Understanding Reactions in Human-Robot Encounters with Autonomous Quadruped Robots

Chan, Yao-Cheng The University of Texas at Austin, School of Information, USA | ycchan@utexas.edu
Hauser, Elliott The University of Texas at Austin, School of Information, USA | eah13@utexas.edu

ABSTRACT
Incidental human-robot encounters are becoming more common as robotic technologies proliferate, but there is little scientific understanding of human experience and reactions during these encounters. To contribute towards addressing this gap, this study applies Grounded Theory methodologies to study human reactions in Human-Robot Encounters with an autonomous quadruped robot. Based upon observation and interviews, we find that participants' reactions to the robot can be explained by their attitudes of familiarity, certainty, and confidence during their encounter and by their understanding of the robot's capabilities and role. Participants differed in how and whether they utilized opportunities to resolve their unfamiliarity, uncertainty, or lack of confidence, shedding light on the dynamics and experiential characteristics of Human-Robot Encounters. We provide an emerging theory that can be used to unravel the complexity of the field as well as assist hypothesis generation in future research in designing and deploying mobile autonomous service robots.

KEYWORDS
Human-Robot Encounter; Human-Robot Interaction; Quadruped Robot; Autonomous Robot; Grounded Theory

INTRODUCTION
With the proliferation of robotics technologies, especially in businesses using robots to facilitate operations (Rindfleisch et al., 2022), encounters with robots in everyday life environments are becoming more frequent. Despite all the benefits provided by robots, reported hostile reactions to robots and robot bullying indicates that there are underlying issues with robot deployments. For instance, in 2014, Smith and Zeller (2017) deployed a hitchhiking robot called hitchBOT to investigate human reactions to it. HitchBot successfully hitchhiked across the world in several trips, however, in 2015, it was found vandalized when it attempted to travel across the U.S. The vandalism against hitchBOT was an unfortunate event and posed a grand challenge to both robotics scientists and Human-Robot Interaction (HRI) researchers: How do humans handle robot encounters in everyday life environments?

To start answering this question, HRI researchers have begun to explore Human-Robot Encounters (HRE). As an emerging research topic of HRI, HRE studies the implicit and indirect interactions between humans and robots when both parties unintentionally encounter each other in everyday life environments. "*Many people affected will in fact not be users of robots but will just 'happen to be there'*" (Rosenthal-von der Pütten et al., 2020, p.1) As HRI studies tend to focus on direct interactions, HRE broadens the scope of HRI research by incorporating other forms of interactions. For example, a college student who is walking on campus encounters a delivery robot walking toward her. In this case, HRE researchers may study how she perceives and reacts to the robot without her actually using it. The interaction between the spatiotemporal co-located student and the robot is subtle, indirect, unintentional, and yet socially profound. The student's perceptions and reactions to the robot are likely to be influenced by factors such as the social cues presented by the robot, the physical environment surrounding them, and the student's social judgment of the robot (Babel et al., 2022). Currently, many organizations adopt quadruped robots for deployment to utilize their enhanced mobility and the ability to carry objects. Their navigation and autonomy capabilities allow them to generate multiple human-robot encounters. However, past studies and news articles showed that the deployment of quadruped robots had received public criticism, and evoked fear and ethical concerns (Yunus & Doore, 2021), indicating there were challenges to wide and comprehensive robot deployment as well as the need for more HRE research.

Given the complexity and understudied nature of HRE research, this study applies Hoda's Socio-technical Grounded Theory (2021) to explore how people react to encounters with Boston Dynamics Spot, a quadruped robot. Grounded Theory methodology is well-suited to study HRE because of HRE's rich social nature, and the methodology can be used to analyze the data collected and generate a theory to explain HRE as a sociotechnical phenomenon. We apply participatory observations in a lab-based HRE study and conduct semi-structured interviews to collect in-depth data. Following Hoda's guidelines (2021), the present study is preliminary and small-scale, and the data collected is not comprehensive enough to generate a mature theory. Therefore, this study focuses on providing an emerging theory that explains the data collected so far and can be used to generate hypotheses in future research. Our emerging theory proposes that human reactions to an autonomous quadruped robot in an HRE scenario are associated with humans' familiarity, certainty, and confidence in encountering robots.

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RELATED WORK

Following Hoda (2021), we conducted a lean literature review before the study, and a targeted literature review after data analyses (p. 14). In this section, we present the works that serve as the basis of our study.

The fast development and deployment of robotics systems in human society increase the chances of humans unintentionally encountering robots, therefore it is of paramount importance to understand this emerging phenomenon. Due to technology limitations, early works on HRE relied heavily on observations and wizard-of-oz setups. Additionally, these works focused more on what people think and behave prior to the actual and direct interactions, and then proposed recommendations to improve interaction quality in general. For instance, Bergstrom et al. (2008) conducted a field study, observed how people react to a humanoid robot in a mall, and classified the people into groups of Interested, Not Interested, Indecisive, and Hesitant based on their speed, orientation, and position. The authors further examined the effect of different types of robot behavior on perceived naturalness and concluded that the match between robot behavior and the type of people would allow them to perceive the robot as more natural. Even though the main focus of this study was not on HRE, it did emphasize the importance of understanding human behavior that was prior to direct interactions. In a recent work on Social Robotics, Avelino et al. (2021) explored the literature on social robots' greeting abilities in encountering new users in a social context. The authors emphasized the importance of first impressions and the development of robot capabilities that would lead to a better experience for new users. The authors also pointed out that future research on Social Robotics should examine how non-verbal communication between robots and humans can lead to better encounter experiences. Both of the reported studies are not HRE research, but they contributed knowledge to different aspects of HRE.

