The use of different feedback modalities and verbal collaboration in tele-robotic assistance

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***Abstract*— This paper explores the effects of different feedback modalities (gripper orientation via peripheral (side) vision and haptic feedback) and verbal collaboration with the service-user on the performance of tele-operators in completing a tele-robotic assisted task. The study also analyses how tele-operator performance varied in relation to their experience of gaming and robotic technology. Tele-operator performance was measured in terms of task completion time (in seconds), how accurately they were able to orient the gripper, complexity of the robot arm trajectory taken for the task and perceived ease of use of tele-operating a robot arm. The results show that while the task completion time increased with the introduction of all forms of feedback, the ability for the tele-operator to accurately orient the gripper (which affects the success of completing the task) also increased. The study also found that the participants gave higher scores for ease of use for the scenarios that included the combined set of feedback modalities, including verbal feedback from the service-user.**

Keywords—tele-operation, tele-robotic assistance, collaboration, feedback modalities, haptics, peripheral vision.

I. INTRODUCTION

A. Motivation

Global demand for health services has been on a steady rise and shows no signs of slowing. By 2050, most countries in the Organisation for Economic Co-operation and Development (OECD) will spend more than twenty percent (20%) of their GDP on healthcare [5]. A factor influencing the high demand for health services is demographic changes and the growth of an aging population. According to the United Nations, the population of people aged over 60 would double, reaching a percentage high of 22% of the entire world population between 2000 and 2050 [33].

With increase in ageing population comes greater need for assistance with activities of daily living (ADLs) like dressing and walking, as well as instrumental activities of daily living (IADLs) like grocery shopping [16; 28] . Nearly 1 in 7 older people in the UK are living with some level of unmet care need [1]. According to the World Health Organisation, the incidence of disability amongst the total world population is at approximately 12% [21]. The shortage of healthcare professionals (formal and informal) to cope with the increasing demands [23; 24] of the rising proportion of older people [34] means that governments and healthcare institutions will have to find ways to reduce healthcare costs whilst providing quality healthcare services. By developing technologies such as assistive robots that can help provide adequate care, needs may be adequately met and older people, as well as people with disabilities, may retain their independence whether they are in hospitals, care homes or in their own homes [10].

Unlike industrial robots that operate in structured environments and require fencing throughout the full extent of their working envelopes to prevent accidents to people, healthcare robots are needed to operate in the real-world with often unpredictable environmental circumstances and operate in close physical proximity to people. The people in an assistive care scenario can often have a range of accessibility requirements, with impaired mobility, sensory systems and cognition. As such, it becomes difficult for a robotic system to operate safely and reliably, and while this technology is still being developed, there are large range of barriers to be overcome before we see assistive robots, function autonomously for personal care tasks, such as feeding and dressing, function autonomously. This study investigates the use of teleoperated robots [31], that can be remotely operated by an expert user, and offer support to a vulnerable user while being able to respond more safely and flexibly in real-world environments.

For remote operators to control the robot effectively, they need to 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. We refer to this type of teleoperation which includes a social element, tele-robotic assistance. This research investigates a range of feedback modalities for the tele-operator to determine the most suitable for remote tele-robotic assistance.

B. Related work

Controlled robots (remote controlled or tele-operated), like Texia [37], have high human intervention level and low autonomy level [13]. For uncontrolled home environments with differing conditions (stairs, doorsteps, hard floor, etc.), it may be difficult for robots to safely navigate and carry out tasks autonomously [38]. A tele-operated robot on the other hand relies on human interventions to compensate for limitations the robot might have and therefore ensures safe human-robot interaction. As a result of the distance between the tele-operator and the robot, the tele-scene, tele-system, and tele-cooperative characteristics of the system must be in a state that ensures safe tele-operation [8]. Having tele-scene characteristics include providing sufficient, authentic and real-time information about the robot-end state as well as robot response feedback to the tele-operator. The tele-system characteristics include appearance, integration of equipment, electromechanical performance, environmental adaptation, and software/hardware stability. Tele-cooperative characteristics reflects in-operation synchronization, as well as cooperative operation with different levels of tolerance.

Tele-operated assistive robots have been developed in different forms and for varying conditions from a simple tele-operated arm using pneumatic artificial rubber muscles [14] to a fully-actuated and anthropomorphic hand [19]. Pamungkas et al. highlighted that teleoperation is improved when the operator has a sense of embodiment within the robot and is thus immersed in the remote environment [4]. Embodiment occurs when feedback is introduced into the system to help the operator experience similar sensations and perceptions to that experienced by the robot [17]. Immersion is the idea of being present in a remote location.

