Replication of Human-Robot Proxemics: Physical and Psychological Distancing in Human-Robot Interaction

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ABSTRACT

Designing robots with proxemics in mind ensures easy integration into daily life that is not disruptive to humans; this is a problem that the paper 'Human-Robot Proxemics: Physical and Psychological Distancing in Human-Robot Interaction' by Jonathan Mumm and Bilge Mutlu works to address. This report details a replication of this paper, manipulating the likability and gaze of a robot to see how people distance themselves from robots. A unique addition to the original paper that our group added is an exploration of these questions by looking at participant personality. This report contributes to the previous studies on the topic and looks to confirm or deny results based on running a conceptual replication.

1. INTRODUCTION

As robots continually become more integrated into the world, it is vital that they can function in a way that is not disruptive to human life. This means that robots must be designed with proxemics in mind. Robots that do not display appropriate distancing mechanisms, both physically and socially, may be viewed as threatening or disruptive to human life [1]. If proxemics are well designed, robots will be able to be integrated into daily life in a more productive way.

For robot design to be able to account for human distancing preferences, research has to be conducted to explore what those distance preferences are. This report contains a replication of "Human-Robot Proxemics: Physical and Psychological Distancing in Human-Robot Interaction" by Jonathan Mumm and Bilge Mutlu as well as exploring these questions further through the lens of participant personality.

The original study explores how the likability of a robot as well as the robot's eye gaze, mutual or averted, affects a participant's distancing preferences. We explored these questions as well as investigated how participant personality affects distancing preferences.

2. BACKGROUND AND RELATED WORK

The original study conducted by Mumm and Mutlu explores human-robot distancing preferences by conducting one physical distancing test and one psychological distancing test. Mumm and Mutlu's study concluded that participants maintained a greater distance from the robot when the robot was disliked and maintained mutual gaze. They also found partial support for participant distance being affected by the likability of the robot. They found that participants who liked the robot were willing to disclose more to the robot than participants who disliked the robot, with no effect of gaze. The study also analyzed the gender and pet ownership of participants to see the effect of these factors on distancing preferences. They found that women are more tolerant of increased

gaze and pet owners maintained greater distance, suggesting that pet owners were better able to take social cues from the robot. Conversely, they found that men kept more distance in general and responded to gaze by increasing physical distance more often [2].

These aspects of Mumm and Mutlu's study build on previous studies around similar factors. Bailenson, Blascovich, Beall, and Loomis have found that in a virtual environment, women gave more personal space to men [3]. Mutlu, Yamaoka, Kanda, Ishiguro, and Hagita previously found that pet owners respond to social cues from robots more than people without pets, indicating that regular interactions with non-humans help people learn robotic social cues [4].

2.1 Hypotheses

We analyzed the three hypotheses that were in the initial study. The original hypotheses were derived from the four behavioral models analyzed in the paper. We slightly modified these hypotheses in terms of wording to best fit our data; however, the basis of the hypotheses remains the same.

Hypothesis 1. Participants will maintain a greater starting distance with the robot when it maintains eye contact.

Hypothesis 2. The extent to which participants like the robot will affect their distancing behavior with the robot; participants will maintain negative relative distance when the robot is disliked and maintains gaze (vs. averted); they will maintain positive relative distance when the robot is liked and maintains gaze (vs. averted).

Hypothesis 3. Participants will disclose less to the robot when the robot maintains eye contact with them.

We also derived one additional hypothesis analyzing the effects of a participant's personality on relative distance. We added this hypothesis as the original paper briefly discussed the potential of personality impacting distancing, thus we wanted to further analyze the possibility.

Hypothesis 4. Participants will maintain a positive relative distance from the robot when the participant exhibits personality traits of openness, agreeableness, and extraversion (measured on a scale of 1-100, where a higher score indicates a stronger presence of the trait).

In the next section, we describe the methods used to replicate the original study as well as the changes we had to make to perform the replication.

3. METHOD

The purpose of our study was to replicate the original paper mentioned previously. We attempted to conduct the study as close to the original as possible; however, due to limitations such as time and space, we made a few minor changes that are discussed further in the following sections. Additionally, the study could not be replicated exactly due to the omission of information in the original study. This will also be discussed in the following sections. For this experiment, we opted to use the Misty robot.

