Human Acceptance of the Cleaning Robot in Grocery Environments During the COVID-19 Pandemic

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Cleaning work is a labor-intensive job that frequently exposes workers to substantial occupational hazards. Unfortunately, the outbreak of coronavirus disease 2019 (COVID-19) has increased the pressure on janitors and cleaners to meet the rising need for a safe and hygienic environment, particularly in grocery stores, where the majority of people get their daily necessities. To reduce the occupational hazards and fulfill the new challenges of COVID-19, autonomous cleaning robots, have been designed to complement human workers. However, a lack of understanding of the new generation of cleaning tools' acceptance may raise safety concerns when they're deployed. Therefore, a video-based survey was developed and distributed to 32 participants, aiming to assess human acceptance of the cleaning robot in grocery environments during the COVID-19 pandemic. Moreover, the effects of four factors (gender, work experience, knowledge, and pet) that may influence human acceptance of the cleaning robot were also examined. In general, our findings revealed a non-negative human acceptance of the cleaning robot, which is a positive sign of deploying cleaning robots in grocery stores to reduce the workload of employees and decrease COIVID-related anxiety and safety concerns of customers. Furthermore, prior knowledge of robotics was observed to have a significant effect on participants' acceptance of the cleaning robot ($p = 0.039$).

INTRODUCTION

Cleaning is a generic and necessary job in a variety of business sectors and workplaces. According to the Bureau of Labor Statistics, as of May 2020, there were nearly two million people employed as janitors and cleaners in the US, and the growing speed of the industry was estimated to be as fast as the average for all occupations (Bureau of Labor Statistics, 2021). Given its labor-intensive nature, cleaning job exposes workers to significant occupational hazards, including both physical and mental work-related injuries (Schwartz et al., 2019). While typical cleaning tasks may have relatively low force requirements, they are usually repetitive, demand awkward postures, and have a strict time limit, making the job have one of the highest workplace incident rates (Bureau of Labor Statistics, 2016).

The outbreak of COVID-19 has raised the expectation for a safe and hygienic environment, especially in grocery stores, where the majority of people get their daily necessities. As a result, janitors and cleaners have been given more responsibilities in order to ensure the safety of customers and employees, which has increased both their workload and likelihood of COVID exposure (Sharma et al., 2022).

To prevent these occupational hazards and fulfill the new challenges of COVID-19, a new generation of cleaning tools, autonomous cleaning robots, have been introduced to complement human workers. For example, autonomous cleaning robots could be designed and implemented to allow businesses to redeploy their cleaning crews, with repetitive and mundane tasks shifted to robots and more value-added and customer-facing tasks (e.g., environmental perception, delicate manipulation, and social communication) retained by human workers (the Retail Analytics Council, 2020). Unlike robot vacuum cleaners, which have been in use within domestic settings for more than a decade (Asafa et al., 2018), the introduction of commercial-grade cleaning robots (e.g., autonomous floor scrubber) into the retail environment may raise new safety concerns due to their larger size and stronger mechanics. The existence of such robots may frighten both employees and consumers who have never been exposed to robots before. Therefore, to efficiently design the autonomous cleaning robot that can co-exist or even interact with surrounding humans in grocery stores, it is necessary to first understand human acceptance of the cleaning robot.

According to A Roadmap for US Robotics (Christensen et al., 2021), robotics applications have been widely used in a variety of fields, including manufacturing, space exploration, and healthcare to name a few. However, in the majority of these applications, robots only engage with people via separate physical contact (i.e., the human and the robot are not co-located) or social interaction (e.g., entertainment, education, and emotional support). The lack of proximate physical interaction, such as that which occurs between a person and a cleaning robot in a grocery store, makes the human acceptance of the robot in this context poorly understood. This is important as a positive acceptance of robots can result in tolerance of and even interest in the robot, a negative acceptance may lead to discomfort or even anxiety when robots are present in close proximity (Nomura et al., 2006).