Passing sensory data to the tele-operator involves exploring the concept of sensory substitution and cross-modal plasticity. Cross-modal plasticity encompasses the brain's ability to re-organise and make functional changes to make up for a sensory deficit [3]. Popular feedback modalities often used in tele-operation include: force feedback, visuals (pictograms, squares, text), audio (auditory tones, words, sonification), tactile (vibrotactile) [25], kinesthetic haptic feedback, contact feedback [32], and auditory biofeedback [26].

Force feedback can reduce task completion time and improve the accuracy of surgeons with high cognitive load [2]. Cutaneous feedback has been found to convey rich information without affecting the stability of the system [20; 27]. Through cutaneous feedback, provided by a moving platform, Meli et al. [20] in a pick and place task found sensory substitution (either by visuals or auditory feedback) less effective. In a needle insertion task, Prattichizo et al. found cutaneous feedback to be more effective than sensory substitution via visual feedback [27]. Using a non-mechanical electro-tactile feedback (derived from the resultant magnitude of the robot's force sensors) and a 3D stereo vision, Pamungkas et al. achieved an immersive and embodied tele-operation [4] when carrying out tasks. The tasks carried out involved controlling the robot to sharpen a knife with a grinder tool-head and using a scalpel tool-head to cut a thin layer of soft dough layered on top of a standard sheet of paper glued to balsa wood. Without the feedback, the knife sharpening task took three times longer to accomplish.

Limited tele-operation studies have been carried out using robots to provide care for either older adults with ageing-related impairments or people with disabilities. Most studies do not include interaction with humans via the robot and as such the emphasis on safety is less critical. Another missing factor in previous studies is the social effect of human (tele-operator) - human (service-user) collaboration on both the tele-operator and the success of the task being carried out.

This research examines the effect of multimodal feedback with and without collaboration between the tele-operator and service-user (the person being assisted). The aim of the study was to examine how different feedback modalities affect user experience and effectiveness of tele-robotic assistance, as well as the effect of tele-operator – service-user collaboration.

II. METHOD

A. Study setup and hypothesis

For this study participants were recruited to tele-operate a robot to carry out a task repeatedly. The chosen task was to pick up and empty the contents of a jar into another container and return the jar to its initial position. This type of assistive task might be performed for a service-user who has mobility difficulties. The role of the service-user was performed by the principal researcher for the experiments reported in this paper. The task was divided into four stages:

Stage 1: Free-space translation and rotation of the gripper from its start position to a position where it's just about to grasp the jar

Stage 2: Grasping the jar and making free space translation to a position where its content is about to be emptied.

Stage 3: Free space rotation and translation of the jar to empty its content into a box

Stage 4: Free space translation and rotation of the emptied jar to its pick-up position

The task, comprising of all of these stages, was repeated seven times with different combinations of feedback modalities and verbal collaboration between tele-operator and service-user as shown in table 3. Verbal collaboration comprised the service-user (principal researcher) providing directional instructions and feedback to the tele-operator.

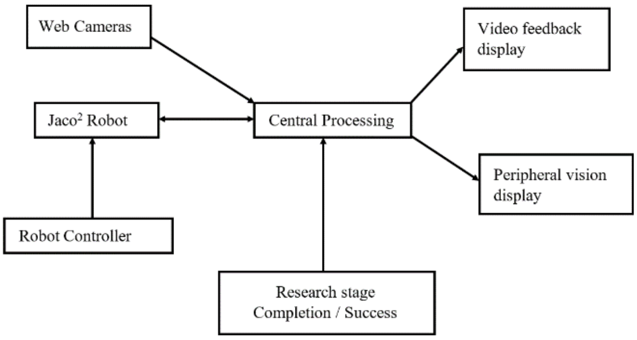

Fig. 1. Setup block diagram

In Figure 1, each block shows the components of the experimental setup and the direction of information flow. The central processing block is a laptop computer. It communicates with the Jaco^2 robot, polling the gripper orientation values from it and mapping the polled data to different feedback modalities. With the principal researcher acting as the service user, he uses sets of buttons to signal the end of each stage and the success or failure of each stage.

