Evaluating Feedback Modalities in a Mobile Robot for Telecare

Noa Markfeld, Samuel Olatunji, and Yael Edan

Department of Industrial Engineering and Management Ben-Gurion University of the Negev, Be'er Sheva, Israel

Abstract. Different feedback modalities while using a mobile robot in a telecare task were compared. An experimental setup in which caregivers teleoperated a robot to perform several tasks remotely, outside the immediate environment of a patient, while they simultaneously managed other secondary tasks was designed. The robot provided feedback related to status information on the robot's path and on tasks it performed. Two feedback modalities (textual and audio) and their combination were investigated to determine the most suitable for a remote operator in a simulated telecare task with secondary tasks. Additionally, the influence of the secondary task location on interaction was evaluated. Experiments with 40 participants with a teleoperated mobile robot revealed that the interaction was influenced mainly by the feedback modality, while the secondary task location had less influence. The feedback modality that combined textual and audio feedback yielded a better outcome as compared to the other single feedback modalities.

Keywords: teleoperation · telerobotic assistance · assistive robots · human-robot collaboration · feedback modalities · secondary task

1 Introduction

As the aging population increases there is increasing demand for caregivers [12]. The shortage of caregivers [11] along with the rising proportion of older people [12] leads to an increased need to support these caregivers. A promising solution to meet these needs is using robots that can support the caregivers and reduce the workload by performing various assistive functions [15]. One of these functions is the ability to remotely perform tasks such as pre-diagnosis, health monitoring, distribution of food, medicine and laboratory specimens [15]. An upgraded role for the assistive robots is to work alongside the caregivers to support their work and enhance efficiency [4]. This enables the caregivers to remotely manage tasks in places and in situations where they cannot be physically present. In many care giving contexts, the caregiver must attend several tasks (primary and secondary tasks) simultaneously. This usually constitutes challenges such as role overload [13]. Teleoperated robots can be employed for some tasks and thereby reduce the workload. A teleoperated robot is controlled by a human operator from a distance and performs tasks (services) as if the operator were on the spot [5].

Caregivers play a major role in providing and coordinating patient care [8]. This care, in addition to other duties, usually involves documenting information on patients, to facilitate care and to provide adequate and timely information for all health-related actions [1]. This is a time consuming task which consequently limits the time dedicated to care of the patient, affects outcomes and also influences the caregiver's work performance [8]. The work involved in documenting is also usually not entirely electronic, as some aspects are sometimes carried out on the desk, on an equipment or at the bedside of a patient. The effect of these differences in location and procedure of documentation on overall performance are not clear cut in previous evaluations [3]. Using teleoperated robots to support these type of tasks therefore requires investigation of the impact on the overall performance for the primary task of care giving and for secondary tasks such as documenting patients' information.

In this research, a hospital environment is simulated 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 caregiver (e.g. a nurse) cannot get near the patient for several possible reasons (e.g., task load, risk of infection). Feedback from equipment used in such care settings in general, have been found to improve patient care by providing alerts when needed [8]. The feedback from the robot can help inform the remote operator on different robotic aspects [2]: the robot's state of operation (e.g, moving towards goal or stopped due to an obstacle; details and constraints in the local environment (e.g., location of door to patient's room ahead, direction of passer-by in the corridor); and on state of the task being performed (e.g., delivery of an item at the desired destination, vital sign checks of the patient). In order to maximize the benefits of such alerts and information in the feedback from the teleoperated system, we developed suitable feedback modalities through which alerts and information can be provided by the robot. We then examined the influence of these modalities on the interaction between the caregiver and the teleoperated robot and on the performance. Additionally, we investigated if the location of the secondary task and the interaction with the feedback modalities influence performance and interaction between the robot and the operator.

2 Materials and Methods

2.1 The experimental system

The experimental system consists of a mobile robot platform, remote user interfaces and a server-client communication architecture that used a rosbridge websocket to connect to the robot operating system (ROS) platform of the robot. Two user interfaces were developed - one runs on the robot while the other runs on the operator's computer. These interfaces (programmed using HTML, CSS, JS and PHP) run within a standard web browser making them independent of the operating system of the device or any specific software.

