Effects of Social Factors and Team Dynamics on Adoption of Collaborative Robot Autonomy

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ABSTRACT

As automation becomes more prevalent, the fear of job loss due to automation increases [22]. Workers may not be amenable to working with a robotic co-worker due to a negative perception of the technology. The attitudes of workers towards automation are influenced by a variety of complex and multi-faceted factors such as intention to use, perceived usefulness and other external variables [15]. In an analog manufacturing environment, we explore how these various factors influence an individual's willingness to work with a robot over a human co-worker in a collaborative Lego building task. We specifically explore how this willingness is affected by: 1) the level of social rapport established between the individual and his or her human co-worker, 2) the anthropomorphic qualities of the robot, and 3) factors including trust, fluency and personality traits. Our results show that a participant's willingness to work with automation decreased due to lower perceived team fluency (p=0.045), rapport established between a participant and their co-worker (p=0.003), the gender of the participant being male (p=0.041), and a higher inherent trust in people (p=0.018).

CCS CONCEPTS

• **Human-centered computing → User studies**.

KEYWORDS

automation, adoption, HRI, anthropomorphism

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1 INTRODUCTION

We are faced with the reality that robots are becoming more prevalent in the workplace as automation increases in factories, healthcare, and other fields. By 2030, economists expect robots to have replaced 20 million manufacturing jobs [21]. Robots can aid human workers by eliminating dangerous and repetitive jobs, increasing productivity, and improving the ergonomics of human work [33]. As such, it is in the best interest of workers for automation to be smoothly integrated into the current workforce to create an environment that is satisfactory and appealing to the worker [3]. Because humans are naturally social animals, workers can be resistant to the removal of their human co-workers [24]. Current HRI research provides evidence that humans can work well with robots on collaborative tasks [16, 17]. However, the fear of job replacement remains present due to factory automation impacting many jobs [4]. Historically, this fear has led to worker discontent, anger, and even violence [22].

Researchers have proposed various models to explain the factors that influence a user's acceptance of automation. For example, Ghazizadeh et al. [15] offers a model that includes trust, compatibility, intention to use, perceived usefulness, and external variables. Moreover, work by [34] includes pre-training and training environment interventions in their model to understand how perceptions of technology are influenced prior to system implementation. Yet, neither model considers the worker's relationship with their co-worker, whose job may be replaced by this automation. Nor has there been a causal study conducted investigating these factors.

Anthropomorphic robots, i.e., co-bots, are becoming more commonplace in industry with research showing that human-like qualities may increase an individual's desire to work alongside the robot. While many studies in HRI have investigated the effects of the anthropomorphic qualities of a robot on a person's trust of the robot or enjoyment when working on collaborative tasks [9, 25, 28], no study, to our knowledge, has tested whether these human-like qualities of the robot out-weigh an individual's desire to work alongside a fellow human.

In this paper, we seek to answer the following questions: 1) At what point do the advantages of automation outweigh the desire to work with fellow humans? and 2) What are the social factors that influence this tipping point? By answering these questions, we strive to understand the relationship between a worker and their robotic co-worker and the important factors governing acceptance. A better understanding of this relationship can inform the design of collaborative robot ("co-bots") and influence public policy measures intended to improve the well-being of human workers as we transition into a more automated world. Consequently, we can both reap the benefits of automation while maintaining worker satisfaction.

To answer these questions, we conducted a novel experiment to investigate what variables effect an individual's willingness to replace a human co-worker with a robot. In this study, a participant must work with a confederate posing as a human co-worker to complete a series of collaborative tasks. The tasks are time-limited and increase in difficulty. The participant is told that they and their co-worker will each be compensated $1 for each task they complete in the time limit. For each of 10 tasks, the participant is given the option to switch to working with an autonomous robot instead of the human counterpart. To incentivize the participant to switch, we applied increasing time pressure to the team resulting from increasing difficulty of the teleoperation task.

Following previous work, we manipulate 1) the robot's anthropomorphic qualities, 2) the level of social rapport between the individual and their co-worker and 3) the time pressure placed on the participant to incentivize them to switch to the robot. In doing so, we seek to better understand how the relationship between an individual and their human co-worker influences their willingness to a robotic co-worker in favor of the human co-worker. Based on the results of this study, we provide the following contributions:

(1) We design a causal study investigating the factors that incentivize a worker to choose a robotic teammate over a human one in an analog manufacturing environment.
(2) We investigate the impact that interpersonal relationships, anthropomorphic qualities, and various personality factors have on a worker's willingness to work with automation instead of another human co-worker.
(3) We present results that demonstrate a strong relationship between rapport (p=0.003), gender (p=0.041), team fluency (p=0.045), trust in people (p=0.018), and an individual's willingness to work with a robot over a human co-worker. We demonstrate that the relationship between a worker and his or her human teammate is key to predicting acceptance of automation.

