# Be the Chair You Wish to See in the World: Eliciting Socially Appropriate Robot Chair Motion

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## ABSTRACT
Social norms are the aggregation of individual expectations based on past experience. To help design socially appropriate robots, we believe it would help to draw on the social instincts from a large number of geographically distributed human robot controllers. We built an online simulation environment to elicit motion paths from human controllers for a robot moving among people. In a crowd-sourced experiment, we recruited online participants (*N*=30) from Amazon Mechanical Turk to pilot a robot through a crowded 3D environment. We subsequently used another set of online participants (*N*=30) to evaluate the social appropriateness of the elicited robot motions. This method can be extended to elicit and evaluate a variety of social robot interactions, and with controllers and bystanders from a variety of cultures.

### Author Keywords
Online experiments; social interaction; by 3D virtual worlds; perspective; human-robot interaction

### CCS Concepts
•**Human-centered computing** → **Human computer interaction (HCI);** User studies;

## INTRODUCTION
In *The Social Life of Small Urban Spaces*, William H. Whyte paints this wonderful vignette of New York street life: "People's movements are one of the great spectacles of a plaza. You do not see this in architectural photographs, which typically are empty of life and are taken from a perspective few people share... At eye level the scene comes alive with movement and color—people walking quickly, walking slowly, skipping up steps, weaving in and out on crossing patterns, accelerating and retarding to match the moves of the others. There is a beauty that is beguiling to watch, and one senses that the players are quite aware of it themselves." [40]

The modern streetscape has not changed drastically since Whyte's time, but soon we may have other players–delivery



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**Figure 1. A chair (red) in a simulated environment inspired by Grand Central Terminal in New York City.**

robots [20, 17, 19], mobile trash barrels [41, 37, 38], and even self-propelled and location-aware tables [8, 10]–joining the theater of the street. To preserve the social dynamic and maintain safety, it is important that machines and autonomous systems be designed to move in socially appropriate ways through the world.

Whyte's observations make plain the insight that *point-of-view* is critical to understanding social interaction. In this paper, we present an online system that we have developed to help elicit and evaluate socially appropriate robot motion in shared public spaces. By hosting online robot environments, we are able to crowdsource control of virtual robots, thereby eliciting what different people in different places feel is acceptable movement for a chair robot in the setting of the virtual environments they are asked to pilot the virtual mobile robot through. We can subsequently refine the dataset of collected movement pathways by asking a second group of online participants to evaluate the robot in these simulated interactions in the context of the same simulated online environment. As part of this work, we investigated the role that *perspective* has on the robot controller's ability to produce movements that are independently evaluated to be socially appropriate.

### Contributions
The primary contribution of this work is the design method of using online virtual spaces to elicit actions and evaluations for mobile systems from a diverse body of people, under controlled circumstances.

It is difficult to articulate the rules of socially appropriate motion because they are contingent and contextual. Since social norms are the aggregation of individual expectations based on past experience, we believe it helps to draw on the social instincts and awareness of a large number of people. Simulated online environments offer one pathway to accomplish this goal.

### Why a chair?

Our simulation and study has the robot operator piloting a chair robot. We selected a chair form factor for our robot because we are moving toward understanding multi-person, multi-robot interaction in public spaces. Chairs are items of furniture which make sense to have in numbers proportionate to the number of people in a space. As Whyte and colleauges note, one of the factors that make for inviting public spaces is having an abundance of inviting places to sit and relax. Chairs can support people, or be in the way. While we acknowledge that chair robots differ substantially in form and affordances than other robots, we are not the first to use this as a platform for investigating interaction [24, 2]. People understand a chair's role in a space without instruction, and do not find it too strange to see a chair moving on its own. Hence, we believe that chair robots are the perfect platform for conducting social experiments in public or quasi-public spaces.

## PRIOR WORK

This research brings together a number of themes that have been important to the design of interactive spaces, human-human and human-robot interaction, as well as virtual and crowd-sourced simulation as experimental venues.

