בסיום כל פעם יש לענות על שאלון קצר בנוגע לאינטראקציה עם הרובוט.

בסוף המחקר תידרשו לענות על שאלון מסכם.

לא מתבצעת שמירה של הפרטים המזהים של הנבדקים. כל נבדק מקבל מספר נבדק אשר מופרד מפרטי הנבדק. כל השאלונים יימסרו בתום המחקר לחוקרת הראשית הממונה על המחקר וישמרו באחריותה.

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

*טופס הסכמה לנבדק*

נושא המחקר: סוגי משוב במערכת משלבת אדם <u>ורובוט נייד</u>

**נבדק יקר,**
**בבקשה קרא את דף ההסבר באשר לניסוי. במידה ויש שאלות, נשמח לענות.**
**בבקשה וודא כי הנך מבין היטב את שלבי המחקר.**
להזכירך, המחקר עוסק באפיון המשוב במערכת משלבת אדם -רובוט. במהלך הניסוי תדרש לבצע מספר משימות אשר דורשות אינטראקציה עם הרובוט שבמהלכן הרובוט ישלח לך משובים בהתאם לשלב במשימה ובהתאם לפקודות שתעביר לו. משך הניסוי לכל היותר שעה.
הניסוי מתקיים בבניין 16 באוניברסיטת בן גוריון בבאר שבע .

אני החתום מטה:*

| | |
|---|---|
| שם  פרטי ומשפחה: | ת.ז. |
| חתימה: | טלפון: |

א. מצהיר/ה בזאת כי אני מסכים/ה להשתתף בניסוי, כמפורט במסמך המפרט את חלקי הניסוי.

ב. מצהיר שהוסברו לי בפירוט כל חלקי הניסויי והסכמתי ליטול בו חלק לאחר שנענו כל שאלותיי לגבי כל  אחד מחלקי הניסוי .

ג. מצהיר בזאת כי הוסבר לי על-ידי החוקרת: *<u>נעה מרקפלד</u>*

1. כי אני חופשי לבחור שלא להשתתף בניסוי וכי אני חופשי להפסיק בכל עת את השתתפותי בניסוי מכל סיבה שהיא .
2. במידה ואני חש ברע או באי נוחות במהלך הניסוי חובה עלי לדווח לנסיין על מנת להפסיק את הניסוי.
3. מובטח שזהותי האישית תשמר סודית על-ידי כל העוסקים והמעורבים במחקר ולא תפורסם בכל פרסום כולל בפרסומים מדעיים.
4. מובטחת לי נכונות לענות לשאלות שיועלו על-ידי.

**יתכן ובמהלך הניסוי החוקרים יצלמו תמונות וסרטונים לצורכי מחקר בלבד.**
במידה ואתה מאשר\ת זאת, חתום כאן:________________

במידה ואת\ה מסכימים שתמונתכם תופיע בפרסומים שונים שיוצגו לציבור אנא ציינו :
☐ אני מסכים שתמונתי תופיע בפרסומים שונים
☐ איני מעוניין שתמונתי תופיע

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

תאריך __________________ חתימת מעביר הניסוי_______________

**אנו מודים לך על השתתפותך במחקר.**

7.2.2 Pre-questionnaires

Dermographique quaternaires

Participant's number *

Short answer text

גיל (age) *

Short answer text

מגדר (gender) *

- ◯ זכר
- ◯ נקבה

TAP quaternaries

אנא ציין באיזו תדירות אתה משתמש \ מבצע כל אחד מהדברים הבאים:

0 : אף פעם
1 : פעם בחצי שנה עד שנה
2 : פעם בחודשיים עד 5 חודשים
3 : פעם בחודש
4 : 1-3 פעמים בשבוע
5 : כמעט כל יום

1. טכנולוגיה נותנת לי יותר שליטה בחיי היומיום שלי
*
2. טכנולוגיות חדשות הופכות את החיים שלי לקלים יותר
*
3. אני יכול ללמוד להשתמש במוצרי ושירותי היי-טק חדשים ללא עזרה מאחרים
*
4. אני נהנה ללמוד להשתמש בטכנולוגיות חדשות
*
5. טכנולוגיה שולטת בחיי יותר ממה שאני שולט בטכנולוגיה
*

NARS quaternaries

אנא ציין את מידת הסכמתך עם האמירות הבאות (NARS):

1 - מאוד לא מסכים

2 - לא מסכים

3 - נייטרלי

4 - מסכים

5 - מסכים מאוד

1. הייתי מרגיש נינוח לדבר עם רובוטים
*

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

3. הרעיון שרובוטים יפעילו שיקול דעת לגבי דברים מלהיב אותי
*

4. עצם העמידה מול רובוט מלחיצה אותי
*

5. אני מרגיש שאם אהיה תלוי ברובוטים יותר מידי, משהו רע עלול לקרות
*

7.2.2 Post-trial questionnaires

אנא ציין את מידת הסכמתך עם האמירות הבאות:

1 - מאוד לא מסכים

2 - לא מסכים

3 - נייטרלי

4 - מסכים

5 - מסכים מאוד

1. ההתנסות עם הרובוט הלחיצה אותי
*

2. הרגשתי נוח עם הצורה שבה הרובוט תיקשר איתי
*

3. אני הבנתי את הרובוט היטב
*

4. תקשרתי עם הרובוט בצורה טבעית
*

5. הייתי מרוצה מהאופן שבו הרובוט תיקשר איתי
*

6. במהלך הניסוי הרגשתי שאני יכול לסמוך על הרובוט
*

7. תשומת הלב שלי הייתה ממוקדת ברובוט בזמן שהוא ביצע את המשימה
*

7.2.3 Final questionnaires

אנא ענה על השאלות הבאות:

1. האם הרגשת הבדל בין התרחישים השונים? אם כן, איזה הבדל?
*

2.איזה סוג משוב הכי אהבת?
*

3.איזה סוג משוב היה הכי ברור להבנה?
*

4. האם הרגשת שהשילוב בין המשובים השונים תרם להבנה שלך או לחלופין העמיס עליך בעת ביצוע עריכת השולחן?

7.2.4 GUI screens

1. **Finish setting the table**

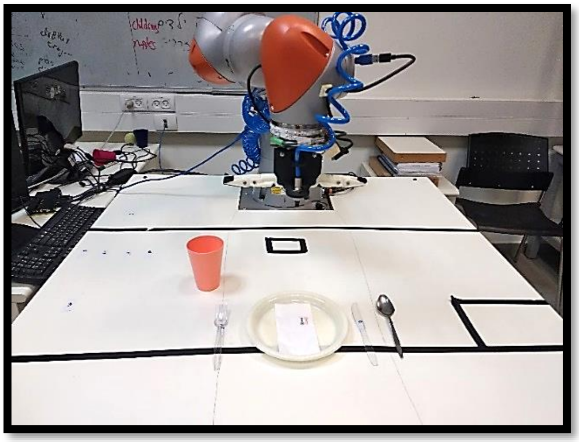

*Figure 7- Finish setting the table*

2. **Bringing an object**:

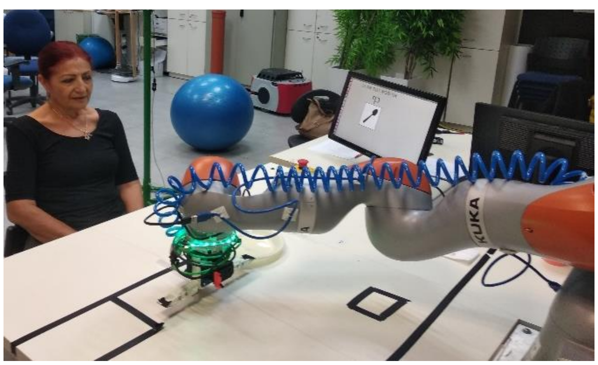



3. **stop**

7.2.5 Experimental setting



7.2.6 User interface




7.2.2 Results

Demographic analysis

| education | | | | | |
|---|---|---|---|---|---|
| | Other | PH.D | Master degree | First degree | High school |
| amount | 2 | 2 | 5 | 5 | 7 |
| precentege | 9.5% | 9.5% | 23.8% | 23.8% | 33.4% |

| Gender | | |
|---|---|---|
| | Male | Femael |
| amount | 13 | 8 |
| precentege | 62% | 38% |

Pre - experiment

**Paired Samples Test**

| | | Paired Differences | | | | | t | df | Sig. (2-tailed) |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | 95% Confidence Interval of the Difference | | | | |
| | | Mean | Std. Deviation | Std. Error Mean | Lower | Upper | | | |
| Pair 1 | like1 - like2 | 3.000 | .577 | .218 | 2.466 | 3.534 | 13.748 | 6 | .000 |
| Pair 2 | conv2 - conv2 | 2.571 | .535 | .202 | 2.077 | 3.066 | 12.728 | 6 | .000 |

## 7.3 Appendix C- study 2

### 7.3.1 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: Different types of feedback in a human-robotic** system

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

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

| | |
|---|---|
| **Name**: **Vardit Sarne-Fleischmann** | **Name**: **Yael Edan** |
| **Department:** IE&M | **Department:** IE&M |
| **Academic position: Phd** | **Academic position: Prof** |
| **University Telephone**: | **University Telephone**: |
| **Mobile Phone:** | **Mobile Phone:** |
| **University Email:** varditf@gmail.com | **University Email:** yael@bgu.ac.il |
| **Other Email:** | **Other Email:** |

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

**Name**: Noa Markfeld

**Department:** IE&M

**Academic position:** MSc Student

**University Telephone**:

**Mobile Phone:** 0522778341

**Email:** noamark@post.bgu.ac.il

## 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

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

12. 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

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.