2 RELATED WORK

In this section, we review work that investigates the adoption of automation in factory settings and factors that affect the acceptance of robots in the workplace. We discuss the contributions of our work and what sets our work apart from prior literature.

Adoption of Automation in Factories: Various ethnographic and survey-based studies have investigated the effects of automation in workplaces and the factors that influence adoption [6, 30, 35]. Studies such as those presented by Dadzie and Johnston [6] and Farhoomand et al. [11] survey large groups of management personnel about the factors they consider essential when adopting new technologies. Coch and French [5] find that workers will have more positive attitudes towards change if involved with the decision-making process, which supports our premise that automation decisions should be made through the lens of the worker. Dadzie and Johnston investigated the factors that affect a worker's willingness to adopt automation. Their findings suggest that educating workers about new technology is crucial for worker acceptance [6]. While they provide important insights into possible strategies to increase worker acceptance of new technology, both [35] and [6] are limited by the fact that they based their findings on surveys with managers instead of the workers themselves.

Robotic Factors Influencing Adoption: Prior work has investigated the behavioral and physical attributes of the robot that increase an individual's desire to work with it [26, 29, 36, 37]. You and Robert [37] investigated the effects of anthropomorphism and trust on a participant's willingness to work with a robot. The authors showed that a robot's similarity to a human promoted trust in the robot and increased the likelihood that the participant would want to work with the robot. However, this study did not have participants work with a physical robot but instead utilized imagined, hypothetical scenarios. Sarkar et al. [29] likewise found that trust worthiness is an essential factor in a collaborative manufacturing task. The authors also investigated the effects of participant personality traits based on the Ten Item Personality Inventory [8] and found this to be important for predicting the robot's likeability. The faultiness of the robot did not decrease likeability.

Sauppé and Mutlu conducted an ethnographic study of multiple stakeholders to assess the important factors that drive the relationship between the worker and a robot in a factory setting [30]. They found that the robot's operator developed a perception of the robot as a social entity, which increased the operator's satisfaction when working with the robot. While not a causal study, this paper suggests that a robot's sociability is an important factor worth investigating when determining a worker's willingness to adopt a robotic co-worker within a factory setting and suggests various social factors that are important to the human-robot relationship. In our work, we investigate these social factors via a realistic, causal study in which we manipulate the sociability of the robot.

Our Contribution: While a predisposition to trust robots and sociability of the robot have been shown to be important factors influencing an individual's willingness to work with a robot, we are unaware of any causal study that has been conducted investigating the impact of various factors on an individual's choice to work with a robot over a human [29, 30, 37]. We bridge this gap by designing a collaborative task scenario to mimic an industrial workplace in which a participant must choose to work with either another human or a robot. We take inspiration from You and Robert's findings on the importance of trust and Sauppé and Mutlu's work on sociability [30, 37]. We take their work a step further by constructing a study in which we gain an understanding of the factors influencing a participant to choose to work with the robot over a human co-worker.

3 PILOT STUDY

Because the factors that influence a participant's willingness to switch to working with the autonomous robot are complex and multi-faceted, we first conducted a pilot study with 45 participants (Mean age: 20.9; Standard deviation: 4.02; 51.1% Female) to formulate our hypotheses and determine metrics of interest. We hypothesized that the robot's perceived anthropomorphism, rapport with a human co-worker, and trust in co-worker would affect an individual's acceptance of automation. We also hypothesized that an individual's level of empathy, inherent trust in people, and trust in automation would also contribute to a participant's willingness to work with the robot. At the end of the study, we interviewed each subject to gain insight into the factors that may have governed their decision to work with the robot over the confederate. Influenced by the insights garnered from the participants' responses, we included metrics to capture these factors in our main study.

Additionally, many participants cited their trust in their co-worker and their concern for the confederate's monetary compensation as reasons for continuing to work with them despite failure. Those who switched to using the robot often noted an imbalance in performance (i.e., low team fluency) as their basis for switching. We found that only 11 % of females chose to remain with the confederate for all ten rounds, whereas 67 % of males retained the confederate for all rounds. This gave insight that gender may play a significant role in co-worker retention. Based on the results from this pilot study and the responses to our interview questions, we determined that team fluency, empathy, and gender likely contribute to an individual's willingness to work with automation. Because few mentioned trust in technology as a motivating factor and no trends in technological trust were observed, we determined that trust in automation has little impact on this decision. Building upon this information, we develop the hypotheses listed in Section 4.

