Expressive Motion in Simple Robotics

by

Jaden Berger

A THESIS

submitted to

Oregon State University
Honors College

in partial fulfillment of
the requirements for the
degree of

Honors Baccalaureate of Science in Mechanical Engineering
(Honors Scholar)

Presented November 29, 2021
Commencement June 2022

AN ABSTRACT OF THE THESIS OF

Jaden Berger for the degree of Honors Baccalaureate of Science in Mechanical Engineering presented on November 29, 2021.

Title: Expressive Motion in Simple Robotics

Abstract approved: ______________________________

Heather Knight

This thesis follows two studies performed with simple robots. The first follows a robot interacting with eight improvisers to create scenes and perform five isolated gestures (towards, away, sideways, spin, and circle) for interpretation. The second follows a group of three robots performing the same five isolated gestures at two different speeds with a participant size of 405. These two studies showed similar trends with away and sideways consistently having negative interpretations while spin had positive interpretations and circle and towards had varied responses. In the second study, it was found that toward was the only gesture where interpretations were dependent on robot speed. These findings help to further the understanding of robot-human interaction and will expand opportunities for simple robots in public spaces.

Key Words: Robotics, expressive robotics, robotic gesture, simple robotics, multi-robot

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I understand that my thesis will become part of the permanent collection of Oregon State University, Honors College. My signature below authorizes release of my thesis to any reader upon request.

Jaden Berger, Author

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Chapter 1: Introduction

Clear and efficient communication between humans and robots is crucial for successful human-robot interaction [8, 7]. Complex robots have an easier time communicating with people, as they can perform more complex actions and replicate elements of human-human interaction. For example, complex robots may have the ability to speak or show words on an interface [1, 29, 30], have facial expressions [6], or imitate human gestures [32, 30]. Simple robots do not have these options and have a harder time communicating without words or complex gestures.

This paper follows two studies. The first is about a robot that was created to play an improvisation game with a human participant. During this game, simple motions were tested and participants were asked to describe the emotion portrayed by each motion. The second study applied these motion findings to multiple robots. A video was taken of a humanoid facing three robots who all preformed the same motion together. An observer was then asked a question about what the robots were communicating.

These two studies allow for a greater understanding of how to communicate with a simple robot. While humans are adept at understanding silent cues in communication, they often rely on complex movements or facial expressions; things simple robots do not have. Finding ways to appropriately communicate without complex motion will expand the use of simple robots.

Chapter 2: Related Works

2.1 Single Robot Expressive Motion and Improv with Robots

Previous work has been done that combines improv and robots, specifically minimal robots. Mathewson et al. [26, 25, 27] trained chatbots to perform improvisational theatre by using a neural network and 102,000 movies. These robots listen to the human participant's line and use algorithms to create computer-generated dialog to reply with. There is also Simone [34], who created Bot Party where six teleoperated robots interact with human improvisers.

While all of these robots perform with human improvisers, they rely heavily on dialogue to communicate. These studies explore how to communicate through motion alone. It has been proven that expressive motion in robotics impacts people's interpretation of robots' intentions, emotions, and character [35, 22, 23]. Robot movements can contribute to increased understanding and a common ground in human-robot interactions [15]. Something that these studies aim to learn more about.

In human-robot interaction, simple gestures, such as moving back and forth or spinning in place, have been shown to have strong communicatory power in single mobile robots [20, 2]. Other aspects of expressive motion have also been studied, showing that people tended to view robots as more approachable at slower speeds

[18] and that path shape and orientation change the attributions that people give to robots [19].

2.2 Multi-robot Expressive Motion

There have been many studies that looked at robot motion and gestures as forms of communication [32, 20, 4, 30, 16, 13]. McNeill [28] researched how humans use gestures, showing that they are an integral part of human-human communication.

Prior work in multiple robots has illustrated similar potentials for multi-robot systems in hand-programmed systems. Works by Fraune et al. [11, 10] show that the type of robot in a multi-robot system changes the perception of them and the likelihood of interaction. Paramaterized systems for multi-robot motion include Guzzi et al. [12] and Santos et al. [33], demonstrating the power of multi-robot expression; however, programmatic gesture for multi-robot systems remains little explored. Human-controlled gestures in multi-robot systems, however, illustrate the communicatory potentials for the domain [36, 3].

Chapter 3: ImprovBot: Single Robot Expressive Motion

This chapter follows a paper that was written for and presented at the RO-MAN conference in 2019 [31]. The methods, data, observations, and conclusions of that paper are included in this paper. The author of this thesis is one of the papers authors but sections have been paraphrased and rewritten to be included in this thesis.

3.1 Introduction

The majority of social interactions do not follow a script. They rely on a give and take from each participant as well as appropriate and contextual reactions. This requires a level of improvisation to inspire more interaction and convey the needs of all parties. Good interactions are often between parties that have good improv skills and spur creativity and inspiration in others. As robots become a more common part of our social lives, it will be expected that they too promote creativity and inspiration in their interactions with people. This may be easier for robots with more complex forms of communication such as screen displays and sound capabilities. Simple robots that only have basic Cartesian motion capabilities have limited options in communication but will still be expected to interact with people. This study uses trained improvisers to help determine if simple robots are capable of being a creative partner in an improv scene and therefore capable of more complex social interactions in the world. This study also uses trained improviser to examine if simple motions can be expressive in robotics.

This study introduces improvisers to a game called *relativity*. In this game, the robot and improviser create a scene, the robot shows its interest or disinterest relative to an imaginary object marked by an X on the floor. Eight train improvisers participated in this game and created two scenes with the robot. In one scene the robot's movement were wizard-determined. In the other scene the robot followed a predetermined sequence of motions. After each scene improvisers were asked questions about their interaction. Improvisers were then shown five individual movements and asked to describe what each movement meant.

Given the study parameters, the study aims to answer the following questions:

1. **Can a simple robot be a creative partner to a human improv performer?** Our goal is to have the robot seen, not as a stage prop, but as a fellow improviser .

2. **Can improvisers expand our understanding of robot expressive motion?** Because improvisers are trained to think outside-the-box, they can be helpful in exploring the possible interpretations to a given robot motion.

Figure 3.1: ImprovBot in a human-robot improv scene with the wizard and research lead off stage.

3.2 Traditional Improv Scenes

In a two-person improv scene, the start is usually a suggestion from the audience. This suggestion is an unanticipated word, genre, object, etc. that serves as the inspiration for the scene [17]. improvisers work together, building on the suggestion and the other improviser's work to create a compelling scene. The scene is ended when an off-stage host calls "scene."

Many improv scenes include a game which adds new rules and elements to the scene [17]. For example, the improv game *Genre* challenges improvisers to periodically switch genres during improv scenes. *First Word- Last Word* is another example where improvisers create a scene but the start of each part of dialogue must include the last word given by the last improviser. This challenges improvisers by adding more restrictions and rules to create a scene around.

Another tool used by improvisers are *offers*. In improv, offers are pieces of information about the scene that help clarify to the audience and other performers what is happening in the scene [24]. Offers can be provided multiple ways: dialogue ("Hey, get out of my house"), how something is said (tone of voice), motions (opening an imaginary door), and body language (puffing out chest to look confident). Offers help to establish the scene as well as move it forward, adding new information and suggesting where the scene should go next.

Offers rely on teamwork to be executed correctly, as do all other elements of improv. Without teamwork scenes quickly become confusing and one-sided. With improvisers alternating offers to each other, they are able to successfully build a creative scene.

3.3 Scenes with the ImprovBot

Knowing the principles of improv described above, a new game was developed. This game challenged improvisers to work with a robot to create a scene.

3.3.1 The Game: Relativity

Relativity involves one robot and one human improviser. The human is set up relative to a marked reference point, as seen in Fig. 3.2. The improviser starts with an opening line, referencing an imaginary object located at the reference point. Next is a cycle, where the robot and improvisers take turns responding to

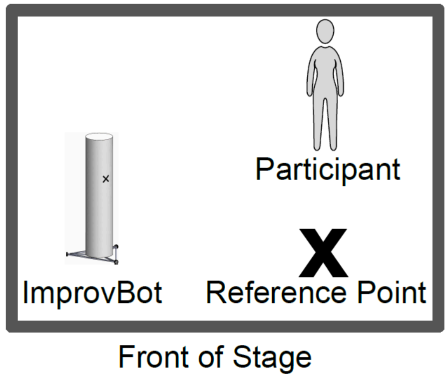

Figure 3.2: Relative position of human, robot and reference point and the start of the game.

the previous offer and contributing to the scene. The game ends when "scene" is called. These steps can be seen in Fig. 3.3. Having a fixed reference point provides something the robot can consistently gesture and reference too. As one improviser stated "The X gives another thing for the robot to react to." The robot can move relative to the X and relative to the improviser, however the latter is more challenging as the improviser frequently moves.