The growing demand for cleaning robots, coupled with the safety concern, makes the evaluation of its implementation emergent and crucial. To this end, the primary aim of the current study was to assess human acceptance of the cleaning robot in grocery stores during the COVID-19 pandemic. In addition, factors that may influence human acceptance of the cleaning robot were also investigated. Results from the preliminary study could contribute to a better understanding of people's acceptance of the cleaning robot in grocery stores.

METHODS

Participants

A video-based online survey developed using Qualtrics survey software (Qualtrics, Seattle, WA) was utilized to obtain the data. Thirty-three participants were recruited from the university student population to take part in this preliminary study. Following data collection, survey responses were manually filtered, with 32 being approved and one being rejected due to the extremely short duration. Among the 32 participants, 20 of them were males and 12 of them were females. Their ages ranged from 21 to 34, with the mean (SD) age of 29.75 (3.89). The study was approved by the University of Florida Institutional Review Board (IRB202100165).

Materials and Apparatus

To minimize face-to-face contact during the pandemic, participants were given the link to the online survey that included video materials. Each video clip was made up of two parts: a real-world recording and a 2D simulation animation (Figure 1a & 1b). The real-world recording was filmed in a high-fidelity grocery environment, with the green-shirted customer acted by a researcher who was searching and picking an item off the shelf, while the other agent, either a cleaning robot (Figure 1a) or a customer in blue pushing the cart (Figure 1b), passed the green-shirted customer in order to travel to the target position and accomplish a certain task (i.e., wiping up spills on the floor for the cleaning robot and picking the item at the target location for the customer in blue). The 2D simulation animation was generated using MATLAB R2019B (MathWorks, Inc., Natick, MA), where the black blocks represented the shelves, the green block represented the green-shirted customer, and the blue block represented the cleaning robot or the customer in blue. In addition, the moving speed of the blue agent in the animation was adjusted to match the cleaning robot or the customer in blue in the corresponding real-world recording.

There was a total of three video clips in the survey, with the duration between 10 to 20 seconds. In each of the videos, the green-shirted customer was either passed by 1) a cleaning robot, or 2) a customer in blue wearing a mask (KN95), or 3) a customer in blue without a mask.

The cleaning robot in the video was simulated using the Fetch Freight Base (Fetch Robotics, Inc., San Jose, CA), a standard robotics platform for research (Wise et al., 2016; Chen et al., 2020; Chen et al., 2022). Modifications to the Freight Base were done to make the entire system roughly 1600 mm tall to better mimic the dimensions of the commercial-grade cleaning robot (e.g., Tennant T380AMR). During the video recording, the researcher tele-operated the robot at about 0.4 m/s, which is roughly the same as the moving speed of the customer in blue pushing a shopping cart.

Procedure

In order to complete the survey, the participant had to go through four sections: 1) the informed consent, 2) a demographic questionnaire, 3) a survey of background and experience questions, and 4) three videos followed by video-related questions. After consenting to take part in the study, participants were first asked to complete a demographic questionnaire including their age and gender identifications. Next, three yes–no questions on background and experience were given to the participants. Each of the questions represents a factor that may affect participants' acceptance of the cleaning robot. The questions are listed as below:

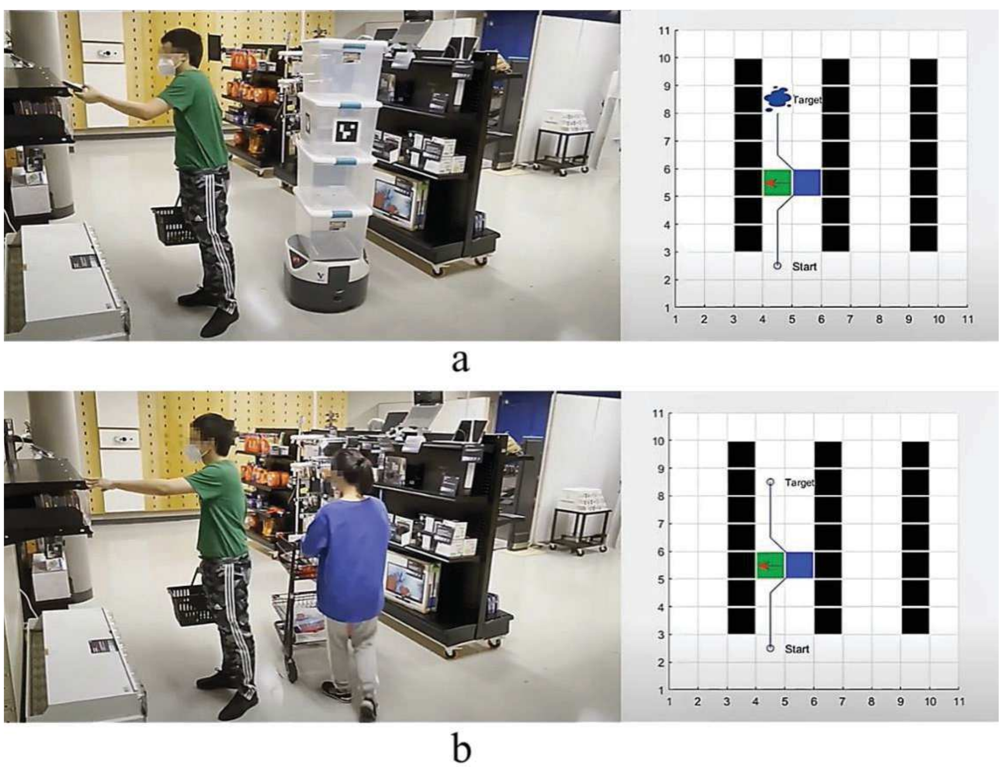

Figure 1. a) A screenshot of the video clip in which the cleaning robot passed the green-shirted consumer; b) A screenshot of the video clip in which the green-shirted customer was passed by another customer pushing a cart.

1. Work experience - *Have you ever used/worked alongside robots in your daily life?*
2. Knowledge - *Do you have any experience with robotic knowledge? (e.g., robot navigation, obstacle avoidance)*
3. Pet - *Have you ever owned a pet?*

These factors were chosen based on our previous research effort (Chen et al., 2021; Smith et al, 2021) and findings from other human-robot interaction (HRI) studies (Strawderman et al, 2017). Subsequently, three videos were given to the participants in a random order. Each of the videos could be played as many times as the participants saw fit. While watching the videos, participants were asked to imagine themselves as the green-shirted customer who was searching and picking an item from the shelf. Each video was followed by a question that asked them to rate their level of comfort in terms of their physical distancing from the other agent (referred hereafter as "spatial comfort") at the time the other agent (could be either the cleaning robot or the customer in blue pushing a cart) passed them on a Likert scale ranging from very uncomfortable (i.e., 0) to very comfortable (i.e., 10). Spatial comfort was the only dependent variable in this preliminary study. As shown in Figure 1, the environment layout was controlled so that the cleaning robot or the customer in blue had to pass right behind the green-shirted customer. The distance between them at the time was less than one meter. According to Proxemics Theory (Hall, 1966), when personal space is invaded, most people experience discomfort, anger, or anxiety. Permitting someone to enter personal space is an indicator of perception of their relationship. Therefore, spatial comfort was used to access human acceptance of the other agent as previous HRI studies did (Joosse et al, 2013; Mumm & Mutlu, 2011).

Statistical Analysis

Kruskal-Wallis H Test, a non-parametric method used on ordinal data, was performed on participants' subjective rating of spatial comfort. Mann-Whitney U Test was then adopted to test the difference between every pair of the three conditions. Furthermore, in order to determine if the factors could influence human acceptance of the cleaning robot, Mann-Whitney U Test was conducted on participants' subjective rating of the spatial comfort. All analyses were conducted using SPSS v26 (IBM Corporation, Armonk, NY) with statistical significance achieved when $p < 0.05$.

