Exploring Minimal Nonverbal Interruption in Social HRI

Paul Saulnier, Ehud Sharlin and Saul Greenberg
University of Calgary
2500 University Drive NW, Calgary, AB T2N 1N4
+1 (403) 210-9502
{p.saulnier, ehud, saul.greenberg}@ucalgary.ca

ABSTRACT
Designing robotic behaviours capable of initiating an interruption will be extremely important as robots increasingly interact with people. In this paper, we evaluate a *minimal* set of physical and nonverbal cues that can be exhibited by a robot to initiate robot-human interruption: (a) speed of motion, (b) gaze, (c) head movement, d) rotation and (e) proximity to the person. We then present a set of studies. For requirements gathering, we started with observations of interruption between humans, with a human actor attempting to interrupt other humans while being constrained to use only a set of behavioural cues that could be mimicked by a simple nonverbal robot. Next, we programmed a robot to exhibit these social nonverbal cues, and tested their feasibility in two separate pilot user evaluations. Finally, we performed an extensive user study of robotic nonverbal interruption across interruption scenarios. People were able to interpret robot behaviour as interruptions, and we identified the dominant cues people used to relate robotic behaviour to interruption urgency.

Author Keywords
Interruption, Human Robot Interaction, HRI.

ACM Classification Keywords
H.5.2 **[Information Interfaces and Presentation]**: User Interfaces-Interaction styles; I.2.9 [**Robotics**]

INTRODUCTION

Robots are expected to become pervasive in our everyday environments. We will expect them to interact with people, and to do so in a socially acceptable manner. For robots to work in such social settings, both robots and humans must understand each other's behaviours and respond accordingly. This is not yet something that we, as interaction designers, fully understand how to do. We do know that interpersonal behaviour is a complex phenomenon that includes language, tone of voice, gesture, posture, body movements, spatial orientation, physical proximity, eye contact, and facial expression amongst other attributes [8]. It is unrealistic (at least for now) for a robot to exhibit this behavioural richness. Thus our driving general question is: are there *minimal non-verbal behavioural cues* that robots can exhibit to communicate their internal state, and are those cues understandable by people? By *minimal*, we mean that we are interested in determining behaviours that rely on only a few simple physical capabilities present (or that can be easily added to) most robots.

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In this paper, we address a narrowed down subset of the above goal: exploring the process of interruption. For people, interruptions are a normal part of our daily life. We change our behaviours to initiate an interruption, where the particular behaviour we exhibit informs the person being interrupted about the importance and urgency of a situation. Our actions are based on our expectations of how others will understand, interpret and ultimately respond to our interruption behaviours.

Designing comprehensible robotic behaviours that are capable of initiating and tuning an interruption will be extremely important as robots increasingly interact with people. Arguably, some classes of robots will be capable of using verbal communication to interrupting users. Yet many robots will be non-verbal, and there are likely many situations where robotic voice conversation would be inappropriate. Thus we are interested in a more fundamental layer of social interruption which involves physicality, movement, interpersonal distance, gaze, etc. We argue that interruption between humans, verbal or not, always includes this physical layer, and that physical layer is extremely important when humans interrupt each other, and when they interpret the other person's interruption. We believe that for robots to be able to interrupt humans in a socially acceptable manner, designers of social robotic interfaces will need to master this fundamental physical layer of interruption.

Robots may have to communicate information to people with different levels of urgency, and as such they may have to interrupt the person in a contextually meaningful and appropriate way, where the person can respond to that interruption accordingly. This leads to our specific research question: are there *minimal non-verbal behavioural cues* that robots can exhibit to communicate interruption urgency, and are those cues understandable by people?

Our paper is structured as follows. We begin with related work that deals with interruptibility in HCI and in HRI. Second, we detail a series of four related studies that we used to gain insights about physical interruption, and to study people's reaction to robotic nonverbal interruption behaviour. We believe that our methodology in its own right carries a contribution to the domain, as it suggests how other robotic behaviours can be explored, developed and analyzed for interruption scenarios. Finally, we present the results from our user study and discuss their significance and implications on future design of nonverbal interruption in social HRI.

RELATED WORK

While robots were traditionally designed for various applications that did not necessarily require social interaction with people, past work in HRI has moved toward explorations of robots that interact with people, for example, as collaborators, personal assistants or as a pets. Example applications include tour guides, remote tele-presence for teleconferencing, and animal therapy [6,7,12].

Indeed, interruption and its effects have been scientifically scrutinized in HCI as well as other technical domains for years. Horvitz et al. found that decreased performance results from inappropriate interruptions to more complex tasks due to higher demands on cognitive capacity [4]. Chapanis and Overbey found that while interruptions changed the way that participants chose to accomplish a task, the actual performance time was not affected [1]. Storch explored whether the style of computer user interface used by a person affects their performance following an interruption, uncovering lessons in human-computer interaction that we believe can be generalized to HRI [10. P. Saulnier, E. Sharlin, and S. Greenberg. Exploring interruption in HRI using Wizard of Oz. In *DVD Proc. 5th ACM/IEEE Int'l Conf on Human-Robot Interaction - HRI'2010*, page 2 pages, Osaka, Japan, March 2-5 2010. IEEE/ACM. Late Breaking Report.