### Perspective

A number of studies in psychology and communications have investigated the effects of perspective on task performance and social communication. Ruby and Decety [31] find that brain patterns of participants instructed to complete a task in a first-person perspective more closely match those of participants who produced the actions themselves, when compared with participants instructed to complete a task from a third-person perspective. Bach et al. [5] find that a first-person perspective helps people better predict the outcomes of their own actions, while Kanade and Hebert [21] find that first-person perspectives help people better understand behavior, intent, and environment compared with birds-eye perspectives.

When controlling robots, Rae et al. [29] find that the height of a telepresence robot has an impact on social determinants including measures of influence and dominance. Perhaps unsurprisingly, then, Shen et al. [34] find that proxemics continue to play a role in human-human interactions mediated by a telepresence robot.

### Simulating Interactions

The gold standard for simulation in the adjacent field of human-vehicle interactions is the large-scale immersive vehicle simulation. Researchers of vehicle drivers, including Carlson-Newberry et al. [6], have found that simulation fidelity has a strong influence on the validity of results, suggesting that we need to be careful in extrapolating our own results. Recent work by Goedicke et al. [15] examines how different forms of fidelity—acceleration and an accurate acoustic environment—can provide deeper insight by modulating which aspects of the experience have the greatest fidelity.

### Robot Movement

Movement-centric design has been prototyped in many different ways to demonstrate intention and expressivity. This includes video prototyping [22, 18], interactive movement examinations, animation studies, and Wizard of Oz studies [18, 23]. These simulations have been used to allow researchers to discover effects including increased confidence in a robot's capabilities due to expressive forethought [18, 36]. These simulation methods provide a freedom of exploration, an economic feasibility, and a rapid prototyping capability [18] generally lacking in physical robot platforms.

A number of studies examine human-robot interactions in the context of the increasing presence of robots in daily life, often taking a design-centric approach as we do here. Dautenhahn et al. [7] find that the route a robot takes and the path by which it approaches a person has a significant impact on the how the person feels about the interaction.

Knight et al. [23] find that the gestures of a robot affect the ability of people to understand the robot. People do not simply relate to robots as objects with human qualities, but also engage in social interactions those robots, for example, giving them names [32] and even expecting that robot behavior will be sufficiently polite that humans will be able to cooperate with them [23].

Forlizzi and DiSalvo [13] highlight the importance of the parameters of movement itself, such as acceleration and curvature, compared with the physical form of the robot, which was found to have a limited effect on participants in an interaction.

To develop robots that will be accepted, predictable, and familiar, some researchers have worked on creating methods to improve social navigation [39, 12]. Avrunin and Simmons [4] collected data on how people navigate around other people, which was used to train robots to navigate like humans. (In fact, some work in this area eschews the robot altogether—Alahi et al. [3] propose a mechanism for predicting human trajectories in a crowded space.)

Prior studies of robots in social settings include Agnihotri et al. [2]'s ChairBot Café, which, like the present study, examines a chair robot in a naturalistic setting. Mutlu and Forlizzi [28] examine how robots are integrated into social environments like hospitals.

Other recent work on robots in social settings includes delivery robots [20, 17, 19], mobile trash barrels [41, 37, 38], and even self-propelled and location-aware tables [**?** 10].

### Eliciting Feedback

In our study, we rely on workers from Amazon Mechanical Turk (AMT), an online labor market that enables researchers to pay to collect data from geographically-distributed online workers. Rand [30] evaluates replication studies using AMT that demonstrate high reliability of self-reported demographics, using IP addresses and demographic information across different AMT studies.

AMT workers have previously been employed to evaluate the social appropriateness—often measured as the legibility and predictability—of robot motion, as by Dragan et al. [9].

## STUDY

To elicit and then evaluate socially appropriate motions for a robot moving in a crowded space, we ran a study in two parts. In the first part, we used a computer simulation running on the Web to elicit motions from human controllers on Amazon Mechanical Turk. We then evaluated those motions ourselves, and used a second simulation on the Web to get feedback on a subset of those elicited motions from a second group of workers on AMT.

