Human Security Robot Interaction and Anthropomorphism: An Examination of Pepper, RAMSEE, and Knightscope Robots

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***Abstract*— The rapid growth in the use of security robots makes it critical to better understand their interactions with humans. The impacts of anthropomorphism and interaction scenarios were examined via a 3 x 2 between-subjects experiment. Sixty 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 in a virtual reality cave. There were significant differences only between Pepper and Knightscope with Pepper rated higher in anthropomorphism, ability, integrity, and desire to use than Knightscope but the interaction scenario has no effect.**

I. Introduction

Security robots are being increasingly employed across various sectors, including public law enforcement and private security agencies, to safeguard individuals and property. In this paper, we define security robots as robots specifically designed to protect humans and properties by deterring illicit activities through security tasks such as monitoring, notifying emergencies to security agents, and maintaining order within a designated area. Security robots provide a unique solution to contemporary security challenges like patrolling and surveillance [1], [2], [3]. Additionally, they offer a cost-effective approach to security assignments involving physical danger, thereby reducing the need for human personnel to be exposed to hazardous situations [3], [4], [5], [6], [7]

Current security robots exhibit a wide range of morphologies with varying degrees of anthropomorphism and are utilized in both indoor and outdoor environments [8]. For instance, robots like RoboGuard [9] and Knightscope [8] lack human-like morphological features, while others such as RAMSEE [10] and Captain C [11] possess some human-like characteristics. Additionally, there are humanoid security robots like RobotMan [7] and NCCU Security Warrior [5].

Although anthropomorphism has been shown to promote the acceptance of robots [12], [13], [14], it is not clear if similar effects will carry over to the acceptance of security robots. More specifically, past research has shown that the impact of anthropomorphism on the acceptance of robots can vary greatly based on the robot's primary purpose and interaction context [15], [16], [17], [18]. Consequently, determining the most appropriate anthropomorphic morphological attributes for security robots remains a challenge.

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This paper contributes to the literature by offering insights into whether or not anthropomorphism can be used to promote security robot acceptance. To accomplish this, we conduct a between-subjects experiment employing a 3 (robot type: human-like robot, character-like robot, mechanical robot) × 2 (scenario: indoor hallway, outdoor parking lot) design. This study provides new insights into the impact of the anthropomorphic design of security robots commonly used in different interaction scenarios.

II. Background

A. 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" [19, P.247]. A common approach to humanizing robots involves manipulating their overall physical appearance [19], [20], [21]. Previous studies have demonstrated that anthropomorphic design has a positive effect on human-related outcomes [17], particularly in social application domains [22], [23], [24]. For example, Barco et al. [25] manipulated three types of robots (anthropomorphic, zoomorphic, and caricatured) and found that people felt higher psychological closeness towards the anthropomorphic robot. Zanatto et al. [26] used robots NAO and Baxter to manipulate 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 [27] also found that participants' perceived 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 our review, only one study, Li et al. [28], 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. 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 our knowledge, no direct connection has been found between anthropomorphism and the acceptance of security robots.

Hypothesis 1: Anthropomorphism will increase the acceptance of security robots.

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B. 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, as different application domains and task types may elicit different expectations towards robots [15], [17], [18]. For instance, a study by Roesler et al. [29] investigated the impact of anthropomorphic design on industrial robots and found that highly anthropomorphic robots were perceived as less reliable. Similarly, Lohse et al. [30] discovered that a machine-like robot was preferred over a human-like robot for tasks with low sociability. In another study, Lin et al. [31] 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.

As future interactions will occur in various dynamic environments, such as campuses, lobbies, office buildings, secure doors, and market checkpoints [32], [33], scenario-based analysis is crucial. For instance, Lyons et al. [33] 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 can be viewed as "opt-in" locations where people choose to go into such as homes than open public places where people do not opt. Therefore, anthropomorphism should have a stronger influence in public settings than in indoor settings.

Hypothesis 2: Interaction scenario will moderate the impact of anthropomorphism; the impact of anthropomorphism will be stronger in an outdoor rather than indoor setting.

III. Method

To address our research questions, we conducted a laboratory experiment exploring the effect of robot type and interaction scenario on human-security robot interaction. For the purpose of this experiment, we 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.

A. Participants

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

B. Apparatus

The experiment was conducted in the Michigan Immersive Digital Experience Nexus (M.I.D.E.N), a 10 x 10 x 10-foot (3.048 x 3.048 x 3.048-meter) immersive audio-visual "cave" environment featuring 3D 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.

