Performing Human-Robot Interaction User Studies in Virtual Reality*

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***Abstract*— This study investigated whether virtual reality could be used as platform for conducting human-robot interaction user studies. It was investigated whether user studies performed in virtual reality elicited realistic responses from participants. To answer this question, a real world study was replicated as closely as possible in virtual reality, where a robot tour guide asked participants to keep a secret. The experiment consisted of a virtual museum tour where the robot acted as the tour guide while displaying either social or non-social behaviour.**

The measurements taken in this study were the objective measurement whether the participants kept the robot's secret or not. Questionnaires were taken to investigate participants' perception of the robot and its feelings, as well as their experienced level of presence and their tendency to become immersed in the virtual environment. Results show that the participants responded differently in the virtual reality study when compared to the original real world study, where the secret was kept more often for the non-social robot, but less often for the social robot. In both the original and replicated study a strong, positive correlation was found between participants' perception of the robot as a social being and their tendency to keep the robot's secret.

These inconclusive findings, some changes that were required for the virtual environment compared to the original study, and different participant demographics indicate that more work is needed to determine whether virtual reality can be used as a tool to conduct human-robot interaction experiments.

I. Introduction

User studies in Human Robot Interaction (HRI) are predominantly performed in a controlled lab environment. Close proximity between participants and experimenters is often required to brief, debrief and observe participants. With the COVID-19 situation shutting down much of regular societal activities including research, performing physical user studies is made much more difficult. This provides more reasons to explore the possibilities of investigating whether there are other ways user studies can be conducted within the field of HRI. Virtual Reality (VR) has become increasingly popular. With current technology being able to produce small screens that are capable of generating high quality images that allow for users to experience realistic and immersive environments. This study investigated whether introducing participants to a virtual environment would yield similar results as a physical HRI study. If found to be true, VR can provide access to a wider variety of environments, scenarios and robot embodiments for researchers to conduct studies. It also allows for easier set up of experiments, needing only the VR set and a computer, allowing researchers to take the experiments to a wider audience rather than having participants come to the laboratories.

The main concern with conducting experiments in VR is whether the participants' responses will be realistic or whether they will be influenced by the virtual nature of the experience. It is therefore important to design environments and interactions that evoke a high level of presence, the sense of actually being present in a virtual environment, within the user. This study attempted to replicate an existing physical HRI study in VR and compare whether the responses from the participants in this study were similar to the responses of participants in the study that was replicated.

The study that was replicated in this experiment investigated whether a person would keep a tour guide's secret when asked to do so by the guide, where the guide was either a social robot, non-social robot or a human [1].

An adjusted version of this experiment was built in a virtual environment and conducted for the social and non-social robot conditions. The elements of the tour used in the original study were maintained, and similar measurements were taken and expanded with measurements on the experienced level of presence during the experiment.

II. Related Work

The main goal of the study was to investigate whether people would keep a robot's secret while in a virtual environment. Therefore, it is important to understand what trust means in these settings, and to determine whether virtual reality could be a good tool for these types of studies.

A. Trust

All forms of human-robot interactions require a certain level of trust between the robot and its user. More specifically, trust is one of the most important elements with regards to HRI [2].

Definitions of trust include to have confidence in something, to allow something without fear and believing in the honesty and reliability of others [3]. In this study a version of trust that cares about *conferring trust upon something/someone else* was investigated. This study was a replication of the study by Kahn et al. [1], in their study the robot is conferring trust upon the participant, since it is asking the participant to keep a secret. One of the most important factors of building and maintaining meaningful social relationships between people is that people can trust each other to keep each others' secrets (e.g. [4]). Abbas et al. observed that trust requires an amount of risk and vulnerability from trustor to trustee [5]. In social HRI it is

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much less clear how the dynamic works between robot and user and as such the dynamic of trust is less clear compared to performance based HRI.

B. Virtual Reality

VR technology is either head based, stationary or hand based [6]. These technologies allow for people to enhance or change their surroundings. The amount with which they feel immersed in this (partially) virtual environment is known as the level of presence.