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

14. 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:

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

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

18. 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.

## VIII. Withdrawal from the Study:

18. Will subjects be informed that they may withdraw from the study at any time? ☒Yes / ☐No

19. 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:

9 Application for Approval to Use Humans as Subjects in Empirical Study

**Signature:** ____________ **Date**: 31/5/20 **Name:** __Yael Edan___________ **Position**: ______________

טופס הסבר לנבדק

**<u>נושא המחקר: סוגי משוב במערכת משלבת אדם -רובוט</u>**

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

מטרת העל בפרויקט הינה בחינת השפעת סוגי משובים שונים במשימה משותפת בין אדם ורובוט נייד באמצעות שליטה מרחוק.

השלב הנוכחי של המחקר והניסוי שיתבצע נערך בבניין 16 במתחם אוניברסיטת בן גוריון בבאר שבע. המחקר עוסק **<u>באפיון המשוב במערכת משלבת אדם ורובוט נייד</u>**. משך המחקר כ-שעה .

במסגרת המחקר תידרש לבצע אינטראקציה עם רובוט נייד במשימה של טיפול בחולים על ידי שליטה מרחוק .

הרובוט הנייד אמור לסייע לך במשימה ולכן נסה להתנהג בצורה טבעית ורגילה כפי שאתה נוהג לתקשר עם אדם אחר בחיי היומיום. בנוסף, חשוב לנו להדגיש כי על הרובוט קיימים חיישני מרחק והוא תוכנת כך שיספיק לפעול אם הוא מזה סכנה ולכן אין צורך לחשוש מהפעולה המשותפת.

הניסוי הנוכחי מתחלק לשלושה חלקים. החלק הראשון מורכב ממספר שאלונים אישיותיים, החלק השני מורכב מביצוע המשימה המשותפת. חלק זה יתבצע שלוש פעמים כך שבכל פעם תקבל משוב שונה מהרובוט על פעולתו . בסיום כל פעם יש לענות על שאלון קצר בנוגע לאינטראקציה עם הרובוט .

בסוף המחקר תידרשו לענות על שאלון מסכם.

כל נבדק מקבל מספר נבדק אשר מופרד מפרטי הנבדק. כל השאלונים יימסרו בתום המחקר לחוקרת הראשית הממונה על המחקר וישמרו באחריותה.

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

<u>נושא המחקר: סוגי משוב במערכת משלבת אדם  ורובוט נייד</u>

**נבדק יקר,**
**בבקשה קרא את דף ההסבר באשר לניסוי. במידה ויש שאלות, נשמח לענות.**
**בבקשה וודא כי הנך מבין היטב את שלבי המחקר.**
להזכירך, המחקר עוסק באפיון המשוב במערכת משלבת אדם -רובוט. במהלך הניסוי תדרש לבצע מספר משימות אשר דורשות אינטראקציה עם הרובוט שבמהלכן הרובוט ישלח לך משובים בהתאם לשלב במשימה ובהתאם לפקודות שתעביר לו. משך הניסוי לכל היותר שעה.
הניסוי מתקיים בבניין 16 באוניברסיטת בן גוריון בבאר שבע .

אני החתום מטה:*

| | |
|---|---|
| שם  פרטי ומשפחה: | ת.ז. |
| חתימה: | טלפון: |

מצהיר/ה בזאת כי אני מסכים/ה להשתתף בניסוי, כמפורט במסמך המפרט את חלקי הניסוי.
מצהיר שהוסברו לי בפירוט כל חלקי הניסויי והסכמתי ליטול בו חלק לאחר שנענו כל שאלותיי לגבי כל  אחד מחלקי הניסוי .
מצהיר בזאת כי הוסבר לי על-ידי החוקרת: <u>*נעה מרקפלד*</u>

1. כי אני חופשי לבחור שלא להשתתף בניסוי וכי אני חופשי להפסיק בכל עת את השתתפותי בניסוי מכל סיבה שהיא .
2. במידה ואני חש ברע או באי נוחות במהלך הניסוי חובה עלי לדווח לנסיין על מנת להפסיק את הניסוי.
3. מובטח שזהותי האישית תשמר סודית על-ידי כל העוסקים והמעורבים במחקר ולא תפורסם בכל פרסום כולל בפרסומים מדעיים.
4. מובטחת לי נכונות לענות לשאלות שיועלו על-ידי.

**יתכן ובמהלך הניסוי החוקרים יצלמו תמונות וסרטונים לצורכי מחקר בלבד.**
במידה ואתה מאשר\ת זאת, חתום כאן:________________

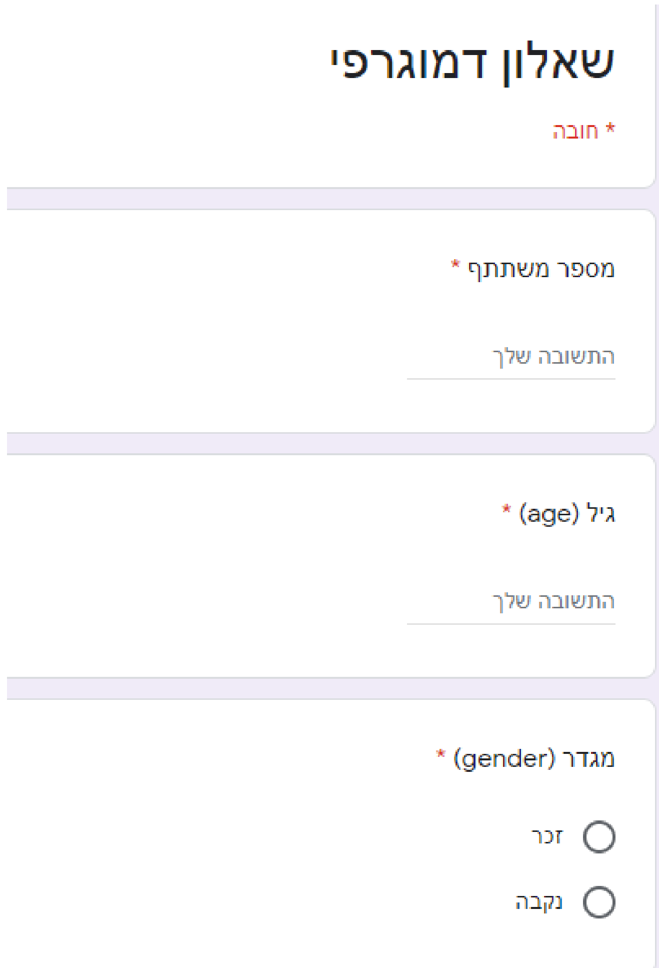
במידה ואת\ה מסכימים שתמונתכם תופיע בפרסומים שונים שיוצגו לציבור אנא ציינו :
☐ אני מסכים שתמונתי תופיע בפרסומים שונים
☐ איני מעוניין שתמונתי תופיע

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

תאריך __________________ חתימת מעביר הניסוי_______________

**אנו מודים לך על השתתפותך במחקר.**

7.3.2 Pre-questionnaires



# שאלון דמוגרפי

* חובה

מספר משתתף *

התשובה שלך

גיל (age) *

התשובה שלך

מגדר (gender) *

זכר

נקבה

## אינטראקציה עם רובוטים

אנא ציין את מידת הסכמתך עם האמירות הבאות:
1 - מאוד לא מסכים
2 - לא מסכים
3 - נייטרלי
4 - מסכים
5 - מסכים מאוד

1.אם הייתי צריך להשתמש ברובוטים בעת ביצוע התפקיד שלי, הייתי מרגיש לא בנוח. *

| | 1 | 2 | 3 | 4 | 5 | |
|---|---|---|---|---|---|---|
| מאד לא מסכים | ○ | ○ | ○ | ○ | ○ | מסכים מאד |

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

| | 1 | 2 | 3 | 4 | 5 | |
|---|---|---|---|---|---|---|
| מאד לא מסכים | ○ | ○ | ○ | ○ | ○ | מסכים מאד |

