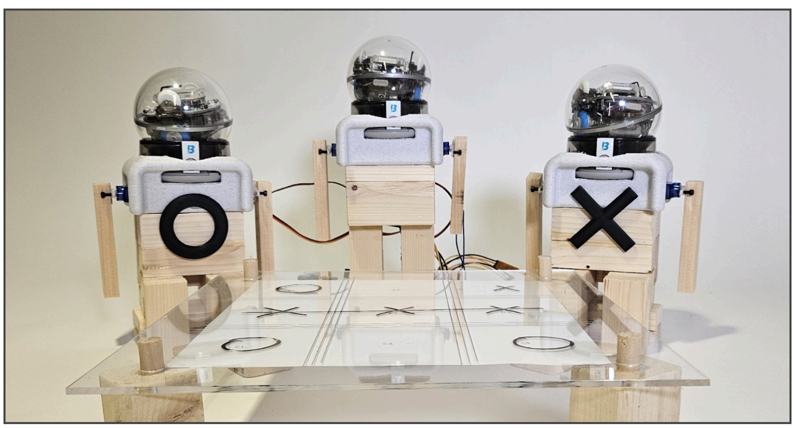
Synchronicity of Arm Movements in Robot Perception



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December 19th, 2023

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CS-0133: Human-Robot Interaction

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1. Introduction

1.1. Relevance

As the prevalence of robots in our society increases, there has also been a rise in research that explores people's perception of robots in social environments. If we want robots to be successfully integrated into society, we must design robots curated towards human behavior. Smaller robots such as Amazon's personal assistant Alexa have already begun to be integrated into many people's daily lives. However as larger and more complex robots are being created and deployed, there are even more factors that must be considered in their design. In previous literature, it has been found that when robots have certain physical features, people are more fond of the robot if these features operate similar to humans. For example, if a robot has eyes, people will subconsciously like the robot more if their eyes blink or track the speaker in a similar fashion to people (Ghiglino). This preference for anthropomorphism is not limited to physical features, but extends to behavioral presentation as well. This notion led us to explore the impact of arm movements on human perception of robots.

1.2. Methodology/approach

The objective of this study was to observe and understand the impact of the synchronicity of robot's arm movement on people's perception of the robots in a group interaction. We included three different scenarios: robots with synchronized arm movement, robots with somewhat synchronized arm movements, and robots with completely unsynchronized arm movements. After each scenario the participant would take a survey with the same questions, and after the final scenario there were additional open ended questions. The data collected from the survey was analyzed to compare how participants' opinions of the robots changed between the three scenarios.

1.3. Results

Overall, participants found it easier to understand who was speaking and reported interactions felt more natural, coordinated, and engaging when arm movements were synchronized or slightly synchronized versus unsynchronized. Additionally, people also had more eye contact with the robot who was speaking when the arm movements were perfectly synchronized with speech. Synchronized arm movements were generally found to make humans perceive the robot as more human-like and approachable.

2. Background

2.1. Literature review

In attempts to make robots seem more approachable, creators often add anthropomorphic features such as faces and arms. In one paper, researchers explored how varying eye movements affected human perception of robots (Ghiglino). The different scenarios included fixed human-like behavior of eye movement, variable human-like behavior of eye movement, and movement significantly slower than the average human. It was found that variable eye movement was deemed most human-like by participants since it seemed natural and less calculated. Similar to this paper, we aimed to determine the effect of variation and synchronicity within the movement of a single aspect of the robot.

While designing the human interaction scenario, it was important to consider how the nature of the robots may impact human perception. Factors that we considered included dialogue, face design, and quality of arm movements. When addressing dialogue, we wanted participants to clearly understand what was asked of them by the robots while not feeling like the robot was trying to control them. In previous studies, it was found that participants preferred an assertive but non aggressive nature of instruction by robot (Thomas). We wanted to explore this concept in a social situation rather than a strict instruction scenario. Since the robots in our study were asking for help from humans, we wanted them to be decisive and assertive without being too aggressive. Additionally, when designing the faces of the robots, we aimed to find the correct balance of anthropomorphism versus animation. According to the uncanny valley hypothesis, faces are generally more appealing to humans the more human-like they appear. However, if a face looks very similar to humans but is slightly off, this actually becomes more disturbing and the human appeal of the face design drops off dramatically (Cheetham). With this knowledge and the use of Sphero robots, which only provided us with a few pixels to design the robot's faces, we opted for a very simplistic design with only eyes and eyebrows. Finally, arm movement has been explored within robots within previous studies, often assessing the functionality of arms that serve an assistive purpose (Guletta). For example, this includes robots whose arms will grab something for a person. However in the current literature there are few studies that explore arm movement as a social means of making humans feel that robots are more approachable. Our novel study aims to explore how variability in human-like arm movements (e.g. pointing while speaking, movement based on emotion) can change human perception of the robot.

3. Methodology

The following section details the study design, electronic components and robot fabrication, algorithm, data collection, parameters, measures, and participants.

3.1. Study Design

This study was designed as a social experiment between 3 robots and a human participant to learn about the participant's impression of the robots as they transcribed a game of Tic-Tac-Toe for the robots. In particular, the research team was interested in understanding the impact of synchronicity between the robots' dialogue and arm movements on the human's perception of the robots. Our hypothesis heading into this study was that the movement being in sync would lead to better reception by the participants.

3.2. Robot Design and Fabrication

The robots were designed with the main consideration being how the arms would be implemented. The decision to use the Spheros was made to avoid taking up the other offered robot options which all had much broader functionality and better suited for other groups that would use them for more than their arm movements. Spheros were a more flexible form factor that we could build and design around, and their spherical shape made them the perfect head. The design process began on paper, drafting out the rough humanoid figure the robot would take, and then moved to CAD modeling using the online tool, OnShape. Figure 1 below shows the initial design. The brown indicates components that were to be fabricated out of wood, and the blue components represent the parts that were 3D printed.