RESULTS

Acceptance of the Cleaning Robot

Table 1 summarizes means and standard deviations (SD) of participants' subjective ratings on their spatial comfort while the other agent (i.e., Robot, Human without a mask, or human wearing a mask) passed by. Results from Kruskal-Wallis H Test revealed a significant effect of the agent type on participants' spatial comfort (H = 10.719, $p = 0.005$). As shown in Figure 2, follow-up Mann-Whitney U Test revealed that compared with the human customer without a mask, participants' spatial comfort was significantly higher when passed by a cleaning robot (U = 311.5, $p = 0.007$) or a human wearing a mask (U = 294.5, $p = 0.003$). P-values of both pairs were smaller than the Bonferroni correction adjusted significance level 0.050/3 = 0.017. While no significant difference in participants' spatial comfort was observed between robot cand human wearing a mask conditions (U = 500.5, $p = 0.876$).

Table 1. Means and standard deviations (SD) of participants' ratings on their spatial comfort.

Agent Type	Mean	SD
Robot	6.75	2.19
Human without a mask	4.50	3.40
Human wearing a mask	6.91	1.92

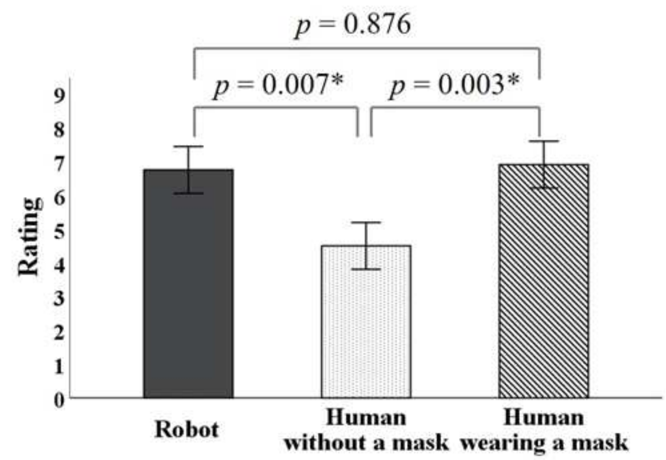

Figure 2. Mean and 95% confidence level of participants' subjective rating of the spatial comfort and Mann-Whitney U Test results.

Factors Affect Human Acceptance of the Cleaning Robot

In order to test which factors could influence human acceptance of the cleaning robot, the effects of gender plus the three factors adopted from previous literature on participants' spatial comfort when passed by the cleaning robot were analyzed using Mann-Whitney U Test. As shown in Table 2, participants' prior knowledge of robotics (e.g., robot navigation and obstacle avoidance) was observed to have a significant effect on their spatial comfort when the personal space was invaded by the cleaning robot. More specifically, participants who had prior knowledge (n = 12) rated significantly lower than those who did not (n = 20), with U = 67.5, $p = 0.039$. Non-significant effects were found in gender (U = 112.5, $p = 0.768$), work experience (U = 85.0, $p = 0.908$), or pet (U = 58.0, $p = 0.329$).

Table 2. Summary of statistical analysis results of factors' influence on subjective rating of spatial comfort when passed by the cleaning robot.

Variable		Percent response	Sample size	Mean (SD) of the rating	p-value
Gender	**Male**	62.5 %	20	6.85 (2.25)	0.768
	Female	37.5 %	12	6.58 (2.15)	
Work Experience	**Yes**	21.9 %	7	6.86 (1.95)	0.908
	No	78.1 %	25	6.72 (2.28)	
Knowledge	**Yes**	37.5 %	12	5.75 (1.96)	**0.039***
	No	62.5 %	20	7.35 (2.13)	
Pet	**Yes**	81.3 %	26	6.92 (2.13)	0.329
	No	18.7 %	6	6.00 (2.45)	