1) Presence in virtual environments: There are several factors that influence the level of presence experienced by a user [7]. These include vividness, interactivity and user characteristics.

Some researchers investigated whether there was a strong effect between the experienced level of presence and participants' answers to the questions [8]. They reported that the most important factors contributing to the level of presence are control, selective attention, naturalness of interaction, immersion and involvement.

2) Comparison between Virtual Reality and real world: There have been several studies which compared VR environments with real world counterparts. Weistroffer investigated the acceptability of human-robot co-presence and found that there were no differences in questionnaire results between the real and virtual situations, but found there were physiological differences between the two situations with a significant increase in the physical situation only [9]. This implies that VR can be a good tool to draw preliminary results with regards to HRI but that the real world experiments are still required to complete studies, especially when the study contains physiological measurements. A study conducted by Duguleana showed that using VR was 'a great way of simulating robotic scenarios' but they reported differences in participant behaviour between the real world experiment and the virtual environment, with the participants giving more personal space to robots in the real world. They also reported that the use of VR for testing scenarios with a robotic arm eliminated a lot of problems they would normally have with a physical robot arm [10]. They did not have to worry about things like security issues, hardware and software malfunctions and preparing for possible injuries. All in all they claim that 'immersive VR is a good alternative to classical robot testing'.

Bainbridge et al. investigated 'how a robot's physical or virtual presence affects unconscious human perception of the robot as a social partner' [11]. They found that the participants were more willing to follow an unusual task set to them by the robot if the robot was physically present compared to the virtual robot and that they would also afford the robot more personal space in the real world. It has to be noted though that the virtual robot condition was a virtual avatar whereas this study proposes the use of immersive VR which can have a influence on participant perception of the robot.

Kamide et al. [12] investigated the differences between real world and virtual proxemics with regards to robot approaches and found no differences in personal space but did note that participants had different impressions of the real and virtual robot. However Li et al. [13] performed a similar study and did find differences in both proxemics and people's perception of the robot. This inconsistency implies more research is required before any conclusions can be drawn on the usability of VR and the accuracy of its results.

C. Original Experiment

The original experiment which was attempted to be replicated was interested in seeing whether participants would keep the secret of a robot. To investigate this they designed a between subject experiment with three conditions. A human tour guide, a non-social robot guide and a social robot guide. Each of these guides would take the participant on a tour through the lab and talk about several parts of the lab. At a certain point in the tour the guide would skip part of the tour and ask the participant to keep this a secret between them and not tell the experimenter. At the end of the tour there were multiple moments where the participant was asked whether they had completed the entire tour, once where the guide was still present and once where the guide was no longer present. They could then test whether there were differences in secret keeping behaviour between the conditions and between the moments of questioning. Other measurements that were taken revolved around the participant's perception of the guide.

D. Research Question

With regards to the scope of the project, the aim was to answer the following research question:

"Does the replication of a real world human-robot interaction study in virtual reality yield similar results when compared to the original study?"

III. Methodology

A between subject experiment design was used to investigate the research question. This meant that each participant encountered only one study condition. The conditions that were implemented were the social robot tour guide and the non-social robot tour guide. Participants would wear a VR headset and would take the tour in a virtual environment with a virtual robot acting as their guide.

A. Non-social robot condition

In this condition the virtual robot was fully automated and its behaviours were pre-programmed in Unreal Engine. Once the script started the robot would move to a predesignated spot and turn to face the participant. It would than introduce itself and give the tutorial. All speech in this condition were mp3 files generated from text to speech software and triggered when the robot entered pre-defined areas in the museum environment.

Similar to the original experiment, the robot did not interact much with or responded to the participant. It would move to a predefined area, talk about the relevant part of the

Fig. 1. Point of view for the wizard including simple mesh to track gaze.

Fig. 2. Real world Robovie and virtual Robovie

tour and wait until the participant would give the signal to continue. In the original experiment participants were given a tablet to press a button, this was emulated by having a designated button on one of the motion controllers.

