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I Get It Already! The Influence of ChairBot Motion Gestures on Bystander Response*

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***Abstract*— How could a rearranging chair convince you to let it by? This paper explores how robotic chairs might negotiate passage in shared spaces with people, using motion as an expressive cue. The user study evaluates the efficacy of three gestures at convincing a busy participant to let it by. This within-participants study consisted of three subsequent trials, in which a person is completing a puzzle on a standing desk and a robotic chair approaches to squeeze by. The measure was whether participants moved out of the robot's way or not. People deferred to the robot in slightly less than half the trials as they were engaged in the activity. The main finding, however, is that over-communication cues more blocking behaviors, perhaps because it is annoying or because people want chairs to know their place (socially speaking). The Forward-Back gesture that was most effective at negotiating passage in the first trail was least effective in the second and third trial. The more subtle Pause and the slightly loud but less-aggressive Side-to-Side gesture, were much more likely to be deferred two in trials 2 or 3, but not a single participant deferred to them in the first trial. The results demonstrate that the Forward-Back gesture was the clearest way to communicate the robot's intent, however, they also give evidence that there is a communicative trade-off between clarity and politeness, particularly when direct communication has an association with aggression. The takeaway for robot design is: be informative initially, but avoid over-communicating later.**

I. INTRODUCTION

People model the intentions of others to coordinate and choose their own behaviors, often using nonverbal cues [1] [2] [3]. This is especially true for incidental interactions, which take place between strangers, for short instances, and when people who are engaged in other tasks. In a restaurant, for example, the customers and waiters interweave their motions with the people delivering and clearing the food. In these shared but low-interaction environments, simple cues such as motion pattern, gaze direction, and expression are projected and interpreted in a fluid dance.

While various past works have investigated robot nonverbal cues [4] [5] [6] [7], this paper explicitly explores how a robotic chair can influence human bystanders. In this paper, we define *bystanders* to be humans that share a space with a robot, but do not have a social or task affiliation with it. Robots in shared environments with humans will not always evoke our attention.

This question came up during an improvisational workshop with 14 participants, in which one of the challenges that the group uncovered was getting by a person or group of people when the chairs wanted to re-arrange themselves into a new pattern. The workshop participants unanimously settled on two potential gestures for a chair to communicate to a bystander that it wants to go by. The hypotheses these gestures inspired follows:

1) H1: The Forward-Back gesture will be seen as aggressive, and be the clearest indicator that the robot wants to get by.
2) H2: The Side-to-Side gesture will be seen as polite, but not clearly communicate what the robot wants.
3) H3: The Pause gesture will be least clear in terms of the robot's objective.

To evaluate these hypotheses, a within-participant repeated-trials experiment was run with 28 participants in

Fig. 1. Robotic furniture could be used in shared human spaces, re-organizing itself as needed. This paper explores the ability of a single ChairBot to communicate non-verbally with human bystanders.

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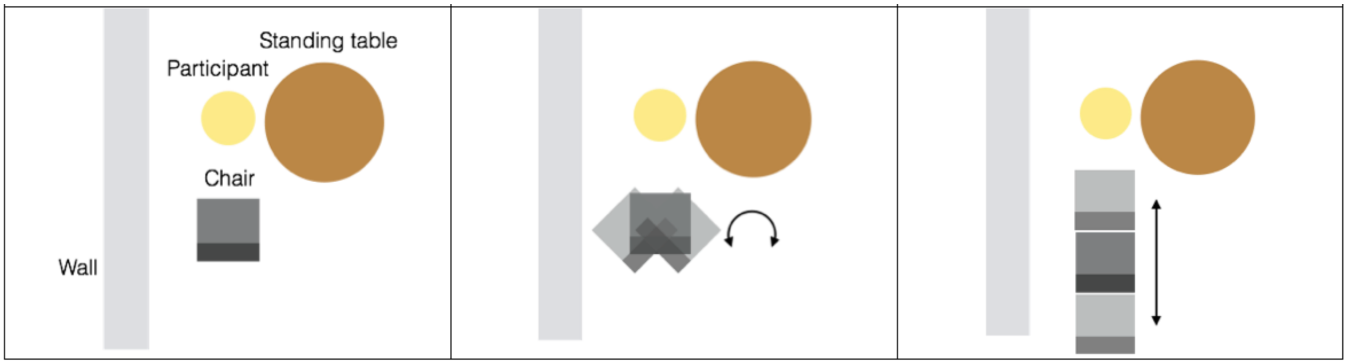

Fig. 2. Experimental Setup across the three gestural conditions: Pause, Side-to-Side, Forward-Back. Please note that participant faces table at the start of each trial and that additional furniture blocks passage to the right of the table.

which people saw a random sequence of the three gestures (one in the first trial, another in the second, etc.). The results validate H1 and H3, however, it turns out that communicating information is not the best predictor of whether people will yield to the robot after the first trail. Instead we find that in later trials, people prefer the politer gestures, possibly because they do not want to be over-communicated to, or perhaps because they find the Forward-Back gesture rude.