11]. In particular, Storch showed that according to participants: on-screen interruption messages are very disruptive; in-person visitors are somewhat disruptive and telephone calls not disruptive at all [10. P. Saulnier, E. Sharlin, and S. Greenberg. Exploring interruption in HRI using Wizard of Oz. In *DVD Proc. 5th ACM/IEEE Int'l Conf on Human-Robot Interaction - HRI'2010*, page 2 pages, Osaka, Japan, March 2-5 2010. IEEE/ACM. Late Breaking Report.

11].

Very few studies paid attention to nonverbal interruption aspects of human-robot interaction, and of those that do, most consider interruption tangentially. Dautenhahn et al. examined different ways in which a robot companion can approach a seated person in a helping context [2]. Satake et al. [9] and Hayashi et al. [3] considered how robots approach people in train stations and shopping malls, respectively. Yamaoka et al. [13] described a model for a robot to appropriately control its position i.e., proximity to the person, when presenting information.

Another study by Mutlu and Forlizzi reveals the possible problems that can be caused in a working environment by a robot that is not designed with interruptibility in mind [5]. In that study, they examined the effects of integrating robot workers into different medical and support units of a hospital to perform tasks such as collecting linen from outside patient rooms with assistance from hospital staff and returning empty food trays to the kitchen. Dramatic differences were found between units, e.g., there was low tolerance for interruptions in medical units.

METHODOLOGY

Our methodology focuses on designing and evaluating minimal robot behaviours for social interruption. To do so, we created a three-step methodological process.

1. Identify, through observations, human interruption behaviours within a particular situation that could be mimicked by a robot.
2. Based on these observed behaviours, design and critique potential robotic non-verbal behavioural cues, where those behaviours are based upon a minimal amount of the robot's physical capabilities (see below).
3. Implement these interruption behaviours using an actual robotic interface and use it to evaluate people's ability to interpret the robotic behaviours.

We have already stated that we are interested in exploring *minimal non-verbal behavioural cues.* By this we mean that we are interested in determining interruption behaviours that rely on only a few simple physical capabilities present (or that can be easily added to) most robots, regardless of whether these have further verbal abilities or not. Our methodology was limited to the following five parameters, which we deemed would provide a solid starting point to our explorations: (a) speed of motion, (b) gaze, (c) head movement, d) rotation, and (e) proximity to the person. Although we explored nonverbal interaction only, it is important to state that some of these factors are associated with ambient sounds, for example, noise generated by motors that drives a robot's movement. Importantly, by looking at minimal non-verbal behavioural cues, we are trying to determine the lower bound of robotic interruption behaviours that could be understood by people.

OBSERVATIONAL STUDY: IDENTIFYING ROBOT INTERRUPTION BEHAVIOUR

Our first question was: can we identify human interruption behaviours within a particular situation that could be mimicked by a robot? We focussed on identifying ways that a robot can interrupt a person to match different levels of urgency and importance, where that person should be able to interpret those interruption behaviours accordingly. Answering this question will prove valuable to designing

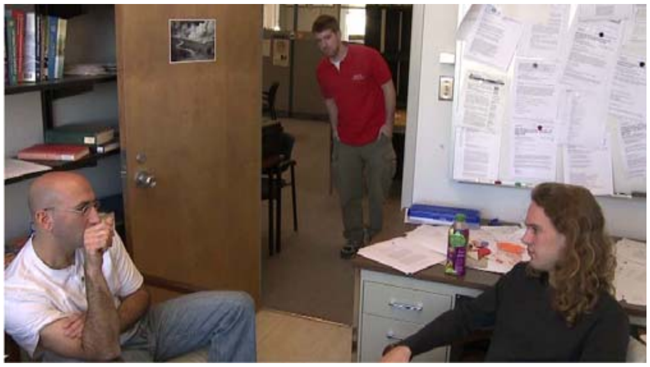

Figure 1: An actor looks inside the office from a distance to interrupt unobtrusively.

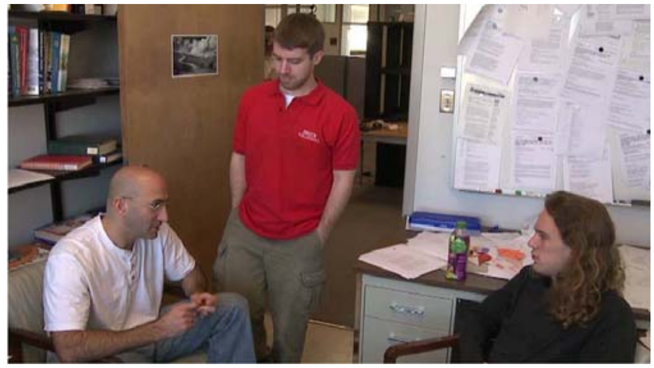

Figure 2: An actor kicks the person's chair while attempting to interrupt him.

robot interruption behaviour that is minimally disruptive to people, while still adequate to convey urgency and importance appropriately within a particular context.