HRE research is expanding but the dearth of it means that it is still understudied. To answer this challenge, Babel et al. (2022) adopted a box-like cleaning robot and deployed it in a busy train station. The authors recruited people who walked past the robot and asked them to answer a questionnaire. They also observed and interviewed the people. Their results showed that people had concerns about collisions between robots and pedestrians, job loss, and inconvenience caused by the robot's lack of communication capabilities. This study provided empirical findings about human reactions to an autonomous robot in public. However, robot vacuums have been available to the public for several years, so people might be more familiar with cleaning robots in general. This leaves the question that if people would react to a more technologically advanced robot in the same way. In one of the most recent works on HRE, Moesgaard et al. (2022) conducted ethnographic research to study how people would react to a primitive mechanoid robot that did not follow social norms. Their results indicated that people not only utilized their prior knowledge of robots and robots' behavior to evaluate them, but also drew upon membership categorization frameworks to make sense of them. The authors emphasized the notion of humans and robots will soon come to co-exist in this world, and HRI research should expand beyond the idea that humans are only direct users of robots, as more and more research has touched upon the indirect interactions between humans and robots. Furthermore, the authors argued that robotics system designers should not only focus on the capabilities of robots but also on how people feel about them, especially in public settings. This argument also implied that HRI researchers should take into account the rich social nature of HRI and HRE in future research. Another HRE work by Hardeman (2021) used a wizard-of-oz setup and conducted field research on 28 people who walked past a wheel delivery robot. The results were similar to Babel et al's (2022) work where people showed concerns about collisions, privacy issues, and the lack of communication capabilities. The topic of this study was similar to our research; however, this study was exploratory in nature and also adopted a primitive robot. Nevertheless, their results seemed to show that people had neutral to positive reactions to the robot.

HRE research is still nascent. The reported works have studied how people perceive and react to robots that they accidentally encounter. However, those works investigated HRE by focusing on how people react to a robot in general, without taking into account the appearance and capabilities of the robots being used. In other words, it is still unclear whether their findings would apply to other types of robots as well as if there were any hidden factors. As presented by Babel et al. (2022), the authors investigated human-robot conflicts using humanoid, zoomorphic, and mechanoid robots, and found that human compliance and acceptance differed between the robots. We argue that the zoomorphic form of Boston Dynamics' Spot may elicit different human cognitive and behavioral responses. Additionally, since the public sale of Spot in 2019, it has received mixed reviews from the public on major social media. A sentiment analysis of Twitter conducted by Moses and Ford showed (2021) that on the one hand, people were amazed by the technology, on the other hand, the dog-like robot's connection to military use scared many people. Most people had not seen dog-like robots in real life and their perceptions of them mainly originated from the impressions of them from watching online videos, movies, and TV shows that showcased robot dogs. The authors called for more research on this topic. To the best of our knowledge, no research has studied how people react to an autonomous quadruped robot when they accidentally encounter one. Therefore, we aim to fill this gap by using Grounded Theory methodologies to explore human reactions to an autonomous quadruped robot and propose an emerging theory that can be adapted to generate hypotheses in future research.

METHODOLOGY

This research followed Hoda's (2021) Socio-technical Grounded Theory. The site of our study was a lab-based HRE study that investigated human perceptions of a quadruped robot (Hauser et al., 2023). We conducted participatory observation while assisting in the data collection for the HRE study, and interviewed the participants to understand their experiences in the study. This work presents our analysis of the experiment and interview data, fieldnotes, observations, and a variety of other sources, such as the original experiment protocol and interview guide.

Detail of the Study Site

A total of 21 participants were recruited from a local university through an email list. Eight of them identified as male and 13 of them identified as female. Seven were undergraduate students and 14 were graduate students. The participants' majors included Information Studies, Computer Science, Latin American Studies, Biochemistry, and Biomedicine Engineering.

The HRE study consisted of (1) a lab-based experiment, (2) a survey, (3) a free-form interaction session with the robot, and (4) an interview. The robot adopted in the experiment was the Boston Dynamics quadruped robot Spot. In the experiment, participants were asked to walk from one end of a simulated hallway to the other end (Figure 1). Meanwhile, the robot was programmed to autonomously walk from the opposite end to where the participants were standing. The participants and the robot would encounter each other roughly in the middle of the hallway. The robot was programmed to avoid the participants autonomously and then keep walking to the destination. The participants were not notified what would happen in the hallway and were only instructed to walk freely and pass the robot however they felt natural. There were two conditions in the experiment, namely Leashed, and Autonomous. For the Leashed condition, a research team member walked together with the robot, holding onto a leash that was tied to it (the robot still walked autonomously). For the Autonomous condition, the robot walked by itself without the leash or and presence of the research team member. The Leashed condition was designed to test whether the presence of a human and canine behavior visual cue would influence the participants' reactions (see Hauser et al., 2023 for more detail). After the experiment, the participants were asked to answer a survey regarding their perceptions of the robot. The free-form interaction session came after the survey. The participants were offered a chance to interact closely with the robot, take photos or videos of it, and ask any questions they might have to the research team. They were also offered opportunities to see the robot perform additional tricks such as sitting down and dancing. After this session, the participants were instructed to join the interview.

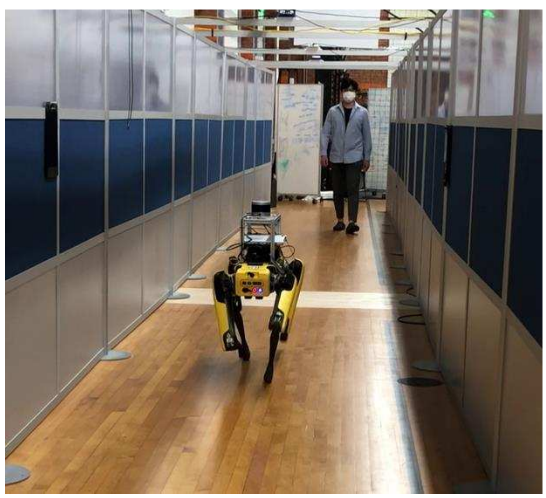

Figure 1. The simulated hallway, both the robot and participants walking in it.

Interview

The interview was semi-structured and consisted of seven core questions, including (1) the participant's experience in the hallway, (2) the influence of the presence of humans, (3) the participant's experience in the free-form interaction session, (4) the participant's speculation of their reactions to the robot in non-laboratory settings, (5) improvements to the robot, (6) the participant's familiarity and prior experience with robots, and (7) the participant's speculations of the robot's purpose in the study. The interview was supplemented with follow-up questions that were prompted by both the participant's answers and the researcher's observations. The first round of interviews (12 participants) lasted around 20-25 minutes and included only the first six core questions. As data collection and analysis happen simultaneously in Grounded Theory studies, we identified a prototypical question "What is the robot doing here" that was commonly raised in the first round of interviews. Therefore, we decided to add the 7th core question for the second round of interviews, which lasted around 25-40 minutes.