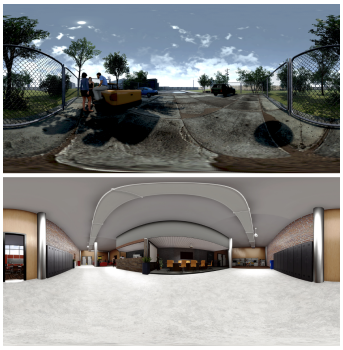

Fig. 1. Panoramic Pictures of the Outdoor Parking Lot Scenario (top) and Indoor Hallway Scenario (bottom)

C. Experimental Design

This study examines the potential impact of two factors: the robot type and the interaction scenario. To explore this hypothesis, we selected three distinct robot types, each with different 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 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 security robot is composed of a torso with an LCD screen displaying the virtual face. Unlike Pepper, RAMSEE lacks a human-shaped head and arms. Lastly, the Knightscope K5 robot is a mechanical robot designed by Knightscope company. This autonomous machine exhibits a streamlined, conical canister-like body which lacks any discernible anthropomorphic features. In selecting suitable robots, we chose a popular human-like robot and two commonly used security robots, each with varying levels of anthropomorphism based on the anthropomorphic robot database [34]. Pepper has the highest anthropomorphism with an overall human likeness score of 42.17. The scores for RAMSEE and Knightscope were not

listed in the database and had to be calculated using the site's Robot Human-Likeness Predictor. RAMSEE received a score of 13.77, indicating a middle anthropomorphism level, while Knightscope scored lowest in anthropomorphism with 3.96.

Two interaction scenarios are 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 us 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 [35] was employed to control the robot's interaction dialogues with participants, with the same researcher controlling the security robot from an unseen location.

Fig. 2. Pepper (Left), RAMSEE (Middle), and Knightscope K5 (Right)

D. Task and Procedure

Participants were guided to an interview room and provided with a brief introduction to the experiment and the security robot. Upon signing a consent form, participants completed preliminary questionnaires and were guided to the experimental room to interact with the security robot.

Throughout the experiment, researchers remotely operated the robots using the Wizard-of-Oz approach. Participants were instructed to complete a series of tasks during their interaction with the 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' identities, 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 authorized, the security robot initiated the third phase. It first reminded participants that they were recommended to wear a mask in this area and then provided information on the benefits of wearing masks and where they were available. During the fourth phase, the security robot asked participants if they had witnessed any suspicious activity in the vicinity. Finally, it 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. 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 and could withdraw from the study at any point.

Fig. 3. Participant wearing VR glasses interacting with a security robot.

E. Measures

Demographic information from the participants was collected. Trust was measured using a 4-item questionnaire adapted from [36], [37]. Trustworthiness was evaluated by an adapted scale based on [38] and include three dimensions: ability, integrity, and benevolence. Perception of robots was assessed by the Godspeed questionnaire [39], which measures anthropomorphism, perceived intelligence, likability, and perceived safety. Desire to use was measured using a modified 5-point Likert item based on [33].

IV. Results

In this section, we present the quantitative results of our study. We utilized ANOVAs to examine the main effects of robot type and scenario on robot acceptance and perceptions, as well as their interaction. A significance threshold of 0.05 was applied. For all significant main effects, post hoc comparisons were conducted using the Tukey correction.

A. Measurement Check

The reliability of questionnaires were checked: trust ($\alpha = 0.853$), 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 [40], [41]. The reliability of perceived safety is $\alpha = 0.640$ after we deleted the first item. The reliability of perceived anthropomorphism is $\alpha = 0.561$.

B. Manipulation Check

To confirm that participants perceived the robots with different anthropomorphism, we examined participants' perceived anthropomorphism using Godspeed questionnaires. Significant differences were observed among 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 posthoc test 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 ($p = 0.29$).

C. Trust

Robot type was not significant, $F(2, 54) = 1.75$, $p = 0.18$, $\eta_p^2 = 0.061$, indicating no difference in trust for 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 scenario was also not significant, $F(1, 54) = 0.07$, $p = 0.79$, $\eta_p^2 = 0.001$, nor was the interaction of robot type $\times$ scenario significant, $F(1, 54) = 0.42$, $p = 0.66$, $\eta_p^2 = 0.015$.

D. Trustworthiness

1) Ability: As depicted in Figure 4, 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 character-like robots with higher ability than 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 $\times$ scenario significant, $F(1, 54) = 0.21$, $p = 0.81$, $\eta_p^2 = 0.008$.

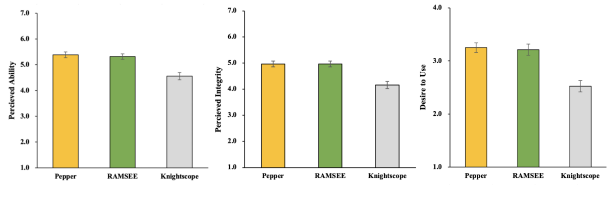

Fig. 4. Effects of anthropomorphism on ability, integrity, and desire to use. Error bars denote 1 standard error.

2) Integrity: A main effect of robot type on the integrity of security robots was observed as shown in Figure 4, $F(2, 54) = 3.60$, $p = 0.03$, $\eta_p^2 = 0.118$. 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 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 effect of scenario ($F(1, 54) = 0.45$, $p = 0.50$, $\eta_p^2 = 0.008$) and the interaction effect between robot type and scenario ($F(2, 54) = 0.07$, $p = 0.94$, $\eta_p^2 = 0.002$) were insignificant.