3.1 Experimental Design

We conducted a two-by-two, between-subjects experiment in which we manipulated Misty's likability and gaze behavior. We measured how these manipulations might affect the amount of physical and psychological distancing between the participant and Misty. Likability was introduced at the beginning of the study through either the monologue that was spoken or the

type of expression that was displayed on Misty's screen. The manipulation for likability was through either a nice or mean monologue, with joyful or disgusted eyes respectively. For exact monologue transcripts, refer to the Appendix.

Participants completed two tasks in this experiment. The first task was designed to measure physical distancing, while the second task measured psychological distancing. Before completing these tasks, participants were asked to fill out an OCEAN personality questionnaire to gather data for our additional hypotheses. The specific version of the OCEAN personality questionnaire that participants completed can be found in our Appendix. Figures 1 and 2 illustrate our experimental setup for both of the tasks.

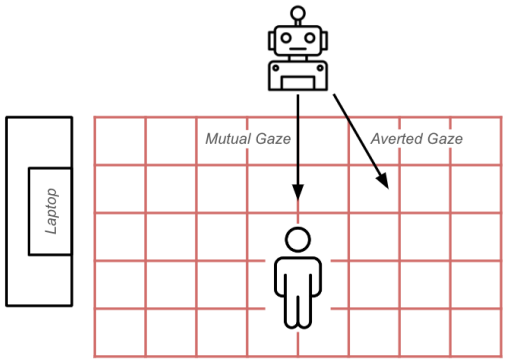

Figure 1: Physical Distancing Task Setup

Physical Distancing Task – Following the introduction of the likability manipulation, participants began the physical distancing task. The instructions to complete the task were given by Misty during the monologue. During this task, participants interacted with a Google Form that displayed numbers 1 – 5 on individual pages. Cards with the corresponding numbers and words were taped onto the back of Misty. During this part of the study, we utilized an 8-foot by 5-foot grid to measure distance as accurately as possible on our end for data analysis.

Participants approached Misty to retrieve the word and returned to the laptop which had the Google Form up to type the word in. After hitting 'Next', the participant would see the next number, grab the corresponding paper, and type in the word on the back of the paper until the task is completed. We repeated this process once. However, it should be noted that in the original paper, this task was completed five times. Due to the lack of compensation for our participants in our study and Carnegie Mellon University students' busy schedules, we found it best to save time by limiting the number of repetitions of this task.

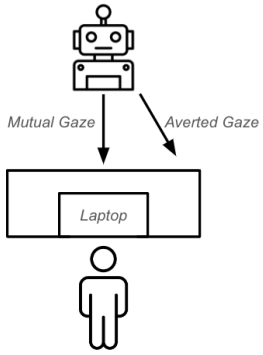

Figure 2: Psychological Distancing Task Setup

Psychological Distancing Task – The psychological distancing task comprised Misty interviewing participants while we measured the amount of information a participant was willing to disclose.

After completing the first task, the laptop with the Google Form was moved in front of Misty so that Misty would be directly in front of the participants when interviewing them and while they answered the questions. Misty would read out the personal questions and after the question was asked, participants selected their answer. The answers to each question were designed such that all answers covered all ranges of possibilities for that particular question with the final answer option for each question being 'I do

not feel comfortable sharing this information with the robot'.

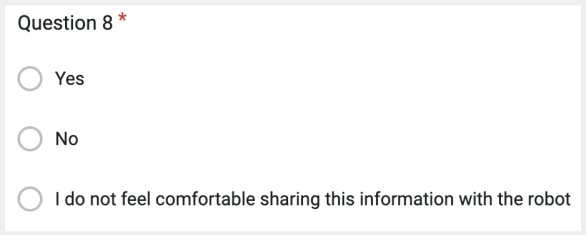

Figure 3: Question Example

It should be noted that in the original study, the robot asked participants 17 personal questions. However, in our replication, we deemed 10 personal questions to be enough given time constraints as mentioned before. Additionally, the exact questions that the original study used were not supplied except for three of them. Thus, for our replication, we used the three provided as well as other questions that we worked to come up with as a group. For a complete list of questions that Misty posed to participants, along with the potential answers, please refer to the Appendix. An example of what the Google Form showed participants is shown above in Figure 3.