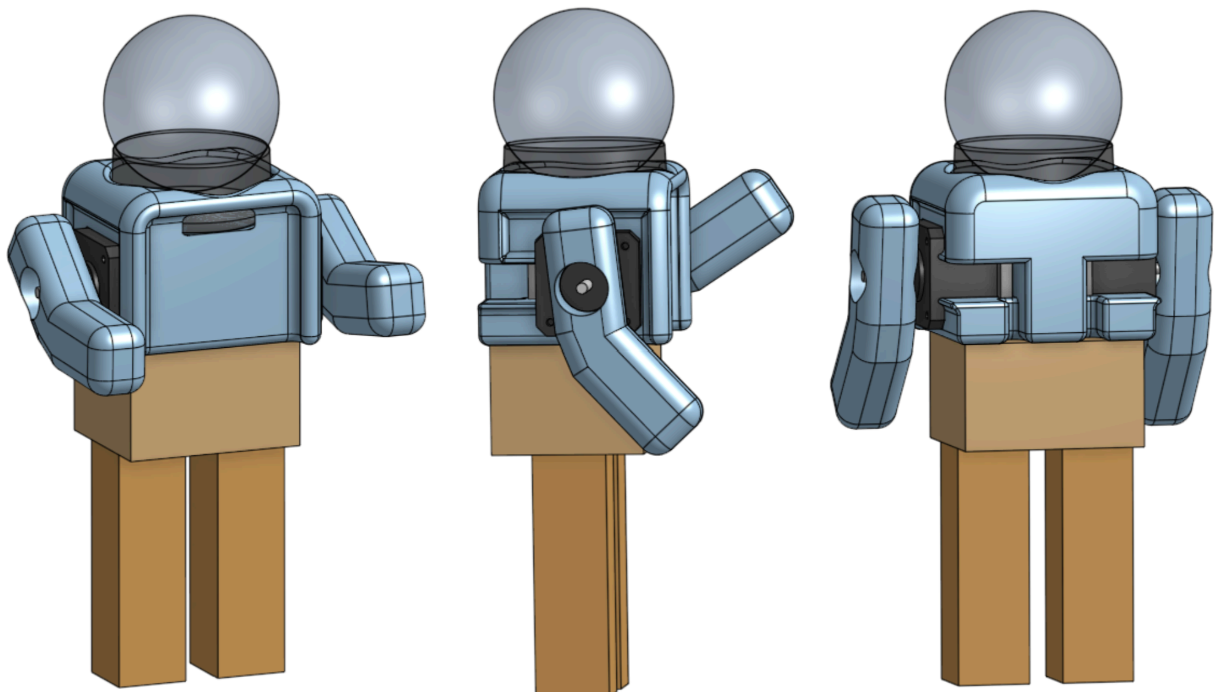

Figure 1: *3 Angles of the Robot Body CAD Model*

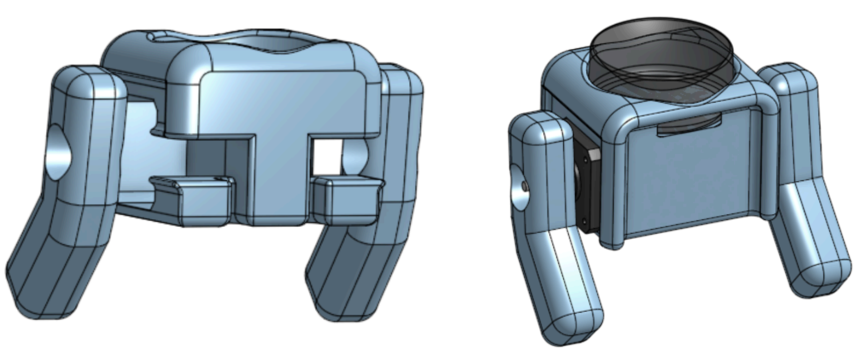

Figure 2: *Robot Body Parts to be 3D Printed*

The blue chest piece was shelled to allow the Sphero and its charging dock to sit snugly inside, acting as the collar/neck and head of the robot. The motors were initially to be stepper motors, but due to limitations in availability, servo motors were used instead. The chest piece was then modified, and the wooden torso elongated to compensate, as shown in Figure 3. The smaller print had the added benefit of being more conservative with the PLA filament.

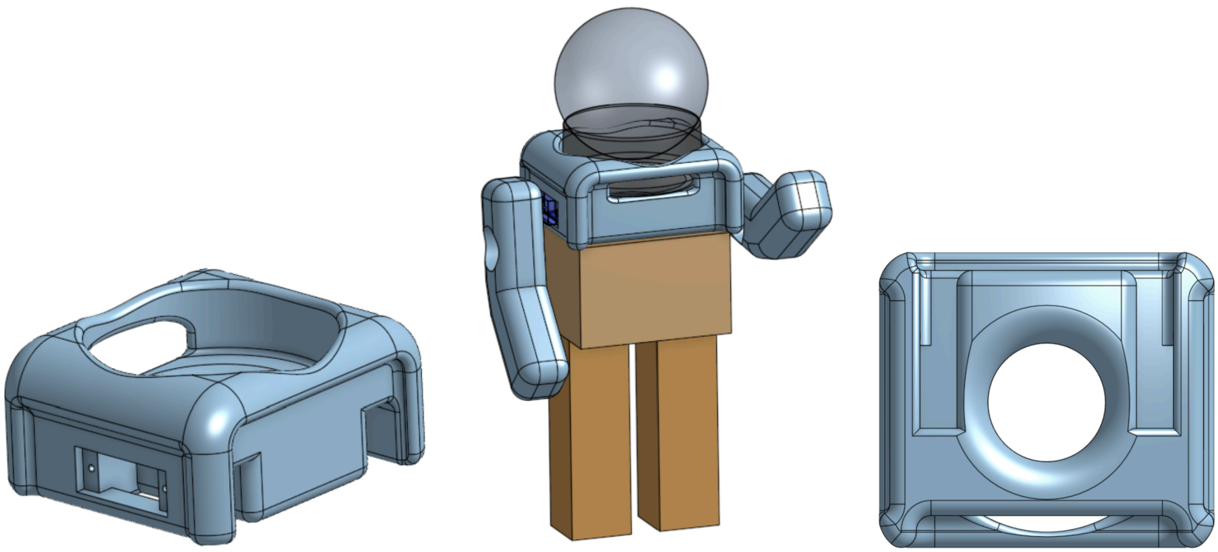

Figure 3: *Updated CAD Model to Accommodate Servo Motors*

The rest of the robot that was not 3D printed was made of wood. The torso was made of stacked wooden beams cut to size. To create leg joints, 2x4 wood was stripped down on the table saw to create thinner sticks. These sticks were then cut to length and fastened together into either straight legs (for the standing robot), or bent legs (for the sitting robots) using wood screws and wood glue. The arms were the most delicate part of the robot, as they were extremely light balsa sticks with servo horns screwed through them.

Figure 4: *Wooden Componenets of the Sitting Robot*

To create the tic-tac-toe table, wooden table legs were first fabricated using the leftover wooden sticks from the robots. These had ⅜” dowels driven into the top that would interface with a laser-cut acrylic square (with a tic-tac-toe grid engraved) that had a hole in each corner. A piece of paper with the square labels (A1 through C3) was fastened underneath the acrylic. The product was a labeled table that could be written on with a dry-erase marker and erased easily.