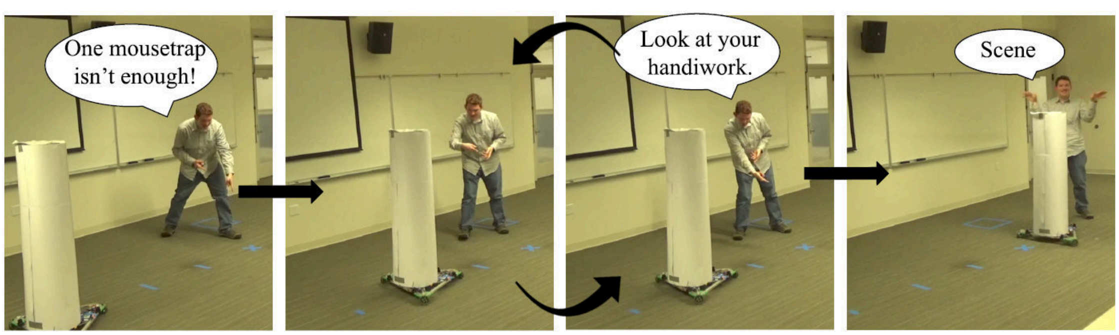

Figure 3.3: Each individual scene has an opening line, multiple cycles of robot movement with a human reply, and then ends when the improviser calls "Scene."

3.3.2 ImprovBot Design

The ImprovBot as seen in Fig. 3.4, is a simple robot consisting of an omni-directional platform and cylindrical body. The body is 1.1 meters tall, 2/3 the height of an average person. This height was chosen to allow the robot to give a human-like presence without being overbearing by being taller than the participants. The body is white with an X being the only defining feature. The X allows participants to quickly understand the robot's orientation without providing details that may skew participants interpretations on the robot and a character/performer. This minimalist body was used in past work in robot communications [22, 23] and is common in social robotics research [35, 14].

The omni-directional platform allows for the robot to perform a variety of gestures including rotation in place and independent movement on the X and Y planes. With the maximum speed at 1.5 m/s and the independence of motion the platform provides more agility than in previous studies [21]. This agility was appreciated by participants, one saying "because of its quick turning, its sudden breaking and going, there was more for me to interpret."

The robot is able to be controlled wirelessly by an off-stage wizard. This allows for the robot to seem like it is acting independently of human control while maintaining a human in control during the study. Previous work in robotic furniture [35, 23] has used this technique and demonstrated the value of wizarded robots especially in exploratory social robotics research.

Figure 3.4: The robot has a simple body with an X marking the front, an omnidirectional platform, and a maximum speed of 1.5m/s

3.4 Study Design

This section describes the process taken in Fig. 3.5. The procedure involves preparing the participant, two scenes playing the game Relativity, isolated movements demonstration, and a post-test interview.

3.4.1 Test Preparation

The participant is provided a consent form and then a description of the rules of the game. The participant is given a chance to ask clarifying questions about the game and for further clarification, a practice round is performed. In the practice round, the participant makes a single offer directed at the reference point. The

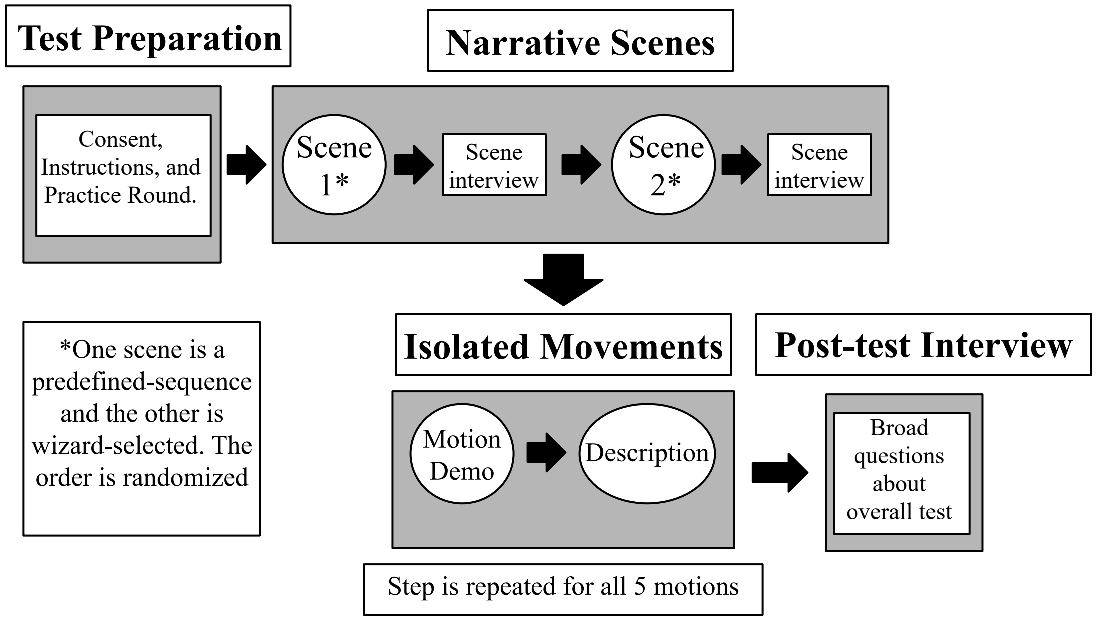

Figure 3.5: Study Procedure: Each participant is prepped with consent forms, instructions, and a practice round. We collect our first data set through two narrative scenes, each followed by an interview. We collect our second data set from motion demonstrations and descriptions. We end with a post-test interview.

robot then makes one gesture in response before the scene ends.

3.4.2 Narrative Scenes

Two narrative scenes are then performed with the robot and participant. For both scenes, the robot is controlled by an off-stage wizard that has full view of what is happening on stage. There are two different scene types: predefined-sequence (a map of pre-selected movements the robot will follow), and wizard-selected (where the wizard decides on a gesture to respond to offers. Scene order is randomized and participants are not informed that there are two different scene types.

After each scene participants answered questions in a short interview. These questions were different than the post-test questions and were aimed to examine how the participant viewed the robot as a partner in the scene. The questions were:

1. *Who Carried Who in the Scene?*
2. *Who Took the Lead?*
3. *Was the Robot Surprising or Unsurprising?*
4. *Was the Robot Flexible or Inflexible?*
5. *Was the Robot Creative or Uncreative?*

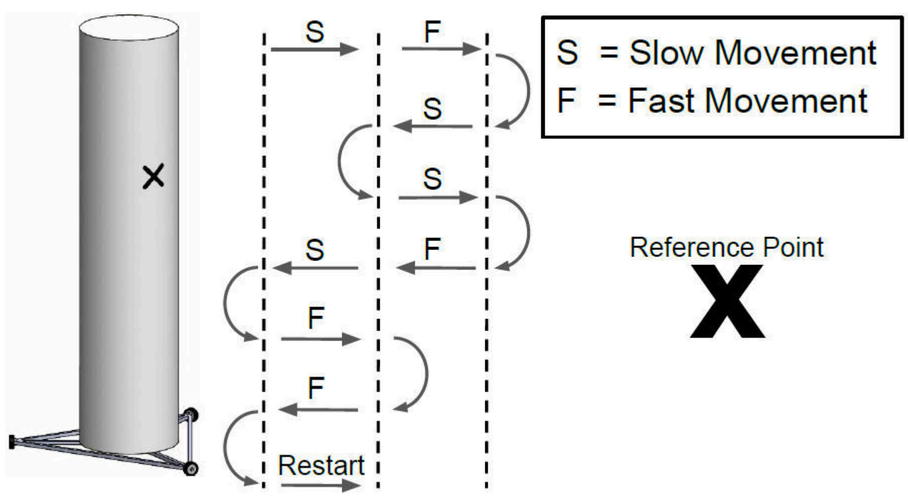

Figure 3.6: Predefined-Sequence Condition: Robot followed motions in top to bottom order. Note that the robot only moves towards/away from X (not forward/back on stage). This contrasts the wizard-selected condition in which all motions are allowed at any time.