3) Benevolence: No significant differences among the Knightscope robot ($M = 4.86$, $SD = 1.03$), the RAMSEE robot ($M = 5.07$, $SD = 1.09$), and the Pepper robot ($M = 5.00$, $SD = 1.24$) were found in participants' perceived benevolence toward the security robot ($F(2, 54) = 0.20$, $p = 0.82$, $\eta_p^2 = 0.007$). The scenario did not influence benevolence, $F(1, 54) = 0.73$, $p = 0.40$, $\eta_p^2 = 0.013$. The interaction between robot type and scenario was not significant, $F(2, 54) = 0.10$, $p = 0.90$, $\eta_p^2 = 0.004$.

E. Perceptions of Robot

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.

2) Perceived Intelligence: Participants perceived intelligence of 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.

3) Perceived Safety: Robot type was not significant ($F(2, 54) = 2.86$, $p = 0.07$, $\eta_p^2 = 0.096$). 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 ($F(2, 54) = 0.80$, $p = 0.45$, $\eta_p^2 = 0.029$).

F. Desire to Use

As shown in Figure 4, robot type has 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 is 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 desire to use security robots showed no difference 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 the scenario was also found to be insignificant, $F(2, 54) = 0.72$, $p = 0.50$, $\eta_p^2 = 0.026$.

V. Discussion and Conclusion

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

This research offers several contributions. First, it highlights the importance of anthropomorphism, which not only promotes the acceptance of social robots [25], [42], [43], [44], but also of security robots. Our study revealed that the anthropomorphism impacts human acceptance of security robots. More specifically, individuals perceived Pepper as having higher anthropomorphism, ability, integrity

(marginally), and a stronger desire to use compared to Knightscope. Despite our findings, the Knightscope robot is an actual security robot while the Pepper is not. This may indicate that the primary purpose of the Knightscope's design may not be to promote acceptance by those that engage with the robot. The design may be driven by purely functional requirements and/or perhaps to even discourage direct human interaction with the robot. Nonetheless, our findings suggest that, future security robots should incorporate more anthropomorphic designs if they hope to promote acceptance.

Second, our study discovered that the character-like robot RAMSEE displayed no significant difference in perceived anthropomorphism when compared to the other two robots. This finding was surprising, as we had hypothesized that a robot with more morphological anthropomorphic features would result in higher perceived anthropomorphism. Although unexpected, we did obtain a weak trend that RAMSEE had higher ability, integrity, and desire to use than Knightscope. One explanation could be that RAMSEE maintains important mechanical and anthropomorphic features simultaneously, which may have led to the lack of distinction in generally perceived anthropomorphism while still retaining some essential anthropomorphic features. Barco [25] also found that participants' perception of the caricatured robot Cozmo tended to be similar to the human-like robot NAO. Another explanation is the influence of complex dynamics of anthropomorphic morphological features that we are currently unaware of [45], [46]. It is possible that specific anthropomorphic features have an impact on security robot acceptance [21]. Therefore, future researchers could compare specific or combinations of anthropomorphic features.

Third, this study did not observe any difference in trust or perceptions of robots among different robot types. This result is inconsistent with previous findings in social domains, which suggest that anthropomorphic robots always engender better perceptions and higher trust [27], [47], [43], [48]. It is intriguing to observe that robot type influenced acceptance but not perceptions of robots. It also impacted trustworthiness but not trust. One possible explanation for this discrepancy is the unique context of the security domain, emphasizing the importance of conducting more HRI research within specific domains. More specifically, we found that the significant impacts of anthropomorphism were linked to differences in ability, marginal differences in integrity, and no differences in benevolence. It is possible that trust may be driven primarily by integrity and benevolence which anthropomorphism apparently has a weaker relationship within the context of security robots. In either case, the results of this study suggest that the exact interplay between anthropomorphism and trust requires further detailed analysis in future research.

Fourth, our study demonstrated that the impact of anthropomorphism on humans' perceptions and acceptance of security robots did not differ between indoor hallways and outdoor parking lots. In comparison to previous research [33], [31], our study expanded the literature beyond static questionnaire contexts by incorporating a simulated robot and real scenarios involving human interaction. The majority of previous security robot studies only adopted the access control task [49], [50], [28], [51], [49], [33]. In order to better simulate real-world security robots, our study deployed multiple security tasks. However, further studies are needed to examine various scenarios such as airports, hospitals, and hotels to verify whether this trend is generalizable.

One limitation of this study is the low reliability of the anthropomorphism item in the Godspeed questionnaire. We recommend that future research employs multiple questionnaires to better assess perceived anthropomorphism [52], [53]. Simultaneously, our reliance on VR simulations may limit the study's external validity. Another limitation is that we only examined acceptance after the initial interaction. Future longitudinal research could deploy security robots in working scenarios to observe people's long-term, more realistic, and stable reactions to these robots.

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