Our approach - which we believe can be generalized to other situations - was to constrain human behaviour to particular physical capabilities that we believed could be reasonably mimicked by a robot, and to then have a person, an informed actor, try to interrupt others using only those capabilities. We monitored that person's behaviour, and later used that behaviour to model robot behaviour (see Video Figure for examples).

Specifically, three people were recruited as "robot actors" and asked to act through five interruption scenarios. These scenarios ranged a spectrum from time-insensitive non-urgent matters to important time-sensitive matters to emergency situations that required immediate attention and action. Within each scenario, the actor had to interrupt two people who were engaged in a meeting inside an office with an open door. The actor was asked to improvise interruption behaviour appropriate to the urgency of the situation. The robot actors were constrained to show only the five previously mentioned parameters that our target robot could replicate, i.e., speed of motion, gaze, head movement, rotation and proximity to the people being interrupted. Robot actors were not allowed to speak or to make sounds. Furthermore, we instructed them to leave if no acknowledgement of their actions was provided after 10 to 15 seconds. An element kept secret from the robot actors was that the people they were interrupting were instructed to ignore the robot actors for at least 10 seconds, to allow the experimenters to have enough time to observe the robot actor's behaviour.

We videotaped the robot actors' actions, and identified characteristic behavioural trends. We saw that our robot actors improvised with a range of body and head movement to match the given scenarios.

For less urgent, less important scenarios, actors used behaviour similar to that shown in Figure 1. In these cases, the robot actor would 'peak into' the office from a distance to see if the people inside the office were busy, and if it would be possible to interrupt without disrupting a more important task. While it is possible for the people seated in the office to notice the actor, it is also possible and appropriate to ignore him or her if desired.

Our robot actors used more disruptive behaviour as urgency and importance increased in the scenarios. One robot actor entered the office running, circled around the people inside a few times before kicking the person's chair and legs until acknowledged, as shown in Figure 2. In these cases, the behaviour was certainly more noticeable to the people inside the office, who were unable to continue their conversation because of the interruption.

As urgency increased, the robot actor generally would not leave, maintain close interpersonal proximity, and hold their gaze until their interruption was acknowledged and addressed.

Indeed, people often added their voice or physical actions, such as knocking, in many interruption scenarios. However, the clear range of behaviour used by the robot actors shows that people can improvise their behaviour using our 5 basic characteristics to interrupt in different ways, and presumably still be understood. This understanding suggests that a robot designed to use similar interruption behaviour will be understood by people.

DESIGNING ROBOT INTERRUPTIONS / 1ST PILOT

We used our observations of interruption behaviour expressed by the robot actors to design and program robot behaviours. Given the technical limitations, our designs are caricatures that try to capture the essence of these behaviours. We decided to evaluate our first prototype in a design critique session [10] as we were aware that we likely wouldn't get this 'right' the first time.

For example, for situations with low urgency and importance, the robot was programmed to move slowly, with fluid head movement. Similar to a person walking by an office, the robot would move to a position where it could observe the person it wished to interrupt (and thus presumably be seen by that person) but would not approach the person. For situations with high urgency and importance, the robot was programmed to move very quickly, with erratic head and body movement, all designed

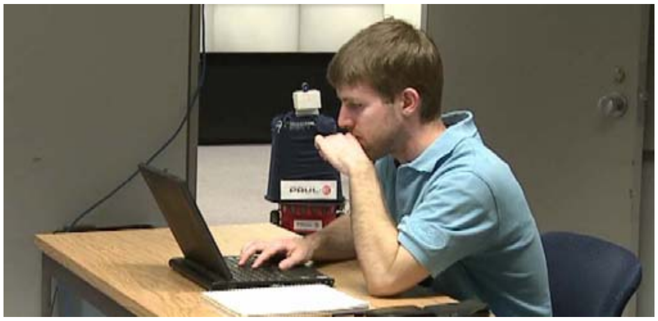

Figure 1: The robot interrupts a participant in a design critique session.

to be as disruptive as possible to the user. The Video Figure provides examples.

For this first pass, we conducted a pilot study/design critique using scenario walkthroughs that included two participants recruited from our laboratory. Our expert participants were asked to help us test, discuss and critique the general suitability of the chosen interruption behaviour when applied to robots, as well as the robustness and nuances of the technical implementation of the robot and its controller software. For the scenario walkthroughs, each participant was seated in a room alone with their laptop computer and instructed to work on a task of their choice. All attempts were made to minimize distractions in the room so that the evaluator could focus on their task. The participant was seated so that the doorway to the room was visible to their right. This doorway was then used by the robot to approach and optionally enter the room to facilitate an interruption that could attract the attention of the participant. Figure 1 shows one low-urgency interruption scenario, where the robot simply passes by outside the door without entering the room. Following each interaction with the robot, the study administrator entered the room to discuss and critique the interaction with the participant before returning to control the robot again.

We used a Pioneer-3DX as the robotic platform, and its behaviour was non-autonomous and was fully controlled using a Wizard of Oz methodology, where the robot was remotely controlled (using a set of pre-programmed macros) by a study administrator sitting outside the room and out of view of the evaluator.