3. אני שונא את הרעיון שרובוטים יוכלו להפעיל שיקול דעת לגבי דברים *

| | 1 | 2 | 3 | 4 | 5 | |
|---|---|---|---|---|---|---|
| מאד לא מסכים | ○ | ○ | ○ | ○ | ○ | מאד מסכים |

4. עצם העמידה מול רובוט גורמת לי למתח *

| | 1 | 2 | 3 | 4 | 5 | |
|---|---|---|---|---|---|---|
| מאד לא מסכים | ○ | ○ | ○ | ○ | ○ | מסכים מאד |

5. אני מרגיש שאם אהיה תלוי ברובוטים יותר מידי, משהו רע עלול לקרות *

| | 1 | 2 | 3 | 4 | 5 | |
|---|---|---|---|---|---|---|
| מאד לא מסכים | ○ | ○ | ○ | ○ | ○ | מסכים מאד |

## שאלון Big Five inventory

אני רואה את עצמי כ:

1 - מאוד לא מסכים
2 - לא מסכים
3 - נייטרלי
4 - מסכים
5 - מסכים מאוד

1. עד כמה אתה פתוח לרעיונות וחוויות חדשות? *

| | 1 | 2 | 3 | 4 | 5 | |
|---|---|---|---|---|---|---|
| מאוד לא מסכים | ○ | ○ | ○ | ○ | ○ | מסכים מאוד |

2. בעת ביצוע משימה, עד כמה חדור מטרה אתה? *

| | 1 | 2 | 3 | 4 | 5 | |
|---|---|---|---|---|---|---|
| מאוד לא מסכים | ○ | ○ | ○ | ○ | ○ | מסכים מאוד |

3. עד כמה אתה מופעל על ידי העולם החיצון? *

| | 1 | 2 | 3 | 4 | 5 | |
|---|---|---|---|---|---|---|
| מאוד לא מסכים | ○ | ○ | ○ | ○ | ○ | מסכים מאוד |

4. עד עמה אתה שם את צורכי האחר לפני הצרכים שלך? *

| | 1 | 2 | 3 | 4 | 5 | |
|---|---|---|---|---|---|---|
| מאוד לא מסכים | ○ | ○ | ○ | ○ | ○ | מסכים מאוד |

5. עד כמה אתה מושפע מלחץ ומחווית כישלון? *

| | 1 | 2 | 3 | 4 | 5 | |
|---|---|---|---|---|---|---|
| מאוד לא מסכים | ○ | ○ | ○ | ○ | ○ | מסכים מאוד |

### 7.3.3 Post- trial questionnaire

# Post trial questionnaire

* חובה

Participant's Number *

התשובה שלך

Trial's Number *

התשובה שלך

**אנא ציין את מידת הסכמתך עם האמירות הבאות:**

1- מאוד לא מסכים
2- לא מסכים
3- נטרלי
4- מסכים
5- מסכים מאד

1. הבנתי את הרובוט היטב *

| | 1 | 2 | 3 | 4 | 5 | |
|---|---|---|---|---|---|---|
| מאוד לא מסכים | ○ | ○ | ○ | ○ | ○ | מסכים מאד |

2. הצורה בה עבר המידע מהרובוט הייתה מובנת לי *

| | 1 | 2 | 3 | 4 | 5 | |
|---|---|---|---|---|---|---|
| מאוד לא מסכים | ○ | ○ | ○ | ○ | ○ | מסכים מאד |

3. הייתי מרוצה מהאופן שבו הרובוט תיקשר איתי *

| | 1 | 2 | 3 | 4 | 5 | |
|---|---|---|---|---|---|---|
| מאוד לא מסכים | ○ | ○ | ○ | ○ | ○ | מסכים מאד |

4. הרגשתי שהמידע שהרובוט נתן לי הגיע בתזמון הנכון *

| | 1 | 2 | 3 | 4 | 5 | |
|---|---|---|---|---|---|---|
| מאוד לא מסכים | ○ | ○ | ○ | ○ | ○ | מסכים מאד |

5. באמצעות המידע שקיבלתי הייתי מודע לפעולת הרובוט *

| | 1 | 2 | 3 | 4 | 5 | |
|---|---|---|---|---|---|---|
| מאוד לא מסכים | ○ | ○ | ○ | ○ | ○ | מסכים מאד |

6. הצורה בה עבר המידע הייתה נוחה לי *

| | 1 | 2 | 3 | 4 | 5 | |
|---|---|---|---|---|---|---|
| מאוד לא מסכים | ○ | ○ | ○ | ○ | ○ | מסכים מאד |

7. הייתי רוצה להשתמש במערכת זאת בתדירות גבוהה *

| | 1 | 2 | 3 | 4 | 5 | |
|---|---|---|---|---|---|---|
| מאוד לא מסכים | ○ | ○ | ○ | ○ | ○ | מסכים מאד |

8. אני חושב שהמערכת קלה לשימוש *

| | 1 | 2 | 3 | 4 | 5 | |
|---|---|---|---|---|---|---|
| מאוד לא מסכים | ○ | ○ | ○ | ○ | ○ | מסכים מאד |

9. אצטרך ללמוד דברים רבים לפני שאוכל להשתמש במערכת זו *

| | 1 | 2 | 3 | 4 | 5 | |
|---|---|---|---|---|---|---|
| מאוד לא מסכים | ○ | ○ | ○ | ○ | ○ | מסכים מאד |

## Assessment of Task load

אנא דרג את החוויה שלך במהלך ביצוע המשימה

עומס מנטלי: עד כמה המשימה דרשה מאמץ מנטלי (מחשבתי)?

נמוך מאד ◯ 1 ◯ 2 ◯ 3 ◯ 4 ◯ 5 גבוה מאד

עומס פיזי: עד כמה המשימה דרשה מאמץ פיזי?

נמוך מאד ◯ 1 ◯ 2 ◯ 3 ◯ 4 ◯ 5 גבוה מאד

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

לא דרש כלל ◯ 1 ◯ 2 ◯ 3 ◯ 4 ◯ 5 דרש מאד

ביצועים: עד כמה מוצלח הצלחת לבצע את המשימה?

כשלו מוחלט ◯ 1 ◯ 2 ◯ 3 ◯ 4 ◯ 5 הצלחה טוטאלית

מאמץ: כמה קשה היה עליך לעבוד בכדי לבצע את המשימה בצורהשבה השלמת אותה?

מעט מאד ◯ 1 ◯ 2 ◯ 3 ◯ 4 ◯ 5 הרבה מאד

תסכול: עד כמה המשימה גרמה לך להרגיש מיואש ומתוסכל?

לא גרמה כלל ◯ 1 ◯ 2 ◯ 3 ◯ 4 ◯ 5 הרבה מאד

7.3.4 Final questionnaire

# Final questionnaire-Telenrsing

* חובה

Participant's Number *

התשובה שלך

1. חשתי בהבדל בין ההרצות השונות (בין החזרות) *

- כן
- לא
- לא יודע

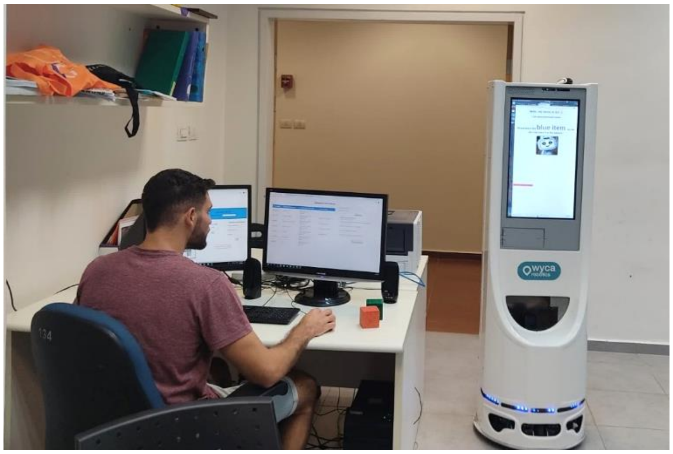
2. במידה וחשת בהבדל בין התרחישים השונים, מה לדעתך היו ההבדלים ?