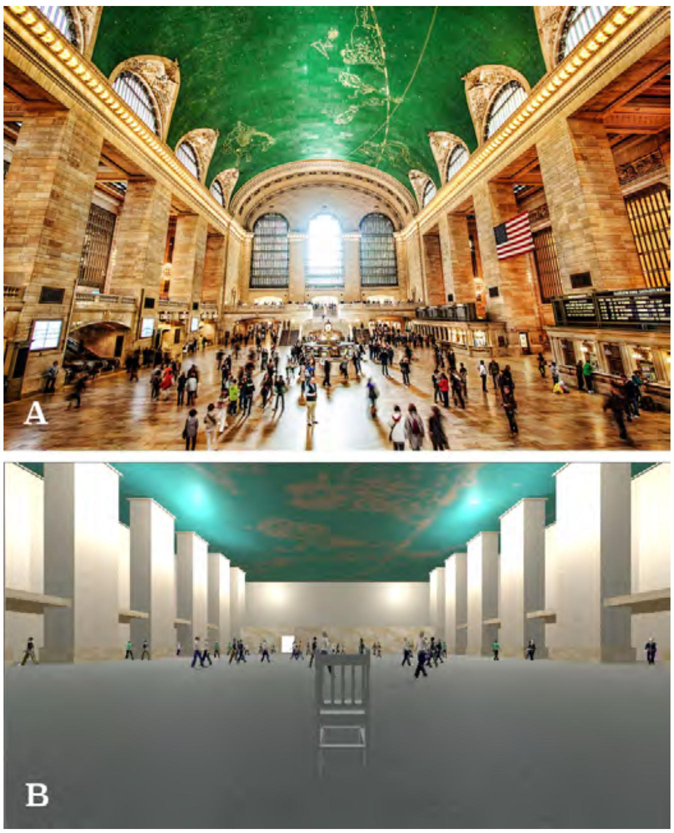


**Figure 2. A: Grand Central Terminal, NYC. [1] B: Grand Central simulation, WebGL.**

### Setup

We used the Unity game engine and development environment to create a simulation of Grand Central Terminal in New York City, an archetypal "crowded space with people." Our simulation shows the perspective of a chair robot whose desired destination is a white-lit room on the opposite side of the hall. Between the chair and the goal are 75 virtual agents in humanoid form walking across the space, each with its own destination on all sides of the hall, animated to appear to be walking purposefully. Unity provides a NavMesh agent "AI" that includes a motion planner that naively avoids other static and moving objects in the hall; we attach this AI to each humanoid agent so that they avoid hitting each other while walking. A screenshot of our simulated environment, as well as a photo of its inspiration, appear in Figure 2.

To distribute our simulation and elicit motion from workers on AMT, we used Unity's WebGL export functionality to create a web page with our simulation embedded inside it. Custom URLs allow us to vary parameters of the simulation during our study, including setting the the camera perspective and top speed of the chair, or to select a pre-recorded elicited trajectory through the hall to play back together with pre-recorded motions of the humanoid agents.

While the simulation is running and the AMT worker is controlling the chair, our system collects motion and interaction data via a custom Node.js server that receives position, orientation, and velocity information for both the robot chair and for all humanoid agents in the hall, over a WebSocket connection, at a rate of 30 samples per second.

### Movement generation

*Method*

To elicit a broad variety of motions, we used Amazon Mechanical Turk to recruit participants to our simulated Grand Central environment. Each participant was asked basic demographic questions including age, gender, experience with video games, and years of experience driving.

We used a 2x2 within- and between-subjects study design, varying the participant's perspective—either above and behind the chair, or at seat level facing forward )see Fig. 3)—as well as chair top speed—either the same speed as the humanoid agents, or 3 times quicker. Our choice of perspective comes from a desire to provide physically-plausible camera viewpoints—it would be easy to incorporate a camera into a chair's seat or seat back—as well as to offer a perspective not often taken by adult humans.

