Human Security Robot Interaction and Anthropomorphism

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Abstract

The rapid growth in the use of security robots makes it critical to understand human interaction with them. This study investigated the impacts of the anthropomorphic nature of robot types and interaction scenarios on human-security robot interaction through a 3×2 between-subjects experiment with 60 participants. Participants were randomly assigned to interact with one of three security robots (Knightscope, RAMSEE, or Pepper) in either an indoor hallway or an outdoor parking lot scenario. Results indicate that there were significant differences between the Pepper robot and the Knightscope robot. The human-like robot Pepper was rated higher with regard to anthropomorphism, ability, integrity, and participants' desire to use than the mechanical-type robot Knightscope. However, no such significant differences were found with the character-like robot RAMSEE. Contrary to the author's hypothesis, the interaction scenario did not influence participants' acceptance or perceptions of the robots. These findings offer valuable insights for the future design and deployment of security robots.

CCS Concepts: • **Computer systems organization** → Robotics; • **Human-centered computing** → Human-computer interaction (HCI).

Keywords: Human-robot interaction, Security robots, Anthropomorphism, Human-robot acceptance.

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1 INTRODUCTION

Security robots are increasingly employed across various sectors, including public law enforcement and private security agencies, to safeguard individuals and property. In this paper, I define security robots as robots specifically designed to protect humans and properties by deterring illicit activities through security tasks such as monitoring, notifying security agents of emergencies, responding appropriately to incidents, and maintaining order within a designated area.

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Security robots provide a distinct solution to contemporary security challenges. For instance, they can effectively perform repetitive and monotonous tasks, such as continuous patrolling and surveillance [2, 37, 44]. Additionally, they offer a cost-effective approach to security assignments involving potential physical danger, thereby reducing the need for human personnel to be exposed to hazardous situations [2, 48]. Moreover, security robots can serve as interactive service platforms, engaging with individuals and providing supplementary information about the area they are protecting [31, 49, 50].

Current security robots exhibit a wide range of morphologies with varying degrees of anthropomorphism and are utilized in diverse application scenarios, including indoor and outdoor environments [24]. For instance, robots like RoboGuard [14] and Knightscope [24] lack human-like morphological features, while others such as RAMSEE [1] and Captain C [53] possess some human-like characteristics. Additionally, there are humanoid security robots like RobotMan [49] and NCCU Security Warrior [31].

Although anthropomorphism has been shown to promote the acceptance of robots [10, 45, 54], it is not clear whether similar effects will carry over to the acceptance of security robots. More specifically, research has shown that the impact of anthropomorphism on the acceptance of robots varies greatly based on the robot's primary purpose and interaction context [16, 26, 41, 42]. Consequently, determining the most appropriate anthropomorphic morphological attributes for security robots to effectively and engagingly assist the public remains a challenge. Overall, it is imperative to investigate the relationship between these factors and people's perceptions and acceptance of security robots before designing and deploying them for public use.

In this paper, I present the quantitative results of a study aimed at understanding how the anthropomorphic nature of security robots and commonly used interaction scenarios affect people's perception and acceptance of these robots. I conducted a between-subjects experiment employing a 3 (robot type: human-like robot, character-like robot, mechanical robot) $\times$ 2 (scenario: indoor hallway, outdoor parking lot) design. The findings offer insights into which security robot designs are advantageous for gaining human trust and trustworthiness, shaping perceptions, and increasing people's desire to use these robots. Additionally, this study explored whether these effects are influenced by specific interaction scenarios.

2 BACKGROUND

2.1 Anthropomorphism and Security Robot

Robot anthropomorphism can be defined as "the representation of robots as humans and/or to attribute human like qualities to robots" [39, P.247]. A common approach to humanizing robots involves manipulating their overall physical appearance [6, 22, 39]. Previous studies have demonstrated that anthropomorphic design generally has a positive effect on human-related outcomes [41], particularly in social application domains [7, 12, 15]. For example, Barco et al. [3] manipulated three types of robots (anthropomorphic, zoomorphic, and caricatured) and found that people perceived higher anthropomorphism and psychological closeness toward the anthropomorphic robot compared to the zoomorphic robot. Zanatto et al. [55] used robots NAO and Baxter to manip- ulate human-likeness in robot appearance and discovered significant effects on robot perceptions (such as likeability, perceived safety, perceived intelligence) and acceptance (trust and compliance). Natarajan and Gombolay [36] also found that participants' perceptions of anthropomorphism had a significant positive relationship with trust.