התשובה שלך

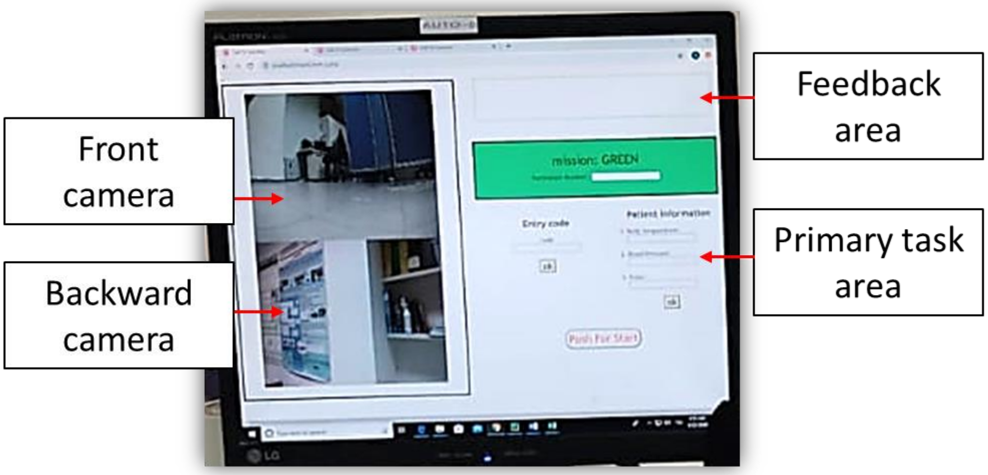
3. איזה תרחיש ההעדפת מבין שלושת ההרצות? *

- משוב קולי
- משוב ויזואלי
- משוב משולב (קולי וויזואלי)
- כולם בצורה שווה
- אחר:

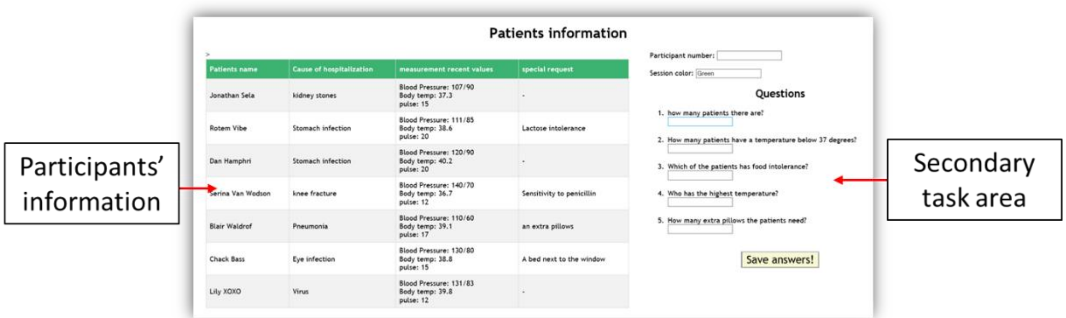
7.3.4 User interface



<u>Main task screen - (left and central panel)</u>

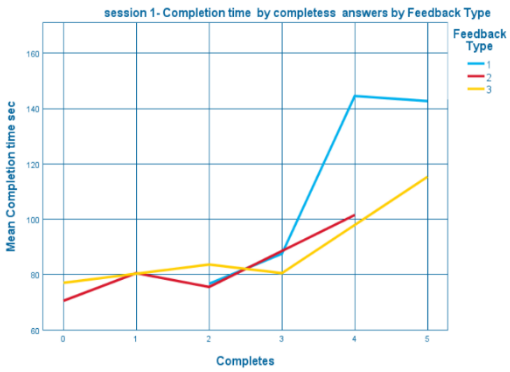


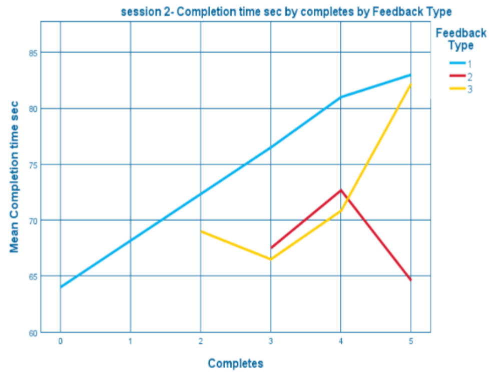

<u>Secondary task screen- (right panel)</u>

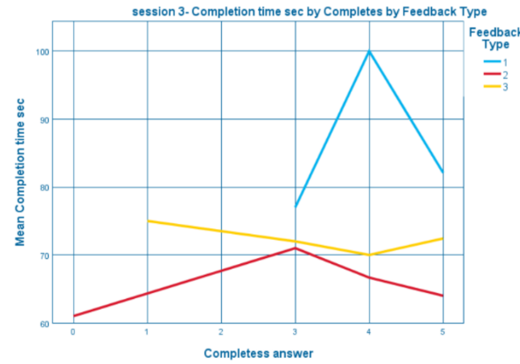


## 7.3.5 Results

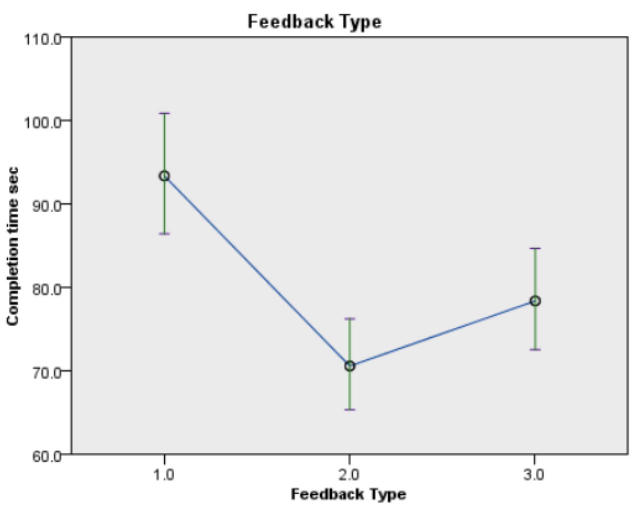
<u>correlation between completeness answer and comletion time</u>




<u>Completion time</u>




<u>OP GLMM results</u>

| Source | F | df1 | df2 | Sig. |
|---|---|---|---|---|
| Corrected Model ▼ | 2.317 | 5 | 113 | .048 |
| FeedbackType | 3.957 | 2 | 113 | .022 |
| location | 0.651 | 1 | 113 | .422 |
| FeedbackType*location | 1.627 | 2 | 113 | .201 |

Probability distribution:Normal
Link function:Identity

## 7.4 Appendix D- Table clearing

# Evaluating levels of automation and feedback in an assistive robotic table clearing task for eldercare

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**Abstract**

Eldercare involves tending for older adults to meet physical, cognitive, emotional and social needs. It has been estimated that about 20-30 percent of the ageing population require some support, but without sufficient caregivers, supply is lower than demand. Moreover, the CoVID-19 pandemic situation places many older adults in dire situations where they must be isolated, and socially distant. This study highlights the potential role that assistive robots could play in offering support at home for the older adults. Particularly, how the level of autonomy of the robot affects interaction and satisfaction. We focused on the use of an assistive robot for a table clearing task while evaluating the level of automation (LOA) and feedback mode that influences suitable and successful interaction of the older adults with the robot. Three LOA modes and three modes of feedback were evaluated in a between-within experimental design setup. Twenty-two older adult, participants interacted with the robot in the table clearing task. Assessment of the interaction was carried out objectively and subjectively. Results revealed the potential of the assistive robots to support the older adults in the task. Implications of the three LOA modes and their relationship with specific forms of feedback were shown to promote successful interaction of the older adults with these assistive robots.

## 1 Introduction

Eldercare encompasses various activities to attend older adults' physical, cognitive, emotional and social needs (Bauer & Sousa-Poza, 2015). These activities vary (Smarr et al., 2012): from activities of daily living (e.g. bathing, dressing), instrumental activities of daily living (e.g. cleaning, meal preparation) to enhanced activities of daily living (e.g. learning new hobbies, or assistance with obtaining new skills). With the growing dearth of caregivers (Bogue, 2013; Super, 2002) assistive robots can become vital in ensuring older adults maintain their independence at home (Allaban, Wang, & Padir, 2020; Smarr et al., 2014). The COVID 19 pandemic worsened the isolation of elders due to the need to maintain social distancing, further emphasizing the need for acceptable robotic solutions for them.

Assistive robots can support human users (Pfeil-Seifer & Mataric, 2005) in many domains. Applications include eldercare (Frennert, Aminoff, & Östlund, 2020), rehabilitation (Fiorini et al., 2019), telenursing (Chen et al., 2020) and companionship (Lee, Kim, Kim, & Kwon, 2017). Deployment however, to date, is very limited (Zhang & She, 2020). Previous studies revealed that older adults were generally open to robotic assistance in instrumental activities of daily living, specifically, activities such as cleaning and clearing emerging as household chores where support is desired (Hall et al., 2019; Smarr et al., 2014, 2012). There are however no or rather limited robots available for the variety of cleaning and clearing tasks in homes, apart from floor cleaning robots (Prassler, Ritter, Schaeffer, & Fiorini, 2000). This leads to the need for more robotic developments in the area of cleaning and clearing which involves robots capable of taking away certain items from the table (i.e., robotic arms) with consent of the user and without overriding the preferences of the user (user-centric perspective) (Masuta, Hiwada, & Kubota, 2011; Prassler et al., 2000; Smarr et al., 2014).