3.4.2.1 Predefined-sequence

In these scenes, the robot follows a preset sequence (Fig. 3.6 of motions regardless of what offers the improviser makes. Motions were selected ahead of time for logistical and narrative reasons. Logistically, this removed the risk of running out of stage space if multiple movements in the same direction were randomly selected. It also guaranteed some variety in movements and speed. Narrative wise, this allowed for the study to see how many different scenes one sequence could inspire.

The predefined-sequence was selected to see if improvisers still found the robot to be a creative partner even when its motions were not selected to specifically respond to each offer. The hypothesis was that in these scenes the participants would find the robot as less creative, uncooperative, and inflexible.

3.4.2.2 Wizard-selected

In these scenes the wizard was allowed to control the robot's gesture in response to offers, however they deemed fit. The wizard was also a trained improviser, giving them the skills needed to know when a participant was expecting a response and what gestures would make good offers.

Wizard-selected scenes allowed for the study of how gestures were perceived in a creative space when contextually appropriate ones were selected. It was hypothesized that participants would find the robot in these scenes as more creative, flexible, and cooperative.

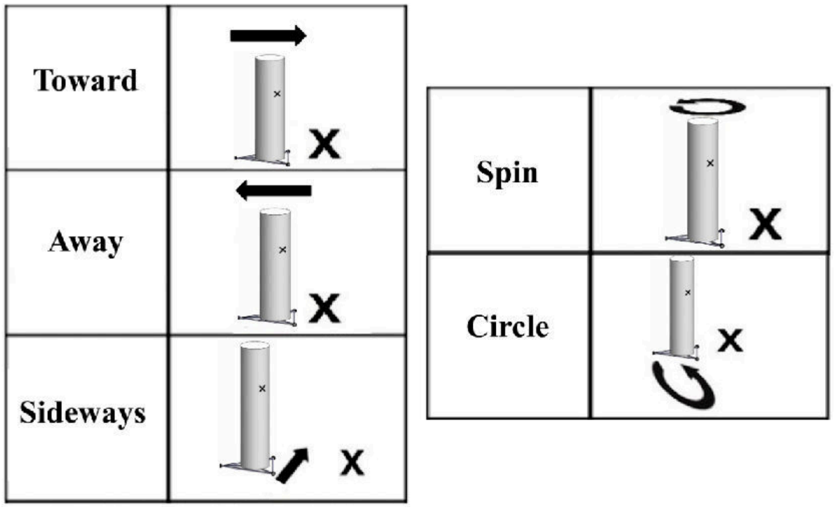

Figure 3.7: These isolated movements are shown in random order to each participant. They are shown a movement, asked what they think the motion means, and then shown the next move.

3.4.3 Isolated Movements

After the two scenes were performed, participants were shown five different isolated movements as seen in Fig. 3.7. The participant is asked to stand on the X and close their eyes. One of the motions is randomly selected and the participant is asked to open their eyes. The robot performs the motion and the participant is asked to describe what the movement means as they've interpreted it. They are encouraged to share the first idea that comes to mind. This is repeated for all five motions.

The motions were selected due to their simplicity and variation in planar movement and speed. Simple movements that can be performed by most robot platforms means that the results from this study can potentially be applied to other systems. Simple motions are also easier to program if this system was automated in the future as the movement require few movement commands.

Performing this study with an improviser provides valuable insight that may not be gained with other participants. Improvisers are trained to interpret gestures and emotions in order to respond to them. They can provide a creative and descriptive interpretation of each movement that will help study how gestures in simple robots are interpreted.

3.4.4 Post-Test Interview

After the scenes and isolated movements, participants are asked post-test questions to gauge their experience with the robot and their impressions. Participants were asked what their impressions on the robot were and what they thought of it. They were also asked about what happened in each scene and what character the robot played to determine what role the robot took as a partner in the scene. The participants were also asked if there were any motions they remembered that stood out to them to determine what motions might be the most expressive. This data is analyzed in the following sections.

3.5 Scene Results

The subject of all the scenes was different, from mermaids trying to escape fishing hooks to strangers arguing over finding vacation tickets on the ground. There were eight participants with a total of sixteen scenes. Due to changes in testing procedure, the first four participants were given the post-scene questions after performing both scenes. The other four were given the questions after each scene. The results shown in this section pull quotes given by the four participants given the questions between scenes. This sample size is small but provides a base for an exploratory study.

3.5.1 Can ImprovBot Develop a Scene?

The first two questions asked of participants aimed to evaluate what role the robot took in co-developing a scene with the participant. The first question was "Who carried who in the scene?"(Fig.3.8). In the predefined-sequence scenes, three out of four participants said that they carried the scene. This meant that they felt they had to make more of the offers and contribute more to building a scene than the robot. In the wizard-selected scenes this flipped, with three out of four participants saying the robot carried the scene.

This is interesting to look at since it implies that the robot appeared more constructive and responsive during the wizard-selected scenes. It shows that in some situations a robot can be the one carrying and developing a scene only through gestures. One participant said that, "the robot was much more engaging this time with movements, it pressured me more" when talking about the wizard-selected scene. The robot was viewed to engage more in the offers and make its own while in the predefined-sequence scene a participant said "I was just giving out suggestions

	Improviser	**Robot**
Predefined Sequence	"I was explaining all the moves. The robot was doing stuff, but I was explaining everything, so I was carrying the robot." "I was carrying the scene, I was making a lot of aggressive moves." "I was the one giving out suggestions and it was just running around."	"At the beginning it was me [carrying], and then it flipped. I felt by the way it turned that it was upset and saying, "I don't want to talk to you," its turning away made me change."
Wizard-Selected	"Me, I was leading with questions and looking for reactions."	"The robot was much more engaging this time with movements, it pressured me more." "It saw the cues I was giving." "There were definitely times I couldn't think of much, so I was using the robot's reactions to inspire me."

Figure 3.8: Four participants were asked after each scene, *"Who Carried Who?"* Answers were divided by scene type (row) and binary answer (column). Gray shows the predominant answer

and it was just running around."

"Who took the lead" was subtly different, asking participants who led in defining the scenes and the direction it took. In this case, the answers were almost unanimous for both scene types. Besides one answer, every participant said that they took the lead in both scenes (Fig. 3.9). This does not mean the robot was not making offers, but rather participants thought that since they were the ones speaking they were often obligated to describe what was happening. One participant said "I don't know how it (robot) could communicate to me what the next thing we're building is," when talking about a scene involving building a playground. So while a robot can carry a scene and make offers, this suggests that the majority of

	Improviser	Robot
Predefined Sequence	"I took the lead...in the role that I chose, I was the higher rank than him." "Me. I was trying to figure out how to not interact with it by just asking questions."	"I started off kind of leading, but with it turning away, it kind of led it."
Wizard-Selected	"I took the lead, I was the one calling him out and he was trying to justify himself." "I took the lead because I felt I had to do something...I don't know how it [robot] could communicate to me what the next thing we're building is." "I led because I was referring to the story. It did acknowledge the story in a sense, but I had to keep leading it along."	

Figure 3.9: Four participants were asked after each scene, *"Who Took the Lead?"*

the time the robot plays a supportive role in scenes.

In the one instance where the robot was described as taking the lead, the robot kept turning away during the scene. The scene itself was about conflict and the improviser said that the robot seemed to be communicating "I don't want to talk to you." This may suggest that in scenes of conflict the robot has more of a chance of taking the lead although more data would have to be collected to support this observation.

3.5.2 Is the ImprovBot Surprising?

In both scene conditions three out of four participants stated that the robot was surprising (Fig. 3.10). Participants seemed generally surprised by how the robot

	Surprising	Unsurprising
Predefined Sequence	"Surprising, I didn't realize how much inspiration I could get from the movements." "Surprising, but I felt that played into the scene well. That became his persona: sloppy but surprising." "Surprising because it would just do stuff."	"I'd say unsurprising."
Wizard-Selected	"Surprising if the reactions fit what was going on in the scene." "It was surprising in its closeness. It startled me, but in a good way." "Surprising, but I liked it. I didn't think it was going to turn around when I took it [the improvised object]...but then it turned around and that added to the scene."	"It reacted appropriately to what I was putting out there, so unsurprising because it felt like we were on the same wavelength."