First impressions of the robot behaviour from the participants were encouraging. Generally, participants were able to discern the meaning and level of urgency and importance from at least some of the robot's behaviour. More importantly, these initial sessions proved valuable at identifying fundamental problems in the design of our robot behaviours, as well as technical issues which caused the robot to malfunction or produce undesirable behaviours. For example, reliability and repeatability were compromised because the study administrator had to manually control the robot at all times. The design critique also revealed problems collecting meaningful quantitative data. Specifically, there was no way to determine, aside from the interview, how participants interpreted specific factors of the robot's behaviour without relating them to the overall experience. For example, how did the speed of motion, type of movement, or physical position influence the sense of interruption? Nor was there any way to quantitatively identify the degree to which these behavioural aspects were effective at conveying information such as urgency and importance in a particular interruption scenario.

REDESIGNING ROBOT BEHAVIOURS / 2ND PILOT

Based on the design critique results, we modified our robot behaviours and redesigned our pilot study to qualitatively and quantitatively test the effectiveness of these behaviours.

First, we changed our scenario details. Instead of having participants choose their own task (which could affect how attentive they might be toward the robot), participants were engaged in a casual conversation with an interviewer (an actor), both seated in an office and oriented in such a way that allowed the participant to see the doorway.

Second, we created ten robotic interruption behaviours using combinations of our behavioural parameters as summarized in Table 1 (the gaze variable captures both gaze and head movement). Scenarios are labelled 1A-F, and 2A-D. Scenarios were designed so that any one scenario had another matching scenario that differed only by a single difference in one of the behavioural properties. For example, behaviours 1A and 1B in Table 1 are both based on subtle robotic interruption via observing the participant from outside the doorway, but they differ in the speed of motion used. This approach thus enables any differences in the participant's interpretation between two scenarios to be feasibly attributed to the single variable that changed its value. Finally, we included an 11th null base case where a robot would be doing an action that had nothing to do with interruptions: slow movement outside the office without any direct interaction with the participant.

		slow speed		*fast speed*	
proximity position	*rotation*	*direct gaze*	*erratic gaze*	*direct gaze*	*erratic gaze*
far from doorway	*none*	1A		1B	
	rotating				
at the doorway	*none*	1C		1D	
	rotating				
next to participant	*none*	1E		1F	
	rotating	2A	2C	2B	2D

Table 1: Behaviour scenarios by factor (speed, proximity, gaze, rotation) used in the 2nd pilot and the main user study.

While the five initial situational behaviours were presented in an increasing order of magnitude, the ten property-based behaviours were arranged to be presented in a scrambled order to the participant, following the null base case. The

Figure 2: A partial view of the Interruptedness Metre used by participants to rank interruptedness in the study's 2nd phase.

design of the behaviours makes it somewhat difficult to make a precise ordering of magnitude. However, we expected that scenarios with fast speed, close, direct gaze, and rotation (Table 1, bottom right) would be higher in interruption magnitude than those with opposite values (Table 1, top left).

Third, we addressed the unreliable robot control issues by creating fully automated pre-programmed behaviour macros that ran autonomously. This relieved the study administrator of the need to manually control the robot's behaviour. It also ensured that all participants would observe nearly identical robotic behaviour.

Fourth, we added a second phase to the study. The robot interrupted the participant conversation, but this time the interviewer stopped the conversation after each interruption and asked participants to quantitatively rank all eleven robot behaviours through the use of a custom ranking device we called 'Interruptedness Metre' (Figure 2). This ranking added another opportunity to gain insight about the participant's experience. With all eleven behaviour scenarios being measured in the quantitative phase, we shortened the first phase to use only four representative behavioural scenarios (including the null base case) to save time.

Finally, we ran a pilot to test this methodology using four participants, none of whom had participated in our previous pilot. Preliminary analysis indicated that changing an individual property of the robot's behaviour had a noticeable effect on the participant's experience. As well, participants had different opinions regarding many of the behaviours, including ones with only subtle differences. Based on these results, we continued to our full user study.

USER STUDY

The user study was designed to extensively test the degree to which particular *minimal non-verbal behavioural cues* used by robots to communicate interruption urgency (Table 1) are understandable by people.

Equipment

Our equipment comprised two major components: (a) the robot platform and (b) a controller workstation station used to control the robot and to record participant comments.

The robot platform is a Mobile Robots Inc Pioneer 3-DX base with a custom body added on top. The base is capable of moving faster than human walking speed and can carry heavy loads. Our custom body consists of a plastic container used to increase the height of the robot, covered by a t-shirt to reduce the robot's mechanical appearance without going as far as serious anthropomorphizing it. The robot's 'head', used to portray head movement and gaze, is just a small cardboard box; depending on the scenario, we could rotate this head left/right and up/down.

The head does not include any facial markings such as eyes, though it does have a clear directional forward position. This minimalist design was done because, as mentioned in our methodology, we wanted to rely on only a generic shape and a few simple physical capabilities of movement that are present in (or that can be easily added to) most robots.