Assistive robotics development focused mainly on development of the software, hardware and control architecture necessary for the robot to successfully perform their designated tasks (Suzuki et al., 2019). Such developments have contributed immensely to robots' capabilities to perform object identification and manipulation, as it takes items from the table (Masuta et al., 2011; Scopelliti, Giuliani, & Fornara, 2005). While these developments have largely emerged successful (Chong et al., 2004; Suzuki et al., 2019), very few studies investigated the interactive role that the robotic arm plays in the different phases of the table-clearing task particularly for the older adult population (Bauer & Sousa-Poza, 2015; Johnson et al., 2020; Portugal, Alvito, Christodoulou, Samaras, & Dias, 2019; Zafrani & Nimrod, 2019). Identifying needs of the older adult population is crucial due to the peculiarities in physical, cognitive and perceptual capabilities compared to other users (Czaja et al., 2019; Mitzner, Smarr, Rogers, & Fisk, 2015).

It is important to ensure that the older adult user stays in control of the process without being overburdened by the task (Czaja, Rogers, Fisk, Charness, & Sharit, 2009). This enables to maintain the interests, preferences and active engagements of older adults in the process while avoiding dissatisfaction (Kaber, 2018), frustration (Scopelliti et al., 2005) or a sedentary lifestyle which could evolve as a result in an unbalanced robot-user role allocation (Czaja et al., 2019). It is also important to ensure balance in the roles of the robot to avoid extremes of overreliance on the robot, misuse or disuse of the robot's automated capabilities (Parasuraman & Riley, 1997). A strategy proposed and tested in different domains is through the introduction of appropriate levels of automation which can be generally defined as the degree to which automation is employed in the task (Parasuraman, Sheridan, & Wickens, 2000). In the context of robot-aided table clearing for older-adults, it can be explained as the extent to which the robot participates in the task of clearing the table.

There are differences in the perceptual capacities and cognition of older adults compared to younger adults (Mitzner et al., 2015). It is crucial to consider the processing speeds, attention and memory capabilities of older adults to ensure that they are constantly informed regarding the robot's activities as it carries out the task (Beer et al., 2012; Hellström & Bensch, 2018). This is related to the feedback provided by the robot which can be defined in this context as the information provided by the robot to the user regarding its intentions, reasoning, plans and actions (Lyons, 2013; Mirnig & Manfred, 2015). This information can be encoded through different modalities (visual, audial, haptic or multi-modal) through which the robot communicates the information to the user (Mirnig, Weiss, & Tscheligi, 2011). The effectiveness of these modes for the older adult population is influenced by the peculiarities, age-related differences and perception-related challenges of the older adults (Cen-Cenelec, 2002). The applicability of the various feedback modes may differ depending on the LOA the robot is operating in (Olatunji et al., 2020). This underscores the aim of this study which is to develop LOA modes and feedback modality combinations and evaluate their mutual influence on the quality of interaction of older adults with a table-clearing robot. The goal is to identify suitable LOA-feedback mode combinations that facilitate successful and satisfactory interactions.

# 2 Methods

## 2.1 Overview

The current research looked at the application of three different levels of automation (LOAs) and three modes of feedback in a robotic table-clearing task with a robotic arm. The task involved the robot clearing eating utensils (e.g., plate, fork, knife) and placing them at another location. LOA and mode of feedback were the independent variables evaluated while overall task performance, user perception and preferences regarding the interaction with the robot were assessed as dependent variables. The experimental system, development of LOA and feedback modes, as well as, their evaluation in user studies are described in the following subsections.

The hypotheses for the study are presented as follows:

H1: LOA will affect the interaction between the user and the robot

H2: Feedback will affect the interaction between the user and the robot

H3: LOA and feedback will have an interaction effect on the interaction variables.

## 2.2 The experimental system

The table clearing system consisted of a robot and a screen-based graphic user interface for user-robot communication. The KUKA LBR iiwa 14 R820 cobot with 7 degrees of freedom was used to reach the various positions on the table in poses convenient for the user (Figure 1). It was equipped with a pneumatic gripper to pickup the cups and suction to handle the utensils.

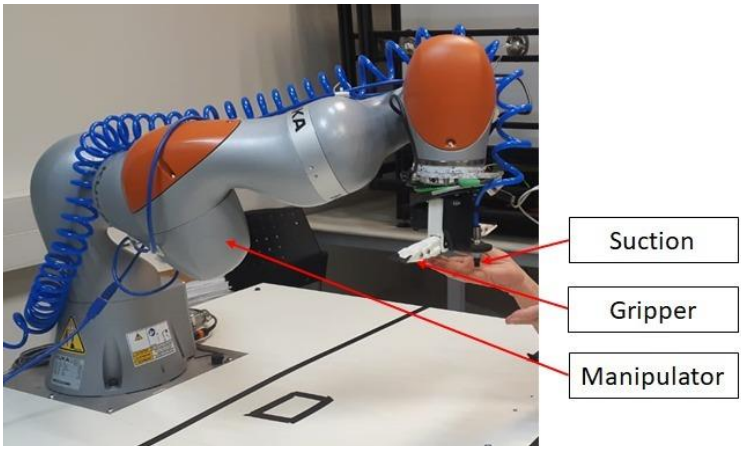



*Figure 13. KUKA robot used for the table clearing task*

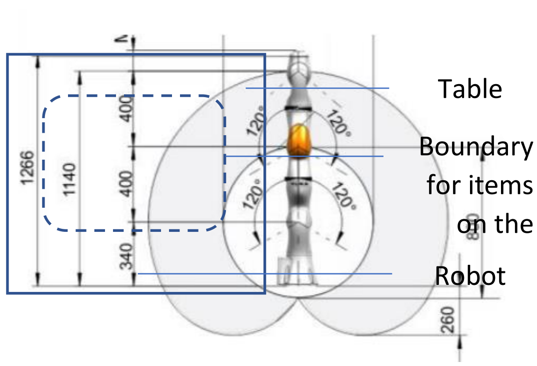



*Figure 14. The robot's range of movement on the table*

The tasks were programmed using Python and executed on Robot operating system (ROS) platform (Schaefer, 2015). The suction and external feedback was setup with a Raspberry Pi which was connected to the robot controller. A graphical user interface (GUI) was developed and used on a PC screen, which was located on a desk to the left of the user (Figure 3) to instruct the user and provide feedback.

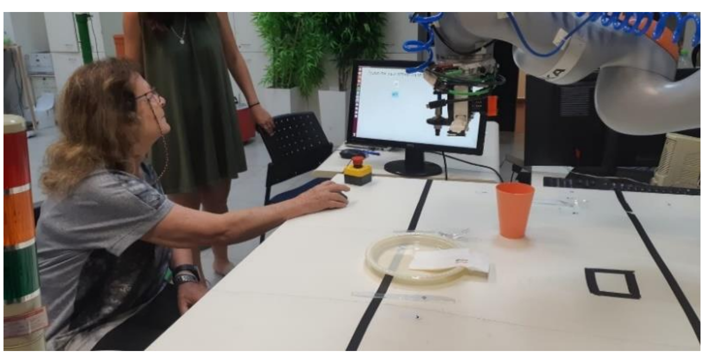


*Figure 15: A participant using the GUI to instruct the robot, note the location of the utensils in front of the user.*

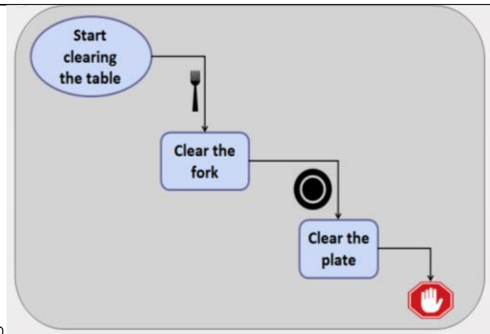
### 2.3 LOA modes

The LOA was developed to ensure that the older adults remain in the loop of the robot's operation at every LOA level and to maintain the availability of the robot to support at every level. This was implemented by varying the robot's degree of involvement in the decisions required for the table clearing task across each of the LOA modes. These decisions include a) when to start the process of clearing, b) what items to take, c) when to take specific items and d) when to stop in the process and are detailed and shown in Figures 4.

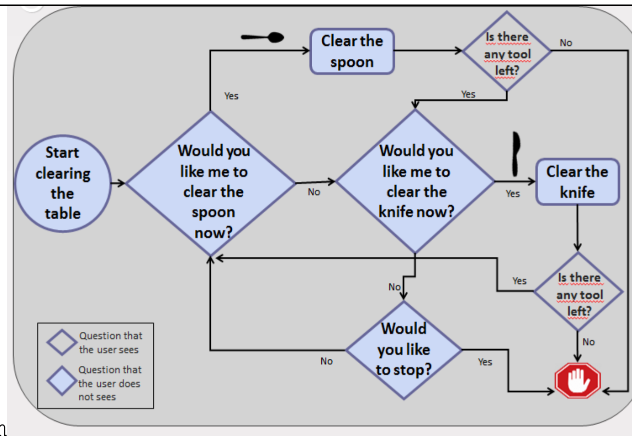
*High LOA (Figure 4a).* The highest degree of robot involvement in the decision-making process with the least user involvement. The robot performs the entire task of clearing the items from the table once the user initiates the process. The user is involved only in initiating the process. The user can stop the robot at any point by pressing the emergency STOP button.