* $p < 0.050$

DISCUSSION

The outbreak of COVID-19 has raised people's expectations for safe and hygienic interactions in their daily lives. As shown in Table 1 and Figure 2, when a human customer entered their personal space, participants felt significantly more comfortable when the other customer was wearing a mask over the one who wasn't ($p = 0.003$), indicating public now accepts that masks are effective at reducing transmission of COVID-19 (Centers for Disease Control and Prevention, 2022). On the other hand, compared to the condition where their personal space was invaded by a human without a mask, participants spatial comfort was significantly higher when a cleaning robot went by ($p = 0.007$). According to the result, it is fair to infer that cleaning robots were not regarded to be a source of COVID-19 virus transmission by the participants. Furthermore, event though the subjective rating of the cleaning robot was comparably lower than a human wearing a mask, Mann-Whitney U Test revealed a non-significant difference between the two conditions ($p = 0.876$), meaning statistically speaking, the effect of cleaning robots on participants' spatial comfort is comparable to that of a human wearing a mask. In summary, based on Proxemics Theory (Hall, 1966) and previous HRI studies (Joosse et al, 2013; Mumm & Mutlu, 2011), in which spatial comfort was used to access human acceptance of the robot, our findings revealed a non-negative human acceptance of the cleaning robot, which is a positive signal supporting the deployment of cleaning robots in grocery stores to reduce the workload of employees and decrease COIVID-related anxiety and safety concerns of customers.

In terms of the factors that affect human acceptance of the cleaning robot, the effects of gender, as well as three other factors adopted from previous literature (Chen et al., 2021; Smith et al, 2021; Strawderman et al, 2017), were tested in this preliminary study. As shown in Table 2, only prior knowledge of robotics (e.g., robot navigation and obstacle avoidance) was observed to have a significant effect on participants' spatial comfort ($p = 0.039$). More specifically, when their personal space was invaded by the same cleaning robot, the comfort level of participants who had prior knowledge of robotic (mean of the rating = 5.75) was significantly lower than those who did not (mean of the rating = 7.35). The result is in line with our previous finding (Chen et al., 2021), i.e., people who are aware of recent advancements in robotics technology tend to have a higher expectation of robot's behavior, such as taking a detour to respect personal space when encountered with a human agent. This explains why participants who had prior knowledge of robotics had a low spatial comfort when the cleaning robot invaded their personal space (Figure 1a). Consistent with Tay et al. (2014), no gender effect was found on human acceptance of the robot ($p = 0.039$). However, the non-significant effects of work experience and pet were contradictory to our original hypothesis. Although participants who had prior experience working alongside robots rated comparably higher (mean of the rating = 6.86) than those who did not (mean of the rating = 6.72), Mann-Whitney U Test revealed a non-significant difference between the two groups ($p = 0.908$). We argue that the non-significant effect of work experience might be due to two reasons. First, the unbalanced sample size, especially the small number of participants with prior experience working alongside robots (n=7), may reduce the statistical power. Second, in the question on participants' working experience with robots, we didn't specify the type of robots, which might be anything from a robot manipulator to a flying drone. As a result, their work experience may or may not contribute to a positive acceptance of the cleaning robot (i.e., mobile robot). The non-significant impact of the pet ($p = 0.329$), similar to the work experience, may be obscured by the imbalance and small sample size of individuals without a pet (n=6). In addition, the term "pet" may be overly broad. "Dog" or "cat" may be better world choices because they are more comparable to the mobile robot than other pets like fish and birds.

Several limitations have to be mentioned in this preliminary study. Due to the COVID effect, the data collection was conducted through a video-based online survey. The experiment severs as a simulation of what participants may experience in the real-world. Even if real-world recordings and 2D simulation animations were included to enhance engagement, participants still needed to use their imagination. As a future step, inviting participants to the lab with a high-fidelity grocery store environment and allowing them to physically interact with the cleaning robot might improve the results' generalizability even further. Sample size is another limitation of the study. Although a total of 32 participants were recruited, only a limited number of them had prior experience working with robots (n=7) or had never owned a pet (n=6). Besides, because all the participants were college-aged students, it was unable to investigate the influence of age on robot acceptance. In order to ensure a larger and more representative sample, distributing surveys using online platforms, such as Amazon Mechanical Turk, may be an optimal solution.

The preliminary study serves as our initial step towards a better understanding of social robots, our future plans include expanding the application area to healthcare, where a safe and hygienic environment is always a necessity, even after the COVID pandemic. Furthermore, a comparison of the robot's appearance, such as humanoid vs. nonhumanoid, might also be interesting to learn about.

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