Robot control is done through direct serial connection to an on-board hidden laptop, where the laptop runs custom C#/C++ software. All sensory monitoring (including obstacle avoidance) occurs on the laptop. Commands to control the robot are sent from the study administrator via a controller station. The robot can also send back timestamps and descriptions of high level events that it is performing back to the controller station (e.g. the robot is approaching the participant).

The controller station, which also ran custom software, served two purposes, where a study administrator could use it to (a) control the robot's behaviour and (b) record relevant participant comments. It comprised a standard laptop with a second monitor, and a wireless router that linked the controller station with the robot. The controller station was positioned so that participant comments could be heard and thus recorded, and where the robot was always within view except when it entered the office. Participants could not see this controller station (or the study administrator) from within the office.

Controller software on the controller station was primarily used to issue high level commands to the robot that triggered predefined macros that executed particular robot behaviour. Manual positioning controls were also provided to let the administrator move the robot to the same starting location (although normally the macro will automatically return to that starting position) after a scenario finishes. The software also supported logging timestamps and other high level events sent back to the station by the robot.

Participants

Twenty participants were recruited through mailing lists at the University of Calgary. Although no particular groups were targeted, the vast majority of participants were a nearly equal mix of male and female graduate students with varied ethnic backgrounds, many of whom were members of the Faculty of Engineering, with ages ranging from 20 to 30. Participants received $15 in compensation. Each study session was approximately 45 – 60 minutes long.

Experimental Procedures

The study consists of two phases. Both were qualitative, while the second was also quantitative. In both phases, the participant and the interviewer were seated in an office (e.g., Figure 3), having a conversation about topics unrelated to robots or the user study. The participant had a clear view of the doorway to his or her right. While the conversation was occurring, the robot underwent attempts to interrupt the participant across a series of scenarios as described previously, where the robot exhibited particular behaviours according to that scenario as described in Table 1. All scenarios began with the robot out of view outside the office. The two phases differed in the particular scenarios used (and thus the robot behaviour exhibited), and whether a verbal interview or ranking by the participants occurred once the robot had completed its behaviour.

The primary purpose of Phase 1 was to gather qualitative and unbiased reactions to interruption. Phase 1 comprised four pre-programmed behaviours initiated by the study administrator that correspond to various scenarios: the null base case, 2D, 1A, and 2A, as defined in Table 1. These scenarios were selected to exhibit a wide range of robot behaviour. However, the scenario order – which was the same across participants - was randomly generated. To reduce predictability of when an interruption may occur, each scenario was separated by a short delay of a few minutes. During each attempted interruption, the interviewer encouraged the participant to talk about their reaction, i.e., the methodology followed that of constructive interaction think-aloud. Everything the participant said was recorded in real time by the study administrator. After the behaviour ended, the interviewer asked further questions about the interruption.

The primary purpose of Phase 2 was to gather additional reaction to the robot's behaviour, and to quantitatively rank the level of 'interruptedness' of each behaviour. In this phase, the robot progressed through all eleven pre-programmed behaviours (the null base case, plus the ten scenarios defined in Table 1), with little delay between them. Following each scenario, the participant was asked to rank how interrupted he or she felt by the robot's behaviour by placing a marker corresponding to the robot's behaviour scenario on our 'Interruptedness Metre' (e.g., **Error! Reference source not found.**). The participant was informed that markers could be placed anywhere on the ranking device, but they could not overlap.

After both phases, participants were interviewed for their final impressions and thoughts.

RESULTS

As described in the previous section, both quantitative and qualitative data were collecting during the user study.

The qualitative data consisted of verbal comments made: by participants during phase 1 and to a lesser extent in phase 2, and during the verbal interview after phase 2. Comments were captured in video recordings, as well as in notes taken by the study administrator in real time. The notes were used

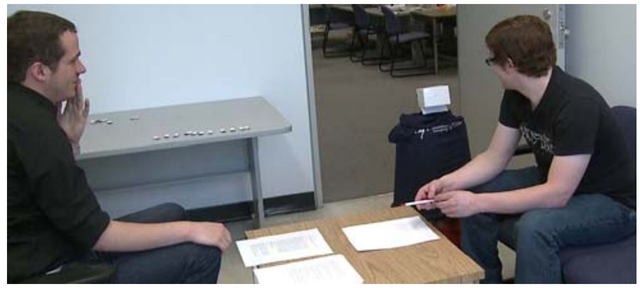

Figure 3: The robot interrupts a participant inside the office

to assist processing the full video recordings. The Video Figure provides examples of particular episodes.

The quantitative data comprised eleven rankings collected from each participant using the Interruptedness Metre during phase 2. Rankings, which were made on a continuous scale from 0 to 100, form the participant's subjective measure of how they interpreted the observed robot's behaviour. A higher ranking corresponded to a *higher* level of interruptedness, while a lower ranking corresponded to a lower level of interruptedness. Rankings were collected from all twenty participants, although one participant's results were discarded due to corruption of their data. Based on the nature of the collected ranking data, a *linear mixed model* was used for our statistical analysis. The model was configured to use the null base case data as the covariate, ensuring that all data analysis took that it into account as the baseline.