The robot platform The robot platform is a Keylo telepresence robot [1]. Its height is approximately 1.64m with a low center of gravity and circular footprint 52cm of diameter. Keylo is equipped with a 24” multi-point high FOV touch-screen. It runs Ubuntu 18.04 LTS, ROS Melodic with a standard ROS API to all its sensors and features. The navigation sensor specifications are: Hokuyo URG-04LX-UG01 lidar (5.6 meters range, FOV 240°); 2 x 4 front and rear ultra-sonic 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.

User interfaces The user interface running on the robot’s browser was designed for the local user (e.g. patient directly interacting with the robot). The remote user interface through which the caregiver teleoperates the robot is displayed on a computer located remotely with the caregiver. The remote user interface was divided into three sections: a left, central and right panel (Figure 1). The video from the camera on the robot is broadcasted on the left panel. Feedback from the robot is displayed on the central panel. This feedback includes status information about: start of the mission, arrival at the destination (e.g. patient’s bed), various conditions along the way (e.g. malfunction/something unexpected on the way or information regarding attention such as code to access the patient’s room).

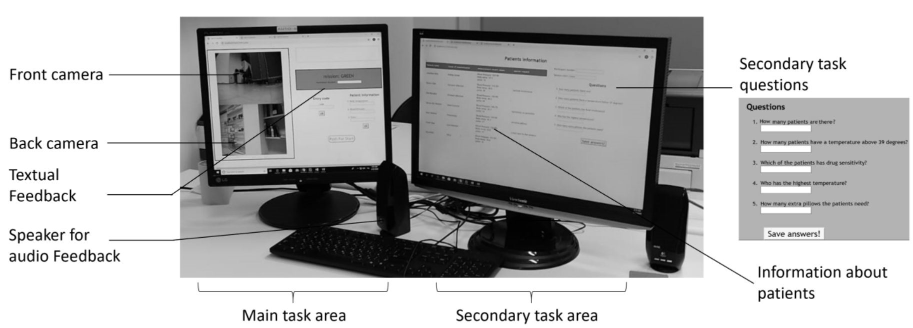

Fig. 1. Remote user interface

The right panel contains information related to the secondary task where participants are expected to answer questions related to the provided information. Two different secondary task locations were considered:

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.

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

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.

The feedback modalities examined were based on previous findings [10]:

Textual - Textual feedback appeared on the central panel in the form of written messages. These messages were designed to convey the information clearly and immediately.

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 textual feedback.

Textual and audio combination - feedback was transmitted to the participant through on-screen messages and voice commands simultaneously.

2.2 Task

The tasks involved navigating the robot from a control position to the location where the patient is. The caregiver sends the robot towards the patient to accomplish the main task while s/he carries out a secondary task. Feedback is provided during the process to indicate important points along the robot's path that require user involvement.

Main task The main task was to deliver food and medicine (which was represented by specific objects in the actual experiment) to the patient and retrieve samples (also represented by specific objects) from the patient. 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, which were represented by an access confirmation to enter a specific care unit) before continuing with its task.

Secondary task The caregiver completes an electronic health record which involves answering some questions related to the patients. This starts once the robot commences the main task of delivery to the patient. The participant is expected to answer the questions according to the relevant information as best they can. Once the robot returns from the patient (main task ends), the secondary feedback section ends.

2.3 Research hypotheses

The first two hypotheses are based on a previous study which revealed that feedback coming from more than one source increases the quality of the interaction [10], similar to work by [2]. It revealed that different feedback modalities improved effectiveness of control: the audio feedback will draw the participant's attention at the appropriate time and the textual feedback will serve as a backup in case the user is focused on the tasks and missed the voice instructions. These studies focused on evaluation with a stationary manipulator robot operated by a user who worked with the robot that was situated nearby [10] and at a distance [2] as opposed to the current work which focused on a teleoperated mobile robot. Also, the main task in these previous studies was a pick and place task with the stationary robotic manipulator. These studies also did not consider the influence of a secondary task, as well as the location of secondary task in the overall interaction. Considering the differences between the previously studied pick and place task and the current telecare task which also involved the potential influences of the secondary task inclusion, we propose the following hypotheses:

H1: A combination of textual and audio feedback modality in a teleoperated task increases the overall performance of users (as measured by the objective variables) relative to a single feedback modality.