The experimental setup is shown in fig. 2. A Jaco^2 robot arm from Kinova [15] was used in the experiments. On the tele-operator end, control of the arm was achieved using the robot's original joystick controller. Videos of the remote location are captured using four cameras and displayed to the tele-operator on a single screen.

Peripheral vision involves the ability of the eye to see objects, movements and changes in the environment outside of the direct line of vision [36]. Information about the gripper orientation is presented as colour changes on

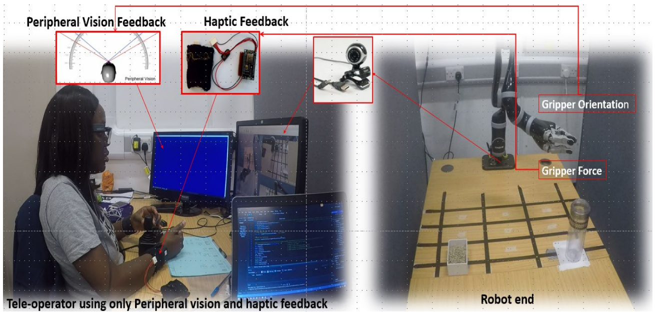

Fig 2. Experimental setup

another screen which is located in the tele-operator's peripheral field of view. Table 1 shows the gripper orientation values mapped to different orientation positions of the gripper and assigned colours. Each position is assigned values from 0 to 5. A score of 5 implies accurate orientation.

TABLE 1. ROBOT GRIPPER ORIENTATION SCORES

Orientation position classification	**Gripper orientation ranges (degrees)**	**Colour representation**	**Assigned values**
Aligned with the vertical axis of the jar	125 - 134, 482 - 492, -221 – -231	Green	5
A little tilted to the the left	134.5 – 140 (0.5 – 5 degrees more than the upper-class boundary of the 'aligned range')	Light blue	2
Farther to the left from the aligned position	140.5 - 482 (0.5 – 41 degrees more than the upper-class boundary of the 'slightly tilted to the left 'range)	Deep blue	0
A little tilted to the right	119.5 – 124.5 (0.5 – 5 degrees less than the lower - class boundary of the 'aligned' 'range)	Light red	2
Farther to the right from the vertical alignment	-221 - 120 (0.5 – 341 degrees less than the lower - class boundary of the 'aligned 'range)	Deep red	0

A WIFI-enabled haptic device (Fig. 3.) was also used to pass information about the gripper orientation to the tele-operator. This device was custom-made by the first author specifically for this study It incorporates 4 vibration motors located inside a soft sports wrist band.

Fig. 3. Haptic device

Table 3 shows feedback and collaborations scenarios for which participants carry out the tasks. To ensure parity, the order of in which each participant completed these scenarios was randomized using Latin Square counterbalancing. The combination of just peripheral feedback and haptic feedback was not included in the experiment because the overall time required for the experiment would have been too long, given all the separate and paired combinations that were carried out, however this has been planned with future experiments. The dependent variables in this study were the overall trajectory (calculated as the sum of the number of discrete robot arm joint movements in x, y and z planes) taken to complete the task, robot gripper orientation, time needed to complete the task and subjective ratings of ease and usability of the system (for the combination of different modalities). The independent variables were scenarios S1-7 (video as feedback only or combination of the other feedback modalities; Table 3). In providing assistance to a potential frail and vulnerable service-user, it is likely that the tele-operator and service-user will interact socially to make the experience pleasant and engaging. Interacting socially will require the teleoperation to speak with the service-user and also lookout for non-verbal communication cues. As a result, feedback modalities were chosen so as not to interfere with this social interaction. The measured variables are shown in table 2. It shows the dependent variables measured, as well as how they were measured.

TABLE 2. RECORDED DEPENDENT VARIABLE

Parameters measured	**How measurement takes place**
Stage completion, success and completion time (in seconds)	Researcher input buttons and in software. At the end of each stage of the task, the researcher presses buttons to signal the end as well as success/failure of each stage. When the buttons are pressed, task completion time, gripper orientation, and the sum of discrete robot joint movements recorded during the task are stored in a text file.
Sum of discrete number of robot joint movements in the x,y and z planes	These values are polled from the robot using KinovaTypes.h, CommunicationLayerWindow.h and CommandLayer.h header files in software
Participants' views on their experiences	Through questionnaires on the system usability scale, SUS (Brooke et al., 1996) and a question "How easy did you find the current system?" with answers from 1 (very difficult) to 10 (very easy)

As the task was carried out by participants, we measured stage completion, success and completion time, the participants' areas of interest in the visual field, the sum of the number of discrete robot arm joint movements in x, y and z planes, participants' physiological data, participants' facial expressions. Some hypotheses were made as the study was planned:

H1: Task repetition improves the time taken to carry out the task, as well the overall trajectory. The overall trajectory is calculated as the sum of discrete robot arm joint movements in the x, y, z planes, as the tele-operator moves the joystick to complete the task.