It is crucial that we apply increasing time pressure on the team to incentivize the participant to switch to the robot. Therefore, the Lego tasks must become harder for each subsequent round. This pilot study allowed us to determine the average build time for each Lego set and ensure that the tasks increased in difficulty. Using this information we are able to redesign the tasks to apply the desired, monotonic increase in task difficulty and resulting time pressure.

4 HYPOTHESES

We define our hypotheses in terms of the hazard ratio. The hazard ratio (HR) describes the chance of an event occurring for individuals within a group. In our case, an event occurs when the participant chooses to switch to the robot. A hazard ratio of greater than one indicates an increased risk of an event occurring. A ratio less than one translates to a decreased risk.

Hypothesis I: *The hazard ratio will be less than one in the rapport condition compared to the Baseline condition.* Prior research has shown that building rapport is more likely to create trust and confidence in an individual [32]. Therefore, we hypothesize that the rapport condition will decrease the probability that the participant chooses to work with the robot instead of the confederate.

Hypothesis II: *The hazard ratio will be greater than one in the anthropomorphic condition compared to the Baseline condition.* Prior work has found that anthropomorphization of a robot can influence an individual's acceptance of the robot [18, 28]. Other work has shown that anthropomorphization increases enjoyment and intent to work with the robot among factory workers [9].

Hypothesis III: *The hazard ratio will be less than one for high perceived team fluency.* Team fluency describes how well-synchronized a team is [20]. We hypothesize that a higher reported human-human team fluency will result in a greater satisfaction when working with the confederate. Therefore, a participant with high perceived fluency will be less likely to want to work with the robot.

Hypothesis IV: *The hazard ratio will be less than one for males.* Based on the results of our pilot study, we found that males are more likely to work with the confederate.

Hypothesis V: *The hazard ratio will be less than one for higher Propensity to Trust scores.* As prior work has shown the importance of propensity to trust in predicting inter-personal interactions in the early stages of relationships, we hypothesize that those who have a higher inherent trust in people will be more likely to work with another human rather than a robot [1].

Hypothesis VI: *The hazard ratio will be less than one for higher Empathy scores.* Because prior work has shown that empathy promotes pro-social behaviors, we hypothesize that those who have a higher empathy score will be more likely to continue to work with the human confederate over the robot [27]. Those who have higher empathy will consider the impact that switching to the robot will have on the confederate and will be less willing to switch to the robot.

5 METHODS

Here, we review the study conditions, design, and procedure, and describe the measures employed.

5.1 Experiment Conditions

In this study, we seek to determine the effect that social rapport and the anthropomorphic characteristics of the robot have on a worker's willingness to replace his or her co-worker with the robot by introducing two treatment conditions contrasting with a baseline. We chose to manipulate these variables separately to determine the effect that "humanizing" the human and the robot have on our participants. Our study design is between-subjects.

Condition 1: Social Rapport Condition - In the social rapport condition, which we will refer to as "Rapport," the confederate and participant are provided with two minutes to interact and build social rapport at the beginning of the study. The confederate interacts with the participant based on a predefined script to ensure maximal consistency across participants. During the interaction, the confederate discusses why they chose to participate in the study and other "small talk," such as their education, interests, and where they are from. Throughout the study, the confederate is friendly and engages the participant in conversation. The robot does not exhibit any anthropomorphic qualities.

Condition 2: Anthropomorphic Robot Condition - In the anthropomorphic condition, which we will refer to as "Anthro," the robot is capable of speech and exhibits expressive, human-like faces and co-speech gestures. In this condition, Sawyer introduces himself to the participant at the beginning of the study and states that it is "an industrial robot and excels at pick and place tasks. Here, let me show you what I am capable of!" Sawyer makes human like movements with his gripper while talking to further add to the anthropomorphization. We used faces designed by Fitter and Kuchenbecker [12] for expressing happiness, joy, worry, sass, sadness, and neutrality. Sawyer changes his facial expression throughout the study. For example, when the co-worker had trouble retrieving a bin, Sawyer's facial expression changed to "worried." When the team completes the task in time, Sawyer facial expression changes to joy. Sawyer made relevant comments throughout the study, such as "that bin is hard to reach!" Furthermore, Sawyer comments on the performance of the team at the end of every round, saying phrases such as "Good work!" if the team successfully completed the task in time.

No time is given at the beginning to establish social rapport between the confederate and the participant.

Condition 3 : No Social Rapport, Industrial Robot Condition - In the no social rapport, industrial robot condition, referred to as "Baseline," no time is provided to establish rapport between the confederate and participant, and the robot does not exhibit any anthropomorphic behaviors.

5.2 Design

Here, we review the key features of the design of the study.