Despite the potential importance of anthropomorphism, we know very little regarding its influence on interactions with security robots. For example, based on my review, only one study, Li et al. [27], looked at the interaction between a robot's appearance and its security task. Researchers designed three types of robot appearances (anthropomorphic, zoomorphic, and machine-like) to perform various tasks, including security guard, tour guide, teacher, and entertainer. However, the study did not find any significant results in participants' performance (active response and engagement), robot acceptance (trust), or perceptions of robots (perceived likeability and satisfaction). Therefore, to the best of my knowledge, no direct connection has been found between the anthropomorphism of robot type and the acceptance of security robots.

Hypothesis 1: Anthropomorphism increases the acceptance of security robots.

2.2 Interaction Scenarios

When investigating interactions between humans and security robots, another important factor that may be easily overlooked by researchers is the interaction scenario. The preference for anthropomorphism in robots is highly context-sensitive because different application domains and task types may elicit different expectations toward robots [26, 41, 42]. For instance, a study by Roesler et al. [43] investigated the impact of anthropomorphic design on industrial robots and found that highly anthropomorphic robots were perceived as less reliable. Similarly, Lohse et al. [29] discovered that a machine-like robot was preferred over a human-like robot for tasks with low sociability. In another study, Lin et al. [28] investigated the contextual factors influencing participants'trust in security robots and found that trust was higher when the robot's decision matched the contextual danger cues.

Given that future interactions will occur in various dynamic environments, such as campuses, lobbies, office buildings, secure doors, and market checkpoints [23, 32], scenario-based analysis is crucial. For instance, Gallimore et al. [18] conducted a questionnaire study to examine participants' desired use of security robots in different contexts. They discovered that there was more agreement among men and women on the use of security robots for indoor locations that people view as "opt-in" locations where people choose to enter, such as homes, than for open public places. Therefore, in this study, I hypothesized that anthropomorphic design would have a stronger influence on the acceptance of security robots in open public settings than in closed indoor settings.

Hypothesis 2: The interaction scenario moderates the impact of anthropomorphism such that the impact of anthropomorphism is stronger in an outdoor rather than indoor setting.

3 METHOD

To address the research questions, I conducted a laboratory experiment exploring the effect of robot type and interaction scenario on human–security robot interaction. For the purpose of this experiment, I chose three security robots with distinct morphological features to create varying levels of anthropomorphism. A 3 (robot type: human-like robot, character-like robot, mechanical robot) × 2 (scenario: indoor hallway, outdoor parking lot) between-subjects design was employed. This study was approved by the University of Michigan institutional review board.

3.1 Participants

Sixty-nine participants were recruited from the University of Michigan for this study. The study involved a duration of 30-40 minutes, and participants received $20 for their time and participation. All participants met the inclusion criteria: at least 18 years old, fluent English speakers, and no history of virtual reality (VR) motion sickness. Nine participants were excluded from the analysis because either the Wizard-of-Oz method failed during their participation or their overall questionnaire scores were beyond 2.5 standard deviations from the mean. The 60 remaining valid participants (30 females, 30 males) ranged in age from 19 years to 46 years ($M = 27$, $SD = 7.08$). Participants were randomly assigned to one condition and the gender was balanced in each condition.

3.2 Apparatus

The experiment was conducted in the Michigan Immersive Digital Experience Nexus (M.I.D.E.N), a 10 × 10 × 10-foot (3.05 × 3.05 × 3.05-meter) immersive audio-visual "cave" environment featuring three-dimensional (3-D) stereoscopic projection on the left, front, and right surfaces. This setup allowed participants to walk freely within the physical boundaries of the space. The VR environments were modeled and programmed using Epic Games Unreal Engine version 4.27, simulating three security robots (Pepper, RAMSEE, and Knightscope) in two different scenarios (an indoor hallway and an outdoor parking lot), as shown in Figure 1. The robots' voices were generated using text-to-speech algorithms employing the Microsoft "David" voice. The Volfoni active-stereo shutter glasses paired with a Vicon motion-capture system were utilized in this experiment. Participants wore VR glasses in one of the VR scenarios and interacted with one of the security robots.