Figure 3.10: Four participants were asked after each scene, *"Was the Robot Surprising or Unsurprising?"*

moved and reacted to offers. When the robot moved according to expectations it was unsurprising, one participant saying "it reacted appropriately to what I was putting out there" which made it unsurprising. When the robot did not move in accordance to expectations it was surprising but that could be viewed as a good or bad thing.

When the robot was surprising in a good way, its movements were unexpected but still contextually aligned with the scene. This helped the robot to build the scenes. In a scene where two people were arguing about found vacation tickets, the robot suddenly turned around, catching the participant trying to steal the tickets. "I didn't think it was going to turn around when I took it (the tickets)... but then it turned around and that added to the scene" the participant stated.

When the robot was surprising in a bad way, its movements did not contextually fit the scene. As one participant said "it would just do stuff" meaning the robot was surprising but not in a way that aligned with the offers being made. Unlike being surprising in a good way which added to the scene, being surprising in a bad way often derailed the scene or made it difficult for the improviser .

However, surprising in a bad way did not always mean the scene was bad. In some cases the uncontextual movements played into the character of the robot. In one scene involving a sword fight the participant said, "that became his (the robot's) persona: sloppy but surprising." The robot was unpredictable in its movements, making it difficult for the participant to attack which added to the scene.

The novelty of the robot may have also played into how surprising it was. Participants were not used to creating a scene with a robot and therefore did not know what to expect. It would be interesting to have participants create other scenes with the robot and see if they still find it surprising. Overall, the responses to this question show further potential for ImprovBot.

3.5.3 Does ImprovBot Stymie or Spur Creativity?

Creativity is vital in improv. Responding to offers in a creative leads to more entertaining scenes. This section explores if the robot spurred creativity by asking participants: *is the robot flexible or inflexible?* and *is the robot creative or uncreative?*

The question considering if the robot was flexible or inflexible was aimed to

	Flexible	**Inflexible**
Predefined Sequence	"Flexible because I was throwing a lot of stuff at it in the scene." "It was flexible in the whole dynamic of it turning and jolting quicker while I was talking. I felt that was very flexible."	"It ended up continuing the bit about how we couldn't get along. It was too repetitive to be flexible." "It was acting independently, making its own decisions rather than making a decision based off what I was trying to get it to do."
Wizard-Selected	"The robot was more willing to go along with what I was doing." "It was flexible in a way that, I could feel its reactions to what I said." "Pretty flexible, it felt like there was [in the robot] an emotion conveyed there." "Pretty flexible. Whatever task I gave it, it was there."	

Figure 3.11: Four participants were asked after each scene, *"Was the Robot Flexible or Inflexible?"*

check if participants noticed a manipulation change between the wizard-selected scenes and the predefined sequence. In the wizard selected scenes all participants said that the robot was flexible while in the predefined sequence only half said it was (Fig. 3.11). This is a notable amount and indicates that robots using predefined sequences may not blend in as well in social situations.

In predefined scenes, when participants found the robot flexible they seemed to be satisfied with the variety of movements and speeds in the sequence. One participant commented "it was flexible in the whole dynamic of it turning and jolting quicker while I was talking." When participants found the robot inflexible, they tended to find the sequence of movements repetitive and the robot continuing to respond to old offers or "acting independently." The reactions to this question do seem promising. Two participants already found the sequence to be diverse enough and two wanted more diversity. It seems possible that a development of a new sequence with more diverse speeds and movements could reduce the amount of participants that view the sequence as inflexible.

In the wizard-selected scenes, all participants found the robots to be flexible. One participant said, "the robot was going along with what I was doing." Participants seemed to feel like the robot was reacting to their offers and going along with their plans. In one scene where the improviser was playing an old man they said that "it [the robot] saw the cues I was giving with being old and rickety...I thought it was a good give-and-take."

This theme was explored further with the question *is the robot creative or uncreative?* Here, the results were the same, with participants agreeing that the robot was flexible during wizard-selected scenes and split between creative and uncreative for predefined sequence scenes (Fig. 3.12). This suggests a high correlation between flexibility and perceived creativity. It also has promising implications that predefined sequence scene may be a workable option for ImprovBot if developed correctly. This can be seen in a scene between two mechanics where the robot suddenly approached after an offer. This interaction was cited when the participant described the robot as creative. This movement was predefined but the robot was perceived as being flexible in a scene and responding to the offer, making it a creative partner.

Some of the reasons participants found the robot uncreative seemed to be because of the role they chose for the robot during the scene. "I was carrying the

	Creative	Uncreative
Predefined Sequence	"Still creative [compared to wizard-selected]. Like when I talked about the car, it suddenly approached." "Creative. I could imagine what it would say just by its movements. I felt that really gave me something to work with."	"I was carrying the creativity because I took control of the scene. I was making everything, all the new things." "Uncreative. I might just be hard on the scene because I didn't like it as much as the previous one."
Wizard-Selected	"Creative...it did feel like a real scene there with another person" "It played the role of an aggressive police officer pretty well, so I felt it was creative." "I think the robot was creative...there were decisions being made there." "Down the middle, it wasn't uncreative, it wasn't super creative..the [robot's] reactions to what I was doing, they were the right actions, but I don't know what else they could have been."	

Figure 3.12: Four participants were asked after each scene, *"Was the Robot Creative or Uncreative?"*

creativity...that may be because of the role I chose for it. Like being a subordinate in the scene makes him less able to be creative," said one participant. Another said "I was trying to figure out how to not interact with it by just asking questions, but I couldn't really think of anything because it's the way I set up the scene." In both these cases, the role for the robot was a subordinate which seemed to restrict the participants creativity in the scene.

In one case, one participant also noted difficulty adapting to the robot as an improve partner as a struggle in their creativity. "I kept asking it open-ended questions like, 'how much does this cost?' but then realized there's no way it can answer that." They stated in the interview. One tip to improve ImprovBot's perceived creativity may be to give improviser's more practice with the robot. Like any improv game, Relativity takes time to learn so improviser's will learn how to interact and what roles are best for the robot.

3.6 Isolated Gesture Results

Eight participants watch five different gestures and were asked to describe what each meant. The wording in responses was sorted by negative, positive, and neutral language. Negative language was either negative descriptors like "creepy," negative actions like "about to yell," or negative emotions like "ashamed." Positive language was the opposite, with descriptors such as "gentle," actions like "wanting to engage," and emotions like "excited." The neutral category was for descriptors that had no clear positive or negative connotation such as "interested yet distracted" or "showing off." Positive language was given a value of 1 while negative was given a value of -1, and neutral a value of 0. These results were then put in a plot in Fig. 3.13 and are discussed in this section. The results showed three main categories in response to gestures: low variance, high variance, and tendency.

3.6.0.1 Low Variance Interpretations

These gestures tended to receive strong negative or positive responses with responses mainly only in one category. The two low variance gestures were away and sideways. These two gestures tended to get negative interpretations by par-

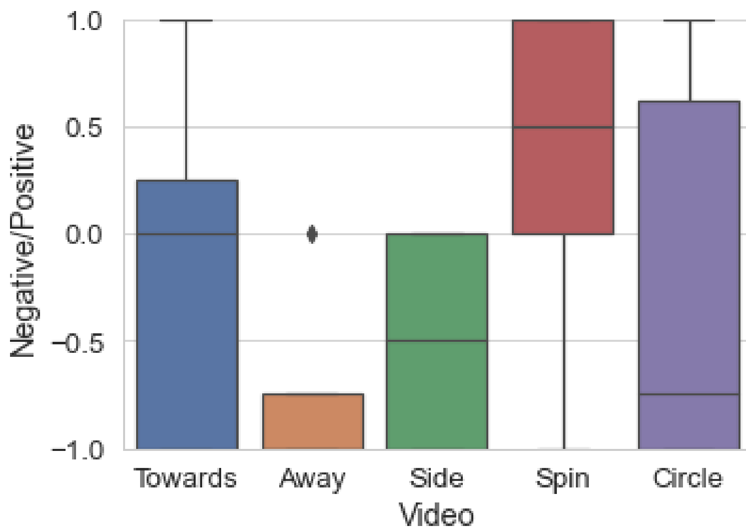

Figure 3.13: The results from improvisers being asked what each gesture meant when performed by the robot. Answers were sorted by negative (-1), positive (1), and neutral (0) language. The mean is shown along with the 25% quarantile, 75% quarantiles and outliers.

ticipants.