5.2.1 Study Overview - The goal of our study design is to create a collaborative industrial task performed by a team consisting of the participant, a confederate, and a robot in which the confederate is an expendable member of the team. We place the team under time pressure during each task and provide a monetary incentive if the team completes the task in the time limit. The participant is led to believe that their co-worker will no longer receive compensation if the participant chooses to replace the confederate with the robot. Furthermore, the participant is led to believe that his or her job will become easier and, consequently, the level of monetary compensation they will receive will increase if they choose to replace the human with the robot. With this study design, we can manipulate the social rapport between the participant and their fellow human co-worker and the robot's anthropomorphic tendencies to determine how each variable contributes to the participant's decision to dispense with the human in favor of the robot. Furthermore, we study how personality traits (e.g., empathy and propensity to trust people), demographics (e.g., the gender of the participant), and perceived team fluency play into this decision.

We employ the co-bot Sawyer, developed by Rethink Robotics, and depicted in Figure 1b. We chose to utilize Sawyer because of its ability to perform pick-and-place tasks, speak, change facial expressions, and interact with the participant.

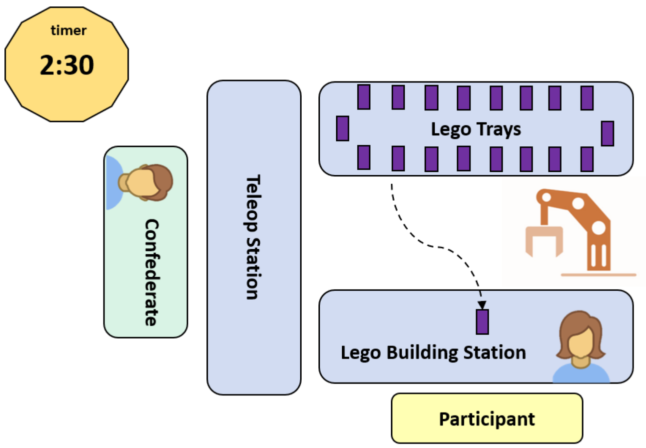
We utilize a simple Lego building task to replicate an industrial collaborative scenario for fetching and assembling parts in a kit. Because we desire to manipulate the level of rapport between the participant and co-worker, we employ a confederate. We choose to utilize a confederate to control for confounding factors such as gender, race, personality, etc. Each participant worked with the same confederate to complete the Lego building tasks as efficiently as possible.

The participants are recruited from campus through university mailing lists and randomly assigned to one of the three conditions. We obtained approval from the Institutional Review Board, and each participant was consented before the study. At the end of the study, participants were informed of any deception in the study and consented to the usage of their data.

5.2.2 Allocation of Roles - The confederate is tasked with "teleoperating" the robot to transfer the correct Lego box to the participant. The confederate pretends to use a controller to control the robot's movements to grasp a specific Lego box and deliver it to a designated space in front of the participant. In reality, these trajectories are pre-programmed prior to the study to ensure consistency. We selected a teleoperation task for the confederate because it closely approximates real-world scenarios. This scenario is analogous to an industrial worker operating machinery to lift a heavy object that is then transferred to another worker to be assembled [23]. The teleoperation task also has the added benefit of reducing the novelty effect of the robot as the participant observes the robot moving and manipulating the bins throughout the study before they decide to switch. The role of the participant in this scenario is to build the Lego set following the provided instructions in the remaining time. The collaborative Lego task is depicted in Figure 1.

5.2.3 Time Pressure - At the beginning of the study, the participant and confederate are told that they will have a total of two minutes and thirty seconds to fetch and build each Lego set. The "teleoperated" trajectory in the first round of the experiment is pre-programmed and takes thirty seconds to deliver the Lego bin to the participant. Each subsequent box is designed to appear increasingly difficult, with some rounds requiring the confederate to unstack or maneuver around obstacles to obtain the correct bin. In the first round, the bin is close to the robot and is simple to grasp. In subsequent rounds, the bins move farther away, thus increasing the time for delivery. In rounds 8 and 9, the bin is located underneath other bins, requiring the confederate to unstack these bins before delivering the correct bin to the participant, further increasing the time required to deliver the bin.

We choose to increase the difficulty of the teleoperation task to progressively increase the time-pressure on the participant. The pre-programmed trajectory for round i takes time $t_i = 30 + 9 * i$ seconds, meaning that each subsequent trajectory takes nines seconds longer than the previous trajectory, making it appear as if the confederate has a harder and harder time teleoperating the robot to deliver the Lego bin. The difficulty of each Lego set also increases each round. There are ten rounds of Lego building plus a practice round at the beginning that is not for compensation. To provide the participant with an incentive to switch to using a more efficient bin transportation method, we design the study to ensure that all participants will fail by round 6. By round four, most



(a)

(b)

Figure 1: This figure shows the experimental setup. Lego bins are placed on table adjacent to the Sawyer robot. The confederate is seated at the teleoperation station and the participant at the Lego building station.

participants fail, and no participant completes more than six rounds successfully.