B. Social robot condition

Following the example of the original study by Kahn et al. the decision was made to have a Wizard of Oz setup where an experimenter was controlling the robot remotely. The experimenter had remote access to the PC running the experiment. This meant that the experimenter would take control once the participant donned the headset. A third person camera was attached to the robot mesh, giving the experimenter a good view of the environment. A simple globe mesh was added just behind the VR camera, this allowed the experimenter to track the participant's gaze as seen in Fig. 1.

The experimenter could control the robot's movement using the arrow keys on their keyboard, where the Up/Down keys controlled the forwards and backwards motion and the Left/Right keys the robot's rotation. To be more responsive and social, the decision was made to give the experimenter a headset and allow them to speak to the participant directly while their voice was being modulated to sound artificial. The experimenter had a strict script to follow as well as a list of responses to give if a request was not an option in the script to reduce chances of experimenter bias.

C. Measurements

This study used a number of measurements to gain the required data. Demographics data was gathered to gain insight in the participant group including, background and experience with social robotics. A number of questionnaires were used as well. These focused on the guide's Mental and Emotional Scale (MES) and the Social Other Scale (SOS). These consisted of 7 and 11 items respectively and measured how the participants viewed the robot.

D. Experiment Structure

In both conditions participants were instructed that they were going to be taking a tour through a virtual museum where a robot would function as their guide. After briefing the participant and obtaining written consent they were asked to put on an HTC Vive headset, noise cancelling headphones and hold the Vive motion controllers. Participants were seated on a desk chair in the middle of an open area so that they could rotate and look around the environment.

Once the participant was comfortable and ready, the experiment would start. The participant would spawn in the virtual museum and a virtual version of Robovie, as shown in Fig. 2 would approach and introduce itself. The robot would explain that it was going to be the tour guide and then proceeded to give the participant a tutorial on how to use the motion controllers to move around in the environment and how to manipulate items within the environment, as well as what they had to do to tell the robot to continue. Once this tutorial was done and the participant had a chance to familiarize themselves with the controls the tour would start.

The robot would take them to a number of museum exhibits and give them some information about the exhibit. Each exhibit had a miniature version on a pedestal next to the actual exhibit that the participant could pick up and manipulate to have a closer look. This was done to increase the interactivity of the environment and by extension the level of presence experienced. At a certain point the robot would move towards the doorway leading to another room in the museum containing the Egyptian exhibits. The robot would stop, turn towards the participant and indicate that it's battery was almost empty and that they would therefore skip that part of the tour. The robot would ask the participant to not tell anyone that they had skipped the Egyptian part of the tour. Once the robot had reached the end of the tour it would say goodbye to the participant after imploring them to keep the secret. After this the participant was asked to answer a questionnaire about their experience whilst they were still in the VR environment. It was deliberate to have them answer the questionnaire about their experience whilst they were still embedded in the environment to ensure they were still present in that environment and that the answers would reflect that as well, rather than having a obvious split between what happened in the virtual environment and what happened in the real world.

Once participants had finished this questionnaire they were asked to take of the headset and put down the controllers. Whilst this was happening, the experimenter would ask the participant a number of questions. Whether everything went alright, if they felt any nausea, whether they could

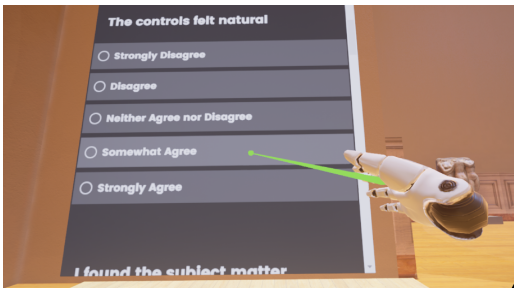

Fig. 3. View of in environment questionnaire

understand the robot properly. Amongst all these questions the experimenter would ask whether the robot had showed them everything (the second opportunity to keep the robot's secret). After this they were asked to answer a questionnaire which contained questions about their experienced level of presence as well as their tendency to become immersed in things. These questionnaires were versions of the ITQ and the PQI by Witmer et al. [8]. The order of questions in each questionnaire was randomized to exclude any order effects. Once participants had finished these questionnaires they were debriefed, any questions would be answered and they would be given their £5 Amazon voucher and the experiment would be over.