Each participant was asked to complete the robot control task four times, once in each condition, with condition ordering randomized using a Latin Squares approach.

Participants were advised to "Try not to hit or scare anyone. Avoid getting in the way!" and to control the chair motion using the keyboard arrow keys; the up and down arrow keys for forward and back, and the left and right arrow keys rotate the chair towards the left or right, respectively. Prior to the four control tasks, participants were offered a "practice round," and clicked a big "Start" button to begin the task.

After completing the control tasks, participants were asked to indicate agreement or disagreement with the following 6 statements on a 7-point Likert scale:

1. I found it easy to navigate the room.
2. I was able to move the chair the way I would want to in real life.
3. I planned my path in advance.
4. I (intentionally or unintentionally) cut people off.

5. I would have controlled the chair more carefully in real life.

6. I controlled the chair in a way that I thought would be perceived as socially appropriate.

We selected these assertions primarily to better understand how the limitations of the simulated system affected participants' perceptions of their own capabilities and the social appropriateness of their actions.

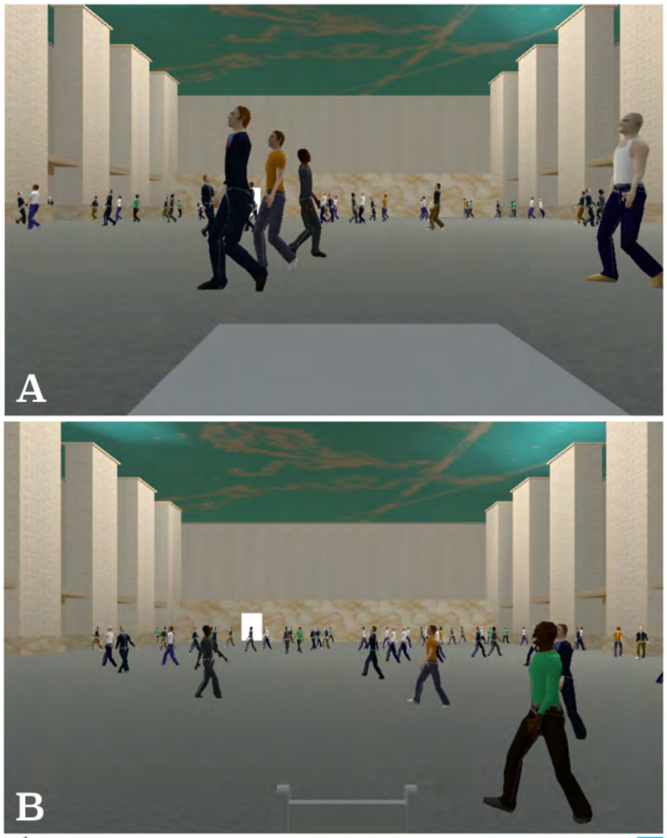


**Figure 3. Controllers are presented with 4 total tasks, each of which has a randomly-assigned perspective, either low (A) or high (B), and a randomly assigned speed, either slow or fast (not shown).**

*Participants*
Participants were recruited from Amazon Mechanical Turk; of $N = 30$ participants, 10 were female, and all ranged in age from 19 to 61, with an average of 36. 16 reported playing video games several times a week, while 3 currently did not play. 3 participants reported not driving, while the remainder started driving at an age between 15 and 31, with a mean of 18.

*Analysis/Post-processing*
After collecting these trajectories, we visualized them to find patterns, commonalities, divergences, and outliers. To do so, we developed a set of features we expected to be relevant to social appropriateness:

1. number of "impacts" with pedestrians, in which the chair comes within a certain threshold distance

2. time spent impacting with pedestrians

3. number of "slow-downs", in which the chair slows down from top speed

4. deviation of trajectory from straight-line to goal

5. time spent near pedestrians.

With the help of these visualizations, we selected 10 representative paths to use for the second part of our study. An example of the visualizations we used is shown in Figure 4.