H2: Combination of textual and audio feedback modality in a teleoperated task will increase the overall positive user perception of the interaction (as assessed through the subjective variables) compared to a single feedback modality.

Studies in a driving scenario show that the farther the display of the secondary task is from the main screen, the lower the performance [16]. This is particularly relevant when the distance is a vertical distance, the response times increase and there are more errors [7]. This inspired the third hypothesis:

H3: Executing the secondary task only on-screen will improve the performance for users compared to executing the secondary task between desk and screen.

2.4 Experimental design

The experiment was designed as a mixed (3 x 2) design experiment with the feedback modality (textual, audio and combination) and the location of secondary task (screen only and combination) defined as the independent variables. The feedback modality was the within-participants variable while the location of secondary task was the between-participants variable. Each participant experienced one location of the secondary task only for each of the three trials involving the the three feedback modalities provided in a random order.

2.5 Dependent measures

Objective Measures For each participant and trial, overall user performance was measured in terms of efficiency, effectiveness and understanding. Efficiency was evaluated as the completion time (in seconds) of the task, the time between the robot's departure and return to the control point. Effectiveness was evaluated as user performance in the secondary tasks since the participants were expected to complete the primary task. The primary task completion time determined the secondary task completion time. Completeness of secondary task is denoted as 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 (global accuracy, GA) and the number of correct answers from total questions that answered (response accuracy, RA). Understanding was evaluated by the reaction time. The reaction time is the time (in 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 from the experimenter during the experiment after the initial explanation of the procedure at the beginning of the experiment.

Subjective Measures The post-trial questionnaires (assessed after each trial) were used to assess usability, understanding, and satisfaction through 5-point Likert scales, with 5 representing "Strongly agree" and 1 representing "Strongly disagree".

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 credit in an obligatory course they took, which was 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 [14], 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 feedback modality. 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

Analyses were performed using a two-tailed General Linear Mixed Model (GLMM) analysis to address non-normally distributed response variables, heteroscedasticity, and non-linear relationships between the mean of the dependent variables and the independent variables. This ensured that both fixed effects and random effects were accounted for. The fixed effects were the feedback and secondary task modes. Random effect was included to account for individual differences among participants. To ensure that analyzed variables conformed to the GLMM requirements, the variables that included time were log transformed. The cumulative logit model was used for variables with ordinal values. The tests were designed with a significance level of 0.05. Mean and median results were also compared for the objective and subjective variables respectively.

3 Results

3.1 Efficiency

The efficiency, measured as the completion time (seconds) of the task (mean=80.27, SD=1.81) was significantly affected by the feedback modality (F(2,114)=13.1, p=0.001). The completion time of those using only audio feedback was lower (mean=70.61, SD=2.75) than that of the participants that used both audio and textual feedback (mean=78.42, SD=2.75). The highest completion time was observed in trials with only textual 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). Completion time of participants was, on average, lower (mean=78.25, SD = 2.49) for the screen-only condition compared to the screen and desk condition (mean=82.34, SD = 2.62).

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 modality 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 either audio or combined feedback (med=5, SD=0.5) compared to when using textual 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=0.97).

The reaction time (seconds) of the participants in the first trial (mean=7.45, SD=0.52) was significantly affected by both the feedback modality (F (2,114) =49.905, p=0.001) and the location of secondary task (F (1,114) =4.94, p=0.028). The combination of textual and audio feedback provided the shortest reaction time (mean=3.68, SD=0.62) when only the screen was used.

3.3 Effectiveness

In terms of completeness, the feedback modality did not significantly affect the number of questions that were answered by the participants (mean=3.7, SD=0.18, F(2,114)=2.17, p=0.12). Participants who experienced textual feedback only have higher completeness score (mean=4.18, SD=0.32) as compared to participants with only audio feedback (mean=3.28, SD=0.29) and with combined feedback (mean=3.71, SD=0.30). 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).