Identifying Significant Behavioural Factors

The robot's behavioural scenarios (shown in Table 1) were designed to enable statistical analysis that identified which of the robot's behavioural factors (such as speed of motion, head movement, etc.) actually had a statistically significant impact on the interruptedness felt by a person due to the robot's behaviour.

Tables 2 through 6 summarize the statistical significance of each individual factor of the robot's behaviour used in the study as well as the interaction between factors. P-values are considered statistically significant based on a threshold of $p<0.05$. These significant values are distinguished using bold text in the tables.

Table 2 summarizes the effect of speed of motion, interacting with gaze and proximity. The speed used by the robot for its spatial motion as well as its head movement was either slow or fast. As Table 2 indicates, speed of motion was significant only when the robot was situated next to the participant. When the robot was located at the doorway of the office or outside the doorway, no significant impact was observed.

Table 3 summarizes the effect of gaze, which interacts with speed. The gaze suggested by the robot's head movement was either directly focused on the participant, or erratic movement where the head was constantly moving in all directions. The data in the table indicates that gaze had no statistically significant impact.

Table 4 summarizes the effect of proximity, interacting with speed. The robot used three proximity positions: next to the participant, at the doorway, and outside the doorway. The data shows that there was no statistically difference between being at the doorway or far from the doorway. However, there was a significant difference between being far from the doorway and being next to the participant. When comparing positions at the doorway and next to the participant, there was only a significant difference at fast speed, and not slow speed.

Table 5 summarizes the effect of rotation, which interacts with speed. For some behavioural scenarios, the robot rotated its body in place while stopped, while it used no body movement when stopped in other scenarios. The data shows that this factor was not statistically significant.

Means

The means presented in Table 6 shed light on the magnitude and direction of differences for the robot behavioural factors that proved significant.

For speed of motion, the differences in interruptedness between slow and fast when the robot is next to the participant are not only statistically significant, they are also large: around 20% each (see Table 6, bottom row is close proximity, 46.2 slow vs. 63.7 fast, and 51.2 slow vs. 72.2 fast).

For proximity, the significant differences in interruptedness are around 25-30% when comparing positions of far from the doorway to next to the participant (see Table 6, 19.3 far from doorway vs. 43.8 next to participant, and 34.6 far from doorway vs. 64.0 next to participant).

As mentioned, our statistical analysis indicates that the differences for gaze and rotation are not significant.

Qualitative Results

We now summarize and discuss the qualitative comments received for both phases of the study: the first qualitative phase, as well as the second phase which was focused on quantitative feedback but also allowed the participant to provide further qualitative reflections. We begin with participant impressions of each scenario in Phase 1. Following that, we talk more generally about particular perceptions people had across both phases.

The Null Base Case: Impressions of the Robot

The null base case occurred first, after the participant was in the office for a few minutes, i.e., the robot passed by the office door without any head movement, and did not gaze into the office. During this episode, about half of the participants commented on the robot's behaviour just as it began moving past the doorway; the others just kept talking to the interviewer, and talked about the robot only when asked by the interviewer when the episode ended. Most said

For Gaze	at participant				erratic
Proximity	far from doorway	at doorway	next to participant		
Scenarios	1A & 1B	1C & 1D	1E & 1F	2A & 2B	2C & 2D
P-Value	0.139	0.360	**0.025**	**0.010**	**0.006**

Table 2: Significance of Speed of Motion

For Speed	at slow speed	at fast speed
Scenarios	2A & 2C	2B & 2D
P-Value	1.000	0.996

Table 3: Statistical Significance of Gaze

Speed/Proximity	at slow speed	at fast speed
Far from Doorway vs. At doorway	1.000	1.000
At Doorway vs. Next to Participant	0.050	**0.000**
Far from Doorway vs. Next to Participant	**0.012**	**0.000**

Table 4: Statistical Significance of Proximity

Speed	at slow speed	at fast speed
Scenarios	*2A & 1E*	*1F & 2B*
P-Value	1.00000	1.00000

Table 5: Statistical Significance of Rotation

		at slow speed		at fast speed	
proximity	rotation	direct gaze	erratic gaze	direct gaze	erratic gaze
far from doorway	none	19.3		34.6	
	rotating				
at the doorway	none	23.8		33.4	
	rotating				
next to participant	none	43.8		64.0	
	rotating	46.2	51.245	63.7	72.2

Table 6: Interruptedness Means by Factor

they first detected the robot because of its noise, even before it was visible through the doorway. Many described the details of how they observed the robot's behaviour using phrases like "it just passed by", "it's coming", and "it disappeared". The behaviour was "calm", and "not disturbing". One participant said the robot looked as if "it could move faster" than it was. Although all participants clearly noticed the robot, one said it was not "super distracting" and that it got his attention in a "polite way". Another said the robot was "minding its own business" and that it "didn't affect the flow of conversation". One found the whole behaviour to be "pretty weird".

Participants were asked what they thought the robot was trying to do, or what its intentions were. None felt that the robot was trying to interact directly with them, but opinions of what it was doing varied. Some assigned social presence to the robot similar to a co-worker just passing by on the way to some other location, or pacing about with no specific mission, or in the middle of accomplishing a task such as delivering messages or moving objects around the office. One even compared the robot to a "child, waiting to be noticed".