H2: The use of feedback improves the accuracy with which the jar is grasped and also reduces the overall trajectory of the gripper as the task is completed.

H3: Verbal collaboration between the tele-operator and a service user improves tele-operator's ease of use of the system and success in completing the task.

H4: Prior gaming and robotics experience improves tele-operators' performance (time taken to carry out tasks and accuracy of grasp).

H5: The introduction of feedback reduces the task completion time.

B. Setting

The study was conducted in the assisted living studio of the Bristol Robotics Laboratory, Bristol.

C. Participants

People with different technological backgrounds, ages, gaming experience, and demography were invited to see if they would like to participate. After completing a consent form, 11 people participated in the study, five men and six women. Participants had a mean age of 29.5 (SD = 7.54), 2.36 mean years of robot experience (SD = 3.2) and mean years of gaming experience of 5.6 (SD = 7.63). None of the participants reported colour blindness and of all participants, 10 participants are right handed and only one participant is left handed.

D. Analysis

Analysis was carried out on the measured variables: stage completion time (s), the sum of the number of discrete robot arm movements in x, y and z planes and perceived usability and user experience information gathered through questionnaires answered by participants (tele-operator) after each task and at the end of the entire study. Non-parametric tests were carried out due to low number of participants as suggested by [7] and [9].

III. RESULTS

A. Ease of Use

The first step of the analysis was to compare participants' subjective rating of the ease of use due to the different feedback modalities. Non-parametric Friedman's ANOVA [7] showed a significant main effect of condition $\chi^2(6) = 37.56$, $p < .001$, suggesting that participants perceived some scenarios to be easier than others. Having a priori hypothesis that adding any type of feedback to visual information will improve perceived ease, all scenarios (S2, S3, S4, S5, S6 and S7) were compared to visual feedback only scenario (S1). The comparison with Wilcoxon Signed Rank tests showed that all conditions with verbal feedback significantly improved participants' ease of use ratings on the task. Comparing S1 with S3 showed a trend after adjusting for multiple comparison with Bonferroni test (p = .009) (Table 3).

Multiple Wilcoxon Signed Rank tests with Bonferroni multiple comparison adjustment were performed (Table 4) to confirm H3. The results confirm that scenarios with verbal collaboration relates to participants' increased ease of use rating with S7 being reported as easiest to use. The Wilcoxon Signed Rank test indicated trend differences with S2, S3 and S5, but no significant difference with S4 and S5. This result further confirms that participants' perception of task difficulty was reduced with verbal collaboration (task completion was perceived as easier compared to conditions with no verbal collaboration). As a second step, analysis on the System Usability Scale (SUS) [29] was conducted to investigate if the system was more usable with particular modalities (a SUS score above a 68 is considered average table 4). Results, although not significant (Friedman's ANOVA $p \geq .312$; Table 3), confirm the same pattern of perceived usability scores – S1 condition was scored with the lowest scores, while conditions with verbal feedback (S2, S4, S6, S7) received higher results.

B. Task performance

Friedman ANOVA's was conducted trajectory and time needed to complete the stage, and rotation accuracy for the grasping of the jar. The mentioned parameters were analyzed for stage 1 because of the effect the success or failure of stage 1 has on the overall success of the task. Also, stages 2 and 3 can be carried out without additional feedback to the video feedback and so the authors considered not including data measured across these stages. Wilcoxon Singed rank test was used to explore further differences for a prior hypothesis that the introduction of additional feedback modalities will yield improved performance in this stage compared to the scenario where only video feedback was used.