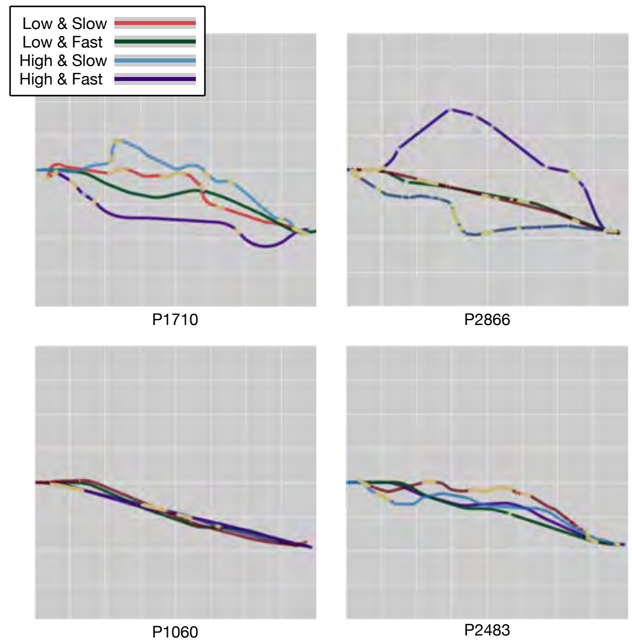


**Figure 4. A sample of trajectories generated by our controllers. Each box represents the four trajectories (one in each condition) for a single controller. Gradient along trajectories indicates a slowdown or stop. Yellow regions indicate collisions with passersby.**

### Movement evaluation
*Method*
To understand whether the elicited motions are socially appropriate, we showed recreations of the paths selected above to a second set of participants. All participants were offered the same perspective, a raised view that shows the entirety of the chair and nearby passersby. We chose a perspective that shows the entire chair, rather than replicating the controllers' perspectives, because we believed that this view would provide the most insight into whether local interactions with immediately adjacent passersby are socially appropriate.

Each participant was asked, in a free response format, whether they believed the chair moved in a socially appropriate manner for each of 5 trajectories individually. Participants subsequently evaluated the social appropriateness of each trajectory by indicating agreement or disagreement with the following 7 statements on a 7-point Likert scale:

1. I would have liked for the chair to move more slowly

2. I would have liked for the chair to stop for people more

3. I understood where the chair was trying to go

4. The people in the space were aware of the chair
5. The chair's motion was respectful of the people in the space
6. The chair's motion made it stand out among the crowd
7. The chair should have moved more like a person would

We selected these assertions primarily to more deeply understand what types of behaviors correlate with social appropriateness; we hoped that the overlap between some of these measures would help us better triangulate around social appropriateness.

**Figure 5. Evaluator view perspective. All evaluators use the same perspective. why this perspective?**

*Participants*
Participants were once again recruited from Amazon Mechanical Turk; of $N = 30$ participants, 11 were female, and all ranged in age from 23 to 60, with an average of 33. 16 reported playing video games several times a week, while 3 currently did not play. 3 participants reported not driving, while the remainder started driving at an age between 15 and 31, with a mean of 18.

*Analysis/Post-processing*
To determine if the changes in perspective and top speed affect controllers' trajectories, we grouped evaluators' responses by the original condition each controller operated within.

## RESULTS
In running a formative design study, our goal was to identify promising avenues for future inquiry. Our primary manipulation was altering controller perspective and chair top speed. We quantitatively measured the effect of each condition by looking at several dependent variables, including number and time spent in "impacts" with passersby. We found that, contrary to our expectations, high or low perspective did not have a strong correlation with impacts count or duration, but that a higher top chair speed was correlated with both fewer and shorter impacts. Figure 6 shows that under slow-chair conditions controllers collided with more than twice as many passersby, while Figure 7 shows a trend across all four conditions, with high-perspective trajectories showing slightly less time in impact.