The other finding was that the sound of the Side-to-Side gesture confounded the politeness of the motion (both improv group and study participants agreed that that would be the most polite motion approach, in theory). This is a good reminder to social robotics developers that while human-behavior can provide a great inspiration for robot behavioral design, ultimately, we also have to take the robot's hardware into account. So at least for this robot platform, the Side-to-Side option is not perceived as a subtle cue.

The paper begins with related work (Section II), the robot motion design workshop (Section III), and the robot test platform (Section IV). Next, it presents the user study (Section V) and results (Section VI). It closes with a discussion (Section VII) and final conclusions (Section VIII).

II. BACKGROUND

This work is motivated by previous work in expressive and social robots - in particular, how one designs such systems. It also builds on the previous work exploring robot furniture.

A. Expressive Robots

Simple robots evoke complex expressions [8] [9] [10]. In the first author's previous work exploring Expressive Motion for Low Degree-of-Freedom robots, she found that bystanders changed their own navigation behaviors depending on the characteristics of the robot motion [11], that the robot's velocity influenced people's likelihood to interrupt it in its task [5], and that the same motion characteristics of robot heads could signal diligence or having-a-great-time [10], depending on the task the robot was performing. These findings have two main implications: first, people apply storytelling to the motion of simple robots that influences their own behavior, and, second, social context, e.g., the robot's functional task, have a great deal of influence on what people think the robot's motion means, perhaps because motion is used for both expressive and functional purposes.

B. Robotic Furniture

Environmental robots, such as an automatic door [7], and furniture elements, such as a robotic ottoman [9], opening and closing drawers [12], and a robotic trash [13] can similarly evoke social responses from people. In these cases, the functional category of the object helps people predict the behavior it might expect from them. For example, a wiggling trash can communicate that it wants someone's trash, while an approaching ottoman can be interpreted as offering itself to someone's feet. People also create storytelling about sequences of their behavior, such as the automatic door that one participant reported as opening, seeing they were coming, then shutting in their face.

III. ROBOT MOTION DESIGN WORKSHOP

The robot motion gestures were developed in an improvisational setting, in which the 14 participants settled on two possible motion gestures as communicating to people that a chair wanted to go by: they thought that one gesture would be more aggressive and the other more polite, but that both might convey the information. The following subsections justify the use of improvisation, and detail the workshop and resulting gestures.

A. Why Improv?

One of the key challenges facing robot designers is to unlock the tacit understanding of how people believe robots should behave, so that these ideas can be shared, critiqued and operationalized. One solution to this challenge is improvisational methods [14], which have been found effective for research data collection in semi-structured settings [15] [16].

Improv creates an environment in which participants feel free and open to explore. Improv also provides methods for shifting the participants body-awareness [17] to the degrees-of-freedom of something else.

Improvisational storytelling involves three rules [17]:

- Celebrate the unexpected (embrace mistakes).
- Support your partner ("yes!").
- Add to the story ("and...")

B. Workshop Description

The workshop is detailed in the numbered steps below. The activities were sourced from [17] and Stanford University's Improvisation coursework, as taught by Dan Klein.

1) **Establishing group trust:** the workshop began with a series of motion and sound based improv-exercises including "sound ball," and acting out one's name with a gesture, as well as celebrating mistakes with a loud "wahoo!".
2) **Establishing body awareness:** walking around the room in different "gravities," with a sticky floor, while avoiding a person A and attracted to a person B.
3) **Shifting body awareness to ChairBot:** participants were invited to move wheeled Stefan IKEA chairs around the room. They conducted motion exercises and chair formation-switching exercises with varied levels of "human-awareness", to get in the "head" of a ChairBot.
4) **Open Exploration:** Participants were asked to improvise scenarios in which the ChairBots interacted with people.

During the open exploration phase, participants explored scenarios in which the robot was trying to influence people, e.g., during a chair rearranging process. They tried out scenarios where: a robot was trying to pass two people talking. A robot was trying to pass when there was closely-spaced furniture. A robot approaching from ahead or behind. The Forward-Back gesture was deemed as the most informative but also came across as somewhat aggressive. A Side-to-Side gesture was deemed politer, as long as the robot was in the view of the person. Other gestures that they decided did not work at all were: spinning in a circle, backing toward the person (why did it turn around?), and so on. The group would comment immediately on what worked and did not and came to a consensus that Forward-Back and Side-to-Side gestures seemed most promising. The other theme that came up was that the person was not an interaction partner of the robot, instead they were simply sharing the same space. Hence the later focus on communicating with human bystanders.