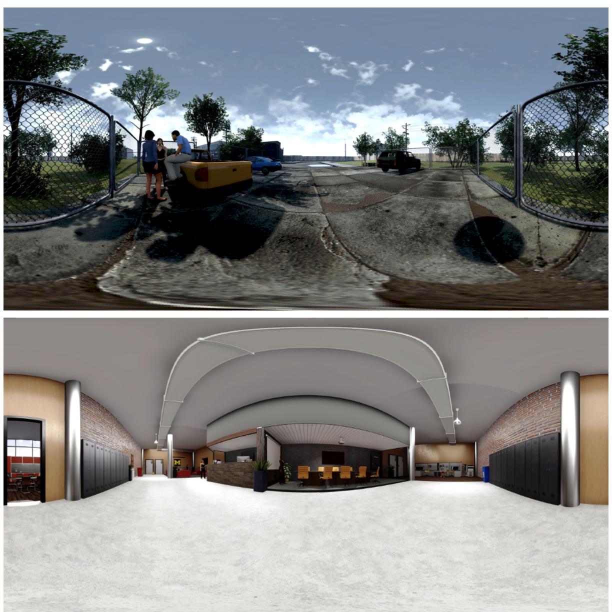

Figure 1. Panoramic Pictures of the Outdoor Parking Lot Scenario (top) and Indoor Hallway Scenario (bottom)

3.3 Experimental Design

This study examined two factors that I hypothesized would influence human interaction with security robots: the robot type and the interaction scenario. To explore the hypotheses, I selected three distinct robot types, each with varying levels of anthropomorphic morphological features. The Pepper robot, developed by SoftBank Robotics, is a human-like robot characterized by its highly anthropomorphic design. As shown in Fig. 2, Pepper features a human-like upper body comprising a torso, a head, and two arms mounted on a mobile omnidirectional base. The RAMSEE robot, developed by Gamma 2 Robotics, is a character-like robot, possessing a moderately anthropomorphic design. This autonomous security robot is composed of a torso with a liquid crystal display (LCD) screen displaying the robot's virtual face (Fig. 2). Unlike Pepper, RAMSEE lacks a human-shape head and arms. Last, the Knightscope K5 robot is a mechanical robot designed by Knightscope. This autonomous machine is specifically engineered for securing large spaces and exhibits a streamlined, conical canister-like body. The Knightscope K5 lacks any discernible anthropomorphic features (Fig. 2).

Two interaction scenarios were utilized: an indoor hallway scenario and an outdoor parking lot scenario. These scenarios were chosen because they are common deployment locations for security robots and allowed me to evaluate participant reactions in realistic settings. To ensure consistency in the experiment, in the initial patrolling task, all robots were programmed to move along the same patrol trajectory with the same movements. Additionally, the height of each robot was controlled to prevent any potential influence. A Wizard-of-Oz setup [38] was employed for this study to control the robot's interaction dialogues with participants, with the same researcher controlling the security robot from an unseen location.

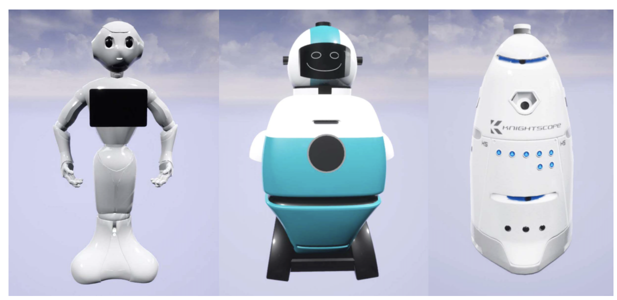

Figure 2. Three Security Robots: Pepper (Left), RAMSEE (Middle), and Knightscope K5 (Right)

3.4 Task and Procedure

At the beginning of the study, participants were guided to an interview room and provided with a brief introduction to the experiment and the security robot that they would interact with. Upon signing a consent form, participants completed preliminary questionnaires. After that, they were guided to the experimental room and donned VR glasses to interact with the security robot.