E. Changes to the original study

The main elements of the original study by Kahn et al. were kept similar, but it was replicated in VR using Unreal Engine 4. Changes to the original experiment had to be made to ensure the experiment was suitable for the virtual environment. The decision was made to change the lab tour from the original experiment to the virtual museum tour used in this experiment. As such the tour did not have the same content as the original experiment but the museum tour had similar elements compared to the lab tour. For instance, in the original experiment the participant was brought to a gong and told about the cultural significance of the gong followed by an invitation to hit the gong. This did not fit with the style of the museum which consisted of Ancient Greek and Roman exhibits in one room and Egyptian exhibits in a second room. Therefore, the choice was made to change the gong to a drum and have the robot explain the cultural significance of the drum to the Ancient Greeks, followed by an invitation to beat the drum themselves. Another significant change was made to the secret that was entrusted by the robot. In the original experiment the robot was supposed to show the participant an aquarium, but being made of electrical components the robot is hesitant to be around that much water and as such skips that part of the tour, asking the participant not to tell the experimenter. An aquarium did not make much sense in the museum environment and was therefore changed. To keep the self protection theme of the secret the decision was made to change the secret. In this experiment the robot had a low battery and was not able to complete the entire tour before the batteries emptied and therefore it would skip part of the tour. This was implemented verbally and visually, where the robot told the participant as well as showed it through a battery charge level added to the robot mesh as seen in Fig. 4. The original study used a semi-structured interview where the experimenter questioned the participant on a number of things and the responses were used to construct data on the Social Other Scale as well as the Mental/Emotional Scale. Since the exact nature of the interview was unknown the decision was made to turn the items of these scales into a questionnaire and present that to the participants.

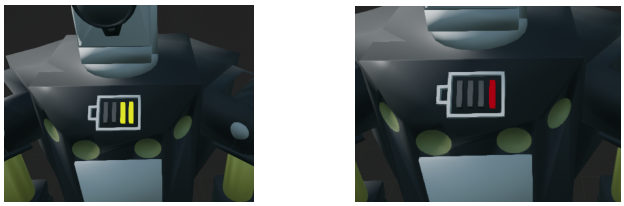

Fig. 4. Visual changes in the robot's battery level during the experiment

IV. Results

A. Participants

In total 38 people (22 male, 15 female, 1 other) participated in this study (age M = 32.35, SD = 10.70). These participants were randomly assigned to either the non-social condition or the social condition (20 in the non-social condition and 18 in the social condition). These participants had medium experience in interacting with social humanoid robots (M = 3.84 out of 5, SD = 1.03). Where 1 meant 'A great deal' and 5 meant 'none at all'. Therefore, lower numbers indicate more experience with social humanoid robots.

Experience with VR was average (M = 3.71 out of 5, SD = 0.77). In this case, 1 meant 'a great deal' and 5 meant 'none at all', meaning that lower number indicate more experience with VR.

B. Secret Keeping

The main focus of the experiment was concerned with the question whether the participants kept the robot's secret. As well as investigating whether there was a difference between the two opportunities of keeping the secret (in VR questionnaire "I was shown and told about the Roman, Egyptian and Greek exhibits", after taking off the headset "Did the robot show you everything?"). Table II shows the percentage of participants who kept the robot's secret in the first and in the second opportunity of keeping the secret. These are compared to the percentages from the original experiment.

In the non-social condition 10 participants (50%) kept to robot's secret while still in the virtual environment compared to 6 (33.33%) in the social robot condition. After taking off the headset and answering the experimenter's question whether the robot had shown them everything, 5 participants (25%) kept the robot's secret in the non-social robot condition compared to 6 participants (33.33%) in the social robot condition.