IV. ROBOT PLATFORM: CHAIRBOT

The Chairbot project involves multiple mobile chairs that can move themselves around. This can make it easy to reconfigure a multi-purpose space, from auditorium seating, to cafe seating, to dance floor seating. Each chair has a Raspberry Pi and Arduino to receive remote network control messages as well as on-board sensor data to help it decide where to go.

The ChairBot design is depicted in Fig. 1, while Fig. 3 displays each chairs major mechanical sub-parts:

1) Stefan IKEA Chair has been augmented with simple castors so it can roll.
2) A laser-cut chassis connects the chair to the robot,requiring four nuts.
3) Neato robotic vacuum cleaner.

Fig. 3. Each ChairBot is comprised of a wooden IKEA chair with added castors, laster-cut chassis, and Neato Robotic Vacuum.

To send commands to the Neato drive system, we connect a Raspberry Pi, powered by an external battery, to the USB port on the Neato. The Raspberry Pis offer a full local Linux OS on a single board. The total cost of the system is $300.

V. USER STUDY

The user study explores the improv-derived motion gestures (Fig. 2) and hypotheses for cuing a bystander that the ChairBot would like to pass. During the user study, 28 participants participated in a series of three trials. Trial order was randomized without replacement between gesture conditions, such that all participants saw all gesture subtypes.

In each trial, the participants were given ninety seconds to complete a word search. The word search was taped to a high table 3.5' from the wall (Fig. 4). The distance between the participant and the wall was intended to make it so that the participants would consider moving out of way, or "yielding," so that the robot could move past them. The activity (e.g., Fig. 5) was intended to simulate a distracted bystander that might share the space with the ChairBots.

While the participants were completing the word search, a ChairBot would approach the participant and perform one of three motion gestures (Fig. 2): moving forward and back; and rotating side to side; or pausing (the control). The robot's motion was wizard-of-ozed from an adjoining room, with the wizard out of view from the participant.

Fig. 4. Example of participant yielding to the ChairBot, robot begins at bottom-left of frame and stops when it reaches the file cabinets.

Fig. 5. Sample word search. Word searches were taped to the table and varied by trial. The concept was to create a motivation for the participant that would conflict positionally with the robot's goal. Source: www.printables.com/

TABLE I
ATTRIBUTION MEANS (3=NEUTRAL).

Scale (1-5)	Pause	Side-to-Side	Fwd-Back
Scary-Innocuous	4.14	3.96	3.77
Abrupt-Smooth	3.10	2.40	2.53
Rude-Polite	3.54	3.15	2.92

The human behavioral measure was whether and how participants would yield to the robot. If there was enough space for the robot to navigate past the human, the robot moved past regardless. Otherwise, the robot returned to its initial position.

At the end of each trial, the room was reset while the participant completed a short survey. In these surveys, participants rated the robot on four 5-point scales: abrupt to smooth, rude to polite, scary to innocuous and unpleasant to pleasant. Participants were then asked to give three adjectives describing the robot, and to write what they thought the robots intent was.

At the end of the three trials, there was a semi-structured interview with the participant giving them the change to further explain their survey responses and contrast the conditions.

VI. RESULTS

A. Attributions

Peoples perceptions of the robot changed based on its movement. In single ANOVA analyses, **robot gesture significantly predicted attribution ratings** for the Abrupt-Smooth (F=3.153, p=0.049*), and Scary-Innocuous (F=3.276, p=0.043*) scales. There was also a trend for gesture to predict Rude-Polite ratings (F=2.609, p=0.080).

Examining the means in Table I, where a lower number corresponds to a more negative experience, one finds that the Forward-Back gesture is rated to be the most rude and scary. Pause is rated as the most polite, smooth and innocuous. Against initial hypotheses, Side-to-Side is rated as most abrupt.

The interviews and surveys found that people most often cited how loud the robot was and how close the robot was. They were used 28/84 times as answers to an open-ended question ("Choose three adjectives that describe the robot's motion"), while the second most common adjectives of annoying/distracting were used only 13/84 times. The amount of noise created by the robot is a function of its construction and not something we could control for this experiment.

People generally had the most positive descriptions of the pausing robot. In the rotating condition, the robot made a lot of noise: "noisy" and "loud" were the two most common adjectives used to describe the robot.

The Forward-Back gesture evokes more negative descriptions: One participant wrote "[this condition] was the one I felt as if the robot was actually trying to harm me because it got so close, and another wrote, It seemed like the robot wanted my attention and was charging me like it wanted confrontation."