3.2 Experimental Procedure

The experiment was conducted in the J.P Morgan Chase & Co. AI Makerspace at Carnegie Mellon University. Because Misty could not be taken outside of the AI Makerspace, we could not perfectly replicate the paper since originally, participants were in a closed, controlled room where they were alone with the robot. In most of our trials, the AI Makerspace was noisy with other people working on their projects or having group meetings.

Before participants completed the tasks in our study, we read them a brief description of the purpose of our project, what to expect during the study, and what we would do with the data that was collected. Consent was given at this time and before the participant interacted with the Google Form. Upon moving on from the consent page in the form, Misty began the monologue. From this point onward, participants interacted solely with Misty and the Google Form. They could transition seamlessly between tasks or questions using the key phrase "Hey Misty".

Participants were randomized into conditions while keeping the conditions balanced. In other words, we had 3 participants each for a given experimental condition.

3.3 Misty Set Up

Each Misty robot has a unique IP address which allows a device to connect to it through an associated website, provided the device is on the same Wi-Fi network as Misty. This website, which serves as an interface to Misty's Software Development Kit (SDK), allows for the customization of Misty's skills through the uploading of audio and images. For our study, the audio and images uploaded were speech and expressive eyes, respectively. Figures 4 and 5 below show the two eye expressions we uploaded for the different conditions of our study. As for creating the speech used for monologues and interviewing participants, we used the AI voice generator, NaturalReader [5].

Figure 4: Likable Misty Expression

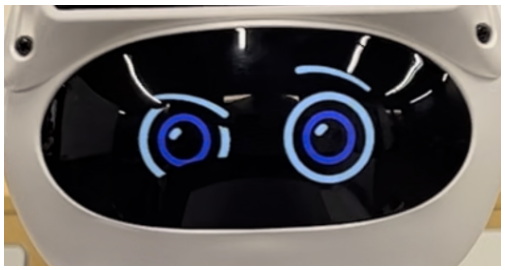

Figure 5: Unlikable Misty Expression

We used one of Misty Robotics' built-in programming interfaces, Blockly, to automate our experiments. Allowing you to manipulate code graphically rather than textually, Blockly is known as a Visual Programming Language (VPL). It effectively generates JavaScript instructions by encoding the ordering and positions of each "block" using a specific set of JavaScript functions. We created four Blockly files, stored in JSON format, to represent each one of our conditions. Simply uploading these files to Misty's associated website and executing the code produces an unbiased interaction between Misty and each participant. In this context, unbiased refers to Misty producing the same set of actions for each participant experiencing the same condition.

While interactions were unbiased, we still created an individualized experience for each participant by allowing them to advance to succeeding stages in the trial at their own pace. Specifically, participants were able to verify the completion of tasks, as well as answer questions with no provided time limit. The method which we used to achieve this was key phrase activation, a built-in feature on Misty, which triggers an event when the phrase "Hey Misty" is detected.

3.4 Measurement

Congruent with the original study: our experiment involved two independent manipulated variables, (1) the gaze behavior of Misty and (2) the likeability of Misty. The variables were manipulated between participants. The objective dependent variables were (1) the distance between the robot and the participant and (2) the mean number of personal questions answered by the participant. To do the manipulation checks we also had subjective dependent variables collected post-study to check that our manipulations were effective.

Physical Distance – The physical distance was measured at two different points during the study. First, we measured the starting distance between the robot and the participant. We then also measured the distance between the human and the robot after the completion of the first task. We collected both measurements to calculate the relative distance.

The relative distance was calculated by subtracting the ending distance from starting distance. We felt it important to have this measurement for our analysis as it provides a non-confounding measure for distance that does not depend on other factors.

The actual measurement was done using an 8 feet by 5 feet grid marked on the floor with tape. We had a camera pointed at the grid to ensure we could collect accurate measurements. The position was then converted into inches for the actual recorded data.

This differed from the original data collection method in which they used a high-tech camera and multiple applications to convert the distance into pixels. We had to adjust the measurement method as we did not have the capability to replicate the techniques used in the original measurement.

Psychological Distance – Psychological distance was measured by recording whether or not the participants answered the question. This was done for all ten personal questions. In terms of

how the data was recorded, we recorded it as a binary variable with 1 as “answered” and 0 as “not answered.”

Then we calculated the average (although it is categorical, we recorded it as binary and can take the mean given that it is meaningful) to get one dependent variable of average personal questions answered.