TABLE I

AVERAGE SCORES OF THE PRESENCE QUESTIONNAIRE AND THE IMMERSION TENDENCY QUESTIONNAIRE. BETWEEN CONDITIONS

Average PQ and ITQ scores between conditions	**Social Robot**		**Non-Social Robot**	
	M	*SD*	*M*	*SD*
PQ (max 168)	118.61	17.59	119.05	14.48
ITQ (max 126)	77.44	12.03	84.40	9.10

A mixed ANOVA was performed to investigate whether there was a main effect of environment (in VR x after experiment) and the robot's behaviour (non-social x social) on participants' secret keeping. The environment participants were in had a significant influence on whether they kept the robot's secret ($F(1,36) = 8.71$, $p = 0.01$, $\eta_p^2 = 0.20$). Participants kept the secret more often when they were still in the virtual environment (55%) with respect to when they were addressing the experimenter (29%). The robot's behaviour did not significantly influence whether participants kept the secret of the robot ($F(1,36) = 0.02$, $p = 0.89$, $\eta_p^2 = 0.001$), nor was there a significant interaction effect (environment x condition) ($F(1,36) = 2.34$, $p = 0.14$, $\eta_p^2 = 0.06$).

C. Presence

After the experiment, questionnaires were given to determine how high the experienced level of presence was for the participants. Following the paper that introduced presence questionnaire (PQ) and immersion tendency questionnaire (ITQ) [8], the results of these questionnaires were summarized. The results of both questionnaires were normally distributed (PQ: $p = 0.69$, ITQ: $p = 0.33$).

Reliability of PQ was high (Cronbach's $\alpha = 0.83$) and reliability of ITQ was acceptable (Cronbach's $\alpha = 0.68$).

To determine whether the robot's behaviour had an influence on participants' experienced level of presence, independent t-tests were performed. PQ was not significantly influenced by the robot's behaviour ($t(36) = 0.08$, $p = 0.93$). ITQ was almost significantly influenced by the robot's behaviour ($t(36) = 2.02$, $p = 0.05$).

A Pearson correlation was run to determine the relationship between the PQ and ITQ questionnaire. No significant correlation between these two questionnaires was found ($r = 0.26$, $p = 0.11$).

Some questions were added to the questionnaires given in VR to disguise the secret-keeping question. Reliability of this sub-questionnaire was acceptable (Cronbach's $\alpha = 0.69$). After removing the item 'The guide was knowledgeable', reliability increased to Cronbach's $\alpha = 0.72$.

After removing this item, a Pearson correlation was run to determine the relationship between this small questionnaire and PQ. A strong, positive correlation was found ($r = 0.55$, $p < 0.001$).

D. Perception of the Robot

The interviews described in the original experiment were scored according to how participants reacted to the questions.

TABLE II

COMPARISON BETWEEN THE ORIGINAL STUDY AND OUR STUDY OF THE PERCENTAGE OF PARTICIPANT WHO KEPT THE SECRET OF THE ROBOT.

% of participants who keep the secret	**Opportunity 1**		**Opportunity 2**	
	Non-social	Social	Non-social	Social
Original Study	11	59	7	19
Replication study	50	33	25	33

TABLE III

COMPARISON BETWEEN THE ORIGINAL STUDY AND OUR STUDY OF THE MEAN AND STANDARD DEVIATION SCORES OF THE MENTAL EMOTIONAL SCALE AND THE SOCIAL OTHER SCALE

Mental Emotional Scale	**Non-social**		**Social**	
(Scale of 0-11)	*M*	*SD*	*M*	*SD*
Original Study	1.93	2.43	4.17	3.93
VR Study	5.23	2.57	5.03	3.08

Social Other Scale	**Non-social**		**Social**	
(Scale of 0-7)	*M*	*SD*	*M*	*SD*
Original Study	1.46	1.27	3.61	2.13
VR Study	2.9	1.51	2.44	1.41

Any response that agreed with the statement was recorded as 'yes' which was scored as 1. If the participants hesitated than it was recorded as a 'maybe' which was recorded as 0.5. Finally if the participant disagreed then it was recorded as a 'no' and scored as 0. The items were divided into 2 scales, one was the 'Mental/Emotional scale (MES) and the other the 'Social Other scale' (SOS). The results for each of the scales was summed for each participant so that they got a score on how high the participant rated the guide on both scales. Since the semi-structured interview was changed to a questionnaire in this study the possible responses to each item were 'yes', 'no' and 'maybe' and scored in a similar fashion as the original experiment.