B. Human Behavioral Response

Human behavioral response annotations included yielding to, not yielding to, or sitting on the ChairBot (Table II). Participants yielded to the robot in only 20% of the trials. While many surveys and interviews suggested participants would have sat on the chair if the table was lower to the ground, few did (2%).

The robot's behavior puts the human behavioral response in context. Despite the low yielding rate, the robot managed to pass the participants in 56% of the trials (Table III). As the robot passed the person in every instance of human yielding, this means that 36% of the trials included a robot passing without human invitation, at least in terms of motion deviation. Some user comments described the robots passing after no-yield response as "impatient," or "inconsiderate." After seeing this behavior, however, they expressed a greater understanding of what the robot was trying to do.

Main result: **An interaction effect was found between gesture condition and trial number** (F=3.425, p=0.013*, two-way ANOVA).

TABLE II

HUMAN RESPONSE SUMMARY (N=84)

Yielding	Not Yielding	Sitting
17 (20%)	67 (80%)	2 (2%)

TABLE III

FINAL ROBOT BEHAVIOR (N=84)

Pass	Return to Start	Sat on
47 (56%)	37 (44%)	1 (1%)

TABLE IV

PROBABILITY OF PARTICIPANT YIELDING BASED ON TRIAL NUMBER AND MOVEMENT CONDITION.

	Pause	Side-to-Side	Fwd-Back
Trial 1	0.00	0.00	0.44
Trial 2	0.20	0.44	0.00
Trial 3	0.25	0.60	0.10

What is fascinating is that in the first trial, people **only** yielded to the Forward-Back gesture. Not a single participant yielded to the Side-to-Side gesture or Pause in the first trail. However, in trials 2 and 3, people are **least likely** to yield to the Forward-Back Gesture. The numerical trends for yielding likelihood are summarized in Table IV.

What could explain this?

VII. DISCUSSION

The results suggest that people can interpret motion gestures from simple robots, and moreover that their responses to such robots are socially complex: their initial responses vary from their later ones.

H1 was largely sustained: The Forward-Back gesture was the clearest communicator of what the robot was trying to do, as supported by the trial 1 behavioral response in which this was the only gesture to which participants ever yielded. Consistent with our initial hypotheses, it was rated as the most rude and scary.

H2 was sustained with one caveat: While the Side-to-Side gesture was rated as more polite and innocuous than the Forward-Back gesture based on Table I means, it was also rated as the most abrupt. This is likely due to the motor noise that participants described as being particularly irritating during the word-puzzle completion. With quieter robots, this gesture might better meet participant needs.

H3 was not sustained: any gesture was not better than no gesture overall. In the first trial, only the Forward-Back gesture communicated the desire to pass, but in later trials, pausing was the most effective strategy, followed by the Side-to-Side gesture. This indicates that once people understand the robot's objective, they prefer the most polite and innocuous behavioral strategy.

VIII. CONCLUSIONS

After people get over the novelty of robotic furniture, it is likely that they will ignore robot requests in ways that interfere with their functional objectives. Because of this habituation, it is important to model the right way for a robot to make requests, both in terms of clarity, but also in terms of likelihood of human response.

There were three main findings in this paper:

First: the Forward-Back gesture was most effective at communicating that the chair wanted to move forward and past the participant. Without pre-conditioning (e.g., seeing the robot move past or a Forward-Back gesture), people were unable to determine what the robot wanted, initially thinking the robot wanted their attention or was offering them a seat. (Which makes sense, given it is a robot chair!)

Second, and most important: participant's likelihood of deferring to the robot changed dramatically between the first and subsequent trails. In the first trial, the the robot needed to communicate what it wanted, so the Forward-Back gesture was the only condition that got a response from people. In the second and third trials, however, most people knew the robot was trying to move past, and they were only willing to help the polite robots. They may have been frustrated by the social ineptness of a robot that has not realized its message has been received and maintain their position of power.

Third: While everyone who brought it up agreed that a Side-To-Side gesture should have been the polite way to get a person's attention in theory, in practice, the Neato emits high pitched noises while doing that rotation that are more grating than transitional motion. More important than asking participants to wear headphones is the simple insight that even the best ideas need to be adapted to the realities of the robot you have. Communication is multi-modal and we should leverage that.

In future work, the authors hope to explore how ChairBots can be used to explore multi-robot, multi-human interaction. What are group gestures a robot might be able to perform, or how might the gestures of one gain significance in contrast to those of the others. In the same way that temporal sequence played a role in this paper, perhaps seeing multiple robots at once could influence their interpretation of particular communications or their preferences of which robot to choose as their seat. Perhaps introverted chairs will be preferred by introverted occupants.

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