In terms of the electronics, the components were wired together and connected on a breadboard. This allowed for easy connections to power, ground and transmission of signals between the ESP32 controller and servos. The 6 DC micro servos were powered by an external 5V, 3A power source. Meanwhile, the microcontroller was powered by a laptop which was preferred over another dedicated power source as the program controlling the servos required input from the user via the Serial Monitor to indicate the trial scenario to be activated.

3.3. Algorithm

The experimental setup for this study required a total of 4 different programs running simultaneously. The Sphero robots which made up the “heads” and “faces” of the robots were each individually running a unique JavaScript program. Meanwhile, the movements of all 6 robot arms were programmed using Arduino and controlled by a single ESP32 microcontroller.

The sequence of events follows the chart below (the color of the cells correspond with the robot that was talking or moving):

Dialogue	Arm Motions
Hi! Anyone want to play a game of Tic-Tac-Toe?	Waves and then points at the board
Yes! I can play with you!	Raises its hand
Ok I can sit out this round. Human, want to watch with me?	Points at human
Cool. Also, human, do you mind transcribing?	–
Good idea, let us have the top left corner be A1 and bottom right be C3	Points at the board
Awesome, I will start. Let us put my cross in the center	Points at the board
Ok, I will but my circle in A1	Points at the board
I will place my next cross in A3	Points at the board
Spicy!	Raises both arms in excitement

C1	Points at the board
Tricky, I will do B1 to block you!	Points at the board
OMG, human, did you see that?	Raises both arms in excitement and then points at human
haha	–
What about circle to C3?	Points at the board
Is this a comeback?	Raises both arms in excitement
Nope, cross in B3 and I win	Points at the board
Ahh, I missed that! So close!	Raises both arms in frustration
Wow, that was such an exciting game, what do you think human?	Points at human
Anyways, good game, good game.	Shakes hands with opponent
Yeah, that was so much fun	Shakes hands with opponent
My turn next!!	Excited arm movements

Table 1: *Dialogue Chart of Robots in the Interaction*

The Spheros were programmed to talk to one another as well as with the human. The timing and sequence of the dialogue between the robots leveraged the Spheros' ability to communicate through infrared (IR) signals. These signals were transmitted on different IR channels. Therefore, while some of the delays in the program were strictly derived from hardcoded delays, others were waiting to start the next sequence.

To start the program, the researcher reset the ESP32 controller which allowed the program to initialize and prompt the researcher via the serial monitor to choose a scenario to be run on the robots. The options were as follows:

1) *Completely Synchronized Arm Movements with Dialogue*
2) *Slightly Unsynchronized Arm Movements with Dialogue*
3) *Completely Unsynchronized Arm Movements with Dialogue*

Simultaneously, given that the Arduino program only controlled the arms, the 3 individual Sphero programs were also initiated.

3.4. Validation Study

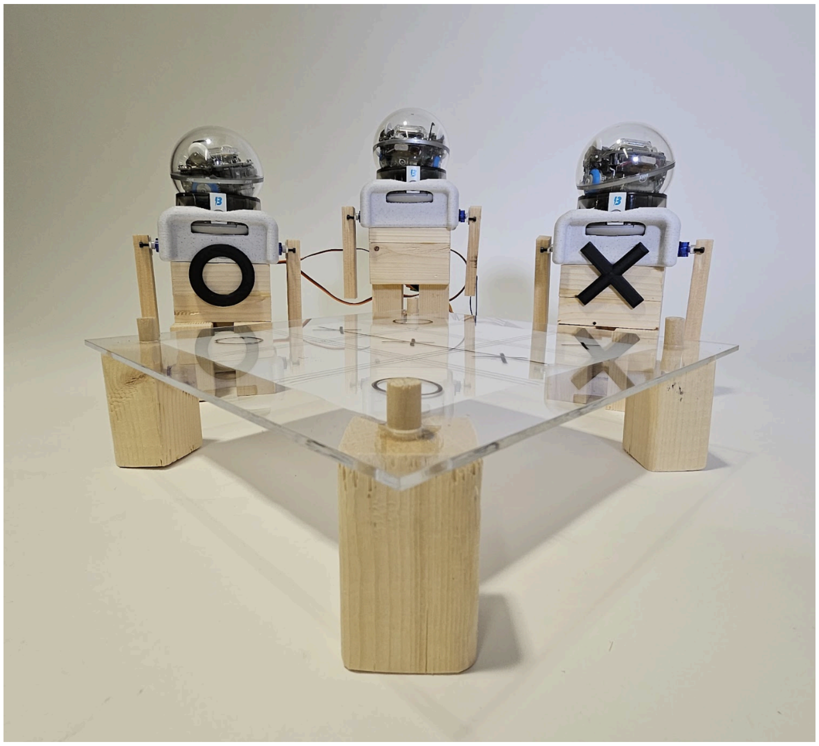

Figure 5: *Set-Up of Robots and Board During Experiment*

During the experiment, the participant encountered the robot interaction scenario three times. The first time involved slightly delayed, unsynchronized arm movements by the robots when speaking to the human. After the interaction, the participant completed the first section of the survey. This portion of the survey involved asking participants how engaged and comfortable they felt with the robots and asking them to identify how much they felt certain adjectives resonated with the robots. After completing the first part of the survey, the robot interaction was repeated. This time, the robots' arm movements were perfectly synchronous with their speech. The participant then completed an identical survey to the one they took after the first round. Finally, they engaged in the third robot interaction where their arm movements were chaotic and completely asynchronous from their speech. The participants then completed an identical survey to the first two rounds, as well as an additional portion that asked them for overall reflections on the experiment. We also revealed the factor of the experiment that we were studying (synchronicity of arm movements with speech) and asked participants if they felt that affected their perception of the robots between the rounds.