Data Analysis and Source

We adopted an integrated data collection and analysis process, which is characteristic of Grounded Theory methods. During the data collection process, the authors reviewed the interview data collected and conducted the initial analysis with open coding and constant comparison. The categories that emerged from the data prompted us to adapt the interview protocol as mentioned in the section above. The participant recruitment ended when we reached theoretical saturation. After the data collection was finished, we conducted iterative data analysis. We first coded participants' reactions in different phases of the HRE study, and then we coded what influenced the participants' reactions. The coding and constant comparisons were conducted iteratively until the theoretical categories emerged. Finally, we conducted memoing to document our interpretations of the theoretical categories which were the reactions in relation to familiarity, certainty, and confidence in encountering an autonomous quadruped robot.

Ongoing participatory observation in robotics research guided the author's interpretation of these findings. The authors recorded and discussed their experiences in assisting with the administration of the HRE study protocol. These experiences prompted follow-up questions for the interviews and informed the interpretation of the interview data as well. Iterative writing, analysis of fieldnotes, and basic memos all guided integrated data collection and analysis.

FINDINGS

We first describe the participants' reactions to the robot. After presenting and illustrating these, we focus on moments where participants described changes or shifts of reactions. Then we analyze the reactions and changes in terms of familiarity, certainty, or confidence, find patterns within participants along these facets, and propose and explain in detail our emerging theory: Human reactions in encountering an autonomous quadruped robot are influenced by their Familiarity, Certainty, and Confidence. (Figure 2). Finally, we describe the phases of the HRE study protocol in terms of the opportunities they present to the participants to increase their familiarity, certainty, and confidence in encountering an autonomous quadruped robot.

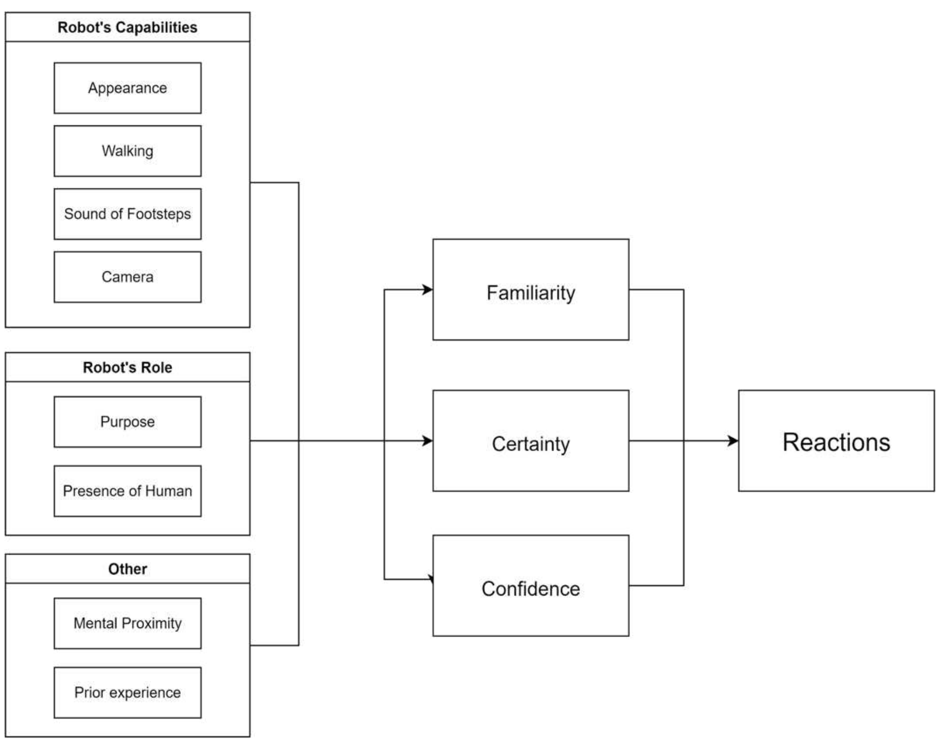

Figure 2. Our emerging theory: Human reactions in encountering an autonomous quadruped robot are influenced by their Familiarity, Certainty, and Confidence.

Participants' Reactions

This section briefly describes the participants' reactions we saw in our data. In the following sections, we elaborate on what influenced participants' reactions and why there were changes in reactions. All participants expressed that they were generally curious and excited about robots, so they wanted to learn more about robots by participating in this study. As for their first impressions of the robot, the participants reacted as surprised, scared, cautious, curious, and not surprised. There were two major inflection points when participants' reactions changed, including (1) the moment when they realized the robot would avoid them in the hallway (i.e. the encounter), and (2) the free-form interaction session. These inflection points made participants who were initially scared or cautious feel relieved, surprised, more comfortable, or become curious and impressed, whereas participants who were initially curious or surprised stayed curious or became excited and impressed. After our coding and constant comparisons of all interview data, the changes in reactions appeared to be the results of changes in familiarity, certainty, and confidence in encountering the robot. During the inflection points, several opportunities were utilized by the participants that helped them gain more familiarity, certainty, and confidence in encountering the robot. These were accomplished by having a better understanding of the robot's capabilities and role, as well as the increased mental proximity between the participants and the robot.

The Relationships Between Reactions, Familiarity, Certainty, and Confidence

This section details our emerging theory characterizing human-robot encounters in terms of participants' familiarity, certainty, and confidence. We first describe what influenced the participants' reactions and how the reactions relate to familiarity, certainty, and confidence. Participants' initial reactions were influenced by their prior experiences with robots and their first impressions of the robot's capabilities, including its appearance, walking, the sound of footsteps, and cameras. Many participants were unfamiliar with the robot, uncertain of what was going to happen, and were not confident enough that it would be perfectly safe to walk to the other end of the hallway. After the encounter, some reported becoming more certain and confident of their understanding of the robot's purpose. In the free-form interaction session, they also increased their mental proximity to the robot by being able to touch it and get close to it. These opportunities helped the participants gain familiarity, certainty, and confidence in encountering the robot. The participants also reported that the presence of a human afforded them a sense of familiarity, and more certainty and confidence that the robot was safe.