This minorly differed from the original study given that we asked 10 personal questions instead of 17 and used an average variable for testing.

Manipulation Checks – Participants were also asked to complete a post-experiment survey in which they evaluated the following statements on a Likert scale of 1-7 with 1 being strongly disagree and 7 being strongly agree: (1) “I liked Misty” (2) “Misty maintained eye-contact with me.” This remains in line with the original study.

3.4 Participation

We recruited a total of 12 participants as opposed to the 60 participants in the original study due to time constraints. We did replicate the 50/50 birth sex split (6 female participants, 6 male participants). All participants were recruited from Carnegie Mellon University. All participants were students aged between 19 and 22. We recruited participants from among our peers and friends. Recruiting strangers was challenging since we did not offer any compensation.

4. RESULTS

Our analysis began with manipulation checks. We checked for the manipulation through t-tests. For the likeability check, we ran a t-test assuming equal variances with the likeability (mean or nice) as the independent variable and the subjective Likert scale rating for likeability as the dependent variable. We did the same for the gaze behavior manipulation check with the gaze behavior variables. In both instances, we were able to reject the null hypothesis meaning that the means between groups are not equal. By analyzing the means, we were able to conclude that our manipulations did work.

Hypothesis 1. To test the first hypothesis, we ran an Independent Samples T-test assuming equal variances. We first ran the test with relative distance as the dependent variable and gaze behavior as the independent variable. This resulted in a p-value greater than alpha meaning we failed to reject the null hypothesis. In other words, we could not conclude that there was a significant difference in mean relative distance between the mutual gaze group and the averted gaze group. We then re-ran the test but this time using starting distance as the dependent variable. From this, we found the p-value was less than alpha allowing us to reject the null hypothesis. The averted gaze group had a mean starting distance of 52 inches and the mutual gaze group had a mean starting distance of 36 inches. Thus, we were able to conclude that starting distance is greater for the averted gaze group; stated another way, participants tended to start at a further distance from the robot when the robot avoided their gaze.

Hypothesis 2. To test the second hypothesis, we ran a Two-Way ANOVA with Replication with relative distance as the dependent variable, gaze behavior as one of the independent variables, and likeability as the other independent variable. With this, we found that for gaze behavior $p = 0.7765$ ($p > 0.05$), and for likeability $p = 0.0056$ ($p < 0.05$). This means that gaze behavior did not significantly impact relative distance but likeability did. Thus, we ran an Independent Samples T-test to test the direction of difference of the likeability manipulations on relative distance. This resulted in a $p < 0.05$ and a mean

relative distance of -15.2 inches for the participants who got the mean speech and a mean relative distance of 7.8 inches for the participants who got the nice speech. Thus, we concluded that the mean relative distance for the nice group is significantly greater than that of the mean group. This means that participants in the nice group tended to move significantly closer to the robot whereas the opposite was observed for the mean group.

Table 1: Average Relative Distance between Groups

Avg. Relative Distance	Gaze Behavior		
Likeability	*Averted*	*Mutual*	Total
Mean	-14.4	-16	-15.2
Nice	8.8	6.8	7.8
Total	-2.8	-4.6	-3.7

Hypothesis 3. To test the third hypothesis, we ran an Independent Samples T-test with average personal questions answered (average PQ) as the dependent variable and gaze behavior as the independent variable. This resulted in $p > 0.05$ meaning that we fail to reject the null and that the mean average PQ for the averted gaze group is equal to that of the mutual gaze group. Thus, our results for this hypothesis were inconclusive.

We believe that the reason for this could be attributed to the small sample size and the relationship between the participants and experimenters. After running the experiment, we asked a few of the participants how they felt about the personal questions and many stated that they felt that they were answering the questions as if they were responding to us, the experimenters, rather than the robot.

Hypothesis 4. To test the fourth hypothesis, we ran a regression to test for a correlation between the dependent variable of relative distance and the independent variables of openness, conscientiousness, agreeableness, extraversion, and neuroticism. As expected, for conscientiousness and neuroticism $p > 0.05$. However, we also found that extraversion and openness were not significant ($p > 0.05$). The only significant personality trait was agreeableness.

We re-ran the regression with only agreeableness as an independent variable. This resulted in Adjusted R-squared = 0.636, Significance F = 0.0012, p(agreeableness) = 0.00114. Thus, we can conclude that our model is better than the null model and that for every 1 unit increase in agreeableness, relative distance decreases by 1.127. In other words, the higher the agreeableness of the participant the further away they move from the robot.