The feedback modality did not significantly affect the global accuracy, GA (mean=0.59, SD=0.04, F(2,114) = 2.07, p=0.13). The GA measure was also not significantly affected by the location of secondary task (F (1,114) = 0.455, p=0.501). In terms of response accuracy, RA (mean=0.71 , SD=0.06;), the influence of the feedback modality (F(2,114)=0.005, p=0.95) and the location of secondary task (F(1,14)=0.342, p=0.56) was not significant.

3.4 User perception

The scores of the questionnaire responses of the participants related to satisfactory communication was significant with respect to the feedback modality (med=3.75, SD=1.22, F (2,113) =10.25, p=0.001). Feedback that contained verbal commands in either audio feedback (med=4, SD=0.99) or combined feedback (med=4, SD=0.99) led to a higher communication score compared to when using feedback that contained only textual modality (med=3, SD=1.23). The feedback modality 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 (med=5, SD=0.93) and combined feedback (med=5, SD=0.93) resulted in a very high score while textual feedback had a reduced score (med=3, SD=1.19). The secondary task location did not have a significant effect on fluency. Fluency score was similar for both secondary task locations (med=4, SD=0.94).

The feedback modality had significant influence on situation awareness (SA) (med=4, SD=1.13; F (2,112) =21.74, p<0.001). The audio feedback yielded higher SA score (med=4.5, SD=0.95) compared to combined feedback (med=4, SD=0.86) and to textual feedback (med=3, SD=1.244). SA was not significantly affected by the location of secondary task (F (1,112) =0.872, p=0.352).

The feedback modality was significant on comfortability (F (2,112) = 14.93, p=0.001). The lowest comfortability score was observed when participants used the textual 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).

Regarding usability, the frequency of use (F(2,112)=10.51, p<0.001) and ease of use (F(2,112)=4.26, p=0.02), were significantly affected by the feedback modality but learnability was not (F(2,112)=0.35, p=0.71). The usability scores were higher when using the audio feedback only (med=4, SD=0.10) compared to the combined feedback (med=3.67, SD=0.11) or the textual feedback only (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).

4 Discussion

This research examined how the feedback modality and secondary task location influence the interaction between a caregiver (for instance, a nurse) and a teleoperated robot and their effect on performance. Results showed that feedback modality had significant effect on the interaction, with a mix of audio and visual feedback yielding best results (supporting H1 and H2). The secondary task location had less influence on performance but influenced some of the performance interaction parameters (supporting H3). More details are discussed as follows:

4.1 Impact of feedback modality

88% of participants preferred voice feedback, of which 67% claimed that feedback that combined audio and textual was most comfortable for them (in line with H2). The difference between the combined feedback and the two other feedback modalities was most significant in the understanding. However, there were also major differences in the effectiveness and efficiency. These contributed to the overall significant values seen through the objective and subjective variables. Even though the audio feedback reduced both response times and completion times, it did not result in the highest 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, consequently lowering the performance quality. This is in line with previous research which showed that sound alone requires higher attentional demand [9]. When the task is simple, concentration required from the caregiver 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. But as the task complexity increases, more concentration is required, and the transition between tasks becomes more difficult and may take longer. In this regard, the combined feedback seems better than the voice-only feedback (in line with H1). This agrees with the conclusions reached in an HCI context [6] where it was stated that auditory information proves superior to textual-only information but that this is not always the case when both auditory and textual modalities were used.

4.2 Impact of secondary task location

The secondary task location did not statistically influence most results. However, better performance scores were obtained when the secondary task was performed on the screen only and not when it was divided between the screen and desk (in line with H3). 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 RA (number of correct answers out of the total answered) was higher when the task was performed on screen only.

This seemed to imply that the transition between desk and screen may have caused more errors. This agrees with a previous study in which multiple eye movements increased user's mistakes [7].

5 Conclusions and Future work

This experiment simulated a hospital environment in which a caregiver teleoperates a mobile robot while performing another task. In this type of scenario where the time, accuracy and understanding of the scenario are critical, we found that the feedback that combined textual and audio feedback modalities yielded better performance, compared to the single modality feedback. Note that, if the goal is to shorten the performance time, audio feedback is optimal. However, due to some of the shortcomings of the audio-only feedback discussed, combined audio and textual feedback is recommended. It is also worth noting that additional visual feedback modalities superimposed on the camera image and other feedback modalities such as haptic feedback were not tested in this experiment. It is important to note that these experiments examined specific scenarios and were not performed with real caregivers. In order to generalize these conclusions, additional experiments examining different interfaces and different tasks must be performed with real caregivers.