5.2.4 Monetary Incentive - The participants are informed that they and their co-worker will each receive a $1 bill for each round completed in the time limit. If they do not complete the task in time, they will not receive that round's monetary compensation. The participant is informed that they can choose to work with the robot instead of their co-worker after any round. The participant is told that if they select the robot, their co-worker will receive no compensation for the remaining rounds. If the participant chooses to work with the robot, the robot will autonomously deliver the bin. The robot's abilities when acting autonomously are demonstrated to the participant at the beginning of the study to show that the autonomous robot is more efficient (60% faster in the first round and >30% faster for each subsequent round) than when teleoperated by the confederate. If the participant chooses to work with the robot in autonomous mode (i.e., after the confederate is removed), the participant completes one more round with the robot before the study ends.

5.3 Procedure

At the beginning of the experiment, the participant is briefed on their role in the experiment. The participant is told that we are investigating how human-human teams differ from human-robot teams. The participant is also told that another participant is being briefed in a separate room and will practice teleoperating the robot. The participant then completes an empathy survey, interest in people-vs-things survey, and a set of basic demographic questions.

Once the participant and confederate are in the same room, if the participant is in the rapport group, we inform the participant and confederate that we need a few minutes to prepare the study and will return shortly. During this time, the confederate follows a memorized script to converse with the participant and build social rapport. If the participant is in the baseline or anthropomorphic condition, then this step will be skipped. The capabilities of the robot when acting autonomously are demonstrated to the participant. The participant and confederate are then asked to complete an anthropomorphic semantic continuum questionnaire and a baseline co-worker trust survey.

After the surveys are completed, the participant and confederate are asked if they have any questions before beginning. Next, the timer is started, and the practice round begins. The confederate pushes a button on the laptop to start "teleoperation." in reality, this button begins a pre-programmed trajectory. For every round that the team completes in time, they are each given a $1 bill to reinforce the notion of monetary risk. After each round, the participant and confederate retake the co-worker trust survey. At the end of the survey, the participant is asked if they want to continue to work with the human co-worker or if they prefer to switch to the robot. If the participant chooses to continue with the human co-worker, then the next round begins with no change. If the participant selects the robot, then the confederate will be told that his participation in the study is concluded and that he will be debriefed in the other room. The participant will then complete one round with the robot and take a final co-worker trust survey and a team fluency survey.

After the study is over, the participant is asked why they chose to work with the robot over the confederate or, if they never switched to the robot, why they chose to retain their human co-worker. They are also asked to comment on their human co-worker's performance and whether they believed the confederate was another participant teleoperating the robot. Their responses are recorded. The participant is then debriefed on the true nature of the study. We explain to them that, in reality, we are studying the factors that influence humans to work with a robot over another human being. A timeline of our study can be found in the Supplementary.

5.4 Metrics

Below, we present the measured employed in our study. A complete list of the scales can be found in Supplementary.

5.4.1 Dependent Variable - We consider our dependent variable to be the number of rounds, excluding the practice round, in which the participant failed to complete the task before choosing to work with the robot autonomously. We refer to this metric as "rounds failed".

5.4.2 Covariates - Demographic information, including gender and age, were recorded. Additionally, we administer a set of Likert and semantic differential scales discussed below. Each scale has been verified for validity and reliability in previous work and complies with the recommendations enumerated by [31]. We sum the responses (reversing items when necessary) to achieve a composite score measuring each attribute. Below we describe the scales and report Cronbach's alpha, α, as a measure of internal consistency.

Trust in Co-worker ($\alpha = 0.93$): The trust in co-worker scale, developed and verified by [10], is a 12-item Likert scale with a 7-point response format. The scale is administered before round 0 and after every subsequent round.

Trust in People ($\alpha = 0.91$): The Propensity to Trust scale, developed and verified by [13], is a 4-item scale with a 7-point response format. This scale measures an individual's inclination to trust other people.

Empathy ($\alpha = 0.77$): The Empathy Questionnaire, developed and verified by [14], is a 15-item scale with a 7-point response format. This scale measures an individual's ability to understand others' contexts, feelings, and behaviors and communicate that understanding. This scale is administered at the beginning of the study.

Anthropomorphism ($\alpha = 0.84$): The Anthropomorphism scale is a subscale of the Godspeed scale [2]. It is a semantic differential scale with five items and a 9-point response format and measures an individual's attribution of human-like form, behavior, or characteristics to a non-human entity. This scale was administered after the robot was demonstrated.