Away had the lowest variance of all gestures with many responses being negative and only a few being neutral. The language participants used were often negative emotions that they interpreted the robot felt such as "anxious," "fearful," or "threatened." Neutral language described the robot as wanting to get away. Away was interpreted as the robot reacting negatively to something in a non-confrontational way.

Sideways had a few more neutral interpretations but still had high amounts of negative language being used. The negative language used here was often negative descriptions of the robot like "creepy," "awkwardly leaving," or "slithering away." The language did not describe the robot as aggressive but not as trustworthy or welcoming either, more as a weird or awkward character.

3.6.1 High Variance Interpretations

High variance gestures tended to receive positive, negative, and neutral interpretations. These gestures were unreliable, they were interpreted differently by participants making their communication power low. There were two moves in this category: towards and circle.

Towards had a truly neutral mean with answers in all categories. In positive interpretations it was “excited” and giving an “abrupt greeting.” While on the negative side, the robot seemed “rushed” and “about to yell.” With the majority of interpretations the robot seemed to be wanting to interact or interacting, engaging with the participant rather than transmitting passive emotions or wanting to get away.

Circle has a negative mean but a wide range of interpretations as well. While towards had interpretations about engagement, circle seemed to inspire the most story telling. Participants said the robot was “turning a blind eye to the situation” and seemed to be saying “look, there’s no one else here.” There tended to be more descriptive answers with fewer one-word emotion answers. This is interesting considering that circle is the most complex movement axially as it does not move only in one direction like towards, away, and sideways or stay on one point like spin.

3.6.2 Tendency Interpretations

This category describes gestures that did not have a low variance but still had a tendency to be interpreted one way. There was only one gesture in this category: spin. The spin gesture had a tendency to be positive with a positive mean and a high portion of answers having positive language, although some answers were negative.

Spin was mainly described as "excited" with three participants describing it this way as "joy/joyful" with two participants using this wording. On the negative side, it was interpreted as showing "disappointment." This tendency shows that this gesture could be used for multiple different communications and the interpretation might change depending on the context. The spin move conveys a very joyful and excited emotion to most but may be used in other communications if the context were changed.

3.7 Discussion

This research aimed at answering two questions. The first: **can a robot fill the role of a human in improv?** As seen in section 3.5.1, the robot can been seen as a partner to improvisers depending on the circumstances. When the scene had the robot using wizard-selected movements the robot was seen as a flexible, creative, and surprising partner who carried the scene. Even when the robot was following a prescribed set of movements in the predefined sequence scenes, it was still sometimes seen as creative and flexible but still surprising. These scene put the pressure on the improviser to carry the scene. In all scene types the improviser was the one that took the lead although this may be due to the them being the only speaking participant in the scene.

In answer to the question **Can improvisers expand our knowledge of communicatory gestures in simple robotics?**, it was seen through participant's answers that they can expand our knowledge and understanding of what some gestures could be interpreted as. This experiment showed that many moves are not universally interpreted as negative or positive. For example, moving in a circle could be interpreted as creepy or gentle and playful.

The two moves that did have more universal interpretations had high amounts of negative language. This poses the question: Are there low variance movements with positive interpretations? While there was the spin movement with a tendency towards positive, that was not the same as the low variance category where all answers were positive/negative or neutral. This could show that negative communication is easier to portray in gestures but would need a separate exploration to conclude.

It should be noted that improvisers are trained to think outside of the box and often offer creative and uncommon responses. While in this study that was useful in expanding the vocabulary used in robotic gestures, it does not provide the interpretations the general public would have. For simple robots in more general environments it would be suggested to do the isolated motions test again with a broader audience.

These isolated movements were also performed after the improv scenes with the robot where participants had created personalities for the robot. The emotions and preconceived notions from these scenes could affect the interpretations of the isolated movements. For example, a scene where the robot was a villain may lead to the improviser interpret ting the isolated movements as more sinister and negative.

When asked, participants seemed eager to work with ImprovBot again. They also wanted to do live shows with ImprovBot which could be a future study to see if having an audience changes the scene dynamic and if the audience views ImprovBot as a partner. A goal for ImprovBot and the game Realativity will be to perform it for a live audience and further exploration, using the audience as a data source as well as the performer.

3.8 Conclusion

This research explored robots in improv by creating ImprovBot to make one-on-one scenes with trained improvisers in a game called Relativity. Relativity was developed to use standard improv concepts like suggestions, offers, and teamwork. Eight participants worked with ImprovBot, a minimal robot, to create scenes and answer questions about how ImprovBot performed as an improv partner. ImprovBot's response to participants in scenes followed either predefined sequence of movements or were selected contextually by an off stage wizard who was also train in improv. Finally, participants watched isolated movements performed by the ImprovBot to try and gain an understanding of how gestures are interpreted in simple robotics.

Chapter 4: Spheros: Multi-robot Expressive Motion

This chapter follows a paper that was written for ICSR in 2021 ([5]). The author of this thesis is the first author of the paper and has therefore included most of the text from the paper.

4.1 Introduction

In multi-robot systems, motion patterns can be seen as gestures, a powerful way for humans to communicate without words. Gestures and body language are strong communication tools in human-human interaction [28], and this study showed gesture is a promising communication tool for multi-robot and human interaction.

This work explores how emotions can be expressed with simple multi-robot motion using five different, synchronous gestures on three simple robots and exploring how speed and context change the interpretation of expression of these gestures.

This chapter finds gesture is the leading variable in robot expression, while speed plays a small role and context plays no role. This reduces the number of variables that need to be considered when designing robots for human interaction, making for a more simple and efficient system.

Gesture	Speed	Context
Towards	Fast	“A robot walks into a party”
Away	Slow	”A robot walks into a meeting”
Sideways		No context given.
Spin		
Circle		

Table 4.1: The independent variables manipulations.

4.2 Study Design

An online video study explored how gesture, speed, and context affected people's perceptions of a multi-robot group. Three Sphero robots were used to create videos for the different variable conditions and Amazon mTurk was used to evaluate these videos.

4.2.1 Experimental Manipulations

Three independent variables were explored to see how they affected people's perceptions of a multi-robot group: (1) gesture, here meaning the way the multi-robot group moved; (2) speed, here being how fast the robots performed the gesture; and (3) the context given to participants about the robots. These three variables aimed to replicate realistic variables in a human-robot interaction and can be seen listed in Table 4.1.

The robots performed five different gestures: towards, away, sideways, spin, and circle, as seen in Figure 4.1. These gestures were inspired by prior work on an expressive single robot [31] and were chosen to be representative of Cartesian

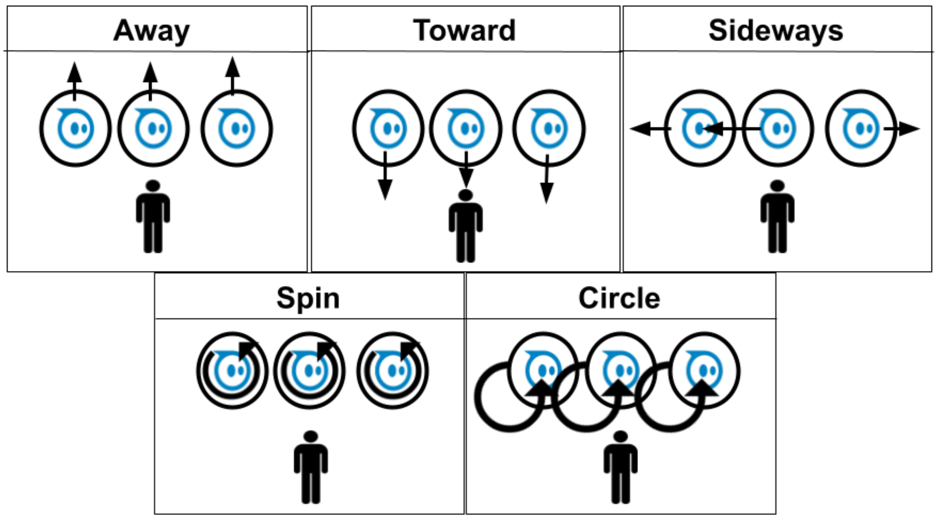

Figure 4.1: Each isolated gesture was performed synchronously with all three robots.

motion with three linear gestures in cardinal directions (towards, away, sideways) and two orientation gestures (spin, circle). These five simple gestures can be combined to create complex motion and it is valuable to understand how each of these basic motions is perceived.