Throughout the experiment, a researcher remotely operated the robots using the Wizard-of-Oz approach. Participants were instructed to complete a series of tasks during their interaction with the security robot. In the initial phase, the security robot patrolled a predetermined route, detected the participant, became active, and approached the participant. It then briefly introduced itself and engaged in a short conversation. In the second phase, the security robot executed an access control task by inquiring about the participants' identity, such as whether they were students or employees at the University of Michigan. It subsequently requested to see their identification, which determined their access authorization. Once participants were authorized, the security robot initiated the third phase of interaction. It first reminded participants that they were advised to wear a mask in this area and then provided information on the benefits of wearing masks and where masks were available on campus. During the fourth phase, the security robot asked participants whether they had witnessed any suspicious activity in the vicinity. Finally, the robot conducted an emotion-detection task by posing questions like, "You seem a little anxious or worried; is everything okay?" Throughout the experiment, participants were encouraged to freely communicate with the security robot, which responded accordingly based on their diverse reactions (Fig. 3). After the interaction phase, participants returned to the interview room and completed a set of post-questionnaires on an iPad using the Qualtrics survey platform. Subsequently, they were invited to participate in a semi-structured interview. Participants were reminded that they could withdraw from the study at any point.

Figure 3. Participant wearing VR glasses communicating with a security robot in the VR environment.

3.5 Measures

Demographic information from the participants was collected. A 4-item trust questionnaire, adapted from [40] and [46], was employed to gauge participants' trust in the security robots. Trustworthiness was evaluated by an adapted scale based on [34] and included three dimensions: ability, integrity, and benevolence. Participants' perceptions of the security robot were assessed using four components of the Godspeed questionnaire [5], which measures anthropomorphism, perceived competence, likability, and perceived safety. Their desire to use security robots was measured using a modified 5-point Likert item based on [32].

4 RESULTS

In this section, I present the quantitative results of the study. I utilized analyses of variance (ANOVAs) to examine the main effects of robot type and scenario on robot acceptance and perceptions, as well as the interactions. A significance threshold of 0.05 was applied. For all significant main effects, I conducted post hoc comparisons using the Tukey correction. A summary of the hypothesis testing is shown in Table 1.

4.1 Measurement Check

The reliability of questionnaires was checked, and trust ($\alpha = 0.853$), trustworthiness ($\alpha = 0.912$), ability ($\alpha = 0.830$), integrity ($\alpha = 0.851$), benevolence ($\alpha = 0.787$), likability ($\alpha = 0.904$), and perceived intelligence ($\alpha = 0.791$) all exceeded the 0.7 recommendation [8, 17]. The reliability of perceived safety was $\alpha = 0.640$ after deletion of the first item. The reliability of perceived anthropomorphism was $\alpha = 0.561$. The factor analysis with varimax rotation was conducted to assess the construct validity [11]. As for the trust and trustworthiness questionnaire, most items exhibited high loadings (≥ 0.70) on their respective components, except for the 7th and 9th items in the trustworthiness questionnaire, which were therefore removed (see Appendix for item text). All remaining items loaded onto their components, providing evidence for the validity of the trust and trustworthiness questionnaire. As for the Godspeed questionnaire, the items of competence all loaded to their own component, while the items of anthropomorphism, likability, and safety loaded onto components other than their own, indicating low validity.

4.2 Manipulation Check

To confirm that participants perceived the robots with different levels of anthropomorphism, we examined participants' perceived anthropomorphism using Godspeed questionnaires. Significant differences were observed in the perceived anthropomorphism among the three robot types ($F = 3.12$, $p = 0.05$, $\eta_p^2 = 0.099$), with mean scores of 2.07 ($SD = 0.44$) for the Knightscope robot, 2.34 ($SD = 0.56$) for the Ramsee robot, and 2.50 ($SD = 0.67$) for the Pepper robot. A post hoc test with Tukey correction revealed a significant difference between the Knightscope and Pepper robots ($p = 0.04$), indicating that the perceived anthropomorphism of the Pepper robot was significantly higher than that of the Knightscope robot. However, no significant difference was found between the RAMSEE robot and either the Pepper robot ($p = 0.64$) or the Knightscope robot ($p = 0.29$).