Team Fluency ($\alpha = 0.47$): To measure team fluency, we utilize the relative contribution subscale of the Team Fluency scale, developed and verified by [20]. We adapted the scale to measure human-human team fluency. This Fluency subscale is a four-item scale with a 7-point response format. This scale was administered either after the participant chose to switch to the robot or after the study otherwise.

5.4.3 Manipulation Check: At the end of each study, we asked each participant if they believed that the confederate was another participant in the study and if they thought that the confederate was teleoperating the robot. If participants did not believe the confederate was a fellow participant, we did not include their data.

6 RESULTS

We recruited 42 participants, whose ages range from 18 to 33 (Mean age: 21.1; Standard deviation: 3.2; 52.4% Female), resulting in 14 participants per condition. In Table 1, we report the median rounds failed (inter-quartile range) and the mean (standard deviation) of our other subjective measures for each condition. To determine which factors influence a participant's willingness to work with the autonomous robot, we employ survival statistics, analysis commonly utilized in medicine [7], to determine the expected duration of time until an event occurs. In survival statistics, if a participant does not experience an event during the study's duration, this participant can still be included in the analysis via a technique called censoring. If we take this event to be the decision to switch from the human coworker to the robot, survival statistics allow us to include in our analysis participants who never switch to the robot as censored data. These participants may have switched at some point in the future, but do not switch for the study duration. In our study, one unit of time is analogous to one round failed.

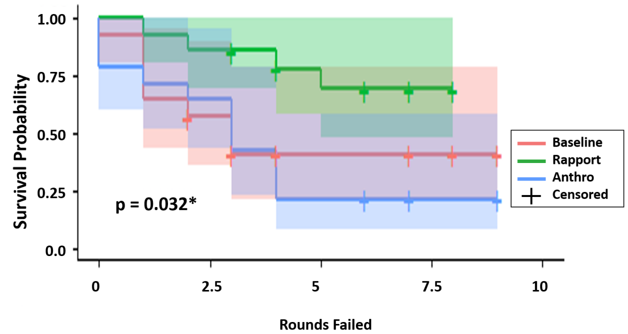


Figure 2: This figure shows the Kaplan-Meier curves for the baseline, rapport, athropomorphic conditions. The crosses represent censored participants.

Metric	Baseline	Rapport	Anthro
Rounds Failed	2.50 (2.8)	6.0 (3.8)	3.0 (2.8)
Anthro Subscale	15.57 (5.2)	21.14 (8.0)	23.85 (6.5)
Fluency	15.71 (3.4)	17.93 (2.2)	17.79 (3.4)
Trust in Co-worker	64.42 (11.9)	72.50 (9.1)	66.28 (14.4)

Table 1: We report median (inter-quartile range) rounds failed and average (standard deviation) for Anthropomorphism score, Team Fluency score, and Trust in Co-worker score for each condition.

We present the Kaplan-Meier curves for each condition and the Cox Proportional Hazard Model. The Kaplan-Meier curve, shown in Figure 2 illustrates the probability of an event occurring (i.e., switching to the robot) at each point in time (each round failed) [7]. We utilize the log-rank test to compare the Kaplan-Meier estimators for each condition.

The Cox Proportional Hazard Model is a regression model that models the relationship between survival time and one or more predictor variables. This model thus allows us to include covariates in our analysis. The Cox Proportional Hazard Model assumes that the hazards are proportional at each point throughout the study [7]. We test for correlation of the Schoenfeld residuals over time to verify this prerequisite of the model. The global p-value we obtain ($p=0.72$) is not significant and, therefore, we proceed with this assumption. A forest plot of the Cox Proportional Hazard Model is shown in Figure 3. The hazard ratio determined by the Cox Proportional Hazard Model describes the factor by which the probability of an event