Participants were quite generous in the social abilities they afforded to the robot, despite it lacking any form of eyes, ears, cameras, microphones, or speakers. Many participants felt the robot was "curious" about their presence, even "spying" or "eavesdropping" on the conversation, because the robot did not "know" who the participant was. One even implied that the robot felt territorial because it was approaching for a "sense of security". Others felt that it was responding to louder talking between them and the interviewer. Some were more specific, saying that the robot "heard its name" (despite the robot not having a name during the study) or the word "robot", and wanted to hear more of the conversation. Many noticed the robot's lack of active behaviour (other than moving by the doorway), and said the robot was not interacting because they were "not paying attention".

2D: fast, erratic gaze, close proximity, rotating

In the next episode, the robot directly approached participants with its most extreme behaviour, where it was active and fast-paced (Table 1, scenario 2D).

Participants initially described this behaviour using active words such as "weird", "big", "racing", "scared", "frantic", "hard to ignore", "in a rush", etc. Many participants said they were "annoyed", "distracted", "disturbed" and "interrupted" by the behaviour, and unable to continue their conversation with the interviewer. The entrance of the robot into the room was described as "forceful" or comparable to banging on a door. Because of the robot's faster movement, its motors made more noise, which one participant described as "different" and "huge".

The behavioural factor mentioned most often was speed. Head movement was also mentioned, but to a much lesser extent. Many participants also noted that the robot came into the room (referring to the factor of close proximity) *vs.* the previous scenario where the robot just passed by the doorway. Very few commented specifically on the robot's body movement while inside the room during the whole study, even though it was persistently rotating back and forth for 15 seconds. One specifically said that the closeness of the robot felt more significant than its movement. Another said it was "kind of weird" that the robot was communicating with body language only, and no verbal communication.

Almost all participants viewed this behaviour as representative of an "emergency", "something [being] wrong", "someone hurt", or something having "happened". Several participants even identified the emergency as a possible "fire", one saying "probably a fire". One said the robot's behaviour indicated that it was necessary to stop the conversation and move out of the room.

Almost all used words such as "important" or "urgent" to describe the potential reasoning behind the interruption. One said this behaviour would be "rude" if it was used to interrupt an important meeting, but not a casual one.

In summary, it is clear that this behaviour was largely associated with "fire" or "emergency" scenarios. Indeed, one participant said the behaviour would be "inappropriate" for a non-urgent interruption such as a greeting.

1A: slow, direct gaze, far from doorway

In the next scenario in Phase I, the robot stood outside the doorway and did not enter the room (Table 1, scenario 1A). Generally, this behaviour was seen as non-interruptive. In all but one case (where the robot was not even noticed), participants noticed the robot in part due to the noise it was making. Comments described how non-interruptive it seemed, for example it was "not interrupting" because it "did not approach too close, but from a distance".

Many participants felt that the robot was acknowledging their presence and "noticing" them, e.g., "this time I'm sure it's noticing us", because of the "head movement". A few said the robot was going by, but was stopping to "listen to the conversation", and that it was "paying attention". Another said it was "curious" and that it was "eavesdropping a bit" because it "overheard the conversation and was interested".

Other participants interpreted robot behaviour as something other than interruption-based. One said it doing "periodic checking, in case we need something". Another said the robot was "peeking inside the room" and then "reporting back to someone else".

2A: slow, direct gaze, close proximity, rotating

In next scenario, the robot operated at close proximity (Table 1, scenario 2A). Participants had varied impressions.

One participant noted that the robot, like a person, was more interruptive when it entered the room, compared to when it did not enter. Another said the robot seemed to be acting with more "maturity" due to the eye contact, and that it was respectful and more "accustomed to social rules". One said he was "surprised by the smooth motion", and that it was "not going crazy".

Many participants surprisingly expressed how they felt emotionally about this interaction, contrasting it to the previous 'urgent' behaviour noted in scenario 2D. Two participants said that this behaviour "didn't scare" them. One said that the previous one had lots of "shaking" and required some "getting used to". Another said the robot was "not very annoying" whereas it was previously "making a lot of noise" and "bothering" him. One participant felt more comfortable, whereas they had been previously worried that the robot might have hurt them in 2D. One participant "preferred" this behaviour.

We now turn to more general impressions of the robot across all scenarios of both phases.

The Robot as a Social Being

Many participants made comments about the robot as if it were a person. One participant said the robot was like a "real being" because it was showing interest in things, going away and then coming back. Another said it moved and tried to gain attention by "barging" in and moving its head. One felt that the robot was "annoyed" that its space was being intruded on. Another suggested that the robot was actually trying to annoy him or do something funny.

Two participants did compare the robot to non-human entities, such as a dog running up to a visitor when entering a house. Another compared the robot to a child entering the room, in a manner that a child might approach his or her parent, to say that someone was annoying them.