Each gesture, except circle, was performed at two speeds: fast and slow. These two speeds were chosen based on the speed range of the Sphero robots. The circle gesture was only performed at the slow speed because the Spheros could not move in a clear circle pattern at faster speeds.

Participants were shown one of three options for context for each gesture and speed combination: “A robot walks into a party,” “A robot walks into a meeting,” or no context. The different contexts were chosen to have similar actions (the robot walks in), but with one formal setting and one informal setting. These

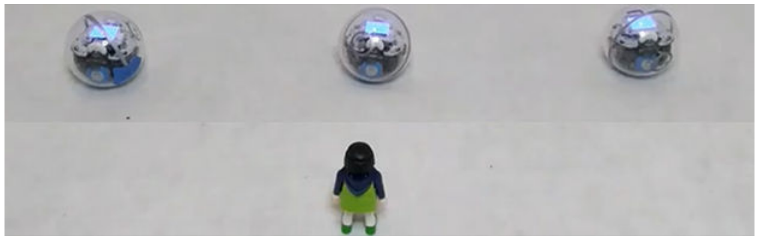

Figure 4.2: Scene setup consisting of three Sphero robots and one humanoid figure.

context options tested if preconceived notions of the robots' purpose changed the perception of their interaction.

4.2.2 Online Study Setup

An online video study was run using Amazon's MTurk Service, which allowed for the exploration of more variables with more participants than an in-person study. Each video opened with three robots in a line in front of a humanoid figure with a plain white background, as seen in Figure 4.2. The robots were placed in a straight line formation to reduce what role the formation played in the perceived communication. The humanoid figure remained stationary while the robots performed synchronous motions. Each participant was shown a video with one of five gestures at one of two speeds with one of three video contexts. Each participant was asked one question out of five possible questions.

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Two questions used a seven-point Likert scale. Participants were given a sentence to finish with a drop down menu of Likert scale responses. For example, the question "The actions taken were [blank]" had the answer options of "very positive," "positive," "somewhat positive," "neither positive or negative," "somewhat negative," "negative," and "very negative." Three of the questions were open-ended, in which participants wrote a response after watching the video and reading the description.

1. **Likert:** The actions taken were [very positive to very negative].
2. **Likert:** The human felt [very welcome to very unwelcome].
3. **Extended Response:** What emotion(s) are the robots portraying?
4. **Extended Response:** Describe the story of what happened.
5. **Extended Response:** What were the robots trying to achieve?

4.2.3 Analysis Methods

The study was between-participants with non-normal data for the Likert scale questions, so Kruskal-Wallis tests and Mann-Whitney U tests were run to determine significance of the data and which pairs were significant. The Kruskal-Wallis tests were run with combined data first sorted by gesture, then speed, then context to determine which parameters changed perception on the robots' emotions.

Each extended response was coded using grounded coding to find important positive, negative, and neutral language used. There were three categories for important language used: (1) robot actions/reactions; (2) robot descriptions; and (3) robot emotions. Each time language that fell under one of these categories was used, it was determined if the language was positive, negative, or neutral. Positive language was given a value of 1 and included words like "welcoming", "joy", and "greeting". Negative language was given a value of -1 and included words like "fear", "run away", and "mean". Neutral language was given a value of 0 and included words like "following", "move back", and "low interest". In each response, the total positive, negative, and neutral language was totaled and averaged to come up with a single response value for each response.

4.3 Results

This study followed three variables in an attempt to see which variables change the interpreted expression of the robots. It was hypothesized that the type of gesture would change how the robots are viewed. Based on the ImprovBot study [31] that had the same motion types for a singular robot, away and sideways would be viewed negatively, spin would be viewed positively, and toward and circle would have a high variance in responses ranging from positive to negative. Similarly, it was hypothesized that the speed of the robots would change the interpretation of the action, with the faster speed being viewed more negatively as the sudden motions may be startling to the viewer. It was also hypothesized that giving a context for the videos would not change the positive or negative views of the robot but would change how participants described the robots' motivations.

Eighty-one participants answered each question for a total of 405 individual participants for this study. Overall, the results showed the largest factor in portraying emotion was the gesture used. Speed had some influence in strength of response. Context did not significantly affect any results.

4.3.1 Participant Attributions of Robot Motion Results

This subsection presents the results from our survey questions, in which participants rated the robots as welcoming/unwelcoming and positive/negative. The data showed a consistent trend in the influence that gestures had in the interpretation of the robots' actions and emotions. Towards and spin were positive/welcoming, away and sideways were negative/unwelcoming, and circle was slightly positive/welcoming, but had a higher variance and neutrality.

[Welcome/Unwelcome] Results. The results for "The human felt [welcome/unwelcome]" showed strong views for the towards, away, and sideways gestures. The spin and circle gestures had a weaker response. It was seen that the sideways and away gestures were viewed as very unwelcoming. Towards was viewed as very welcoming and spin was somewhat welcoming. Circle was viewed as slightly welcoming, but was more neutral than any of the other gestures, as seen in Figure 4.3. The Kruskal-Wallis p-value was 8.89×10^{-12}, which showed significance in the data. The Mann-Whitney U test then showed further significance in pairwise comparison illustrating that the gesture performed significantly change the interpretation of the robots' states. The slow speed added more variance or neutrality for each gesture. Away, sideways, and spin had significant difference between fast and slow with p-values of 6.463×10^{-4},1.979×10^{-3}, and 4.405×10^{-2} respectively.

However, this difference did not change the meaning of the movement between welcoming and unwelcoming; it simply skewed the slow speed towards neutrality. Results can be seen in Figure 4.4. Context had no significant results.

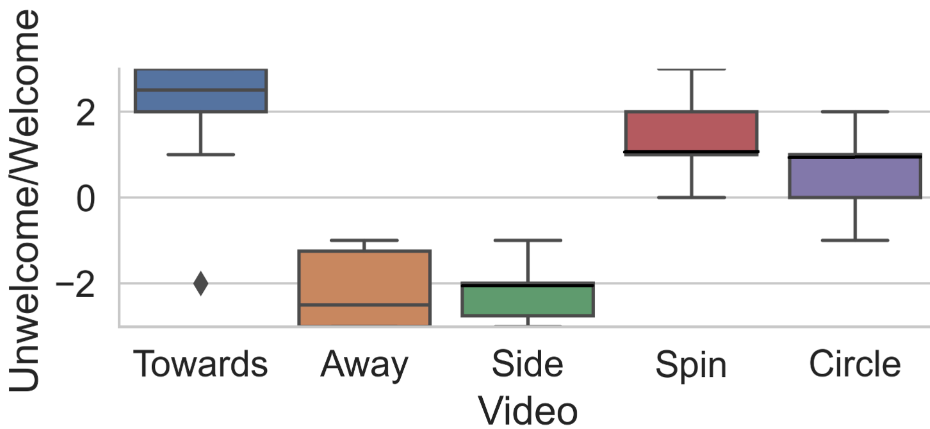
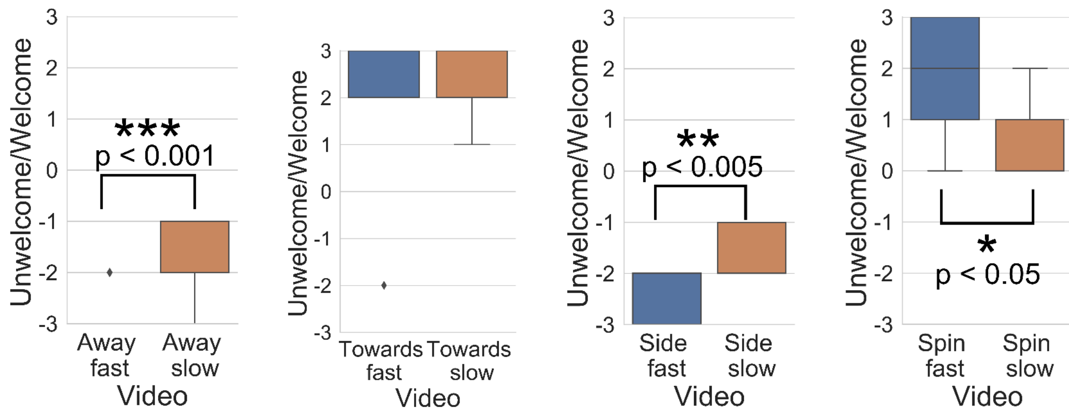


Figure 4.3: The results from the answers to the question "The human felt [welcome/unwelcome]" for the gestures. An answer of very unwelcoming was given a -3 value and an answer of very welcoming was given a 3 value. The mean is shown along with the 25% quarantile, 75% quarantiles and outliers.