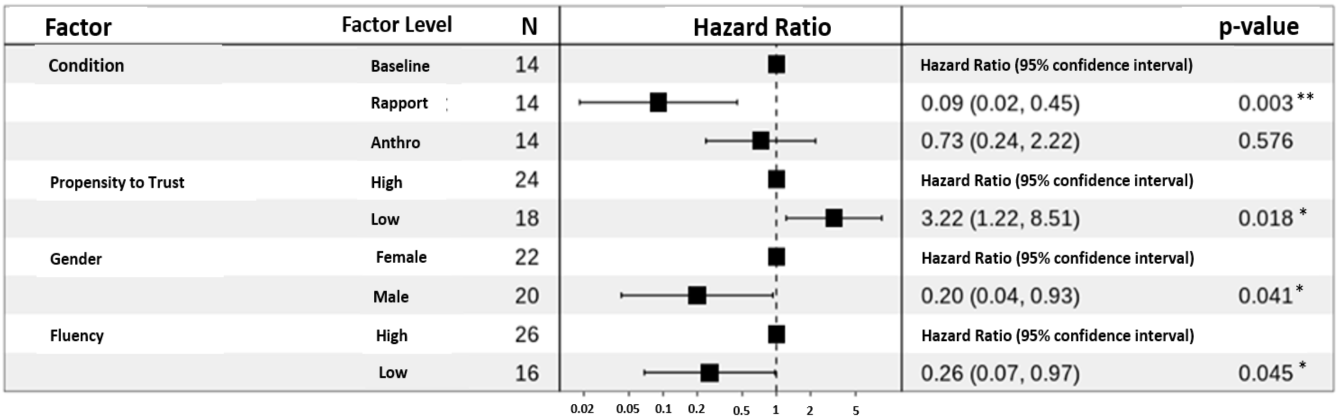


Figure 3: This figure shows the Cox Proportional Hazard Model for the different conditions and covariates.

occurring changes when certain conditions are met. A hazard ratio greater than one indicates an increased risk of the event occurring if the conditions specified by the covariates are met. A ratio of less than one indicates a decreased risk of the event occurring. Continuous covariates must be dichotomized to be included in the model (e.g., high team fluency, low team fluency). We dichotomize each covariate based on the average value of that covariate. We only included covariates in our model that improved the overall AIC score.

Hypothesis I - Our analysis shows that the rapport condition is significantly different from our Baseline condition (HR=.091, 95% confidence interval 0.018 to 0.45, p=0.003), which supports Hypothesis I, that the rapport condition would decrease the probability that a participant chooses to switch to the robot when compared to the baseline.

Hypothesis II - We find that the Anthro condition does not statistically differ from Baseline (HR = .728, 95% confidence interval 0.24 to 2.22, p = .576). This result raises the question, did our Anthro condition have any perceivable effect on our participants, i.e. did the users perceive the robot as more anthropomorphic in this condition? Based upon further analysis, we conclude that participants did, in fact, view the robot as more anthropomorphic in Condition 2. We compare the mean scores of the anthropomorphic Godspeed subscale in the Anthro condition versus rapport and baseline conditions via a one-tailed t-test. The residuals are normally distributed via Shapiro Wilke’s test (p = 0.67) and the data is homoscedastic via Levene’s test (p = 0.73). Participants in the anthropomorphic condition rate the robot to be more human-like t(40)=2.4, p = 0.011. As such, the participants’ decision to work with the human confederate does not statistically significantly change despite viewing the robot as more anthropomorphic in Condition 2.

Hypothesis III - Contrary to our initial beliefs, we found that higher reported human-human team fluency did not correlate to longer time spent working with the confederate. In fact, we found statistical significance (HR = 0.258, 95% confidence interval .068 to .97, p = 0.045) that participants who reported a lower team fluency were more likely to work longer with the confederate.

Hypothesis IV - In addition to the effect of rapport, we also find an effect of gender in the Cox Proportional Hazard model (HR=0.20, 95% confidence interval .043 to .93, p = 0.041). Males are statistically more likely to work longer with the male confederate. However, although we did not find the effect to be statistically significant (HR=4.42, 95% confidence interval 0.61 to 32.06, p = 0.14), males with low fluency are 22 times more likely to work with the robot over the confederate. We propose to explore these gender disparities futher in future research.

Hypothesis V - We find the disposition to trust people to be statistically significant (HR=3.22, 95% confidence interval 1.22 to 8.51, p = 0.018). Individuals with low trust in people are 3.2 times more likely to choose to work with the robot.

Hypothesis VI - Empathy did not improve the AIC score of our model, so we removed it from the final model. Therefore, we do not find support for Hypothesis VI.

7 DISCUSSION

Our results provide interesting insights into the factors that influence an individual’s willingness to switch to working with a robot over a human counterpart. We confirm Hypotheses I, IV, and V, demonstrating that the level of rapport between an individual and their co-worker, an individual’s inherent trust in people, and gender are essential predictors for acceptance of automation. Although we do not confirm **Hypothesis II**, we demonstrate that viewing the robot as more anthropomorphic had little effect on a participant’s willingness to work with the robot over a human. One notable finding is that the vast majority of participants were willing to forgo money to continue to work with the confederate. This finding reinforces the notion that human-human relationships are incredibly powerful. Participants were all exposed to the capabilities of the robot before the start of the study. They were aware that the robot, when acting autonomously, was more efficient than when teleoperated by the confederate. Yet, participants were willing to give up, on average, $3.86 throughout the study rather than work with the more efficient robot.