*Medium LOA (Figure 4b)*. A moderated degree of robot involvement in the decision- making with more user involvement. The robot seeks the consent of the user before taking each item from the table. The robot suggests removing a specific item and the user must approve the action. If approved, the robot performs the operation. If the offer is not approved, the robot offers to take another item from the table till all items have been considered.

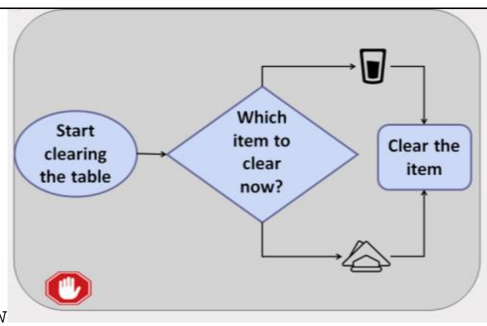
*Low LOA (Figure 4c).* The user's degree of involvement in the decision making is the highest while the robot acts according to the user's commands. The user initiates the process, decides upon an item s/he desires to take off the table and instructs the robot to clear the desired item. The robot clears the item requested and waits for the next instruction without suggesting any specific item to be cleared.




High




Medium




Low

*Figure 16: High LOA*

*Figure 17:Medium LOA*

*Figure 18: Low LOA*

### 2.4 Feedback modes

Three feedback modes were designed to ensure that sufficient information is provided to the older adult users to keep them informed (Mirnig et al., 2014) while ensuring not to overload them with information (Lyons, 2013).

i. GUI screen. Each time the robot brings a certain tool to an elderly person, a message appears on the GUI screen providing details (Figure 7).

ii. LED. Each time the robot brings a certain tool to an elderly person, the LED on the end of the robotic arm turns green (Figure 8).

iii. Voice recordings. Each time the robot brings a certain tool to an elderly person, a recording is played detailing what the robot is doing.

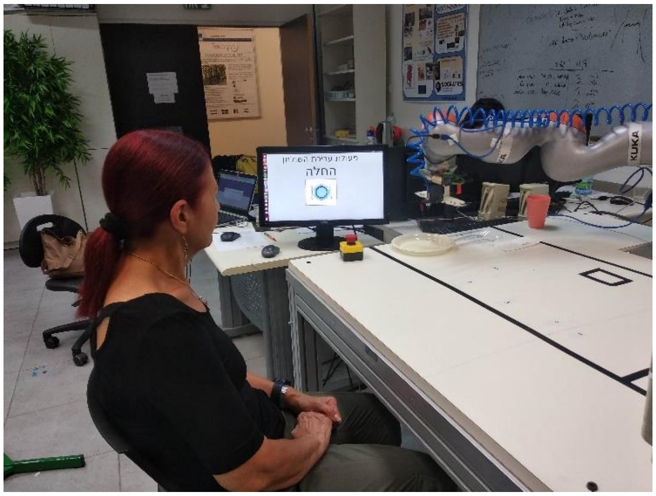
| | |
|---|---|
|  | Put the screen enlargement here |
|  | Explain in more detail about the LED as it is hard to see. Also, why LED is important, this was not included in the introduction |
| Voice, explain where the voice comes from, what kind of voice | Specify the text |

*Figure 19: A participant experiences feedback from the robot through the GUI*

*Figure 20: A participant experiences feedback from the robot through LED*

### 2.5 Participants

22 older adults (9 Females, 13 Males) aged 70 to 86 (mean=74, SD=4.12) participated in the study. 2 of the participants possessed a Ph.D., 5 had a master’s degree, 8 owned bachelor’s degree, 7 had a high school-based education and 3

were of alternative education. Participants were recruited through an ad which was publicized electronically. They were healthy individuals with no physical disability who came independently to the lab. Participant completed the study separately at different timeslots, to ensure no contact between them.

### 2.6 Experimental Design

The independent variables were the LOA modes and feedback modes while the dependent variables were interaction-related variables (detailed in subsection 2.7). The experiment was set with a mixed between and within participants design with the LOA modes as the within participants variable, and the feedback type as the between participants variable. Participants were assigned randomly to one of the three feedback types conditions. All participants completed the same table clearing task for the three levels of automation. The order of the three iterations was counterbalanced between participants, to accommodate for potential bias of learning effects.

*Table 7. Experimental Conditions.*

| | | **LOA** | | |
|---|---|---|---|---|
| | | ***Low*** | ***Medium*** | ***High*** |
| **Feedback** | ***GUI*** | Condition 1 – LG **User chooses** which item the robot clears each time and receives visual feedback through the **GUI** screen | Condition 4-MG **Robot suggests** the item to clear, awaiting **user consent** before proceeding. User receives visual feedback through **GUI** screen | Condition 7-HG **Robot implements all actions** except **user vetoes.** User receives visual feedback through **GUI** screen |
| | ***LED*** | Condition 2-LL **User chooses** which item the robot clears each time and receives visual feedback through **LED** | Condition 5-ML **Robot suggests** the item to clear, awaiting **user consent** before proceeding. User receives visual feedback through **LED** | Condition 8-HL **Robot implements all actions** except **user vetoes.** User receives visual feedback through **LED** |
| | ***Voice*** | Condition 3-LV **User chooses** which item the robot clears each time and receives audial feedback through **voice** recordings | Condition 6-MV **Robot suggests** the item to clear, awaiting **user consent** before proceeding. User receives audial feedback through **voice** recordings | Condition 9-HV **Robot implements all actions** except **user vetoes.** User receives audial feedback through **voice** recordings |

### 2.7 Dependent measures

The interaction-related variables were assessed objectively and subjectively (Table 2). The objective measures that were collected during each trial included effort, accuracy, efficiency, engagement, comfortability, fluency and understanding, as detailed below. Subjective measures assessed via questionnaires included reliability, satisfaction, understanding, engagement, and comfortability.

*Table 8. Dependent Variables*

| | Dependent Variable | Measurement |
|---|---|---|
| Objective measures | **Effort** | Heart rate change |
| | **Accuracy** | Number of errors that occurred during the trial? Entire task? |
| | **Efficiency** | $Efficiency = 1 - \frac{time\ of\ trial\ i}{total\ duration\ of\ trials}$ i = trial number |
| | **Engagement** | Gaze duration at the robot - The length of time the participant looked at the robot out of??? Per trial, per task, per experiment - explain |
| | | Gaze duration at GUI - The length of time the participant looked in the direction of the GUI screen out of??? Per trial, per task, per experiment - explain – what about number of times it looked? Or is this not relevant?? |
| | | Gestures - The number of gestures made by the participant towards the robot during the task |
| | **Comfortability** | A categorical variable between 1-3 representing the proximity of the participant to the robot. 1 represents a distance away from the robot and 3 represents a very close proximity so that the participant touches the table surface. |
| | **Fluency** | Idle time (in sec?) |
| | **Understanding** | The number of clarifications made by the participant during the experiment |
| | **Order of LOA trials** | A categorical variable between 1 and 3 representing the order of the automation levels experienced by the participant. |
| Subjective measures | **Perceived Reliability** | How much the person perceives the robot as reliable? |
| | **Satisfaction** | The degree of contentment the person experiences |
| | **Understanding** | The extent to which the person comprehended the task |
| | **Engagement** | The felt- involvement of the participant in the task |
| | **Comfortability** | The amount of comfort the person experiences during the task |

### 2.8 Procedure

Participants were invited to the lab one at a time. Following consent participants were asked to complete a preliminary questionnaire consisting of demographic questions, Technology Adoption Propensity (TAP) (Ratchford & Barnhart, 2012) and Negative Attitude toward Robots Scale (NARS) (Syrdal, Dautenhahn, Koay, & Walters, 2009). Then, they were assigned a group (with one particular feedback mode) and participated in 3 table clearing task sessions corresponding to 3 different LOA modes. Participants completed a short post-session questionnaire after each task clearing trial and a final questionnaire at the end of the three sessions. The post-session questionnaire used 5-point Likert scales with 5 representing "Strongly agree" and 1 representing "Strongly disagree". The final questionnaire addressed the differences perceived by the participants between the three trials.

### 2.9 Analysis

A two-tailed General Linear Mixed Model (GLMM) analysis was performed to evaluate for a positive or negative effect of the independent variables. User ID was included as a random effect to account for individual differences. LOA and feedback type were utilized as fixed factors while all objective and subjective variables were used as dependent variables.