[Positive/Negative] Results. The purpose of asking participants if the robots' actions were positive or negative was to see if people thought the robots were acting in a positive or negative way toward the human. The results for this question were varied more than [welcome/unwelcome], but showed similar trends with away and sideways being viewed as negative, towards and spin being viewed as positive, and circle being viewed as slightly positive with variance. Spin had the lowest variance in answers and was viewed as somewhat positive. Towards and circle were also viewed as somewhat positive, but with a higher range in answers. Sideways and away both had very high variance. Away was somewhat negative



(a) The away gesture

(b) The towards gesture

(c) The sideways gesture

(d) The spin gesture

Figure 4.4: The results from answers to the question "The human felt [welcome/unwelcome]" for each gesture at two different different speeds.The mean is shown along with the 25% quarantile, 75% quarantiles and outliers. Results include all motion types and speeds.

and sideways was viewed as negative, as seen in Figure 4.5. The Kruskal-Wallis p-value was 3.95×10^{-5} which showed significance in the data. The Mann-Whitney U test then showed further significance in pairwise comparison illustrating that the gesture performed does significantly change the interpretation of the robots' states. Speed did not change any of the gestures to be viewed as the opposite (positive or negative), but the slower speed pushed results to be more neutral. This additional neutrality at the slow speed was significant in the sideways gesture with a p-value of 2.150×10^{-2}. These results can be seen in Figure 4.6. Context had no significant results.

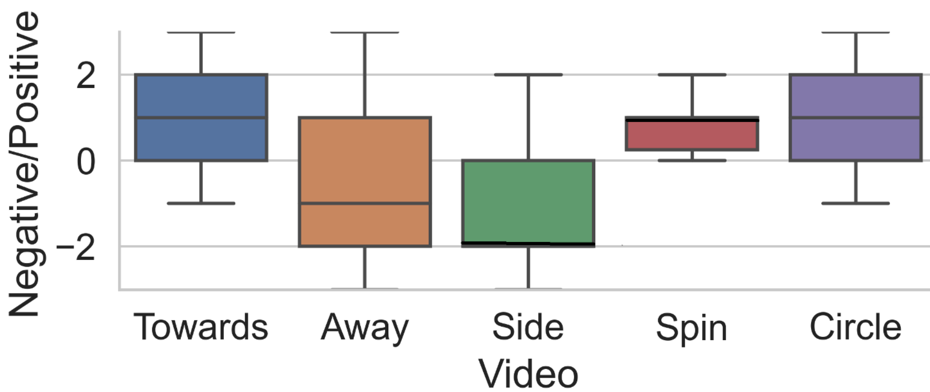
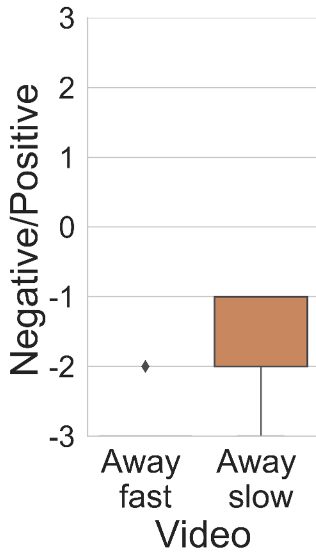


Figure 4.5: The results from the answers to the question "The robots actions were [negative/positive]" for the gestures. An answer of very negative was given a -3 value and an answer of very positive was given a 3 value. The mean is shown along with the 25% quarantile, 75% quarantiles and outliers.

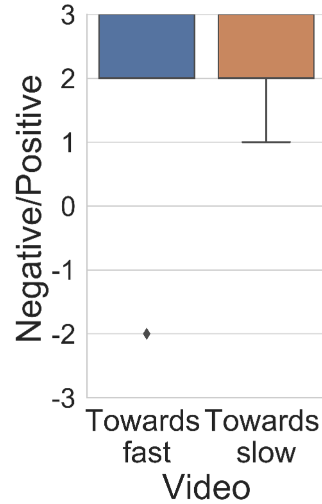
4.3.2 Extended Response Results

The purpose of the extended response questions was to get more extensive data on how the robots were viewed. By asking participants to write their responses, the reasoning behind each response became easier to determine. Overall, the results were similar to the Likert scale results where gesture was the leading variable and speed had some effect on the perceived expression of the robots. The special case in these results was the towards gesture, which switched interpreted expressions based on speed. Context did not have any significant results.

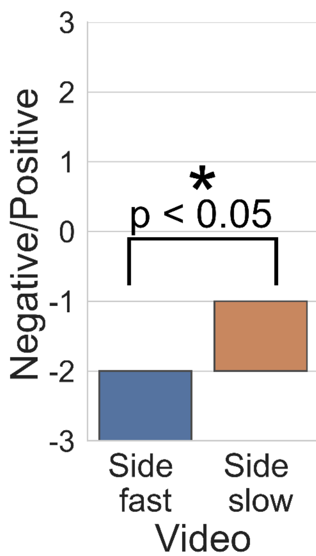
Motion Results. These results helped to solidify the understanding of how each gesture was viewed. The Kruskal-Wallis test p-value was 1.45×10^{-10} meaning the data set had significance. Gestures affected participants' views on whether interaction between the robot and the human was described positively or nega-



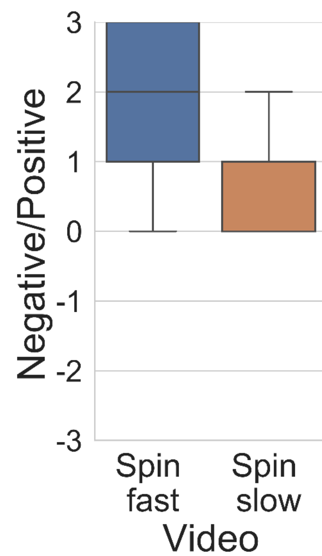
(a) The away gesture



(b) The towards gesture



(c) The sideways gesture



(d) The spin gesture

Figure 4.6: The results from answers to the question "The actions taken were [negative/positive]" for each gesture at two different different speeds. The mean is shown along with the 25% quarantile, 75% quarantiles and outliers. Results include all motion types and speeds.

tively. Results can be seen in away and sideways led participants to think the robots were afraid and uncertain. The robots were often described as running or walking away. They were also described as "scared," "fearful," and "unwelcoming." Most descriptions did not include language of aggression, but rather avoidance and wariness of the human. Spin was viewed positively with the robots' emotions often being described as joyful, excited, and happy. The spin was sometimes described as a dance or an expression excitement or joy. Circle was also sometimes described as a dance or a performance for the human. Many similar descriptors were used for circle, but with the addition of words like confusion and frustration. The towards gesture was highly variant because in these responses the gesture was dependent on speed.