4.3 Trust

The main effect of robot type was not significant, $F(2, 54) = 1.75$, $p = 0.18$, $\eta_p^2 = 0.061$, indicating no difference in trust among the Pepper robot ($M = 5.11$, $SD = 1.10$), the RAMSEE robot ($M = 5.12$, $SD = 0.86$), and the Knightscope robot ($M = 4.54$, $SD = 1.36$). The main effect of the scenario was also insignificant, $F(1, 54) = 0.07$, $p = 0.79$, $\eta_p^2 = 0.001$, as was the interaction of robot type × scenario, $F(2, 54) = 0.42$, $p = 0.66$, $\eta_p^2 = 0.015$.

4.4 Trustworthiness

The robot type had a significant main effect on participants' trustworthiness ($F(2, 54) = 3.31$, $p = 0.04$, $\eta_p^2 = 0.109$). Post hoc analysis revealed a marginal significant effect, with the Pepper robot ($p = 0.07$) and the RAMSEE robot ($p = 0.09$) receiving higher trustworthiness scores than the Knightscope robot, as shown in Figure 4. However, we did not find a significant main effect of scenario ($F(1, 54) = 0.62$, $p = 0.44$, $\eta_p^2 = 0.109$) or an interaction effect between scenario and robot type ($F(2, 54) = 0.14$, $p = 0.97$, $\eta_p^2 = 0.005$). To explore the effect of trustworthiness on its components (i.e., ability, integrity, and benevolence), I conducted further analyses on each component.

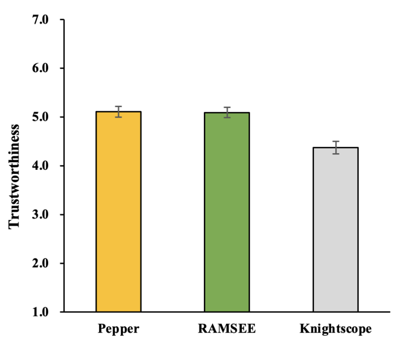

Figure 4. Effect of robot type on trustworthiness. Error bars denote 1 standard error.

4.4.1 Ability.

As depicted in Figure 5, the robot type exerted a significant impact on the perceived ability of security robots, $F(2, 54) = 3.50$, $p = 0.04$, $\eta_p^2 = 0.115$. Post hoc analysis revealed that participants perceived the Pepper robot to have a higher ability than the Knightscope robot ($p = 0.05$), suggesting that a human-like robot elicits a higher perception of ability compared to a mechanical robot. We also found a marginally significant difference between the RAMSEE robot and the Knightscope robot ($p = 0.09$), which indicates a trend that people perceived the character-like robots with higher ability than the mechanical robot. The difference between the RAMSEE robot and the Pepper ($p = 0.98$) robot was insignificant. The main effect of scenario was not significant, $F(1, 54) = 0.35$, $p = 0.56$, $\eta_p^2 = 0.006$, nor was the interaction of robot type × scenario significant, $F(2, 54) = 0.21$, $p = 0.81$, $\eta_p^2 = 0.008$.

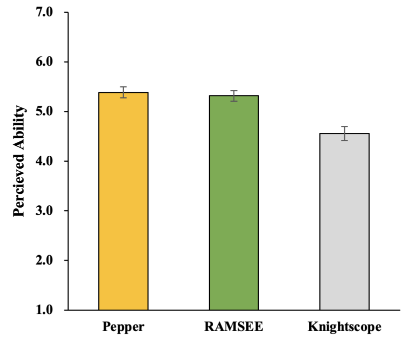

Figure 5. Effect of robot type on ability. Error bars denote 1 standard error.

4.4.2 Integrity.

A main effect of robot type on the perceived integrity of security robots was observed as shown in Figure 6, $F(2, 54) = 3.60$, $p = 0.03$, $\eta_p^2 = 0.118$. Post hoc comparisons found marginal significant differences between the Knightscope robot and the Pepper robot ($p = 0.06$), as well as between the Knightscope robot and the RAMSEE robot ($p = 0.07$). This suggests a trend in which the perceived integrity of the Knightscope robot ($M = 4.16$, $SD = 1.28$) was lower than that of the Pepper robot ($M = 4.97$, $SD = 0.97$) and the RAMSEE robot ($M = 4.97$, $SD = 0.98$). The main scenario effect ($F(1, 54) = 0.45$, $p = 0.50$, $\eta_p^2 = 0.008$) and the interaction effect between robot type and scenario ($F(2, 54) = 0.07$, $p = 0.94$, $\eta_p^2 = 0.002$) were both insignificant.