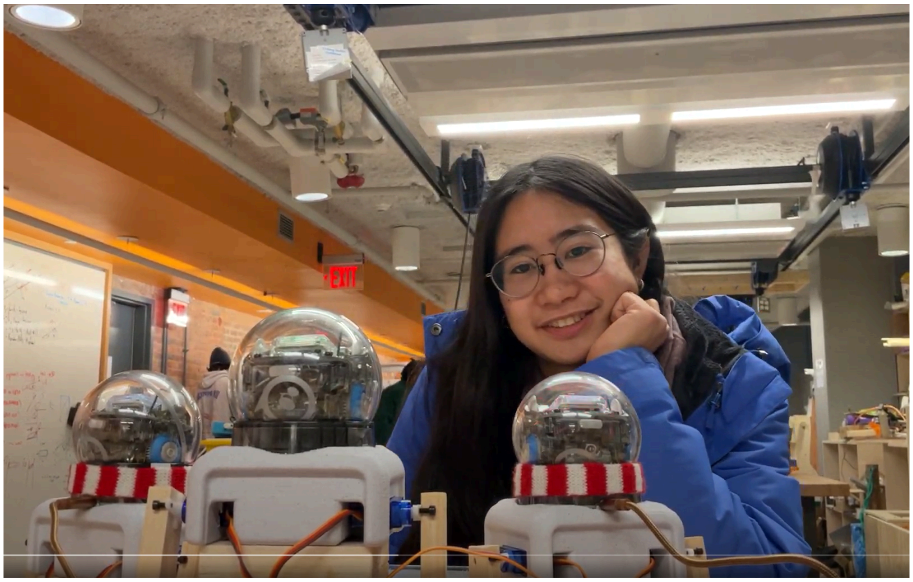

Figure 6: *Participant 12 During First Trial*

3.5. Data Collection

Two methods of data collection were used during the experimental process. The first was in the form of a survey. The second method of data collection was through video recording. Every trial was recorded from an angle where the subjects' eyes and gaze would be visible throughout the scene. Afterwards, the footage was reviewed to track how long each subject made "eye contact" with the robots during their interaction. This data was then analyzed and put into context with each variation of the interaction.

3.6. Measures

For each subject, identical surveys were given after each of the three trials, and after the entire experiment, a final survey was administered asking the participant their overall perception of the study.

Link to survey: https://tufts.qualtrics.com/jfe/form/SV_3wSGx1EYC37cW58

Survey after each trial:

1. On a scale of 1-7, how engaged did the robots make you feel? (1= very unengaged, 7 = extremely engaged)
2. On a scale of 1-7, how comfortable did the robots make you feel? (extremely uncomfortable, extremely comfortable)
3. How easy was it to tell who was speaking? (1 = extremely difficult to understand, 7 = very easy to understand)
4. Please use the sliding scales to indicate how strongly each word resonates with the interaction (0 = does not apply at all, 100 = applies completely)
    a. Cute

b. Welcoming
c. Engaging
d. Coordinated
e. Intelligent
f. Natural
5. How did the robots make you feel?

Final survey:
1. How could this interaction be improved?
2. Do you think the presence of faces on the robots affected how you felt about the robots/interaction?
3. How impactful was the difference in arm/speech coordination? (1 = not impactful at all, 7 = extremely impactful)
4. Any other comments?

3.7. Participants

Participants of this experiment were undergraduate and graduate students at Tufts University. Some participants were contacted beforehand to partake in the experiment and others were approached on the day of the experiment and recruited in the Nolop Makerspace. All of the participants are engineers or study in a STEM-related field. This was not by design, but a result of the social circles of the experimenters. There were 12 participants total, each being subjected to the three trials of synchronized, semi-synchronized, and unsynchronized arm movements, given a survey after each trial, and then given a final survey after the experiment. A brief introduction was provided in the beginning to prepare the participants of what they would be experiencing before the trials began. After the experiment, which was conducted carefully to ensure raw and unbiased results, the experimental variable was revealed.

4. Results

We broke the data generated by our study into two parts: quantitative and observational. Both of these categories led to visualizations in the form of charts. We gathered this data using Qualtrics surveys, as well as analysis of the video recordings of each of our trials.

4.1. Quantitative Data

For our quantitative data, we used surveys after each of the three scenarios to ask participants to rate how welcome and comfortable they felt. Our main concern when analyzing this data was that each person's resting scale may vary. For example, one person may feel "somewhat welcomed" and input a 6 out of 7, while another person may input a 3 out of 7 for the same feeling. To reduce this fluctuation, we have decided to analyze the differences between scenarios for each user, rather than the flat values. This likely reduced the variability between participants. For example, regardless of a person's resting scale, scenario 2 (somewhat synchronized arm movement) may have made them feel 2 points more welcome than scenario 1 (unsynchronized arm movement). In contrast, scenario 3 (synchronized arm movement) may have made them feel 4 points more welcome than scenario 1.

Our survey included 3 Likert scale questions:

1. How engaged did the robots make you feel?
2. How comfortable did the robots make you feel?
3. How easy was it to tell who was speaking?

In the tables below, abbreviations are used to save space as follows:

- SAM: synchronized arm movement (arms move while robots talk)
- SSAM: somewhat synchronized arm movement (arms move while robots talk with a slight delay)
- USAM: unsynchronized arm movement (arm movement has no relation to robot speech)

Participant Raw and Comparative "Engaged"					
#	USAM	SSAM	SAM	SSAM - USAM	SAM - USAM
1	7	7	7	0	0
2	5	5	6	0	1
3	4	5	4	1	0
4	6	6	6	0	0
5	6	6	6	0	0
6	6	7	6	1	0
7	6	7	7	1	1
8	4	5	5	1	1
9	6	5	5	-1	-1
10	2	6	3	4	1
11	5	3	4	-2	-1
12	6	7	7	1	1

Table 2: *Participant responses to the survey question "How engaged did the robots make you feel?". White boxes contain raw responses, and green boxes contain calculated differences. The data in the green boxes is what we used for data analysis and visualization.*

Participant Raw and Comparative "Comfortable"					
#	USAM	SSAM	SAM	SSAM - USAM	SAM - USAM
1	7	3	3	-4	-4
2	3	6	6	3	3
3	3	4	4	1	1

4	5	4	6	-1	1
5	5	3	4	-2	-1
6	6	6	7	0	1
7	6	3	4	-3	-2
8	1	3	3	2	2
9	5	6	5	1	0
10	5	4	5	-1	0
11	5	4	4	-1	-1
12	6	2	4	-4	-2

Table 3*: Participant responses to the survey question "How comfortable did the robots make you feel?". White boxes contain raw responses, and green boxes contain calculated differences. The data in the green boxes is what we used for data analysis and visualization.*

Participant Raw and Comparative "How easy was it to tell who was speaking?"					
#	USAM	SSAM	SAM	SSAM - USAM	SAM - USAM
1	6	7	6	1	0
2	5	2	5	-3	0
3	4	5	6	1	2
4	4	6	5	2	1
5	3	3	2	0	-1
6	6	3	5	-3	-1
7	6	2	3	-4	-3
8	2	6	6	4	4
9	6	4	7	-2	1
10	2	5	7	3	5
11	5	6	5	1	0
12	5	2	4	-3	-1

Table 4*: Participant responses to the survey question "How easy was it to tell who was speaking?". White boxes contain raw responses, and green boxes contain calculated differences. The data in the green boxes is what we used for data analysis and visualization.*