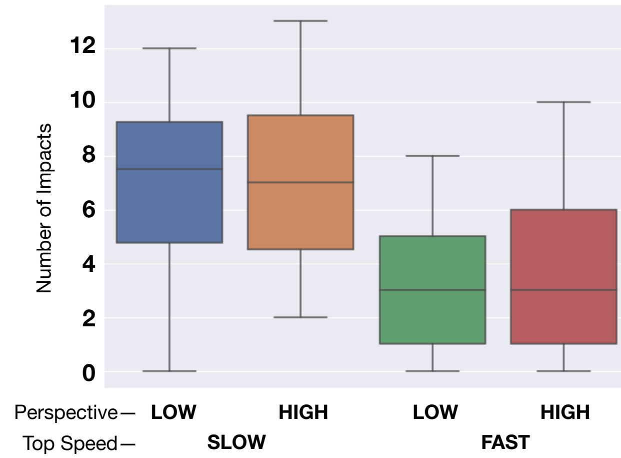


**Figure 6. Plot of impact counts by robot control manipulation.**

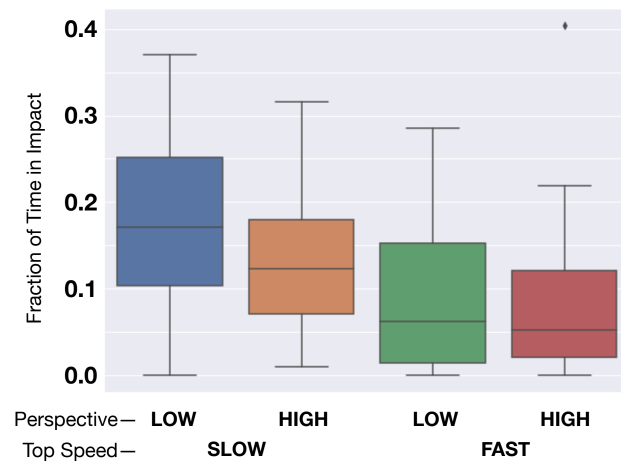


**Figure 7. Plot of impact counts by robot control manipulation.**

In addition to trajectories, we looked for markers that might suggest correlation between behavior in our simulation and behavior for a similar task in real life. Responses to two Likert-scale assertions in particular spoke to this question:

1. I was able to move the chair the way I would want to in real life.
2. I would have controlled the chair more carefully in real life.

For assertion 1, just 2 of 30 participants disagreed; for assertion 2, only 6 out of 30 participants disagreed with the assertion.

We also took a qualitative approach to finding trends among trajectories by condition; Figure 8 overlays all paths and suggests that a higher top speed correlates with paths that deviate more from the straight-line path.

## DISCUSSION
In our own work tele-operating robots in and away from public spaces, perspective affects our ability to understand the social

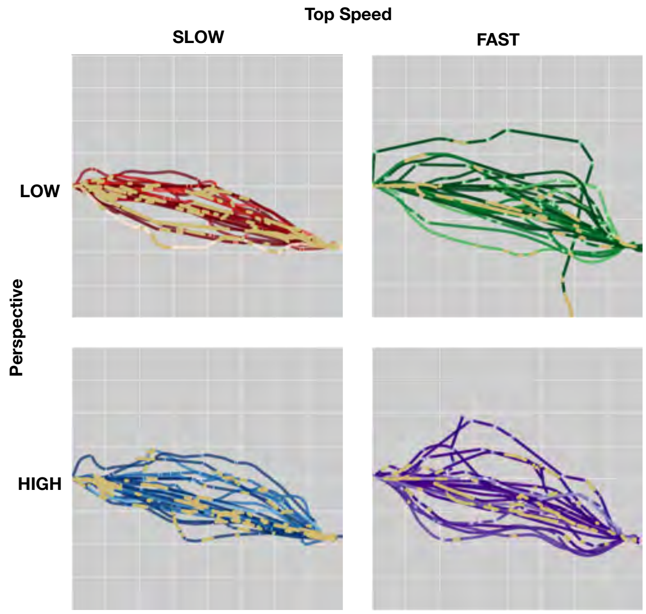


**Figure 8. All paths by condition. Each line represents a single controller's trajectory in that condition. Gradient along trajectories indicates a slowdown or stop. Yellow regions indicate collisions with passersby.**

implications of our actions. However, our preliminary study of two different perspectives in a simulated environment did not yield statistically significant results.