1) Overall trajectories - Sum of the number of discrete robot arm joint movements in x, y and z planes

Friedman's ANOVA was not significant (*p* = .259), indicating that the robot trajectories taken were similar across all conditions. However, Scenarios S5 and S6, compared with S1 required the most convoluted trajectories (highest values

TABLE 3. MEANS AND STANDARD DEVIATION FOR EASE OF USE SCORES ACROSS CONDITIONS AND WILCOXON SIGNEDRANK TESTRESULT FOR PAIRWISE COMPARISON

Feedback and Collaboration Scenarios	**Mean**	**SD**	**S2**	**S3**	**S4**	**S5**	**S6**	**S7**
S1 (Video Feedback only)	5.55	2.84	Z = 2.83, p = .005, r = .60	Z = 2.32, p = .02, r = .50	Z = 2.82, p = .005, r = .60	Z = 0.76, p = .439, r = .17	Z = 2.68, p = .007, r = .57	Z = 2.81, p = .005, r = .60
S2 (Video Feedback and Verbal collaboration)	8.00	1.55		Z =1.87, p = .062, r = .40	Z = 2.12, p = .034, r = .45	Z = 1.96, p = .05, r = .42	Z = 0.96, p = .336, r = .21	Z = 2.41, p = .016, r = .51
S3 (Video Feedback and Peripheral Vision)	6.82	2.27			Z = 2.38, p = .017, r = .51	Z = 1.22, p = .22, r = .26	Z = 2.12, p = .034 r = .45	Z = 2.44, p = .015, r = .52
S4 (Video Feedback, Peripheral vision and verbal collaboration)	8.55	1.04				Z = 2.44, p = .015, r = .52	Z = 0.56, p = .58, r = .12	Z = 1.67, p = .096 r = .36
S5 (Video Feedback and Haptic feedback)	5.91	3.11					Z = 2.68, p = .007, r = .57	Z = 2.62, p = .009r = .56
S6 (Video Feedback, Haptic feedback and verbal collaboration)	8.36	1.29						Z = 1.82, p = .068, r = .39

S7 (Video Feedback, Haptic feedback, Peripheral vision and verbal collaboration)	9.00	0.89							

for the sum of joint movements), while S7 had the simplest trajectory needed to complete the task.

TABLE 4. MEANS AND STANDARD DEVIATIONS FOR ARM TRAJECTORIES AND TIME NEEDED TO COMPLETE STAGE 1, ORIENTATION ACCURACY IN STAGE 1 AND EACH CONDITION SUS SCORES.

	Sum of discrete number robot joint movements		**Time for completion (seconds)**		**Orientation accuracy scores**		**SUS**	
Feedback Scenario	Mean	SD	Mean	SD	Mean	SD	Mean	SD
S1 (Video Feedback only)	266.50	113.84	84.92	28.36	2.27	1.95	63.18	22.08
S2 (Video Feedback and Verbal collaboration)	155.50	12.02	87.02	33.35	1.64	1.91	73.64	15.43
S3 (Video Feedback and Peripheral Vision)	150.50	27.58	125.16	71.64	3.55	2.11	66.36	16.06
S4 (Video Feedback, Peripheral vision and verbal collaboration)	135.50	6.36	110.61	44.56	5.00	0.00	73.64	13.48
S5 (Video Feedback and Haptic feedback)	327.50	236.88	138.74	69.20	1.55	2.30	64.32	18.27
S6 (Video Feedback, Haptic feedback and verbal collaboration)	391.50	133.64	115.54	50.91	1.91	2.17	70.45	17.85
S7 (Video Feedback, Haptic feedback, Peripheral vision and verbal collaboration)	122.50	62.93	121.27	27.24	4.45	1.21	71.82	16.21

2) *Time needed to complete stage*

Friedman's ANOVA on time needed to complete each stage suggests that there was a main effect of modality ($\chi^2(6) = 13.01$, p = .043). Paired Wilcoxon Signed Rank test comparisons between all scenarios with S1 indicated differences with S3, S4, S5, S6 and S7 (p = .026, p = .033, p = .010, p = .041 and p = .021, respectively; Table 5). However, these differences were not significant after multiple comparison correction. The only approaching significance difference was between S1 and S5 – Video and Haptic Feedback (Z = 2.58, p = .010).