The Robot as a Machine

A few participants described the robot as a machine. One said its procedure was "smooth", because of the "mechanics or software". Another suggested that the robot was exhibiting certain behaviour because it was "broken" or "damaged". Yet another felt that the robot was "examining the perimeter, becoming familiar with its surroundings, and mapping out objects". One said the robot seemed to be "analyzing" them, collecting data, taking pictures, and recording audio.

Surprisingly, only a small number of participants suggested the robot was running through "programmed" behaviour or being controlled by the study administrator during the study. We actually expected more participants to make this conclusion, as the robot's appearance did not imply any possession of adequate sensors or intelligence that would enable fully autonomous operation.

Politeness when Interrupting

A common theme used in describing the robot's behaviour in many scenarios was politeness. Many participants felt the robot had some intention, but that it chose to defer that intention when it noticed that a conversation was in progress. One participant thought the robot wanted to "say something" that was "not important", but that it "changed its mind" because of the conversion, and that it would "come back later". Another felt the robot was coming for a "scheduled meeting", but that it was "waiting outside". Many participants defined this behaviour as either "normal", "better" and "more gentle" than other scenarios where the robot had used much more extreme behaviour. Another said the robot was "looking for someone" on behalf of someone else, and that it was "trying to say something", but did not say anything because it "didn't want to interrupt" the conversation. Similarly, another participant said the robot was "trying to look for an opening in the conversation" so that it could "add to it".

A couple of participants interpreted authority as a factor, and compared the behaviour to someone who "is waiting for a superior to finish" and that the matter was not "urgent", as the robot was not "actively catching attention". Another participant saw the robot as a "messenger" or "servant". Another felt the robot was acting as a servant, but for someone else.

While most participants used comments that implied some element of politeness, one participant said the robot was "impolite" because it was just "staying there and staring", though even this person noted that the robot "didn't want to interrupt".

Familiarity with Robot

Two participants commented on their increasing familiarity with the robot across scenarios. One said the robot made a bit of noise and was distracting in a way that was "out of character", implying a certain familiarity with some behaviour that was "in character" for the robot. Another said he had "seen the robot too many times before" and that he was becoming "more sensitive" to noticing it over time. Another didn't look at the robot much because it was becoming a "common occurrence", while another said he was getting "used to" the robot.

DISCUSSION

Based on the results of the user study, we now have several insights about robot interruption behaviour.

First and foremost, we have verified that robots can convey urgency about an interruption situation using only basic elements of its physical behaviour. Our quantitative results statistically show that both speed of motion, and proximity to the person can both provide a range of interruptibility over urgency. This alone is a significant contribution, as it demonstrates simple behaviours that can be used by any robot capable of physical movement (e.g., a Roomba) to convey interruption context. This behaviour is even feasible for robot implementations that lack gaze or precise body rotation movement, as we found these factors to be statistically insignificant in our study. While other factors did not exhibit statistical significance, anecdotal comments from participants do suggest that some form of eyes, head, or indication of forward direction is needed. This too can be easily added to simple robots, e.g., by 'painting eyes' onto its front. When the robot was distant or not gazing directly, participants did not feel they were ones that the robot wanted to interrupt. Instead, they seemed confused when the robot was close, moving frantically but not making eye contact, and that the robot was searching for someone else when far away. In both cases, it is helpful to equip the robot with some method of identifying who it wishes to address in an interruption scenario.

Second, participants had no trouble at all thinking of the robot as a social entity. Many participants saw the robot as more than just a machine and referred to it as a social being with its own desires, goals, and thought process. In less than an hour after meeting the robot for the first time, participants were noting that they were already becoming familiar with the robot and its behaviours. This is important, as it is critical that people accept robots at social entities if they are expected to coordinate interruptions with them.

Indeed, the interpretation of politeness in the robot's behaviour provides confirmation that a robot can communicate interruption urgency in a way that minimizes disruption. Clearly, there are cases, emergencies for example, where being 'polite' may not be important, so long as the person understands the message. However, minimizing disruption could be very important in cases where a robot is attempting to interrupt a busy person for a non-urgent matter, e.g., a non-critical robot telling a person that it will soon need to be recharged.

Finally, our results reveal people may have preconceived notions of certain robotic behaviour that is inappropriate in almost any scenario. For example, frantic and fast movement close to the participant was mostly seen as just plain annoying by many participants, or at the very least associated with a fire or other emergency, thus making it inappropriate for any other less critical scenarios to prevent any false alarms.

CONCLUSION AND FUTURE WORK

Reflecting on our research question, we have found that it is certainly possible for a robot to use a minimal set of non-verbal behavioural cues to communicate interruption urgency in a way that is understandable by people. These results are encouraging for the development of future robots, as they show that any robot can be designed to interrupt appropriately without the need for humanoid or advanced animatronics, or complex sets of behaviours.

Future work is needed to examine how different interruption behaviours translate into working environments beyond offices like the one we used, such as public places, high stress working environments, and in the home. Future work could also explore differences in interpretation of interruption behaviour across different cultures with varying societal norms and familiarity with robots. Exploration could move beyond interpretation and into ways to design robots that are capable of learning appropriate interruption behaviour based on past experiences and their own observations of human-human interactions.

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