Prior Experience with Robots

Participants' prior experience with robots influenced their first impressions of the Spot platform. Every human has their own prior experiences, familiarity, or associations with robots. To some people, encountering a robot may be as normal as encountering a car. To others, a robot may appear as an out-of-this-world species. Even though encountering robots is still uncommon for most people nowadays, some participants reported that they had seen dog-like robots in movies or TV shows before. Yet interestingly, their reactions differed. Some participants had seen dog-like robots before and they were curious about the experiment. *"I've seen such a form. So I was just reminded of them. And I was really curious to see what it does and what the experiment really is." - P04.* Other participants remembered that dog-like robots were like predators in movies so they would need more time to be more familiar with it. *"Because I watch a lot of movies, where robots do come to life. It was walking like a dog or like a predator. So it did feel a little bit, it would take time getting used to." - P12.* One participant was cautious of the Spot platform because dog-life robots were weaponized in a TV show. "*In Black Mirror, the robot is exactly like this dog. And there's a sword that comes out of it. The sharp thing comes out of its body and it attacks you, so I was like really cautious if something is just going to pop out of it." - P19.*

Robot's Capabilities - Appearance

To most of the participants, the HRE study was the first time they saw a Boston Dynamics Spot in real life. Without any information about the Spot platform given to them prior to the study, they were unfamiliar with the Spot platform and uncertain about what it can do or was going to do in the study. *"I was like, asking myself questions about what's gonna happen next." - P10.* Due to its dog-like appearance, some participants implicitly treated the robot as a wild animal. They seemed to expect that the robot would act like a certain animal and projected some stereotypical wild animal behaviors onto the robot. *"kind of similar maybe to some other animals like a black panther, like those animals, because those animals usually have long legs and are good at running*". - *P06*. This projection made some participants cautious because of the possible outcomes of encountering a wild animal. "*Probably because this [robot] had limbs. That doesn't have limbs [other delivery robots]. I know that cannot charge and cannot run like an animal behind me. But this doesn't give me the same security." - P07.* To others, the connection between the robot and wild animals was even alarming as they thought the robot might hurt them when they got closer to it. "W*hen it was walking towards me, it definitely looked like a dog. When it came closer, it wasn't like fear but it was just a momentary shock. Like, what if it jumps on me*?" - *P12*. The answers showed that the unfamiliarity with the robot and the uncertainty of its capabilities made some participants react negatively. On the other hand, participants who recognized Spot as a robot that looked like a creature were intrigued by its appearance.

"I would say the looks of it stood out to me, the way it looked modern and robot-like, and also, like a creature at the same time. So that is what intrigued me. And I found that interesting. Me being maybe more on the techie side, curious about technology, and like future technology and stuff, I'm more comfortable with it. Because I see the possibilities." They seemed to be comfortable with Spot because they perceived Spot as a robot. This perception allowed them to associate Spot with technology and afforded them more confidence and certainty that Spot would behave like a robot. "*Yeah. I mean, I was pretty confident walking by, I wasn't worried or anything like the robot or something would happen to me*" - *P01.*

Robot's Capabilities - Walking

Due to technological constraints, the Spot platform continuously stepped in a fixed rhythm when walking or turning in order to prevent falling over, producing a kind of marching gait. This was a major difference in gait compared to the relative smoothness and stillness of quadrupedal animal movements. This marching gait seemed to make participants less confident that it was safe when they were approaching the robot. *"When it started walking like* 'Ta Da Ta Da'*, I got a little startled. But then I had in my mind that it's going to come towards me. So I was, overall scared." - P07.* The robot's ability to walk was frequently cited by participants in interviews. Some participants described the robot's quadrupedal gait as unusual, particularly its mechanistic character. *"I did feel like the walk, or the style of it walking was a bit mechanical. So when I first saw it coming, walking towards me, it took me a second to get used to that." - P14.* This unfamiliarity led to a feeling of surprise. *"When it started moving, I was a little taken by like okay, this moves a little differently." - P08.* Some participants commented that even though they knew being near to the robot was safe, its unusual gait made them nervous simply because they were not used to it. *"When it started walking, it kind of made me nervous, to be honest […] Like I knew that it was safe, but it's not something that I'm used to." - P15.* The robot's gait was cited multiple times as something that needed improvement, especially when participants were asked whether the robot would be suitable for deployment outside a laboratory environment. "*After it walks a little bit naturally and makes lesser noise, then it would make sense, then it would easily blend in with the surroundings as well. Not necessar[ily that] it should look like a natural dog. But it will easily blend in"* - *P16.* This answer implied that participants presumed most other people would be unfamiliar with quadrupedal robot gaits. There were also other participants who identified the robot's gait as its major difference from the more familiar quadrupedal walk of a dog.. "*It looked to me like a dog. [...] But the thing is, it was maintaining its pace, which dogs do not, generally mostly might not do. They might walk faster or slower. So I figured that it's not a dog."- P18.* Such comments reveal both the novelty of robotic gaits and the association of quadruped robots with canines.

Robot's Capabilities - The Sound of Footsteps

In the HRE study, the hardwood flooring made the robot's footsteps loud. Several participants were initially surprised by the sound of the footsteps because they were simply louder than expected. "*That thumping noise that it was making, that was also, again, because I was not expecting it to make that noise, so when it started, I was just taken aback.*" - *P08.* The unexpected noise from the footsteps was even scary to another participant. *"When I saw it, it was fine. But then it started walking it was really loud. That's the first thing I noticed. And I feel like if it was a little quieter, I wouldn't have been as nervous or scared around it." p02.* The sound was also a cue that seemed to make some participants perceive the robot as a wild animal. *"I didn't know that it makes that noise that horse makes." - P07.* Despite being surprised by the sound, several participants soon realized that the reason why the footsteps were loud was because of the hardwood flooring of the hallway, and the sound might be normal had the robot walked on a cement floor. *"The sound of it walking kind of struck me, but I kind of think the possible reason can be that it was a wooden floor. [...] But if it is maybe a normal, cement road, or like, ground or a track, maybe it wouldn't sound that much." - P17.* The recognition of the effect of the physical environment helped the participants understand why the robot was making the sound, and the negative reaction was not as strong as others.