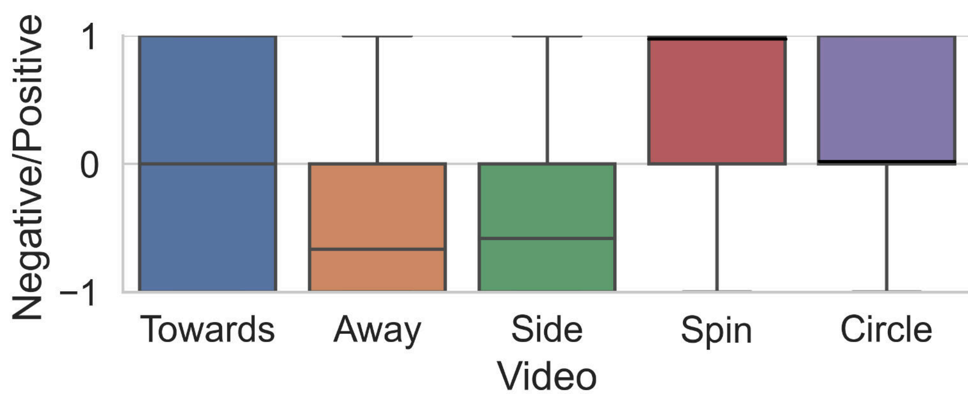


Figure 4.7: A comparison of the descriptors used by participants for the five gestures in the extended response questions. Robot actions, emotions, and descriptions were taken from responses and categorized by positive(1), negative(-1), and neutral(0). The mean, 25% quarantile, 75% quarantiles, and outliers are shown.

Speed Results. Speed was studied to gain an understanding of how it affects interpretation of expression. Two Kruskal-Wallis tests were run. One tested the two speeds across all gestures and results were not significant, meaning speed itself does not surpass gesture in interpreted expression. The second included all five gestures at two different speeds, which was significant with a p-value of 3.39×10^{-10}. The Mann-Whitney U test showed statistical significance between fast and slow within the towards gesture. For away, sideways, and spin, the fast and slow speeds did not change the perceived expression of the robots. The slow speed created more neutral responses for each gesture. The only motion where speed did affect the response was the towards motion. At a fast speed, the towards motion was interpreted as negative with participants saying the robots were “trying to block the human” and “confront the human angrily.” At a slow speed the towards motion was interpreted as positive with participants saying the robots were “trying to greet the human.”

4.4 Discussion

Of our three experimental variables – gesture, speed, and context – gesture significantly predicted communicatory interpretations across the board. Below, we summarize the major interpretations of each of the five evaluated robot group gestures:

- **Move away** was rated negative, indicating fear/uncertainty or disengagement from the interaction. This is akin to work in autonomous car communication in which a car backing up from a four-way intersection was seen as letting other cars go first [37].

- **Sideways** was also rated as a negative affect communication, potentially indicating fear or uncertainty relative to the approaching human figurine.

- **Towards** had more complex and varied social interpretations, indicating object of attention (as per [19]), but leaving the robots' attitudes toward the humans up for grabs. In this case, speed showed a significant interaction effect with gesture: **slow towards** was seen as welcome, engaging, excited, whereas **fast towards** was seen as aggressive/confronting across the open-ended responses. This indicates that future robot designers should take these factors into consideration when designing the nuances of a multi-robot approach [9].

- **Spin** was interpreted very positively, indicating “super happy,” “joy,” or other happy emotions.

- **Moving in a circle** had more variation in interpretation ranging from neutral/happy to confused/frustrated. More functional context might help disambiguate the intent or goal of this gesture; however, it does not seem to have a clear signal without additional cues.

While speed did not flip the view of most gestures, the slower speed tended to significantly neutralize the perception of the gestures. Each gesture still remained negative/positive or welcome/unwelcome, but the slower gestures were less strong in those categories.

Chapter 5: Comparison

This comparison is between the resulting interpretations of the gestures performed by the robots in each study. It should be noted that a full comparison cannot be made as the studies have many differences between them.

The first study had a robot that was involved in Improv scenes with trained improvisers. After these scenes, the robot performed five isolated gestures and participants were asked to describe the meaning of the movements. There were eight participants and it was a study done in-person. The study resulted in the gestures being sorted into three categories: low variance (where all answers were positive/negative or neutral), high variance (where answers were positive, negative, and neutral, and tendency (where answers tended to lean toward positive/negative but there were a few in the other category).

In this study, towards and circle were high variance with towards having a neutral mean and circle having a negative mean but both having answers ranging from negative to positive. Away and sideways were both low variance and interpreted as negative with away having the most negative interpretation of all gestures. Spin had a tendency for positive interpretations but had negative responses as well.

The second study followed a group of three robots that performed the same five gestures at two different speeds. There were several different questions that could be asked of participants after viewing one of the gestures at one speed. This study had 405 participants but was done online with each participant only seeing one gesture at one speed and not all of them.

This study showed that speed only significantly affected one gesture: towards. With towards, in the open ended sections the faster speed created negative interpretations and the slower speed created positive interpretations. Away was still highly negative with very little variance in both the extended response and Likert scale questions except for one Likert question where the away gesture at a fast speed had high variance. Likewise, sideways was also highly negative in both question categories. Spin was a highly positive gesture with slightly more spread than away and sideways but still with a majority of positive interpretations. Circle tended to have a the highest variance with a slight tendency toward positive.

While these studies differ in many ways, one being in-person and the other online, each having different robots and different questions with different final goal, there are still comparisons that can be made. It can be seen that the five gestures tended to have similar interpretations in both studies. Away and sideways were both highly negative with a low variance across studies. Spin in the first study had a tendency towards positive interpretations while in the second it was interpreted as positive with some variance. Circle had high variance in both studies but tended towards negative in the first and positive in the second.

Towards became a special case for gesture due to study tests with speed. In the ImprovBot study, towards was a high variance a neutral gesture. However, the speed for the gesture was not highly regulated a varied some between participants. The second study suggested that speed changed the interpretation of the gesture with a slower speed leading to positive interpretations and a faster speed leading to negative interpretations. It could be proposed that the variable speed in the ImprovBot study led to the high variance in the gesture interpretations.

Overall, the interpretations across studies were similar. This suggests that these five simple gestures conjure strong meanings that do not change between single and group robot performance. This is especially true for the away, sideways, and spin gestures that had low to medium variance and were interpreted the same across both studies.

Chapter 6: Conclusion

This paper covered two separate studies. The first study created a simple robot thats goal was to perform improvisation with a human partner. The robot could not speak, display words, or communicate in any way besides basic movements. This study aimed to see if the robot of this type would be a sufficient improv partner and how a set of five simple motions were interrupted by improvisers. The study found that the robot could inspire creativity, and was viewed as a partner in scenes although participants always took the lead in the scenes. When isolated motions were performed, sideways and away had a low variance in responses with a trend towards interpretations being negative. Spin had a tendency for positive responses with a few negative responses, and circle and towards had a high variance of responses.

The same five isolated movements were used in the second study. These gestures were performed by a group of three robots to see how these movements translated in multi-robot expression. This study also examined how speed and context would affect these motions. The study found that like the first study, away and sideways were both interpreted as negative with a low variance. Spin had a tendency for positive responses and circle had a high variance. It was found that speed did not majorly affect these motions except for towards where speed changed the interpretations from positive when at a slow speed to negative at a fast speed. Context played no role in interpretations.

By comparing these two, it can be seen that many of the gestures are interpreted the same way whether in a multi-robot group or performed alone. For the three gestures with medium to low variance in both studies: away, sideways, and spin, this shows that these gestures are a powerful communicator in simple robotics. For the towards gesture, evidence on how speed affects the interpretation of the motion helps to describe why towards was high variance in the first study where speed was not highly controlled. This comparison also shows that the circle motion has low communication powers and suggests that basic communicatory gestures do not change in interpretation in single or multi-robot groups.

The next steps in this study would be to repeat studies with more exact study conditions so these can be a better comparison. Additional simple gestures could also be added to explore more communication power as well as expanding the categories interpretations are sorted into (more categories than just negative and positive). The current studies and comparisons do highlight the power of gesture in non-verbal communication and how simple robots can still communicate without need for more complex forms of communication. The studies broadens our understanding of robotic gesture and can be used for robots in social situations. For example, a robot tasked with greeting people could now communicate that they are happy/excited to see someone by performing the spin gesture which was mainly interpreted as positive.

It is important that robots are able to communicate clearly and efficiently to better the public's view of them. By performing these studies it can be seen which gestures will provide clear and concise communication and which gestures should not be performed to avoid confusion. The studies also help to prove that simple robots are able of communicating and participating in social interactions and what factors majorly impact communication which could lead to simplifying design variables in the future.

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