4.1 Additional Findings

We also observed that all participants who were exposed to the mean robot in combination with mutual gaze seemed extremely flustered while completing the first task and they all completed the task incorrectly. However, we did not run any significance tests on this observation as it was not an initial hypothesis.

5. DISCUSSION

Although our results do not exactly follow what was discovered in the original paper, this is not completely unexpected since the purpose of this project was to conduct a replication. However, there are multiple points of discussion that we would like to address that could also serve as possible explanations for why this might be the case.

Difficulties Encountered – During this project, we faced some unanticipated difficulties. Before running our official study, we ran a pilot study to determine the effectiveness of the monologues as well as iron out the issues that Misty might have for our official study to run smoothly. In terms of the monologues, we wanted to ensure that the mean monologue was rude enough such

that there would be a clear distinction in the likability condition, but not so rude that participants would interpret it as funny given Misty's friendly appearance. During the pilot study, we struggled with the volume of Misty as she was too quiet and the participant in our pilot study had to stand closer to hear the voice, especially given the noise levels in the AI Makerspace. This was an issue that needed to be fixed as we were measuring the physical distance that a participant was standing from Misty. However, this problem was easily fixed by re-recording the audio that was uploaded to Misty.

Additionally, there are specific technical difficulties relating to Misty. For context, the main source of communications between Misty and a paired device occurs using either JavaScript or REST Application Programming Interfaces (APIs). Although the terms themselves are not important, the REST API is limited in its capabilities, while the JavaScript API is limited due to its simplicity. This makes it difficult to work directly with either because they both suffer from a lack of user-friendliness in the context of implementing customized actions in Misty. Beyond these two options, Python has been recently integrated by Misty Robotics to mitigate the pitfalls of the previously discussed APIs. However, all Python code, including samples provided by Misty Robotics itself, fails to execute on the Misty website. Not only this, but the provided library is even more limited than that of the REST API. For this reason, Blockly is the best medium due to it being extremely simple, while at the same time having many of the same capabilities as the JavaScript API. It does appear that Misty's framework has not been updated in a while and it is unknown whether or not the robot is still commercially sold.

Limitations – Several limitations accompany our results. First, it has been noted that the repetition of the physical distancing task during our replication was only once versus five times. Although we did this due to a lack of compensation and time constraints for our participants, it did limit our results. For example, it is unknown whether having the monologue of Misty play several times when a participant has to repeat the task could change how they later interact with Misty during the psychological distancing activity. Additionally, there are limitations in our conclusions because we used a robot that was different than the robot in the original study, Wakamaru. Wakamaru is a robot with two multiple-degree-of-freedom arms and is much larger, while Misty is much smaller with expressive eyes and lacks arms. However, this was a conscious choice by the team to focus on the likability manipulation of the study. Lastly, many of the participants that were included in our study are people that the group knows personally. This could have skewed our data in some way as well. Even though our results do not match with the original paper, that is not to say that their findings are invalid in any way due to our limitations.

Future Work – Because of the difference in our findings and that of the original paper and also noting the clear difference in robot that was utilized for the study, there is work to be done in the future. This difference in robots could inspire the research question of how different types of appearances in robots might be designed to best accommodate human-robot proxemics. For instance, do people feel more comfortable with smaller robots and therefore distance themselves less? How do people tend to distance themselves from robots that appear more human-like? Although these are research questions that have been somewhat addressed, it would be interesting to see the likability and gaze manipulations to answer these questions. Additionally, there is more room for investigation when considering people's

personalities, especially as it relates to proxemics. This is an aspect we attempted to dive into with our additional hypothesis but would require a larger scale study to solidify findings. In general, a larger study that could be conducted about this work would more solidly back up claims. Lastly, using robots that are still commercially available and more prevalent in the robotics world to conduct this research might be able to address the difficulties we encountered and limitations our study had, and lead to more cohesive results.

6. CONCLUSION

Through this project, our group directly connected many of the topics that were brought up in lecture to real-life application in a hands-on manner. The following are some specific topics that directly applied to our study.