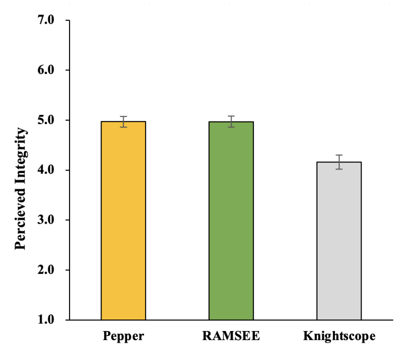

Figure 6. Effect of robot type on integrity. Error bars denote 1 standard error.

4.4.3 Benevolence.

No significant differences were found among the Knightscope robot ($M = 4.86$, $SD = 1.03$), the RAMSEE robot ($M = 5.07$, $SD = 1.09$), and the Pepper robot ($M = 5.00$, $SD = 1.24$) in participants' perceived benevolence toward the security robot ($F(2, 54) = 0.27$, $p = 0.77$, $\eta_p^2 = 0.010$). The scenario did not influence benevolence, $F(1, 54) = 1.14$, $p = 0.29$, $\eta_p^2 = 0.021$. The interaction between robot type and scenario was also insignificant, $F(2, 54) = 0.09$, $p = 0.92$, $\eta_p^2 = 0.003$.

4.5 Perceptions of Robot

4.5.1 Likeability. The main effect of robot type ($F(2, 54) = 2.22$, $p = 0.12$, $\eta_p^2 = 0.076$), the main effect of scenario ($F(1, 54) = 0.71$, $p = 0.40$, $\eta_p^2 = 0.013$), and their interaction effect ($F(2, 54) = 0.65$, $p = 0.52$, $\eta_p^2 = 0.024$) on likeability were all insignificant.

4.5.2 Perceived Intelligence. Participants perceived intelligence of the three robots showed no significant differences ($F(2, 54) = 1.33$, $p = 0.27$, $\eta_p^2 = 0.047$), with neither scenario ($F(1, 54) = 0.71$, $p = 0.40$, $\eta_p^2 = 0.013$) nor the interaction of scenario and robot type ($F(2, 54) = 0.70$, $p = 0.50$, $\eta_p^2 = 0.025$) having a significant impact.

4.5.3 Perceived Safety. No significant differences were found among the three robot types ($F(2, 54) = 2.86$, $p = 0.07$, $\eta_p^2 = 0.096$). Additionally, the scenario did not exert a significant influence on safety ($F(1, 54) = 0.21$, $p = 0.65$, $\eta_p^2 = 0.004$). Interactions between robot type and scenario were also insignificant($F(2, 54) = 0.80$, $p = 0.45$, $\eta_p^2 = 0.029$).

4.6 Desire to Use

As shown in Figure 7, robot type had a statistically significant impact on participants' desire to use the security robot ($F(2, 54) = 4.08$, $p = 0.02$, $\eta_p^2 = 0.131$). Post hoc analysis results revealed that participants significantly preferred the Pepper robot over the Knightscope robot ($p = 0.04$). There was also a trend that people preferred the RAMSEE robot over the Knightscope robot ($p = 0.06$). However, the comparison between the RAMSEE robot and the Pepper robot ($p = 0.99$) was not statistically significant. Additionally, the study found no difference in participants' desire to use security robots between the outdoor parking lot and the indoor hallway scenarios ($F(1, 54) = 0.22$, $p = 0.64$, $\eta_p^2 = 0.004$). The interaction between robot type and scenario was also found to be insignificant, $F(2, 54) = 0.72$, $p = 0.50$, $\eta_p^2 = 0.026$.

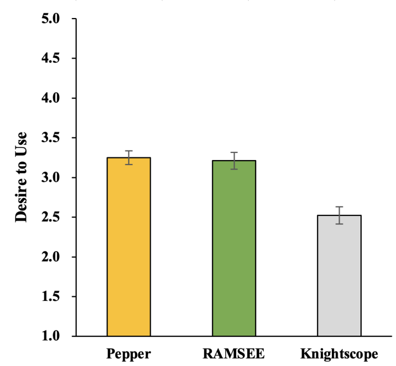

Figure 7. Effect of robot type on desire to use. Error bars denote 1 standard error.