3) *Orientation of the Gripper*

Friedman's ANOVA on robot orientation while completing stage 1 suggests that there was main effect of modality ($\chi^2(6) = 26.79$, p < .001; Table 7). Paired Wilcoxon Signed Rank test comparisons between all conditions with S1 (video feedback only) indicated a significant improvement in orientation in S4 (Z = 2.60, p = .009) and a trend significance between S1 and S7 after multiple comparison adjustment (Z = 2.41, p = .016).This result is consistent with the subjective ease of use and SUS results, indicating that verbal feedback is important for successful task completion

4) *Impact of Gaming and Robot Usage Experience*

It was predicted, that participants' gaming and robot usage experience will be related to their performance. Spearman's rho correlation coefficient indicates that there was a significant negative correlation between participants gaming experience and stage 1 completion time in S7 (*Spearman's rho* = -.707, *p* = .022) suggesting that participants with greater gaming experience completed stage 1 in S7 more quickly.

Furthermore, robot experience was negatively related to time needed to complete stage 1 in S1 (*Spearman's rho* = -.66, *p* = .027) and sum of the number of discrete robot arm joint movements (overall robot arm trajectory) needed to complete stage 1 in S5 (*Spearman's rho* = -.7815, *p* = .025). The more robotics experience participants had the less time they needed to complete stage 1 in S1. Similarly, with greater robotics experience, the sum of the number of discrete robot arm joint movements needed to complete stage 1 in S5 decreased. As S1 and S5 were conditions without verbal feedback, this suggests that verbal feedback helps people without gaming or robotics experience to reach the levels of people more used to such tasks (gamers and robot users/researchers).

5) *Order effects*

To control for possible order effects, Friedman's ANOVA was performed to investigate if participants' ability to correctly orient the gripper, perceived ease of use, completion time and sum of the number of discrete robot arm joint movements needed to compete stage 1 reduced with every attempt at completing task. Investigation on time needed to complete stage 1 of the task with non-parametric Friedman ANOVA showed that participants were significantly quicker to complete the task depending on the attempt, χ^2 (6) = 22.35, *p* = .001. The Wilcoxon Signed Rank test indicated that compared to attempt 1, time needed to complete attempt 4, attempt 6 and attempt 7 significantly decreased (Z = 2.70, p = .007, r = .58, Z = 2.67, p = .008, r = .57 and Z = 2.67, p = .008, r = .57, respectively), while this decrease was at a trend compared to attempt 3 and attempt 5 (Z = 2.30 p = .022, r = .49 and Z = 2.50, p = .013, r = .53). Using the Friedman's ANOVA test, neither ease of use, completion time nor sum of the number of discrete robot arm joint movements needed to compete stage 1, were affected by having more practice at completing the task ($x^2(6) \leq 9.14$, p ≥ .166; Table 5).

TABLE 5. MEAN TIME NEEDED TO COMPLETE STAGE 1, ORIENTATION ACCURACY, AND SUM OF THE NUMBER OF DISCRETE ROBOT ARM JOINT MOVEMENTS FOR STAGE 1 AS WELL AS EASE OF USE RATING AS A FUNCTION OF CONDITION PRESENTATION ORDER

	Time to complete stage 1		**Orientation accuracy for stage 1**		**Trajectory for completing stage1**		**Ease of Use**	
Order	Mean	SD	Mean	SD	Mean	SD	Mean	SD
1	358.50	96.54	2.18	2.36	653.00	192.67	7.64	2.11
2	315.52	81.93	2.18	2.36	563.20	270.68	7.64	2.54
3	288.15	89.58	3.73	1.85	467.75	233.67	7.09	2.74
4	270.97	97.69	3.09	2.30	482.29	160.28	7.09	2.55
5	243.60	83.22	2.55	2.11	489.13	262.11	7.64	1.80
6	206.63	51.60	3.27	2.10	325.25	166.49	7.73	2.53
7	199.83	58.92	3.36	2.34	284.25	142.67	7.64	2.50

IV. DISCUSSION

The challenge of not being physically present to carry out tasks may present problems for tele-operators and may reduce the efficiency with which tasks are carried out. Tele-operators completed a pick-and-empty task, picking up a jar containing sunflower seeds and emptying the contents into another container using different feedback and collaboration scenarios.

Results from the ease of use questionnaires answered after each task showed that the use of feedback improved how easily participants were able to carry out tasks with varying levels of difficulties. How easily participants were able to carry out the tasks varied with the different types of feedback provided. Results also show that verbal collaboration improved participants' perceived ease of use of the system for all feedback scenarios with scenario 7 proving to be the easiest. This confirms hypothesis 3, H3 and the findings of Kraut et al. in their study on the effect of collaboration in performance of physical tasks [18]. For scenarios without collaboration (S1, S3, and S5), scenario 3 had the highest ease of use score while scenario 1, our baseline scenario, had the lowest ease of use score. This pattern also reflects in scenario 1 having the lowest score on the system usability scale while scenarios with collaboration have higher scores on the system usability scale. It might be suggested, that the more information about the system and process tele-operators have, the more confident and comfortable they were. There are suggestions of improved performance from research involving multimodal feedback when additional modalities are employed to support or enhance user activities [6; 30].