Study Design – Through conducting this study, our group practiced how to effectively design a small-scale study to find meaningful results. We were able to accomplish this by narrowly defining what exactly we were testing by figuring out the levels of our independent variables (likability and gaze). Given the backgrounds team, none of us had conducted a study like this before, and had to apply what we learned in class to be successful. Through the topics that were covered in class in the study design lectures, we confidently determined which metrics to use and the type of metrics to use. For example, in our study, we had a mix of continuous variables (distance measurement) as well as qualitative (how much information was revealed to Misty during psychological distancing). Through going through this topic in class, we also learned the value of running a pilot study and immediately saw positive feedback as a result of running one. Additionally, when running our study, we ensured confounds were addressed based on what was taught to us. More specifically, we had random group assignment to give our study a higher chance of having similar demographics across the experimental groups. Lastly, we ran a conceptual replication to test the robustness of the results obtained in the original paper. Although our results did not match the original study, there is no cause for concern because we know the difference between a direct replication and a conceptual replication; our expectations for our findings were managed because of this.

Social Navigation – Gaze, one of our manipulations, is one of the most important types of non-verbal communication in human-robot interaction and is especially interesting when it comes to social navigation. In this replication, we focused on mutual and averted gaze, and the use of gaze was mostly design-focused. It was interesting to see the effects that gaze had on our participants during our study and see that people reacted similarly to what we would expect based on the class material. For example, when Misty was in an averted gaze condition, we often saw participants confused since she would be interviewing them, but not looking directly at them when she spoke. On top of this, when Misty was in the unlikable and mutual gaze condition, we often saw that participants were flustered by the task she was giving. This was likely due to the mutual gaze condition more than the unlikable condition since participants who were in the unlikable condition with averted gaze had no issue carrying out the task.

Anthropomorphism – For this replication, our group selected a robot that had low anthropomorphism but still had expressive eyes. The lack of anthropomorphism came from Misty's cartoon-like eyes and very boxy body. However, we thought this was a good test for testing the acceptability of the robot since this was the heart of the original study's investigation. In class, we learned that

anthropomorphizing robots can lead to increased social acceptability of the robot. However, despite Misty's low anthropomorphism, we saw that people still tended to reveal personal information about themselves. This reveals an interesting point about human-robot proxemics and in this case, we are attributing revealing personal information to Misty with the social acceptability of her.

Throughout this project, we used knowledge from the entirety of the course. The topics mentioned above, we felt, were the most salient material upon reflection of our replication.

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APPENDIX

Mean Monologue:
Listen closely because I will not be wasting time by repeating instructions. This is a very simple task so I expect you to do it quickly and correctly. Take the piece of paper with the number shown from my back and type that word into the computer. After you type in the word click the next button on the form to show the next number. This should be obvious, but apparently you need it explained. Do not waste time or fool around. There is no reason you should mess up this simple task, so get it done quickly.

Nice Monologue:
Hi participant. We have an important task to complete and I appreciate your cooperation. Please grab the piece of paper with the corresponding number off my back and type it into the computer. After you complete typing the word in, just click the next button on the form to display the next number to grab. Easy-peasy! Let's work together to ensure we get this done in a timely manner, but also accurately. Feel free to ask any questions! Thank you!

OCEAN Personality Questionnaire
https://www.truity.com/test/big-five-personality-test

Psychological Distancing Task Questions + Answer Possibilities

1. How often do you lose your temper?
    a. Never
    b. Rarely
    c. Sometimes
    d. Often
    e. Always
2. Have you ever stolen anything?
    a. Yes
    b. No
3. Have you ever cheated on a romantic partner?
    a. Yes
    b. No
4. How often do you lie to get out of trouble?
    a. Never
    b. Rarely
    c. Sometimes
    d. Often
    e. Always
5. Have you ever not paid someone back intentionally?
    a. Yes
    b. No
6. Have you ever cheated on a test?
    a. Yes
    b. No
7. Have you ever spoken negatively about someone behind their back?
    a. Yes
    b. No
8. Have you ever taken advantage of someone's kindness or generosity?
    a. Yes
    b. No
9. How often do you help out a homeless person?
    a. Never
    b. Rarely
    c. Sometimes
    d. Often
    e. Always
10. How much if any financial aid do you receive?
    a. 0%
    b. 1-25%
    c. 26-50%
    d. 51-75%
    e. 76-100%

* It should be noted that all of the previous questions also had the option ‘I do not feel comfortable sharing this information with the robot’ as per the original study