We expected perspective to matter in part because a number of studies show correlations between perspective and a variety of social indicators, including perceived status, comfort, and more?. We operationalized perspective in our study by providing a high-level camera view showing the back of the chair and a broader view of surrounding passersby for some controller trajectories, and a low-level view from the seat of the chair, at roughly knee-height of the passersby, for the other trajectories.

We were not sure exactly how perspective effects would manifest in our study, though we expected at least some differences in trajectories, in performance, or in social appropriateness. Perhaps we did not observe any effects because the effect sizes are small and we were not able to measure them with our mechanism, or because the nature of the task does not intersect with those attributes of social appropriateness that are affected by perspective.

Two results from the controllers' set of Likert-scale assessments stand out: first, that a substantial majority of controllers believed that would have controlled their chair more carefully in real life. Controllers acknowledge that there is something different about the simulation—perhaps the knowledge that the people are just "AI players" as in a video game, and not weary commuters returning home from a long day at the office, reduces the perceived cost of hitting them with the chair and changes the social calculus.

Second, however, nearly every controller reported that they were able to move the chair the way they would have wanted to in real life, suggesting that although controllers may have moved more carefully in real life, they felt that they had the tools to move appropriately. Perhaps a different initial prompt, or a different simulation type, would have elicited trajectories that collided with fewer passersby—but this self-report suggests that the range of trajectories observed would not necessarily be fundamentally different with a more extensive control mechanism.

Giving people a simulated perspective on a possible future scenario enables us to anticipate prospective responses in a way that is not possible otherwise. We assume that having people pilot the robot reduces the space of exploration to what is reasonable at least in one person's mind, and thus reduces the search space for socially appropriate motion in a non-arbitrary fashion. We may not have generated a definition of socially appropriate motion, but we do have new insights into what to investigate next.

Although we did not find the perspective effect we expected, we did find strong effects based on the *chair's top speed* that have design implications for a real-life robot: in particular, it appears that top speed reduces collisions with passersby in two ways: first, by enabling controllers to avoid collisions in the first place by outmaneuvering passersby, and second by extricating themselves from a collision more quickly after noticing that one has occurred.

As mentioned earlier, we are proposing this method not as a replacement for live prototyping with real robots, but as providing an additional data point early in the robot design process, before all hardware-oriented decisions are finalized. As noted by Huffman and Ju's movement-centric design [18], experimenting with movement before designing hardware allows that hardware to be designed with a better understanding of what that hardware will be asked to do.

In the present study of robot chair motion, the surprising correlation of chair speed with reduced number and duration of collisions informs us that socially appropriate motion is likely to require that our robots have the capability to move faster than a typical human walks. This is a non-trivial constraint to deliver in a physical robot, and this simulated environment provides a strong rationale for prioritizing it.

## Limitations

### *Simulations vs. Real World performance*

Of course, any simulated environment will have limitations to external validity. Our expectation is that the results of trends and relevant dimensions in simulator studies will hold true in physical settings. Driving simulation studies, for example, have been a mainstay of transportation research for many years, and generally yield results that correlate to on-road behavior [25, 33, 26]. However, as Mullen et al. point out, while simulator driving behavior approximates on road behavior, it does not replicate on-road behavior [27]. Hence, some efforts to make common instrumentation and measures to study on-road driving in-situ are also needed to complement this work. However, the value in such simulations is that the allow comparisons and elicitations that would be hard to gain otherwise.

*Human movement fidelity*

The primary limitation of any simulated environment, this one included, is fidelity. Controllers are limited in their view and perspective—they can only see what we are showing them—and limited in the type of control offered, having only arrow keys and no control over overall speed. However, the control mechanisms and limitations are not unlike those faced by teleoperators of robots, and hence the motion inputs might predict what teleoperators will do in various situations.