Acknowledgements This research was supported by the EU funded Innovative Training Network (ITN) in the Marie Skłodowska-Curie People Programme (Horizon2020): SOCRATES (Social Cognitive Robotics in a European Society training research network), grant agreement number 721619. Partial support was provided by Ben-Gurion University of the Negev through the Helmsley Charitable Trust, the Agricultural, Biological and Cognitive Robotics Initiative, the Marcus Endowment Fund, and the W. Gunther Plaut Chair in Manufacturing Engineering.

References

1. Ash, J.S., Berg, M., Coiera, E.: Some unintended consequences of information technology in health care: the nature of patient care information system-related errors. Journal of the American Medical Informatics Association **11**(2), 104–112 (2004)
2. Bolarinwa, J., Eimontaite, I., Dogramadzi, S., Mitchell, T., Caleb-Solly, P.: The use of different feedback modalities and verbal collaboration in tele-robotic assistance. In: 2019 IEEE International Symposium on Robotic and Sensors Environments (ROSE). pp. 1–8. IEEE (2019)
3. Burnie, D.J.: Electronic health records documentation in nursing: nurses' perceptions, attitudes and preferences (2010)

4. Christoforou, E.G., Avgousti, S., Ramdani, N., Novales, C., Panayides, A.S.: The upcoming role for nursing and assistive robotics: Opportunities and challenges ahead. Frontiers in Digital Health **2**, 39 (2020)
5. Eliav, A., Lavie, T., Parmet, Y., Stern, H., Edan, Y.: Advanced methods for displays and remote control of robots. Applied ergonomics **42**(6), 820–829 (2011)
6. Kalyuga, S., Chandler, P., Sweller, J.: Managing split-attention and redundancy in multimedia instruction. Applied Cognitive Psychology: The Official Journal of the Society for Applied Research in Memory and Cognition **13**(4), 351–371 (1999)
7. Katsuyama, R.M., Monk, D.L., Rolek, E.P.: Effects of visual display separation upon primary and secondary task performances. In: Proceedings of the IEEE National Aerospace and Electronics Conference. pp. 758–764. IEEE (1989)
8. Kossman, S.P., Scheidenhelm, S.L.: Nurses' perceptions of the impact of electronic health records on work and patient outcomes. CIN: Computers, Informatics, Nursing **26**(2), 69–77 (2008)
9. Lee, S.C., Kim, Y.W., Ji, Y.G.: Effects of visual complexity of in-vehicle information display: Age-related differences in visual search task in the driving context. Applied ergonomics **81**, 102888 (2019)
10. Markfeld, N.: Feedback design for older adults in robot assisted table setting task. Ben-Gurion University of the Negev, Beer Sheva, Israel (2019)
11. Murray, M.K.: The nursing shortage: past, present, and future. JONA: The Journal of Nursing Administration **32**(2), 79–84 (2002)
12. Organization, W.H., et al.: Ageing (2020)
13. Perkins, E.A., Haley, W.E.: Compound caregiving: When lifelong caregivers undertake additional caregiving roles. Rehabilitation Psychology **55**(4), 409 (2010)
14. Syrdal, D.S., Dautenhahn, K., Koay, K.L., Walters, M.L.: The negative attitudes towards robots scale and reactions to robot behaviour in a live human-robot interaction study. Adaptive and emergent behaviour and complex systems (2009)
15. Vandemeulebroucke, T., Dzi, K., Gastmans, C.: Older adults' experiences with and perceptions of the use of socially assistive robots in aged care: A systematic review of quantitative evidence. Archives of Gerontology and Geriatrics p. 104399 (2021)
16. Wittmann, M., Kiss, M., Gugg, P., Steffen, A., Fink, M., Pöppel, E., Kamiya, H.: Effects of display position of a visual in-vehicle task on simulated driving. Applied ergonomics **37**(2), 187–199 (2006)