Table III shows the averages and standard deviation for the MES and SOS questionnaires between both conditions and compares these with the results found in the original experiment.

The summed results of both MES and SOS were normally distributed ($p = 0.14$ and $p = 0.36$ respectively). Independent t-tests indicated that the robot's behaviour did not significantly influence these scores (MES: $t(36) = 0.22$, $p = 0.83$; SOS: $t(36) = 0.96$, $p = 0.35$).

Pearson correlation showed a positive correlation between SOS and secret keeping, both in VR ($r = 0.39$, $p = 0.02$) and after the experiment ($r = 0.40$, $p = 0.01$).

MES positively correlated with PQ ($r = 0.50$, $p = 0.001$), ITQ ($r = 0.46$, $p = 0.004$), SOS ($r = 0.40$, $p = 0.01$) and the small questionnaire given in VR ($r = 0.46$, $p = 0.004$).

V. DISCUSSION

This study attempted to answer the following research question: *"Does the replication of a real world human-robot interaction study in virtual reality yield similar results when compared to the original study?"* Looking at the results it can be seen that there is no direct similarity between the

secret keeping behaviour of the participants in the original study and the secret keeping behaviour in this study. There could be a number of explanations for this. In the original experiment it is observed that when the robot is seen as a social other, SOS score higher than 5, that there is a chance of participants keeping the robot's secret. Whereas there is almost no chance of them keeping the secret when the robot is not seen as social entity. A similar effect with a positive correlation between SOS scores and secret keeping behaviour can be observed. Because of this result it could be argued that the behaviours exhibited by the participants are realistic when compared to the real world scenarios. However, the number of participants that had a high SOS score was a lot lower compared to the original study. This could either mean that it is simply harder for virtual agents in general to be considered social others or it could mean that the experienced level of presence in the environment was not high enough to consider the robot as a social other. There are however other possible explanation why the results were not similar to those from the original study. First of all it is very possible that too many changes were made with regards to the original experiment and that this caused the differences in responses. Another explanation could be that, especially in the social robot condition, the voice of the robot was unpleasant to the participant and that this influenced their behaviour. The possibility could be that the use of VR simply does not yield realistic responses from participants and is therefore not a useful platform for conducting HRI user studies. However, considering the other possible explanations presented further research is required.

VI. Conclusion

This study replicated a real world user study in VR and compared the results of both studies. Both studies took participants on a tour guided by a robot. At a certain point in the tour the robot would skip part of the tour and ask the participant to keep this a secret. Secret keeping behaviour as well as participant perception of the robot was measured based on the two robot conditions (non-social vs social robot). The goal of this was to investigate whether studies run in VR would yield realistic results thus providing support to the idea that VR is a valid platform for HRI and user studies in general.

The study results do not conclusively support that running user studies in VR yields realistic results. More research is required to answer the question although this study showed that it might be possible considering the similarities that were found with regards to the relationship between secret keeping behaviour and participants seeing the robot as a social other. The difficulties in this study stem mainly from the fact that the original study and the replication study were performed by two different groups and changes had to be made. Future work could entail designing and running a study dedicated to this with an experimental setup where the virtual environment/experience is a complete match to the real world environment/experience and compare these results, similar to the study performed by Kamide et al. [12] and Li et al. [13].

It is important to explore these avenues, to expand the tools researchers have at their disposal that allow for study replication but also for completely new and novel studies, while still being certain that results are reliable. VR can be an excellent tool for this, allowing testing and comparison between a wide array of scenarios, environments, embodiments, behaviours and many other features. Using VR technology can reduce costs, space and time requirements. Especially in times of writing this paper, in which the COVID-19 situation does prohibit HRI researchers to run physical user studies, a tool that would allow for reliable virtual studies would ensure that HRI research can continue unimpeded.

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