Robot's Capabilities - Camera

Several participants noticed the cameras on top of the Spot platform. Some of them were curious about the camera's utility. *"I was asking more like technical questions about the camera and the laptop attached. I'm still curious about that. Like, was the robot able to sense that I walked up on this side of the hallway, and then it changed its path? Is that what happened?" - P02.* Others were concerned about privacy issues. "*If people on a street see that there's a camera on this thing, and it's recording them or seeing them, then they might feel like okay, this is an invasion of my privacy or something." - P20.* In general, privacy issues did not seem to be the main trigger for the participants to react negatively. Participants seemed to acknowledge that cameras were essential for autonomous robots, and our society was already full of cameras, such as smartphones and street cameras. In other words, the participants were already familiar with the idea of being exposed to cameras and that the robot's cameras were not used to spy on them. *"There will be scenarios that I might think that it is kind of recording, or is it watching or who is watching or whatever it is. But I do agree on the point that if there is a robot working, delivering stuff, I wouldn't mind." - P17.*

Robot's role - Purpose

During the interview, a prototypical question "What is the robot doing here" was frequently asked by the participants. This question prompted us to try to understand if knowing the robot's purpose was important, and if there were any changes in the reactions after knowing that the robot would avoid them. Firstly, some participants were curious about what the robot was going to do. *"It was the point of just passing through, and I didn't know what was going to happen. So I was just curious about that what the interaction would be" - P04.* Having little certainty about the robot's actions was uncomfortable for some participants. "*I was kind of thinking about who's gonna make way for the other. Am I gonna crash into the robot or something? So that kind of made me feel a bit uncomfortable." -P20.* Upon reflection, participants replied that they would be less cautious had they known what the robot would do. "*If I know that the robot is just to walk from that side to this side, which I already knew. And the robot might change its path to stay in its lane, then I could be a little less cautious. And also, I would say safe, because I know what it's trying to do and what it can be, it might not do anything to me. It's just completing its work." -P18.* After knowing that the robot would change its lane and avoid the participants, some of them felt excited. "*I just felt excited about seeing how it avoided me" - P05.* Another participant seemed to become a lot more confident in encountering the robot. *"It sensed my movement, and it changed its direction. After that, I became extremely normal. I was like, okay it's a good robot. After that, I have been completely warmed with it." - P07.* In addition, some participants also increased their familiarity with the robot and confidence in walking across it by associating it with typical pedestrians, and the robot was just tasked to do something. *"I felt like it had a mission, the robot doesn't care about me, it was tasked to move from point A to point B." - P10.* Some participants felt that it was important to know the purpose of autonomous robots because robots were developed by humans, so their actions were determined by the intentions of the developers. "*Maybe it's being controlled or it's been made, it's been programmed by humans, I would be curious to know what was the human thought process or like why did they think it's okay to let the robot out?" - P14.* Another reason why knowing robots' purposes was important was that humans' actions might depend on the robot's purpose. *"I feel like it's important to know, like, if it's an emergency, you can get out of his way. But if it's like running deliveries or whatever, then you don't have to be as conscious about it. As long as the purpose of the robot is always clearly stated, no one's gonna have a problem with it" - P21.* This was also an indication that being more certain of robots' purpose can have reciprocal benefits to both humans and robots. Overall, knowing what the robot would do was a resolution to many participants' uncertainty about the encounter. *"I now know that it's a robot, and what it does, like how it walks. So I was pretty much okay, knowing what this is." - P08.*

Robot's role - Presence of Human

In the Leashed condition of the HRE study, there was a research team member walking alongside the robot with a dog leash tied to it. The presence of a human next to an autonomous quadruped robot resembled a typical human-dog dyad which increased the participants' familiarity with encountering the robot. *"I think because we're at a stage with robots, like they're so new. That seeing a person with a robot, you can recognize a person. There's this familiarity factor. Like I can recognize a person and if a person's okay with this robot, it must not be scary, or anything like that. Maybe that's why I wasn't extremely uncomfortable with it." -P13.* The higher familiarity with the human-robot dyad was also comforting to some participants. "*Having a person holding the robot was very comforting" - P02*. Some participants also commented that besides the familiarity factor, they can also judge if a robot was safe by assessing the human next to it. Additionally, if the robot caused something, the human could be held responsible. *"I can see the human, and I can judge his intentions, and even if something is going wrong, I can hold him accountable". - P19.* Some participants commented that having a human present meant that the robot was under control, which offered some certainty and confidence that encountering the robot was safe. *"Maybe more secure, that at least a human is having a hold of the robot. So if something happens, just in case, they have at least control over it," - P17.* Some participants assumed that robots would have an emergency button, and humans could shut it off if anything dangerous happens. *"I will just assume that there was an off button, you can just put on the code and they'll shutdown, or you can just shut it down manually. So I didn't feel worried about that at all." - P09.* Another participant made an interesting comment that since robots do not have emotional control, then having a human controlling it will make people feel safer. *"Since robots in our society are not normalized yet. I feel robots need to be controlled by humans with EQ, robots don't have EQ. So if it's going to do something dangerous to children, maybe in a park, humans need to have a button to shut it down." - P07.*

The Mental Proximity Between the Robot and the Participants

In the free-form interaction session, the robot was stationary at first and some participants felt the robot was friendlier compared to when it was walking. *"When I was nearer to the robot, it was standing there quiet so that I felt like it's more friendly." - P21.* The sense of friendliness could be a result of knowing that the robot would avoid the participants and the lack of loud footsteps. Additionally, when the research team operated the robot to perform additional tricks, many of the participants felt fascinated by it and became more interested and curious about what else it can do. *"I was surprised that it can lay down as well. Like, I think after the second interaction, it makes me* *feel more curious and more positive on the robot because it can do a lot of tricks." - P11.* The interaction session was also an opportunity for the participants to get close to the robot and observe its machinery and technological parts. *"After I took a closer look at all the components and everything. I was amazed how it was working perfectly with all the heat running through." - P09.* Many participants took the chance to interact with the robot directly. *"I was like getting near it. And I wanted to see it sit and I want to take pictures of it." - P07.* The direct interaction, such as photo taking and touching, gave the participants more certainty that the robot was safe. "*When I touched it, I felt more like safe with it in a way, it made it more real, I think it stops becoming something that like I can't reach or something that I shouldn't be able to touch, or like not interact with. It was more like Oh, you're here. I'm here. We're in the same space." - P15.* The increased mental proximity between the participants and the robot was a resolution to many participants' negative reactions to the robot earlier in the hallway. *"During the second time, when seeing the stepping scene or how it turned or how it behaved, I don't feel that like scared." - P05.* Some participants also mentioned that they became more curious about the robot when they felt like they were closer to it. "*I feel like closer to it, I was like oh, what else can you do? I want to know more about it. I think from far away, it looks scarier, like oh I don't know how big it is, or how fast can it move, but once I was like up close, I was like oh it's just a robot. I feel like I want to know more and more, like intrigued." - P10.*