## 3 Results

### 3.1 Demographic Analysis

### 3.1.1 TAP - Technology Adoption Propensity

The majority (75%) of the participants firmly believed that technology provides increased control and flexibility in life. However, 40% of them reported low self-confidence regarding the general sense of being technological, as well as regarding their ability to quickly and easily learn the operation of innovative technologies. Only 5% of the participants reported high confidence in quickly learning such innovative technologies. The remaining 20% were indifferent. Nevertheless, 75% of the participants reported that they enjoy acquiring new technological skills. About 40% of the participants believed that they are being overly dependent on technology and even enslaved by it, while 27% were indifferent about it.

### 3.1.2 NARS – Negative Attitude toward Robots Scale analysis

Twenty percent of the participants had low negative view of robots, 20% had high negative attitude and 60% were neutral (mean= 13.5, SD=5.56). Additionally, 20% had highly negative attitudes toward situations which include robots, 30% were neutral while 50% had low negative attitude toward such situations. 30% had highly negative attitudes toward robot's social influence whereas 70% were neutral. With regards to the concept of robots having emotions, 30% had a highly negative attitude toward the concept, 40% were indifferent and 30% had a low scale negative attitude towards it.

### 3.2 User perception and preferences

The majority (86%) of the participants responded that they were not stressed about interacting with the robot, while 7% indicated otherwise. A depiction of the level of satisfaction of the participants is presented in Figure 9. The vast majority of the participant (18 participants in the high LOA, 17 in the medium LOA and 15 in the low LOA) reported that they were very satisfied when interacting with the robot.

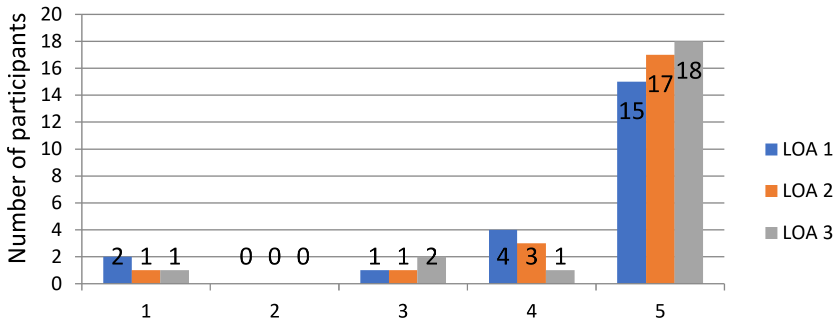



*Figure 21: Satisfaction level distribution*

Regarding reliance on the robot, 6% of the participants indicated that they fully trusted the robot, while about 11% said they did not feel they could trust the robot. The participants who had doubts about the robot said it was related to robot errors during the mission. The more the robot made mistakes, the lower the perceived reliability was (Pearson correlation = 0.426).

Half of the participants (50%) preferred the high LOA with 41% of the participants indicating that they would like to use the robot in a daily task such as clearing the table, while about 27% did not indicate such interest (Figure 10). Some participants noted that the size of KUKA may be too large for their home and preferred a more portable robot to perform the same operation.

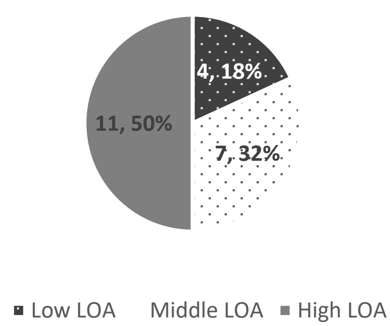



*Figure 22. LOA preference ( percentage of participants)*

### 3.3 Order effect

The order in which the participants experienced the LOA mode (which was random for each participant) had an impact on their satisfaction (*p=0.003*), and on their LOA preference (*p=0.002*). The significant difference in preferences was when the order of LOA did not occur in order of increasing LOA: 2->1->3 or 3->1->2.

Most of those who experienced a low and then high level of automation felt that control was taken away from them. They made comments such as, "Why is he (the robot) not listening to me this time?", "Let's see if he brings the kind of item I want when he did not ask for my opinion".

### 3.4 Objective performance

Results reveal that the LOA mode had more significant effects on most of the objective variables: on *accuracy (M=0.18, SD=0.39)*, *efficiency (M=70.21, SD=14.69)*, *gaze GUI (M=17.96, 11.84)* and *fluency (M=57.13, 14.63)* confirming *H1*.

Feedback, and the interaction of LOA mode and feedback was significant on some variables (confirming *H2* and *H3*). Feedback and the interaction variable between LOA and Feedback (Feedback*LOA) had significant effect on *accuracy* (detailed in Table 3).

*Table9 . Summary of assessments (significant results are marked)*

| | Effort | Accuracy | Efficiency | Engagement | |
|---|---|---|---|---|---|
| | HR | Errors | Total time | Gaze GUI | Gaze robot |
| LOA | .912 | .012 | .000 | .000 | .009 |
| Feedback | .128 | .037 | .819 | .465 | .587 |
| LOA * Feedback | .376 | .012 | .861 | .747 | .938 |

| | Fluency | Comfortability | Understanding |
|---|---|---|---|
| | Human idle time | Proximity | Questions |
| LOA | .001 | .134 | .101 |
| Feedback | .244 | .082 | .723 |
| LOA * Feedback | .545 | .738 | .150 |

There was also an interaction effect of LOA and feedback on the number of gestures expressed by the participant to the robot during the experiment (*p=0.017*).

## 4 Discussion and conclusions

The research demonstrates the influence of LOA and feedback on different aspects of interaction of older adults with an assistive robot. The experimental results give insights into preferences and expectations of the older adults in the assistive task of clearing a table. Some of the major findings are discussed as follows:

### 4.1 User perception towards the assistive robot

Most of the participants expressed their willingness to use the robot or a similar one in their home to assist them, emphasizing the relevance of the developed system. This is consistent with previous research that older adults expressed interest in the robot assisting with difficult tasks, saving time, performing undesirable tasks, reducing effort, and performing tasks at a high-performance level (Fausset at el., 2011). For an older adult to accept technology, such as robotics, the benefit has to be clear (Ezer at el., 2007; Caine at el., 2009). Many of these tasks were physical in nature (e.g., cleaning kitchen or Bathroom) (Beer et al., 2012). However, a considerable number of the participants reported that they would prefer a smaller version of the robot since they lived in a small apartment home, where space was limited. Therefore, the robot design must be adapted to fit the working environment constraints. Some participants also suggested that the robot should give more feedback after the task to update the user on the actions that have been carried out.

### 4.2 Characterizing the effect of LOA and feedback on the interaction

Most of the participants were comfortable interacting with the robot and also trusted the robot. Trust is an essential element for older adults and robot care providers to work effectively (Czaja et al., 2019). The vast majority of the participants felt the difference between the various levels of automation, and noted preference for the highest level of automation. This could be due to the least idle time which the high LOA produced, which is a desirable in the behaviour of most assistive robots (Smarr et al., 2014). It could also be due to the order effect of the LOAs experienced.

It was also observed that participants made the highest number of gestures to the robot at the highest LOA mode. This, on one hand could indicate engagement of the users but on the other hand could also indicate some form of desire for more communication with the robot, which was not as prominent as in the highest LOA. This emphasizes the importance of feedback, since that is what carries the user along in the task (Lyons, 2013). Examining the type of feedback, it appears that at the high level of automation, when the feedback was provided as voice recordings, the difference was most significant. This seems to point to the relevance of voice feedback for assistive robots in a social setting as used in this study. Voice feedback tends to engage the users more, giving the robot some form of personality as companion carrying out the task alongside the user (Avioz-Sarig, Olatunji, Sarne-Fleischmann, & Edan, 2020). The preferred type of feedback was voice recording feedback. It is therefore not surprising that the combination of the voice feedback and high LOA tends to increase the participant's involvement, especially at a high level of automation. It is recommended that these observations be further investigated in other scenarios, with other kinds of tasks, other forms of feedback and additional measures for engagement.

It was also observed that feedback through the GUI screen for this task was not as effective because the participants rarely looked at the screen, probably because they were concentrated on the robot. Therefore, it is recommended to further examine other types of feedback that could be suited for the task such as haptic feedback or a screen on the assistive robot itself. However, these observations could also be due to the novelty effect, after a certain period of time users might become accustomed to the robot and prefer visual feedback like a GUI screen or a different LOA mode.

### 4.3 Limitations and Future work

The observation made regarding the effect of the order of LOA experienced revealed the necessity to ensure that the order participants experience the LOA modes should be carefully considered. It is important to ensure that participants do not experience the feeling of control being taken from them. Thus, it is recommended to gradually increase the control the participants experience in future studies. This can help prevent the bias that may be introduced into satisfaction or fulfilment they receive while interacting with the robot.