In our simulation, passersby move like zombies. In reality, human-robot interactions form a dynamic system: people respond to robot motions, and these responses in turn influence human controllers' actions for their robots. People in real situations respond in ways that these simulated agents cannot, and these responses are likely to be critical to the design of human-robot interactions in crowded spaces. These limitations make it hard to draw conclusions about how humans behave in the real world. For example, we cannot conclude that perspective does not matter—only that it did not matter in our simulation. But we can conclude that attributes that do affect human control—such as robot top speed—are worth investigating further in physical hardware. Hence, we feel the methods we devised are well suited for design explorations that occur at the front of a process which will subsequently be tested in physical environments, but should not be used to draw summary judgements about human people's preferences or patterns on their own.

*Fairness and Transparency for Crowdwork*

For this study, we recruited Mechanical Turk workers from the United States, and paid crowdworkers who performed our original piloting task $2 USD. Payment for our second evaluation task $2.50 USD. Based on our pilot testing of the task, we estimated that the first task should take 10 minutes, and the second 15 minutes. The equivalent hourly wage for the work is $10-$12 USD, above the US Federal minimum wage [35, 16]. The actual mean time on tasks was 23 minutes for the first task and 19 minutes for the second task. We approved payment for all completed tasks, regardless of quality of response.

## CONCLUSION

In this paper, we presented a design approach to help design socially appropriate robots, drawing on the social instincts of a large number of geographically distributed human robot controllers. Our online simulation environment elicited motion paths from human controllers (recruited from Amazon Mechanical Turk), for a robot moving among people, and evaluations of those motion paths from human participants (also recruited from Amazon Mechanical Turk) in the same online environment.

Going into this project, we expected perspective to influence how controllers chose paths through the space. However, controllers who were given a chair-seat-level perspective on the crowded hall the robot was situated did not have observably different capability for producing socially appropriate motion than controllers given a seat-back-top perspective. Instead, we found that top robot speed played a larger-than-expected role: controllers whose chairs moved faster were more likely to successfully avoid passersby, and hence, were deemed to be more socially acceptable.

We posit our contribution as a design tool, intended to be used to help narrow the design space that is all the motions that are possible for a robot to make to the that which includes only socially acceptable motions. Our goal with this tool is to help designers identify motion or interaction affordances [14] that are needed for socially appropriate interaction early in the design stage. We expect this to be used early in the design process, and that the learnings from this system to be later validated in physical interactions in-situ. For example, we might validate the online finding that faster robots are more nimble and therefore more socially acceptable, but it is altogether possible that the physical threat of actual high-speed robots in proximal space would be deemed to be less socially adept. However, this system helped to identify top robot speed as an important consideration in investigating the social interactions.

Looking ahead, this work provides a platform with which to explore multi-robot interaction. The scenarios we are exploring are some of the most challenging for robots, one which often makes real robots freeze in place [**?** ]. Using various multi-controller crowdsourcing mechanisms [**?** ], we can start to think about how socially appropriate motion should occur when there are multiple robots and multiple robots in the same space, and investigate what mechanisms for motion design yield the most socially acceptable motions in concert.

One of the most exciting directions that this work opens up is the possibility of designing for greater cultural inclusion. As interactive products are increasingly deployed to global markets, new simulation methods are needed to give designers insights about how different people in different places will respond to their designs. Our work is a step towards a new era of design wherein the social expectations and responses of a wider range of people can be elicited at design time rather than at product validation time, after hardware development when changes are costly. Moving forward, we hope to use this platform to explore the cross-cultural variations in social norms, and also to better understand the consequences of "social accidents" which can occur if interactants have different expectations of their transactions [11].

In conclusion, a number of sensing, networking and distributed robotics technologies are poised to transform our urban public spaces and social hot spots. Whether this is a utopian or dystopian vison has much to do with the social appropriateneses

## ACKNOWLEDGMENTS

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