Task repetition reduced the task completion time as hypothesized in H1 and confirmed by [22] but did not have any effects on the accuracy with which the task was carried out. The results did not agree with the second part of H1 stating that task repetition reduces the overall trajectory as the task is carried out. The introduction of feedback did increase the task completion time for all scenarios in contrast to what was initially hypothesized in H5. The increased task completion time is also in contrast to expected general effect of the use of feedback. Akif et al. [11] and Chanyoung et al. [12], for example found that the use of feedback reduced the task completion time in their tele-operated vehicle for obstacle avoidance. The type of haptic feedback according to [35] also has an effect on results. Several factors could have contributed to the increase in task completion time. One of such could be the amount of information tele-operators have to process whilst carrying out the task. Another possible reason could be the task type and difficulty level. Even though the introduction of feedback did increase the time taken to complete the task, there was significant improvement in the gripper orientation before grasp confirming H2. Although not significant, the sum of the number of discrete robot arm joint movements in x, y and z planes taken to complete stage 1 also decreased with the introduction of feedback, confirming the second part of H2. With each attempt, participants became quicker to complete a task. However, this did not influence their perceived ease of use (no significant order effect). Considering the influence that feedback had on the trajectory taken to complete the task, even though there was no statistically significant effect, scenario 7 had the least values for the sum of the number of discrete robot arm joint movements in x, y and z planes. Scenario 2 produced the highest mean value for the sum of the number of discrete robot arm joint movements in x, y and z planes for task completion.

For gripper orientation accuracy, scenario 4 resulted in the tele-operator being able to achieve the most accurate gripper orientation, followed by scenario 7 and scenario 3. The gripper orientation accuracy is very important for successful grasp and can therefore affect the overall result of the task. Even though the scenarios that yielded the best gripper orientations had a longer task completion time, this might be acceptable for high-risk tasks.

As hypothesized in H4, prior gaming experience was indeed an advantage to successfully completing stage 1 but as shown, verbal collaboration increased the chance of success for participants without prior gaming and/or robot experience. For tele-operation applications that emphasise safety and precision, like assisted care provision or tele-surgery, these results are positive as task completion time can be traded for greater accuracy, task success and better user satisfaction. Based on our experiments described in this paper, when verbal collaboration does not take place, a combination of video and peripheral feedback, was found to be the optimal way for providing feedback (Scenario 3). This is based on the ease of use rating given by teleoperators. However, when verbal collaboration is introduced then using a combination of video, peripheral and haptic feedback results in the highest rating of ease of use (Scenario 7). This combination also results in the highest gripper orientation accuracy and lowest trajectory.

V. FUTURE WORK

For better classification and improved significance of results, the experiment will be carried out with more participants, including older-adults as service users to provide verbal feedback, and carers in the role of tele-operators. Also, the same experiment will be carried out with different tasks and the introduction of additional feedback modalities. Additional tasks, which reflect further possible assistance that older adults might require due to their disabilities, will also be considered.

VI. CONCLUSION

In this paper, we examined how different feedback modalities affect user experience and effectiveness of tele-robotic assistance, as well as the effect of tele-operator – service-user collaboration. A service-user (researcher) and tele-operator (participants) engaged in verbal conversations as the participants carried out a pick and pour task. It was noted that the human-human verbal collaboration increased the time participants took to complete the tasks compared to when there was no verbal collaboration. Experiments on how the different feedback modalities augmented the user experience and effectiveness of the control showed improved effectiveness of control when feedback was introduced with peripheral vision having the greatest effect size. Participants also noted that the tasks became easier with the introduction of different feedback or combination of feedback. As effective as the feedback system is, authors recognize that a major drawback to tele-robotic assistance healthcare support currently is the individual cost of the robots. To address the current pressures on healthcare systems due to an ageing population, tele-robotic assistance could be a more cost-effective and efficient approach to providing personalized care on a large scale, where a single tele-operator could reach a larger number of service-users. This could off-set the cost of the robots, which are likely to reduce over time.

VII. REFERENCES

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