After averaging these differences (values in green), we were able to get the average differences in each response. By treating the unsynchronized arm movement (USAM) trial as a baseline, we were able to compare these results to see how they would change depending on the type of arm movement. The averages are shown on the table below and plotted

Participant Average Comparison with USAM as Baseline for 1-7 Likert Scale			
	Engaged	Comfortable	Easy to tell who's speaking
SSAM vs USAM	0.5	-0.75	-0.25
SAM vs USAM	0.25	-0.166666667	0.583333333

***Table 5**: Table of Averages for difference when compared to USAM for Likert scale responses*

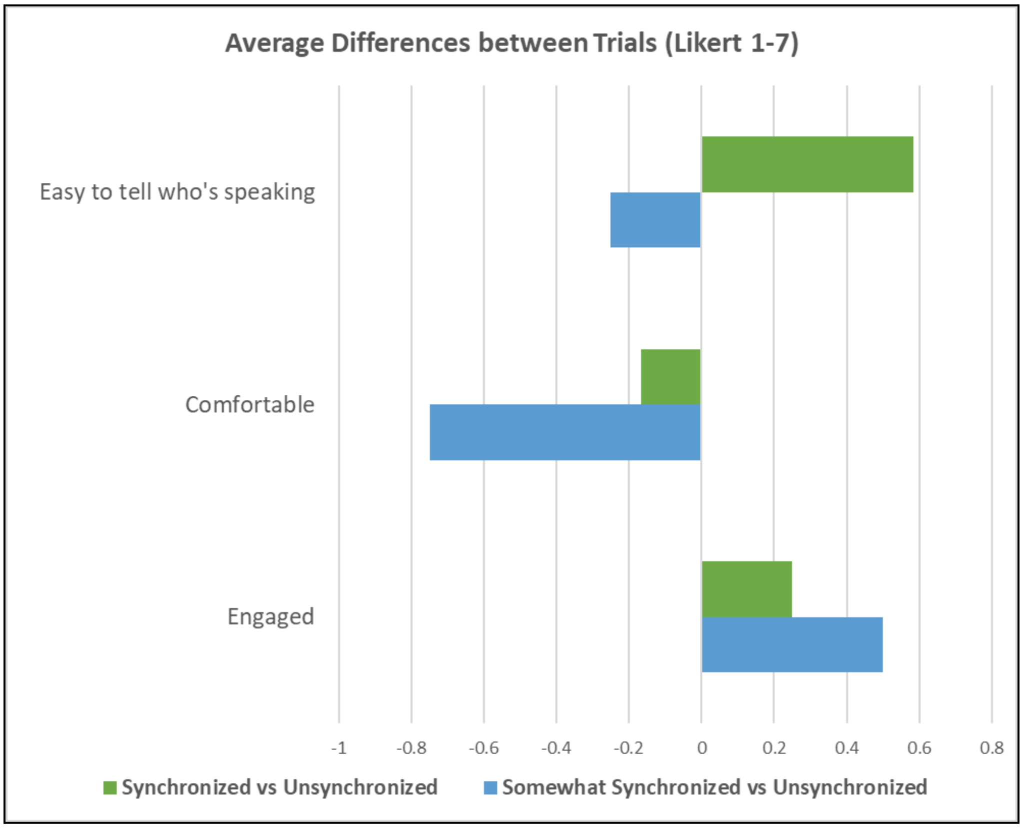

***Figure 7:** Bar chart centered on zero, showing the difference in Likert Scale between scenarios when compared to USAM baseline, as per survey questions listed in the Study Protocol section above.*

At a glance, it is interesting to see that there is not a clear cut correlation between synchronicity and user comfort, engagement, or ease of telling who is speaking. While we may have expected synchronicity to automatically improve interactions, this was not the case.

<u>Easy to tell who's speaking:</u>

Fully synchronized arm movements were undoubtedly beneficial to helping identify the correct speaker. However, it seems like arm movements that were slightly out of sync (somewhat synchronized) may have been more disruptive than completely unsynchronized arm movements. One theory is that since unsynchronized arm movements were completely unrelated, they were easier to ignore, and therefore less distracting to determine which robot was talking when compared to the somewhat synchronized arm movements.

Comfortable:
Oddly enough, the participants were on average more comfortable with fully unsynchronized arm movements. There were some comments about how the robots were "creepy" or "unsettling". We suspect that the somewhat synchronized arm movement (arms moving slightly before or after speaking) must have been more unsettling than either fully synchronized or fully unsynchronized movements.

Engaged:
Participants reported to be more engaged for the somewhat synchronized arm movements than others. This may be due to the order in which we ran these trials (SSAM > SAM > USAM), with participant engagement decreasing with each trial as they get accustomed to the robots and the novelty wears off.

Our survey asked a few more quantitative questions, which involved asking the participant to rate how much select keywords (cute, welcoming, engaging, coordinated, intelligent, natural) resonated with the robots. The averages, calculated using the same method as the Likert data above, are shown in the table below. The full data tables are featured in the appendix.

Participant Average Comparison with USAM as Baseline for 1-100 Scale						
	Cute	Welcoming	Engaging	Coordinated	Intelligent	Natural
SSAM vs USAM	-3.5833333	-5.5	-1	4.083333333	6.25	2.583333
SAM vs USAM	0.91666667	0.416666667	0.25	7.833333333	3.41666667	8.333333

Table 6: *Table of Averages for difference when compared to USAM for 1-100 scale responses*