5 DISCUSSION

In this study, I investigated the effects of robot type and interaction scenario on participants' perceptions of robots and their acceptance. The results demonstrated that robot type significantly influences the acceptance of security robots, particularly in terms of their perceived ability and integrity and people's desire to use them. However, the impacts of the interaction scenario and the interaction effect were not observed. Next I discuss the study's contributions, limitations, and potential future opportunities.

This research offers several contributions and implications. First, it extends the existing human–robot interaction (HRI) literature by specifically examining the influence of robot type in the security domain. In line with prior research on social robots [3, 4, 19, 25], this study revealed that robot type significantly impacts human acceptance, with participants exhibiting higher acceptance for human-like robots compared to mechanical robots. More specifically, individuals perceived the human-like robot Pepper as having higher anthropomorphism, ability, and integrity (marginally), and participants showed a stronger desire to use Pepper in comparison to the mechanical robot Knightscope. This finding supports the notion that anthropomorphism plays an important role in the design of robots within the security domain. Consequently, I recommend that future security robots should incorporate more human-like design, as opposed to plain mechanical features, in order to maximize people's acceptance of them.

Second, this study found that the character-like robot RAMSEE displayed no significant difference in perceived anthropomorphism when compared to the other two robots. This finding was surprising because I had hypothesized that a robot with more morphological anthropomorphic features would result in higher perceived anthropomorphism. Although unexpected, I did find a weak trend that the RAMSEE robot had higher perceptions of ability, integrity, and participant desire to use than the Knightscope robot. This outcome was unanticipated given that the important consideration for this research was the idea that humans perceive robot types in varying levels of anthropomorphism, and that the level of anthropomorphism people see in a robot influences their interaction with the robot. One explanation could be the distinct characteristics of the RAMSEE robot. It maintains important mechanical and anthropomorphic features simultaneously, which may have led to the lack of distinction in generally perceived anthropomorphism even though the robot retains some essential anthropomorphic features. Barco et al. [3] also found that participants' perception of the caricatured robot Cozmo tended to be similar to that of the human-like robot NAO. Another possible explanation is the influence of complex dynamics of anthropomorphic morphological features that we are unaware of [35, 56]. It is possible that specific anthropomorphic features have a direct impact on robot acceptance in the security domain [6]. Therefore, researchers could compare specific anthropomorphic features or combinations of these features to further investigate which anthropomorphic aspects shape the acceptance of security robots. My research team and I plan to conduct a qualitative analysis of the interview data to get a further understanding of these ideas.

Third, in this study I did not observe any difference in trust or perceptions of robots among different robot types. This result is inconsistent with common findings in the social domain, which suggest that anthropomorphic robots always engender better perceptions and higher trust than mechanical robots [19, 33, 36, 51]. It is intriguing to observe that robot type influenced robot acceptance but not perceptions of robots. Furthermore, robot type affected trustworthiness but not trust. These findings underscore the importance of conducting HRI research within security domains. At the same time, the exact interplay of anthropomorphism, trust, trustworthiness, perceptions of robots, and people's desire to use the robots needs to be analyzed further in more detail in future research.

Fourth, this study demonstrated that humans' perceptions and acceptance of security robots did not differ between the indoor hallway scenario and the outdoor parking lot scenario. Additionally, I did not find any interactions between robot type and scenario. In comparison to previous research [28, 32], this study expanded the literature beyond static questionnaire contexts by incorporating a simulated robot and real scenarios involving human interaction. The results suggest that the scenario may not have a significant influence on perceptions or acceptance of security robots in real interactions, indicating that future security design might focus more on robot design. However, further studies are needed to examine various indoor and outdoor scenarios such as airports, hospitals, hotels, law enforcement facilities, and communities to verify whether this trend is generalizable.

Simultaneously, to better simulate real-world security robot scenarios, this study deployed security robots to perform multiple security tasks, including access control, mask detection and reminders, and emotion detection. The majority of previous security robot studies only adopted access control tasks, which check participants' identification to simulate human-security interactions [18, 18, 21, 27, 30, 32]. However, real-world security robots are often required to perform more complex tasks, such as patrolling, detecting strangers, detecting suspicious behavior, providing guidance, and more. By broadening the scope of the security robot's tasks beyond traditional access control tasks, we can gain a better understanding of how humans interact with security robots in more complex and diverse security scenarios.