In our study, only one participant (P03) stayed not surprised and not curious throughout the study. When asked why she was not surprised, she replied: *"I mean, I've been around robots before, not a crazy large amount. But I've seen robots similar to that one walking or seeing pictures and media online, things like that."* This answer seemed to indicate that she was already quite familiar with the Spot platform and well-informed about its capabilities. Furthermore, when we tried to probe why she had the unsurprised reaction by asking if she knew what the robot was going to do in the experiment, she replied *"I was expecting it to have some sort of reaction. But like, it did. I wasn't crazy surprised. I went Oh, okay."*. The answer seemed to imply that she believed robots were typically tasked to do something. This was evidenced by her later response: *"I mean, I guess I was expecting it to do something as I walked by. Such as make sure it didn't run into me"*. Similar beliefs were expressed by other participants. *"The robot is supposed to be created by humans to do certain tasks." - P15.* The assumption that the robot's purpose was to support humans made P03 not surprised by the robot's actions. P03 also was the only one who decided to skip the free-from interaction session, because she felt like there were no more interesting things to see, and she disengaged herself from further interactions with the robot. *"I didn't think much would change besides just me approaching it, and it would walk around like it did before."* - P03.

Opportunities Offered by the Study Protocol

Sensitizing on moments of change in reactions lets us view the HRE study as a set of opportunities for the participants to change or update their perceptions of the robot. In the HRE study, the participants had a change in reactions in two moments. The first moment was when the participants and the robot encountered each other. Passing the robot was an opportunity that gave the participants certainty that the robot would not run into them or physically harm them. In other words, the robot's action was a resolution to the participants' uncertainty about its purpose in the HRE experiment. The second moment was the free-form interaction session. This session allowed the participants to directly interact with the robot and ask any questions they might have. With direct interactions, several participants increased their mental proximity to the robot and their reactions and perceptions of the robot became more positive. The presence of humans was another opportunity that helped the participants speculate the robot's role in the HRE study. The resemblance of the human-dog dyad presented a sense of familiarity and that the robot was under control. These helped the participants gain certainty and confidence in encountering the robot. Other than the HRE study, the interview session provided opportunities for the participants to reflect on their experiences in the study. During the interview, several participants took the chance to ask questions they might still have. The answers they received helped them gain more familiarity with the robot.

DISCUSSION

Reaction, Familiarity, Certainty, and Confidence

Our emerging theory proposes that human reactions to encountering an autonomous quadruped robot in an HRE scenario are associated with familiarity, certainty, and confidence. Before the encounter in the experiment hallway, the participants were not aware of the robot's purpose. Therefore, their reactions to the robot largely depended on their prior experience and familiarity with robots in general as well as their certainty and confidence in encountering the robot, which was influenced by their perceptions of the robot's capabilities. In terms of the robot's capabilities, we identified several categories, including appearance, walking, the sound of footsteps, and camera. After the encounter, participants were naturally made aware that the robot would avoid them in the hallway, hence the participants' reactions changed to more positive. In other words, the participants gained more familiarity, certainty, or confidence in encountering the robot by having a better understanding of its purpose. In the free-form interaction session, the participants had more opportunities to directly interact with the robot. They took the chance to get close to it, touch it, or take photos of it. These opportunities increased their mental proximity with the robot and hence gained familiarity, certainty, and confidence in it. The presence of a human next to the robot mimicked a typical human-dog dyad, which increased the participants' familiarity with it. Additionally, the presence of a human seemed to imply that the robot was under control, therefore, it provided a sense of security, and the participants' certainty and confidence increased, and they replied that they would feel better about it if there was a human next to it. Opportunities to increase familiarity, certainty, and confidence were keys to participants' resolution or relief from their negative reactions and uncertainty, and lack of confidence in their ability to predict and understand the robot.

We anticipate that one may argue to replace familiarity, certainty, and confidence with trust, and we can empathize with this argument. Trust has been proven to influence human-robot interactions where appropriate trust is key to successful collaborations between humans and robots (Khavas et al., 2020). Research has also investigated how to maximize trust through the design of transparency in robot systems (Matthews et al., 2020). Our study does not adopt trust as the main influence on reactions because trust is multi-dimensional. A review and meta-analysis study of trust in HRI conducted by Hancock et al. (2021) identified six categories of trust antecedents. In addition to the complexity of trust, it is typically measured using scales (Yagoda & Gillan, 2012). We do agree that trust has the potential to explain some of the human reactions in our data. However, no participants mentioned their trust in the robot in the interview, and the complexity of defining trust prohibited us from claiming trust as the driving factor in our data.

Implications for Future Research

The lab-based HRE study protocols presented here resemble real-world HREs but are implementable in a controlled setting. Although any lab-based study will suffer from reduced ecological validity compared to in situ research, our results benefited from our protocol's higher controllability. As HRE is still nascent, our lab-based approach helped us explore select facets of HRE phenomena. Using the Grounded Theory method, we identified familiarity, certainty, and confidence as key factors influencing participants' reactions to the robot encounters. These can inform hypothesis generation for future work on HRE with both quadruped and other robot platform types.

These findings might also inform innovation in the development of specialized HRE survey instruments. It is likely that familiarity, certainty, and confidence are not measured by currently available HRI survey instruments such as the Godspeed Questionnaire (Bartneck et al., 2009) and the Negative Attitude Toward Robots Scale (Nomura et al., 2006). The effects of the presence of humans and robot purpose, which surfaced from the interview and our observations, are also likely not adequately measured by existing HRI survey instruments. These effects will most likely continue to play a role in how humans handle robot encounters, and future HRI research may consider mixed methodologies to encompass the social nature and usability of robot deployments (Seibt et al., 2021). Triangulating interview data with quantified survey data can equip researchers with an integrated perspective to interpret the results and better understand how humans can co-exist with robots.