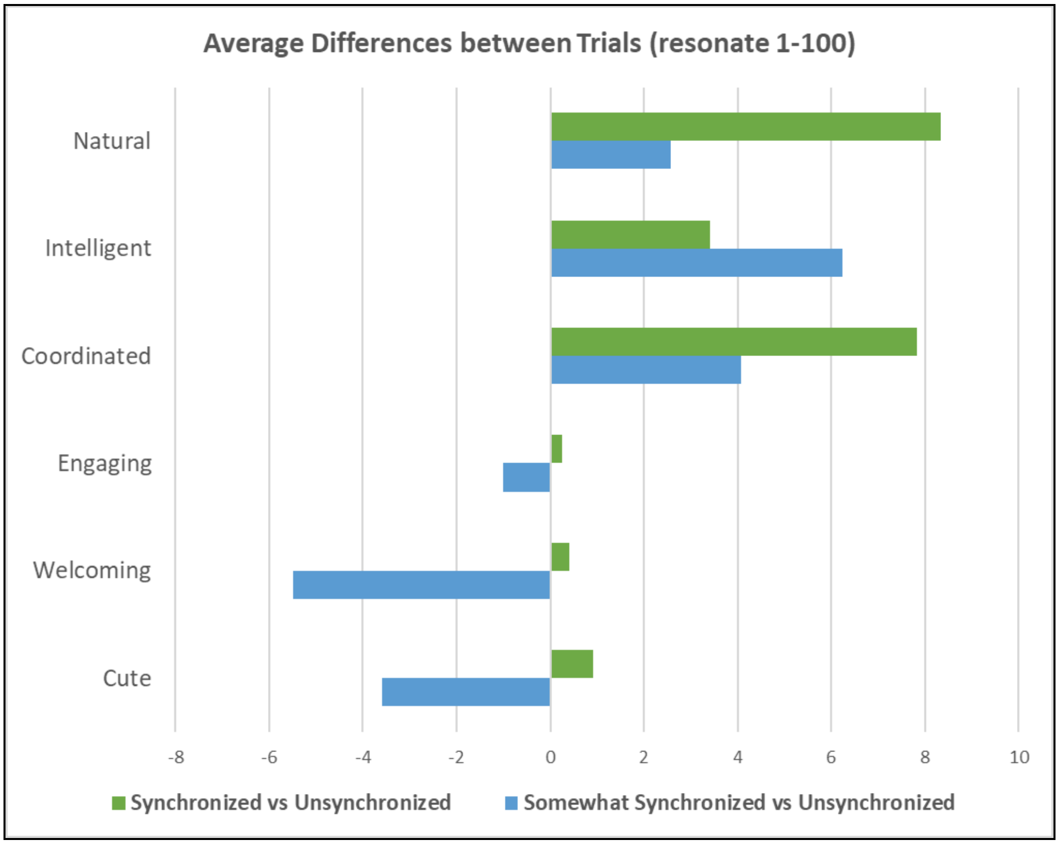

Figure 8: *Bar chart centered on zero, comparing the average resonance of certain keywords with scenarios using differences in a 1-100 scale between scenarios where 1 indicates no resonance and 100 indicates complete resonance. Keywords are from the survey questions listed in the Study Protocol section above.*

The chart above shows the average differences in keyword resonance between the scenarios, analyzed in the same manner as the Likert scale questions shown previously. As expected, robots with fully synchronized arm movements are seen as the most natural and coordinated. The resonance with these two keywords is lower with somewhat synchronized arm movements, but is still higher than unsynchronized arm movements.

Fully synchronized arm movements also have an edge above other trials when it comes to how engaging, welcoming, or cute they are. However, it seems like somewhat synchronized arm movements perform significantly worse in those three metrics when compared to both fully synchronized and unsynchronized trials. This may be due to the aforementioned “unsettling” factor of having robots that were almost natural and human-like, but just slightly off-putting.

When it comes to how intelligent the robots seem, the fully coordinated arm movements may have humanized the robots a bit too much, and lost the calculative nature usually associated with robots in favor of cuteness and warmth.

At the end of each participant's data collection, we asked them to rate on a Likert scale how impactful the difference in arm/speech coordination was in how coordinated the robots felt. The average response is shown below

Impact of Arms/Speech on Perceived Coordination	
Average Likert Score	5.083333333 (Somewhat impactful)

***Table** 7: Average for how impactful arm/speech coordination was in how coordinated robots felt to participants*

The participants were oblivious to the topic of how changes in arm movement affected robot perception until this final question, so it was interesting to see them reflect upon the past 10 minutes. This data is likely too biased to be taken at face value, but interesting to see regardless.

4.2. Observational Data

Through the use of cameras, we were also able to gather observational data from each study via video recordings. The observational metric we wanted to study was eye contact. We wanted to see how synchronicity of arm movement would affect the total amount of time the participant looked at the robot currently speaking/interacting. Since the time of each robot speaking was uniform across all scenarios, we were able to compare the amount of eye contact made between scenarios. By measuring this as a percentage of the total time the robots are talking, we were able to see how the average eye contact changed between scenarios. The results of the eye contact analysis are shown in the chart below.

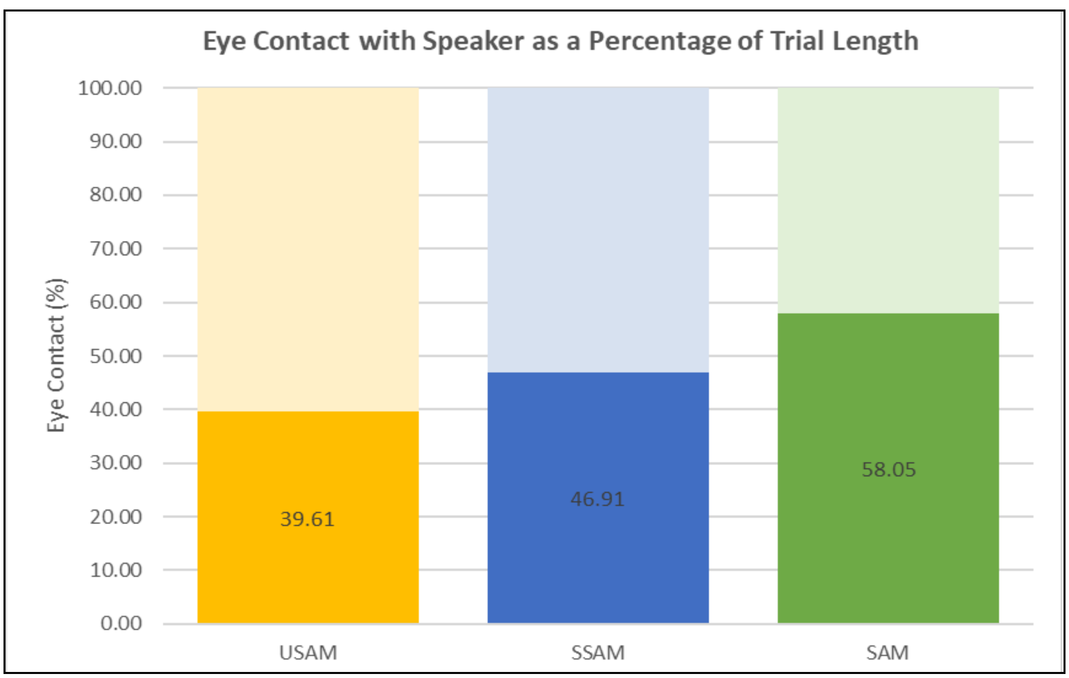

***Figure 9:** Bar chart comparing the average % eye contact across the three scenarios*

Eye contact percentage

Promisingly enough, our data shows that there is a positive correlation between synchronicity of arm movements and the amount of eye contact made with the speaking robot. We suspect that because human eyes are naturally drawn to movement, the more synchronized a robot's arm movements were, the easier time the participants had with identifying the speaker. Not only does this help with accurate identification of the speaker, but it also helps with the speed of said identification. This is likely why there is still notably more eye contact in the SAM trials compared to the SSAM; participants are able to determine the speaker earlier, and are able to maintain eye contact for a longer period of time before the next speaker.