LOA design was suited for the table setting task and may not have incorporated all interaction-related behaviours of the robot that could influence the preferences of the older adults. Some other details in the information processing and communication with the user could also be moderated in terms of different degrees of robot’s involvement. This gives the opportunity to further expand the definitions and applications of LOA to other aspects of the interaction.

The older adults in this study were mostly healthy, physically and cognitively fit participants. Further studies should explore the possibility of examining the system with other categories of older adults who may have different forms of physical or cognitive challenges. Long term studies could also be conducted to explore the possibility of adaption which could influence LOA and feedback preferences.

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**תקציר**

תוחלת החיים עולה, ויחד עם עלייה זו גדלה במהירות אוכלוסיית הקשישים בעולם. עם זאת, אוכלוסיית המטפלים אינה עולה בשיעור דומה, דבר המגביר את הצורך בפיתוח פתרונות שיסייעו למבוגרים. רובוט תומך חברתי, מספק פתרונות על מנת לענות על הצריכים אלו של האוכלוסייה המבוגרת. פיתוח רובוטים חברתיים לקשישים והשפעתם הוא שדה הנחקר ברחבי העולם, אך אתגרים רבים נותרו ודורשים מחקר נוסף. חשוב להבין לעומק מה גורם לאינטראקציה בין הרובוט לקשישים להצליח, על מנת להשיג רובוט המציע גישה טבעית, אתית, בטוחה ויעילה.
מחקר זה בחן את האינטראקציה בין רובוטים לסיוע חברתי לבין האוכלוסייה הלא-טכנולוגית, תוך התמקדות במבוגרים ובמטפלים. יצירת אינטראקציה מוצלחת היא משימה מאתגרת. לשם כך רובוטים חייבים להיות מסוגלים לתקשר באופן טבעי עם בני אדם באופן מילולי ובאופן לא מילולי. אחד הגורמים החשובים ביותר באינטראקציה בין האדם לרובוט הוא משוב. בניסויים שלנו הוערכה השפעת המשוב על היבטים שונים המשפיעים על ביצוע המשימות: רמות אוטומציה, רמות שקיפות, רמות מידע ומיקום המשימה המשנית. הניסויים בוצעו בסדרה שבה מסקנות מניסוי אחד שימשו כקווים מנחים לתכנון הניסוי שלאחר מכן.

החלק הראשון של המחקר בחן סיוע לאוכלוסייה קשישה בסביבתם הביתית בעזרת רובוטים. ניסוי ראשוני זה שימש כמקרה בוחן לחקר גורמי השפעה שונים. בניסוי זה השתתפו 14 משתתפים מבוגרים (8 נשים, 6 גברים), בגילאי 62-86 (ממוצע 69.8). המשימה שנבחנה בניסוי זה הינה משימת עריכת השולחן, אשר בוצעה במשותף על ידי מבוגר ורובוט אשר תוכנת בשתי רמות אוטומציה (LOA) ושתי רמות שקיפות (LOT) . משימה זו, מאופיינת ומיושמת עבור זרוע רובוטית , KUKA iiwa LBR בעלת 7 דרגות חופש, המתאימה לשיתוף פעולה בטוח עם האדם. המחקר, בחן כיצד LOA ו- LOT משפיעים על איכות האינטראקציה (QoI). ה- QoI הוא מבנה הטומן בחובו שטף, הבנה, מעורבות ונוחות במהלך האינטראקציה.

בחלק השני המשכנו לבחון סיוע רובוטי לאוכלוסייה המבוגרת בסביבה הביתית. לשם כך השתמשנו באותה מערכת כמו במקרה הבוחן תוך הוספה של שינויים ושדרוגים בהתאם לסוגי המשוב שבחנו. מחקר זה בחן את ההשפעה של שיטות משוב שונות על האינטראקציה בין האוכלוסיה המבוגרת והרובוט המסייע במשימת עריכת השולחן. במחקר השתתפו 21 מבוגרים (13 גברים, 8 נשים) בגילאי 70-86 (ממוצע 74, ס.ת 4.12). שני סוגי משוב שונים (חזותיים ושמיעתיים) ושילובם הוערכו בשלוש רמות מידע (LOI). המשוב הוויזואלי כלל שימוש בנורות LED ובמסך GUI. המשוב השמיעתי כלל התראות (צפצופים) ופקודות מילוליות.

בחלק השלישי נמשכה בחינת שיטות המשוב על סביבתם היומיומית של מבוגרים תוך שינוי הפלטפורמה הרובוטית והמשימה שנבדקה. במקור, רובוט נייד, Keylo (WYCA רובוטיקה) תוכנת לסייע למבוגר במשימת קניות בסביבת סופרמרקט. עקב מחלת ה- COVID-19 אשר התפשטה ברחבי העולם והצורך לשמור על אוכלוסיית הקשישים ולבודד אותם הניסוי שונה. הניסוי התמקד בבחינת הממשק למטפלים, אוכולוסיית משתמשים נוספת אשר אינה טכנולוגית. בנוסף, סביבת הניסוי השתנתה לסביבה מאתגרת ורלוונטית יותר, סביבת בית חולים. ניסוי זה מדמה סביבת בית חולים בה המטפל (משתתף) מעביר תרופות או אספקה אחרת למטופל ומקבל דגימות ממנו. 40 סטודנטים (27 נשים, 13 גברים) באוניברסיטת בן-גוריון גויסו כמשתתפים לתפקיד המטפל (גיל ממוצע 26.5, ס.ת 1.11 ). מחקר זה בחן שני סוגי משוב על מנת לקבוע מהו סוג המשוב המיטבי לסיוע טלא-רובוטי במשימת שליטה מרחוק עם משימות משניות. כמו כן, בדקנו אם מיקום המשימה המשנית משפיע על שיתוף הפעולה בין הרובוט למטפל. בניסוי הוערכו שתי שיטות משוב שונות (חזותית

ושמיעתית) והשילוב שלהן עם שני מיקומי המשימה המשנית של המטפל. האינטראקציה נמדדה במונחים של ביצועים אובייקטיביים (יעילות והבנה) ובתפיסת משתמשים (שביעות רצון, עומס עבודה ושימושיות).

מסקנה עיקרית משלושת הניסויים מתייחסת להשפעה החיובית של משוב קולי על איכות האינטראקציה בין המשתמש לרובוט, ללא קשר לסביבת המחקר ולאוכלוסייה הנבדקת. יתר על כן, השילוב של פקודות מילוליות עם משוב חזותי נמצא יעיל ביותר. השימוש במשוב רב חושי משלב ומעצים את היתרונות של כל סוגי המשוב. השימוש במשוב זה תרם באופן חיובי במשימה מורכבת הכוללת סביבה רועשת וכן לאוכלוסייה שיכולותיה אינן הומוגניות. יתר על כן, על המשוב להכיל כמות נמוכה של מידע על מנת למנוע עומס ובלבול בקרב המשתתפים, במיוחד כאשר מדובר באוכלוסייה מבוגרת. נמצאו מספר קווים מנחים המתייחסים למשוב אינטראקטיבי בהתאם למשתנים שלנו. רמת האוטומציה הגבוהה הביאה לביצועים הטובים ביותר עבור האוכלוסייה המבוגרת. בהתאם לכך, רמת השקיפות הוגדרה ברמה הנמוכה על מנת למנוע עומס ובלבול בקרב המשתתפים. כמו כן, רמת המידע המומלצת הינה רמה המספקת את המידע רק בנקודות חשובות במסלולו של הרובוט ובכך מפחיתה את העומס הקוגנטיבי על המטפל. מיקום המשימה המשנית לא הביא להבדלים משמעותיים, אך יתכן כי  משימה משנית מורכבת יותר תביא לתוצאות אחרות.

מחקר זה מציג את החשיבות של תכנון המשוב בשיפור האינטראקציה של מבוגרים עם רובוטים מסייעים. שימוש מהימן במשוב יגביר את הביטחון במערכת הרובוטית גם באוכלוסייה שאינה רגילה לטכנולוגיה. שיפור תכנון המשוב יוביל לשיפור האינטראקציה ויאפשר השתלבות אמיתית של רובוטים מסייעים חברתיים בחיי היומיום.

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אוניברסיטת בן גוריון בנגב

הפקולטה למדעי ההנדסה

המחלקה להנדסת תעשייה וניהול

**סוגי משוב שונים במערכת משולבת אדם- רובוט במיקוד הגיל השלישי**

מאת: נעה מרקפלד

מנחה: פרופ' יעל אידן

חתימת המחבר: ________________ תאריך: 14.01.2021

אישור המנחה: _________________ תאריך: 14.01.2021

אישור יו"ר ועדת תואר שני מחלקתית: ______________ תאריך: 18/1/2021

ינואר 2021

אוניברסיטת בן גוריון בנגב

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