We provide an exploratory but nuanced account of the sources and dynamics of participant fear during encounters with quadruped robots. Fear of robots was pervasive but not universal among our participants, in line with survey-based results of the general U.S. Population (Liang & Lee, 2017). The Spot platform's appearance, movement, and sound were all potential sources of the experience of fear during the encounter. Media portrayal of robots being used as weapons in both fictional and journalistic coverage was also referenced by participants when discussing their fears. Our study protocol offered opportunities to help the participants increase their familiarity, certainty, and confidence in the robot, which mitigated the negative emotions and reactions of participants who utilized these opportunities. This suggests that studies of fear during robot encounters should consider utilizing opportunities to touch, be near, and ask questions about robots at some appropriate point in their experimental designs. Furthermore, our findings suggest that prolonged exposure or chances of direct interactions with robots are key to improving the quality of human-robot interactions. We join calls for more longitudinal studies of human-robot encounters (Hart et al., 2022); these are urgently needed to clarify the dynamics between participant experience and familiarity with robots in particular as autonomous mobile service robots continue to proliferate in public spaces.

A major finding in our study was that knowing the robot's purpose mitigated participants' negative emotions and reactions. We use this to argue that HRI research into bystanders' perceptions of robot purpose should complement existing work on the intelligibility of robots and tasks or objectives in human-robot teaming scenarios. This is not only for the success of robot deployments but also for the underlying ethical concerns (Wirtz et al., 2018). Robot personality is also a potential research direction for HRE studies. Research on robot personality has shown that humans tend to project personality onto robots (Fussell et al., 2008) as well as recognize a robot's personality through its designs (Chien et al., 2022). Our interview data also demonstrated that some participants projected a robot personality onto the robot, such as the "friendly" mentioned above. HRE studies using humanoid robots, service robots, or customer-facing robots may benefit from considering the effect of robot personality on their robot deployments (Whittaker et al., 2021), or examine how robot personality can influence people's familiarity, certainty, and confidence in encountering robots.

Limitations

We identified some challenges in our study. Firstly, the social nature, complexity, and unpredictability of HRE imply that there are many factors influencing how humans perceive and react to robots. Several of the identified factors in our study are context-dependent, such as the sound of the footsteps, the presence of humans, and the free-form interaction session. Our study only examined one aspect of HRE which was encountering a quadruped robot while walking across a hallway. Additionally, our study protocol provided opportunities to resolve some of the participants' questions or doubts. These opportunities may not be applicable to in-the-wild HRE studies, as most people may just walk past the robots without explanations provided. From our data, it is unclear how people would perceive robots if their questions were not resolved. Therefore, our findings do not entail all aspects of HRE and can only partially explain how humans react to robots when encountering them.

Secondly, our interview protocol also focused more on how the participants reacted or felt about the robot as well as how they formed their reactions and feelings. This protocol allowed us to investigate more specifically the design aspects of the Spot platform. However, this protocol did not offer the opportunity to understand how the robot can be deployed in different contexts, or how the robot can be tasked with different roles. Future research may attempt to take into account the robots' tasks and investigate how human reactions may be influenced.

Finally, studies have shown that humans form mental models of robots based on their appearance (Fink, 2012). The Uncanny Valley theory (Mori, 1970) describes the effect of the consistency between robots' appearance and behaviors. The theory has also been validated by numerous studies (Ciechanowski et al., 2019; Kim et al., 2019). Since our study focused on a relatively advanced quadruped robot, our findings may not reflect how humans react to other types of robots. Therefore, future research should adapt our findings if using different types of robots. Additionally, one aspect of our study protocol presented a human-robot dyad that resembled a human-dog dyad. This resemblance increased some participants' familiarity with the robot and mitigated some of their concerns. However, this might have contradicted the idea of robots being autonomous. As commented by one of the participants, having a human next to a robot might not always be ideal. *"It wouldn't make sense because the robot is supposed to be created by humans to do certain tasks. And if a human has to be present all the time, it doesn't make sense, right? So if the robot should be autonomous, it should be able to do everything on its own." - P12.* More research is needed to investigate the presence of humans next to autonomous robots.

CONCLUSION

The development of autonomous quadruped robots allows organizations and businesses to deploy robots to facilitate business operations. The deployment of robots will generate multiple human-robot encounters. However, how humans handle robot encounters in everyday life environments is still understudied. This work fills this gap by adopting participatory observation in a lab-based HRE study and applying Grounded Theory methodologies for data collection and analysis. The novel study protocol allowed us to explore human reactions to an autonomous quadruped robot, Boston Dynamics Spot, in a lab-based scenario that preserved the relevant aspects of real-world encounters. Our major contribution is an emerging theory that explains the relationship between human reactions, familiarity, certainty, and confidence in encountering an autonomous quadruped robot.

Encountering an autonomous quadruped robot such as the Spot platform was still an unusual experience for most participants. When they first saw the robot in the HRE study, they relied on their prior experience to speculate about the robot's capabilities for judgments. With one exception, participants' first impressions were some combination of curious, surprised, cautious, or scared. After the encounter, participants had a better understanding of the robot's purpose in the HRE study, and hence some of their doubts or questions were answered. In the free-form interaction session, the participants had a chance to directly interact with the robot. Those who did so reported that this opportunity helped them realize that the robot was safe and was something they could touch or use. As a result, their mental proximity to the robot increased. The encounter and the interaction session were two opportunities offered by our study protocol to resolve the participants' unfamiliarity, uncertainty, and lack of confidence in encountering. We suggest other HRE studies consider adding such opportunities as appropriate for their research goals.

This work can serve as the theoretical basis for future research in mobile autonomous service robot design and deployment. Our emerging theory that reactions are associated with familiarity, certainty, and confidence sheds light on the dynamic and experiential characteristics of HRE. Future studies can adapt these findings and our emerging theory to generate, develop, and refine hypotheses, and revise or develop specialized HRE survey instruments.

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REFERENCES

Avelino, J., Garcia-Marques, L., Ventura, R., & Bernardino, A. (2021). Break the Ice: a Survey on Socially Aware Engagement for Human–Robot First Encounters. *International Journal of Social Robotics*, *13*(8), 1851–1877.

Babel, F., Hock, P., Kraus, J., & Baumann, M. (2022). Human-Robot Conflict Resolution at an Elevator - The Effect of Robot Type, Request Politeness and Modality. *2022 17th ACM/IEEE International Conference on Human-Robot Interaction (HRI)*, 693–697.

Babel, F., Kraus, J., & Baumann, M. (2022). Findings From A Qualitative Field Study with An Autonomous Robot in Public: Exploration of User Reactions and Conflicts. *International Journal of Social Robotics*, *14*(7), 1625–1655.