One limitation of this study is the low reliability of the anthropomorphism item in the Godspeed questionnaire, as well as the low validity of the Godspeed questionnaire. Despite being one of the most frequently used questionnaires in HRI studies [52], it has been found to have low validity in previous research studies, with items not measuring their intended constructs but instead measuring some convolution of them [20]. My study also found that items in the Godspeed questionnaire do not load on factors. The development of the Godspeed questionnaire lacks methodology and does not provide any clear testing of its structural psychometric validity [47], which may result in the insignificant results of perceptions of security robots. Therefore, we recommend that future research employ multiple questionnaires to better assess perceived anthropomorphism [9, 47] and other perceptions. Simultaneously, our reliance on VR robots and environments constrained the study's external validity. As such, this study serves as a starting point for encouraging further field research involving real robots in authentic environments to provide guidance for real-world security robot design. Another limitation is that this study only examined acceptance after initial interaction. Future longitudinal research should deploy real security robots in working scenarios to observe people's long-term, more realistic, and stable reactions to these robots. By doing so, we can gain a more comprehensive understanding of how people interact with security robots in the real world and how to design these robots more effectively.

6 CONCLUSION

This study delved into the impact of robot type and inter- action scenarios on users' acceptance of security robots. By centering this research on security robots, I not only broadened the scope of the existing HRI literature, but also highlighted the significance of anthropomorphic design in security applications. Furthermore, I explored the moderating influence of various scenarios on user acceptance. Overall, this study enriches the HRI field and offers valuable insights that can inform the development of security robot design guidelines, which can benefit both researchers and practitioners in the creation of future security robots.

Appendix. Trust and Trustworthiness Questionnaire Items

The trust questionnaire used in this study was adapted from [40, 46] and the detailed items are shown in Table 2. The trustworthiness questionnaire was adapted from [13, 34] and the detailed items are shown in 3. To assess the validity of the questionnaire, I conducted a factor analysis using IBM SPSS v.28. The majority of items exhibited high loadings (≥ 0.70) on their respective components after varimax rotation in the

Table 1. Results of Hypothesis Testing

Hypothesis	Results
H1) Anthropomorphism → Acceptance	Partially supported
Anthropomorphism → Trustworthiness (ability, integrity), Desire to use	Supported
Anthropomorphism → Trust, Benevolence, Perceived safety, Likeability, Perceived intelligence	Not Supported
H2) Interaction scenario moderate the effect of anthropomorphism	Not Supported

Table 2. Trust Questionnaire

Item	Source
I would be comfortable giving this security robot complete responsibility for its security task.	Robert et al. [40]
I would have no problem allowing this robot to help identify my card.	Robert et al. [40]
I would speak freely when the security robot asked about situations.	Schoorman and Balliger [46]
I trust this robot enough to rely on its help and recommendations.	Robert et al. [40]

Table 3. Trustworthinesss Questionnaire

Item	Attribute	Source
The security robot is very capable of performing its job.	Ability	Mayer and Davis [34]
I feel very confident about the security robots' skills.	Ability	Mayer and Davis [34]
The security robot I worked with communicated clearly.	Ability	Esterwood and Robert [13]
I like the security robot's values.	Integrity	Mayer and Davis [34]
The security robot was dependable.	Integrity	Esterwood and Robert [13]
The security robot could be counted to do its job.	Integrity	Esterwood and Robert [13]
The security robot is very concerned about others' welfare.	Benevolence	Mayer and Davis [34]
My needs and security are very important to the security robot.	Benevolence	Mayer and Davis [34]
Security robot would not knowingly do anything to hurt me.	Benevolence	Mayer and Davis [34]

roated component matrix, signifying that they effectively measured the intended construct. However, the seventh and ninth items in the trustworthiness questionnaire failed to meet this criterion, indicating potential unreliability in measuring trustworthiness. As a result, I removed these items from the questionnaire, leading to all remaining items loading onto their own component, which supports the construct validity of the questionnaire. Simultaneously, the reliability of the trust and trustworthiness questionnaires exceeded the benchmark criterion of 0.7: trust ($\alpha = 0.853$), ability ($\alpha = 0.830$), integrity ($\alpha = 0.851$), benevolence ($\alpha = 0.787$). Consequently, we consider the measure of trust and trustworthiness to be relatively robust.

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