Additional interesting observations made, though not data intended for analysis, was that some of the subjects would mimic actions of the robot that they found humorous or particularly emphatic. The figures below show a subject raising their arms after the robot gestures.

Figure 10: *Spectator Robot Raising Arms in Emphasis "Spicy!"*

Figure 11: *Participant 1 Raising Arms to Mimic Robot in Gest*

4.3. Other Data

We elicited open responses from the participants at the end of each trial, as well as some final responses at the end. However, the open response data was less quantifiable and used more for gathering feedback. Full responses are listed in the appendix at the end of the paper.

Common trends for "How did these robots make you feel?":

The participants fluctuated between thinking the robots were cute and goofy, or uncanny and confusing. Some noticed the variations in arm movement synchronicity, while others felt some frustration on the robots not pronouncing words clearly enough. While the instructions were simple, some participants felt rushed and unclear about what they were supposed to do. We developed these instructions after having tested these robots extensively, and may have benefitted from slowing the whole conversation down a bit to benefit the participants, who have never been exposed to these robots before.

Helpful feedback:

The best feedback we received was to create a short primer session for each participant before they begin the 3 trials. This would familiarize the participant with the robots, voices, and equipment, and prevent them from having to learn on the go during the first trial and skewing results. Other feedback involved not having robots say words that may be misconstrued as false instructions, for example "spicy" may be heard as "5C".

5. Discussion

5.1. Contributions

This paper aimed to address the gap in the literature on the impact of non-assistive arm movements on human perception of robots. In our study, the arms did not function to assist the human or drive the outcome of the interaction; the arm movements were instead used as a means to explore how arm movement can change human perception of social interactions. Participants found the robots to be most natural and intelligent when their arm movements were aligned with their speech. Additionally, most participants felt that the synchronization of the arm movements did affect their perception of the robots when asked directly. This goes to show that when designing robots to interact with people, they are more likely to be well received if they have perfectly synchronized and expressive arm movements. Furthermore, there is a very clear upward trend of eye contact directly correlated with the synchronicity of arm movement. The unsynchronized arm movements drew eye contact only 39.61% of the trial runtime, while the somewhat synchronized arm movements drew 46.91%, and the synchronized arm movements drew 58.05%. However, people found the somewhat synchronized arm movements significantly less cute and engaging than the unsynchronized robot. This conclusion shows that synchronization of arm movement does not have a direct correlation with human appeal in all categories.

To summarize the quantitative data, it seems like synchronicity of arm movements with robot speech definitely helps improve robot perception, but only if it is done well. While the fully synchronized arm movements were widely well received over most metrics, there were many instances where participants reacted more negatively to the somewhat synchronized arm movements over the unsynchronized arm movements.

5.2. Future Work

There is plenty of work left to be done in determining the effects of movement on robot perception. While our study delved into varying synchronicity, it did not study variations in the amount of movement or type of movement. Our study is a good foundation for future, larger studies to be made.

There were a few ways we could have improved the study if we were to do it again. It was pointed out that a lot of our participants were using the first of three trials to get acquainted with the robots and equipment. We would have benefitted from making a short primer session or activity to familiarize the participant with the system before entering trials. We also could have randomized the order of trials, instead of running them in the same order for each participant. This would work better with a larger sample size (ideally around 100 people). Additionally, subjects mentioned they were too focused on scribing to notice the robots’ behavior. Creating and interaction that is less task-based may help with that.

6. Conclusion

As the structure of robots becomes more complicated, it is important for the people who create them to be intentional about their design choices. In this study we aimed to determine the impact of the synchronization of arm movements with speech on human perception of robots. Participants were asked to scribe a game of tic-tac-toe being played by robots in three different scenarios which had variation in the synchronization of the robots' arm movements and speech. Their perception of the robots was recorded through surveys and video recordings of the interactions. After analyzing their responses, it was found that synchronized or slightly synchronized arm movements were perceived by people as most natural and coordinated. Furthermore, people maintained eye contact with the speaking robot most frequently when their arm movements were synchronized with speech. Finally, the majority of participants felt that the synchronization of arm movements impacted their perception of the robots. Therefore, when designing robots it is important to consider the timing and action of arm movements since they play a significant role in human interaction. Increased arm movement can help humans feel that robots are more natural, but one must carefully design these movements to ensure they do not instead cause an adverse reaction.

7. Acknowledgments

Team member responsibilities:

Sharika Kaul:

- Creating and designing qualtrics survey
- Conducting research analysis for literature review
- Running data collection session on 12/9/2023
- Collecting survey results from each subject
- Final report: Introduction, Background, Methodology, Discussion, Conclusion

Selina Spry:

- Electrical design and set up wiring
- Creating the dialogue script for the interaction
- Developing the 3 individual JavaScript programs for the Sphero Robots
- Programming of the ESP32 controller and operational logic
- Debug and testing of electrical components
- Running data collection session on 12/9/2023
- Final report: Methodology

Michelle Kim:

- Design of physical components
- CAD modeling of robot bodies
- Fabrication of robot bodies
- Developing questions for Qualtrics survey
- Running data collection session on 12/9/2023

- Filming each trial during data collection
- Photographing and media logging throughout fabrication
- Final Report: Method + Discussion

Nathan Wang:

- Fabrication of robot bodies
- Fabrication of tic-tac-toe table
- Testing electronic components
- Developing questions for Qualtrics survey
- Running data collection session on 12/9/2023
- Filming demo video for setup
- Data analysis
    - Qualtrics quantitative data analysis
    - Video recording observational analysis
    - Visualizing data in tables and bar charts
- Final report: Results + Appendix + Discussion

Our 12 respondents

- Alexa Watson
- Andrew Daetz
- Nico Zucchi
- Helen Matthews
- Caroline Henley
- Srisharan Kolige
- Angela Tsou
- Jonah D'Alessandro
- Marc Alenn Jean Mary
- Harrison Wilson
- Michael Turner
- Angelica Cheng

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Resources Used

- 3x Sphero BOLT
- Sphero Edu app
- Arduino app
- Laptop running arduino program to select experimental scenario
- Qualtrics
- Microsoft Excel
- iPad Mini camera
- Nolop makerspace (to construct "bodies" for Spheros)
    - Components used
        - Power supply
        - Power adapter
        - Breadboard
        - Wires
        - ESP32 microcontroller
        - 6 hobby servos
        - Wood 2x4
        - PLA filament
        - Acrylic
        - Screws
    - Machines used
        - 3D printer
        - Table saw
        - Miter saw
        - Power drill
        - Laser cutter