Bartneck, C., Kulić, D., Croft, E., & Zoghbi, S. (2009). Measurement Instruments for the Anthropomorphism, Animacy, Likeability, Perceived Intelligence, and Perceived Safety of Robots. *International Journal of Social Robotics*, *1*(1), 71–81.

Bergstrom, N., Kanda, T., Miyashita, T., Ishiguro, H., & Hagita, N. (2008). Modeling of natural human-robot encounters. *2008 IEEE/RSJ International Conference on Intelligent Robots and Systems*, 2623–2629.

Chien, S.-Y., Chen, C.-L., & Chan, Y.-C. (2022). The influence of personality traits in human-humanoid robot interaction. *Proceedings of the Association for Information Science and Technology*, *59*(1), 415–419.

Ciechanowski, L., Przegalinska, A., Magnuski, M., & Gloor, P. (2019). In the shades of the uncanny valley: An experimental study of human–chatbot interaction. *Future Generations Computer Systems: FGCS*, *92*, 539–548.

Fink, J. (2012). Anthropomorphism and Human Likeness in the Design of Robots and Human-Robot Interaction. *Social Robotics*, 199–208.

Fussell, S. R., Kiesler, S., Setlock, L. D., & Yew, V. (2008). How people anthropomorphize robots. *Proceedings of the 3rd ACM/IEEE International Conference on Human Robot Interaction*, 145–152.

Hancock, P. A., Kessler, T. T., Kaplan, A. D., Brill, J. C., & Szalma, J. L. (2021). Evolving Trust in Robots: Specification Through Sequential and Comparative Meta-Analyses. *Human Factors*, *63*(7), 1196–1229.

Hardeman, K. (2021). Encounters with a seemingly autonomous sidewalk delivery vehicle: interviews with incidentally copresent pedestrians (Master's thesis).

Hart, J., Hauser, E., Baker, S., Biswas, J., Jiao, J., & Sentis, L. (2022). Longitudinal Social Impacts of HRI over Long-Term Deployments. *Proceedings of the 2022 ACM/IEEE International Conference on Human-Robot Interaction*, 1258–1260.

Hauser, E., Chan, Y.-C., Hemkumar, G., Chonkar, P., Dua, D., Mendoza Enriquez, E., Kao, T., Gupta, S., Wang, H., Jiao, J., Mirsky, R., Hart, J., Biswas, J., & Stone, P. (2023). "What's That Robot Doing Here?": Perceptions Of Incidental Encounters With Autonomous Quadruped Robots. *First International Symposium on Trustworthy Autonomous Systems*, To appear in Proceedings of TAS'2023.

Hoda, R. (2021). Socio-Technical Grounded Theory for Software Engineering. *IEEE Transactions on Software Engineering*, *48*(10), 3808–3832.

Khavas, Z. R., Ahmadzadeh, S. R., & Robinette, P. (2020). Modeling Trust in Human-Robot Interaction: A Survey. *Social Robotics*, 529–541.

Kim, S. Y., Schmitt, B. H., & Thalmann, N. M. (2019). Eliza in the uncanny valley: anthropomorphizing consumer robots increases their perceived warmth but decreases liking. *Marketing Letters*, *30*(1), 1–12.

Liang, Y., & Lee, S. A. (2017). Fear of autonomous robots and artificial intelligence: Evidence from national representative data with probability sampling. *Advanced Robotics: The International Journal of the Robotics Society of Japan*, *9*(3), 379–384.

Matthews, G., Lin, J., Panganiban, A. R., & Long, M. D. (2020). Individual Differences in Trust in Autonomous Robots: Implications for Transparency. *IEEE Transactions on Human-Machine Systems*, *50*(3), 234–244.

Moesgaard, F., Hulgaard, L., & Bødker, M. (2022). Incidental Encounters with Robots. *2022 31st IEEE International Conference on Robot and Human Interactive Communication (RO-MAN)*, 377–384.

Mori, M. (1970). Bukimi no tani (the uncanny valley). *Energy*, *7*(4), 33–35.

Moses, J., & Ford, G. (2021). See Spot save lives: fear, humanitarianism, and war in the development of robot quadrupeds. *Digital War*, *2*(1), 64–76.

Nomura, T., Suzuki, T., Kanda, T., & Kato, K. (2006). Measurement of negative attitudes toward robots. *Interaction Studies*, *7*(3), 437–454.

Rindfleisch, A., Fukawa, N., & Onzo, N. (2022). Robots in retail: Rolling out the Whiz. *AMS Review*, *12*(3), 238–244.

Rosenthal-von der Pütten, A., Sirkin, D., Abrams, A., & Platte, L. (2020). The Forgotten in HRI: Incidental Encounters with Robots in Public Spaces. *Companion of the 2020 ACM/IEEE International Conference on Human-Robot Interaction*, 656–657.

Seibt, J., Vestergaard, C., & Damholdt, M. F. (2021). The Complexity of Human Social Interactions Calls for Mixed Methods in HRI: Comment on "A Primer for Conducting Experiments in Human-robot Interaction," by G. Hoffman and X. Zhao. *J. Hum.-Robot Interact.*, *10*(1), 1–4.

Smith, D. H., & Zeller, F. (2017). hitchbot: The risks and rewards of a hitchhiking robot. *Suomen Antropologi: Journal of the Finnish Anthropological Society*, *42*(3), 63–65.

Whittaker, S., Rogers, Y., Petrovskaya, E., & Zhuang, H. (2021). Designing Personas for Expressive Robots: Personality in the New Breed of Moving, Speaking, and Colorful Social Home Robots. *J. Hum.-Robot Interact.*, *10*(1), 1–25.

Wirtz, J., Patterson, P. G., Kunz, W. H., Gruber, T., Lu, V. N., Paluch, S., & Martins, A. (2018). Brave new world: service robots in the frontline. *Journal of Service Management*, *29*(5), 907–931.

Yagoda, R. E., & Gillan, D. J. (2012). You want me to trust a ROBOT? The development of a human–robot interaction trust scale. *Advanced Robotics: The International Journal of the Robotics Society of Japan*, *4*(3), 235–248.

Yunus, A., & Doore, S. A. (2021). Responsible use of agile robots in public spaces. *2021 IEEE International Symposium on Ethics in Engineering, Science and Technology (ETHICS)*, 1–5.