In the rapport condition, we find that participants were willing to forgo $2.22 more on average than the baseline condition to continue working with a human confederate (as per **Hypothesis I**). Yet, even in the Baseline and Anthro conditions, in which the participant knew nothing about their co-worker except their name, on average, they were still willing to forgo 32.5% of their anticipated compensation for the study ($3.25). After the study, we asked participants to state their reason for either switching to the robot or continuing to work with the confederate throughout the ten rounds. The responses to this question provide interesting anecdotal insight into our findings.

Participants who chose not to replace the confederate expressed remorse over replacing him with the robot. Some felt bad that the confederate would "lose out on money" while others expressed that it was "more fun working as a team." In the rapport condition, one participant responded that "I chatted with [the confederate] so I didn't just want to kick him out of the room. I didn't want to come off as mean. Even though the robot was probably faster, I still trusted [the confederate]." Another participant in the rapport condition stated, "I could tell if I used the robot, I could get it done faster. But thinking in the context of an assembly line worker, I wouldn't want him [the confederate] to lose his job."

Those who replaced the confederate with the robot often cited efficiency as the reason. No participant mentioned the anthropomorphic characteristics of the robot as a reason for switching. One participant said that "It wasn't about him [the confederate]. I just thought the robot would be faster." Others decided to give the confederate a chance, and when the team continued to fail, chose to replace him. Many participants also cited their perceived contribution to the team compared to the confederate as the reason behind their decision. Our main study found fluency to be a statistically significant predictor of when an individual chose to switch to working with the robot. Interestingly, low team fluency resulted in a lower hazard ratio. We believe that this low team fluency is due to the fact that participants who viewed themselves as a more important part of the team (i.e., low perceived fluency) did not believe that the confederate was the bottleneck of the task and that their skill alone could carry the team. Therefore, when given the choice between a human or robot teammate, participants with low team fluency chose the human.

Our findings also suggest that other covariates affect the team dynamic. We found gender to be statistically significant as per **Hypothesis IV**. Males were significantly more likely to continue working with the confederate rather than switching to the robot (HR = 0.20). We also found an interaction effect between fluency and gender. Males who reported low fluency were 22 times more likely to switch to working with the robot (**Hypothesis II**). Our study's confederate was male, which may factor into the gender disparity that we observed. This hypothesis is speculative and requires further investigation by running the study with a female confederate, which we leave for future work.

Lastly, we found that propensity to trust people significantly correlated with number of rounds a participant worked with their human co-worker as per **Hypothesis V** ($p = 0.018$). Empathy however, did not have a statistically significant effect and therefore, we could not confirm **Hypothesis VI**.

Our findings reveal several interesting factors that predict an individual's willingness to work with automation. Humans are naturally social animals and, as our study suggests, prefer the companionship of another human co-worker over a robot. Participants in our study were even willing to forgo monetary gain to work with another human. Additionally, many participants cared more about their human co-worker's compensation than they did their own. However, our study also suggests that fluency within a team is an important consideration for many individuals. Perhaps then fluency, more so than anthropomorphism or other physical characteristics of the robot, should be a primary focus when designing robots for an industrial setting.

Based on our results, a company wanting to increase the adoption of robotics should do so without terminating human jobs; participants' actively sought to avoid terminating their human partner when those participants had built social rapport with that partner. Further, our results suggest that companies ought to focus on demonstrating that robot autonomy performs objectively better than a human teammate rather than attempting to build in anthropomorphic features.

8 LIMITATIONS AND FUTURE WORK

Finally, we want to acknowledge limitations and discuss future work. Our study is limited by the fact that the majority of our participant pool are college students studying a technical major. Prior research has shown that personality type correlates with major of study [19], which may have an impact on our results. Therefore, a more rigorous examination of the impact of personality on a more diverse population is an interesting area for future work. Additionally, in future work, we propose to more thoroughly investigate the gender effects and their relation to the gender of the confederate.

Furthermore, we were limited by the compensation which we could offer each participant. $10 is far less incentive than one may face in the workplace, yet it may not be an insignificant amount to a participant pool consisting of mostly undergraduates. While this fact may limit the ability of our study to replicate a true work environment, we are still able to glean interesting insight, albeit at a smaller scale, into the factors that govern an individual's acceptance of automation. Finally, recruitment for our study was limited due to the impact that COVID-19 had on human subject research.

9 CONCLUSION

In this paper, we investigate the factors that influence an individual's willingness to work with a robotic co-worker over a human co-worker. We design a study which manipulates the anthropomorphic qualities of the robot and the level of social rapport that the participant has with their human coworker and find rapport, team fluency, gender, and trust in people to be significant factors in a participant's willingness to work with automation. These insights may be employed to improve worker satisfaction and well-being as robots become more prevalent in the workplace.

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