8. Appendix

Tables for qualtrics survey results involving rating resonance of keywords on a scale of 1-100:

Participant Comparative Keyword Resonance "Cute"		
#	USAM vs SSAM	USAM vs SAM
1	-5	-4
2	7	12
3	9	-5
4	-7	-11
5	-1	-19
6	-21	-11
7	-26	-10
8	70	66
9	-9	-8
10	37	17
11	-38	-16
12	-50	0

Participant Comparative Keyword Resonance "Welcoming"		
#	USAM vs SSAM	USAM vs SAM
1	10	5
2	-8	2
3	-17	-15
4	-56	-10
5	-9	-11
6	37	9
7	-14	-9
8	20	49
9	-6	-8
10	23	19
11	-34	-13
12	-12	-13

Participant Comparative Keyword Resonance "Engaging"		
#	USAM vs SSAM	USAM vs SAM
1	10	1
2	-11	4
3	4	-9
4	-13	-2
5	-1	-1
6	23	8
7	-4	-7
8	-55	-25
9	11	11
10	26	7
11	-27	-9
12	25	25

Participant Comparative Keyword Resonance "Coordinated"		
#	USAM vs SSAM	USAM vs SAM
1	22	13
2	21	26
3	27	-6
4	-9	-8
5	-10	25
6	-20	-10
7	-12	-6
8	0	16
9	-4	1
10	38	37
11	-7	8
12	3	-2

Participant Comparative Keyword Resonance "Intelligent"		
#	USAM vs SSAM	USAM vs SAM
1	3	4
2	21	23
3	21	1
4	16	14
5	0	0
6	17	17
7	-17	-10
8	0	0
9	21	16
10	5	3
11	9	-5
12	-20	-22

Participant Comparative Keyword Resonance "Natural"		
#	USAM vs SSAM	USAM vs SAM
1	18	-8
2	35	48
3	-22	-2
4	15	6
5	-36	-34
6	11	0
7	3	58
8	20	32
9	3	9
10	9	0
11	8	-5
12	-33	-4

Tables for open responses to “How did these robots make you feel?” at the end of each trial:

“How did these robots make you feel?” after each trial			
#	SSAM	SAM	USAM
1	It was funky	fun	they were cute
2	It's quite interesting. They're very cute, and they definitely read as anthropomorphic. With such limited degrees of freedom, they are definitely still robots to the eye. Perhaps some idle movement would add some life.	They're quite cute. I like the arms in the air, handshake, etc. The gestures add a lot.	The arm movements were definitely excessive in this trial and happened at strange/unnatural times (O's first move isn't exciting enough for a double arm raise, I think). Interesting how much that impacts the perception.
3	Goofy	Bored	Funny
4	Interested	Engaged	Engaged
5	I felt included, it was cool	It felt the same as before	It felt faster this time so I was more nervous about getting it right but I was also more used to the process.
6	they made me feel engaged, kind of fun because of the banter. felt like hanging out with a couple of friends	probably the same as before, but i felt the introduction was a little short so yeah and maybe slightly less natural	felt slightly less intelligent and less banter maybe i am not sure
7	Robots made me feel confused	Less confused than before	Interesting
8	Engaged but a little bit uncomfortable - unsure of HOW to engage/should I interact with them	More comfortable after understanding the interaction	I was pretty upset about them moving at different times than when they were talking/when others were talking
9	Like I was in between friends being sassy with each other but fun tho	Pretty good pace was easier to follow this time	Okay a lil awkward sometimes felt a bit of a gap in conversations sometimes
10	The simulation made me feel somewhat apprehensive and made me think about the uncanny valley. These robots were not quite human-like enough to induce the discomfort of a human-like face	This time around, I was comforted by the repetition of these actions, which solidified the human-engineered actions/reactions of the	On this last time around, the voices began to induce some confusion for me. There seems to be a mismatch between voice and robot-player. Threw me for a loop!

	with a robot generated voice per se, and I was comforted by the visible hardware behind the robots — knowing that specific code has been written to execute these robots' actions.	robots. I am pondering how a more dynamic/AI governed robot would make me feel.	
11	creepied out	slightly less creeped out	creeped out
12	It was funny, but I felt shy. It might be because the people conducting the study were right there.	It was more comfortable because it was the exact same routine	I felt a lot more comfortable to just respond the way I wanted to or to draw random things on the board

Tables for feedback responses in final survey:

Feedback Questions in Final Survey			
#	How could this interaction be improved?	Do you think the presence of faces on the robots affected how you felt about the robots/interaction?	Any other comments?
1	if they started in different spots	yes, the heads spinning was interesting	
2	I think a "primer" or orientation sequence before the actual trials would be extremely helpful. I don't trust my survey responses for the first trial, since I was still getting used to what I was looking at.	I think the level of movement/reaction was crucial. Too little, and the test felt less engaging, and too much and the test felt very unnatural.	Cool stuff! I think with a few minor tweaks to the testing, you'd be able to tease out some great data.
3	If it changed	Somewhat	
4	Sometimes it was confusing who was talking because more than one of the robots had their arms moving.	Yes for sure. Definitely makes it feel more natural	
5	I didn't find it super easy to tell based on appearance who was talking, but I could by where the sound was coming from.	Yeah, I thought it was cute :)	This is really cool thanks guys
6	i think the scenarios could have been different because it was the same sequence all 3 times	yeah it was nice	i actually did not notice much of a difference in their hand movement
7	It was a bit hard to tell what they were	I didn't notice the faces	It was very cool!

	saying. I thought "spicy" was 5C and couldn't tell whether they were saying a game move or just comments.		
8	Different voices with different/corresponding appearances for each robot would improve my ability to track the interaction when their motions are being confusing	I didn't really notice faces, just movements and sometimes the lighting up of the heads	
9	Would say a more direct light on chest maybe since although one lights up fully they all are still a lil lit up whoich sometimes takes extra second to realize or if they moved as they spoke to catch my attention.	Yes them having a head was much mroe reassuring and seeing them move too.	Think it is really cool and it went well
10	Tough to say whether a more human-like interface would be more disturbing or welcoming — I guess see the uncanny valley framework to evaluate this!	The lack of distinct eyeballs made it less intimidating — the spheroid heads and robotic voices made it distinctly machine-like	Good work Nathan and Michelle (and team!)
11	the voices either sounding less human or more human	yes it felt like i was looking at brains	interesting
12	It would be interesting if the researchers were not sitting next to the participant. Also, maybe the voices could be more distinct,	Yes, I love the little dance at the end with their face. It was very cute.	