Solve the Sphero

An exploration of how encouragement from a robot affects task performance, group cohesion, and sentiment towards the robot in a group setting

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1 Introduction

Workplace robots are moving from the factory floor to the office. As this transition takes place over the coming decades, questions about safe and effective human-robot workplace interaction – long relegated to industrial assembly lines – are becoming increasingly relevant for knowledge workers. Robots will have to successfully integrate into preexisting, human-centric office environments, navigating both the physical space and the intricacies of workplace communication. This paper examines aspects of effective human-robot workplace communication, with a focus on robot encouragement in a group environment. Communication is a challenging domain even for humans. Workers must be able to give and receive information clearly, while maintaining a healthy, cordial environment. This is a particularly difficult task for robots as they lack any innate knowledge of human understanding and emotional states. Instead, their behavior must be intentionally designed around these variables.

This paper is an observational study that examines the effects of encouragement in human-robot communication. We recruited individuals in their 20s and 30s to participate in a series of collaborative games using a Sphero Bolt robot. The human participants were divided into groups of three or four individuals, each group independently working with a Sphero to solve a sequence of four games. The games were of varying difficulty but all required the humans to interact directly with the robot's sensors. Furthermore, every game had two possible variants with either less or more encouragement. We measured the groups' performance in completing the games, changes in group cohesion, and participants' sentiment towards robots. This approach expanded on existing studies by deliberately recruiting young individuals with college or graduate education, the demographic most likely to encounter office robots at some point in their

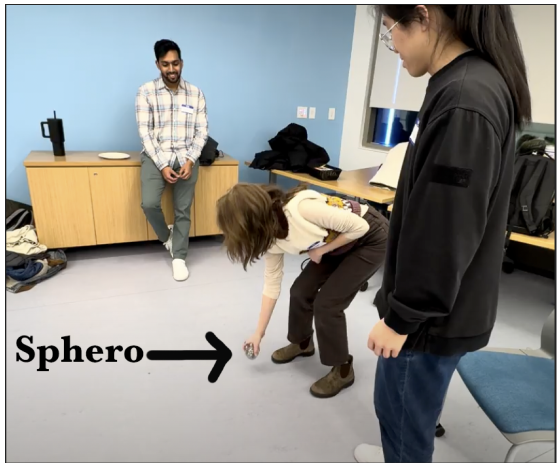

Figure 1: Study participants playing the Coordinate Game.

future careers. We also implemented a wider range of robot behaviors including moderate anthropomorphism.

Contrary to our expectations, higher levels of robot encouragement generally did not lead to better outcomes. Participants tended to take a similar amount of time in completing game tasks no matter the level of encouragement. In the most challenging games, increased encouragement even had a negative effect on group cohesion and sentiment, causing frustration while the participants struggled to solve a gameplay puzzle. Nonetheless, overall sentiment towards robots remained mostly positive, with a majority of surveyed participants indicating that robots could make good team members.

2 Background

The problem that we are focusing on revolves around understanding how encouragement from a robot affects the overall performance and group cohesion of a team. This area of research encompasses four key aspects, robots used in a learning environment to encourage children: robots used to encourage elderly people through daily tasks, robots used to motivate athletes for training, and lastly, encouragement used in robots for better group collaboration. Currently, the predominant focus of research in this domain revolves around robots encouraging in a group setting to foster better collaboration.

Within the domain of robots that encourage groups, several studies have examined the potential of fostering better collaboration amongst group members and increased team performance. Ravari, Parastoo Baghaei, et al. [1] showed that a robot's encouragement of group discussion can enhance social engagement of group members, leading to improved learning and enjoyment. H. Tennent, S. Shen and M. Jung [2] showed that the robot with encouraging behavior and matching movements (instead of random movements or no movements) balanced participation, and improved group task performance. However, a major limitation of this study was that the robot only used non-verbal encouragement. E. Short, et al's [3] paper on the robot moderation of a collaborative game explores socially assistive robotics, revealing unexpected outcomes as participants scored higher in performance-equalizing conditions, emphasizing positive correlations between participant helpfulness, group cohesion, and the frequency of robot mentions. In a study done by Y. Tanizaki, et al [4], the researchers explored the impact of robot utterances on collaborative learning, comparing three groups with different praise methods. The results indicated that collaborative learning with a robot using onomatopoeia or a method without adjectives/adverbs is more effective than when adjectives/adverbs are employed in communication. In summary, these studies collectively suggest that robot encouragement holds promise for fostering collaboration and enhancing team performance. However, the nuanced impact of diverse encouragement methods, including verbal and non-verbal approaches, requires further exploration.

Our study builds upon this prior work by incorporating different modalities of encouragement, such as speech, to create a slightly more anthropomorphic robot. Additionally, we are looking at the collaboration and performance amongst a group of strangers in an attempt to mimic the societal trend of young professionals in the STEM field interacting with robots in a work environment. Lastly, we track the participant's sentiment towards the robot as we believe that this is crucial for designing robots that can function in a group setting.

3 Algorithm

There were four primary algorithms implemented in the study, one for each game on the Sphero: the Shaking game, the Obstacle game, the Coordinates game and the Luminosity game. Every algorithm has an encouragement and non encouragement version. The specific implementations can be found in the Additional Materials section for each algorithm discussed below.

3.1 Preliminaries

These algorithms are defined mathematically, although the logic is specific to the Sphero Bolt robot due to the sensors required for each algorithm.

3.2 Shaking Algorithm

The Sphero, equipped with an accelerometer, detected the acceleration in real time. The sum of acceleration in the x and y directions was used as a key parameter for the Shaking game. When the acceleration was less than 0.8g, it was defined as too slow; between 0.8g and 3.0g was considered moderate speed; and acceleration above 3.0g was deemed too fast. The requirement to pass the Shaking game was to continuously shake the Sphero at a moderate speed. The Sphero was capable of recording the time taken by the user from the start to the end of the game. During the game, the main LED display would show either a check mark if the shake rate was correct, a cross if it was too slow, or flash blue if the speed was too high. Once the desired shake velocity was maintained for 5 episodes of 2 seconds each, the Sphero updated its LED with a winning display and notified the user with a sound. The encouragement version of the game would output various messages including "You are on the right track. Just a bit more to go!" and "Great effort! It would be a good idea to let your teammate have a try." These messages occurred intermittently throughout the game. The version of the game without encouragement remained the same on all aspects except that no audio messages were output to the user.

3.3 Obstacle Algorithm

The participants needed to solve a maze by using visual and auditory cues provided by the Sphero. The first cue was a green LED and a trotting sound. This cue indicated that the participant needed to shake the Sphero to move onto the next phase of the maze. The second cue was a blue LED screen and a spring noise. This cue indicated that the participant needed to toss the Sphero in the air. In total 10 moves were required to complete this game by either shaking or tossing the Sphero. In the encouragement version, the Sphero outputted various messages such as "You are so good at this!" and "To sidestep, I need to move quickly from side to side." The version with no encouragement followed the same logic except there was no additional encouragement cues added.

3.4 Coordinate Algorithm

The Sphero kept track of its coordinates using a combination of the internal distance sensor and the gyroscope sensor. The goal of this Sphero was to get to target coordinates. The Sphero would update its LED with a color indicating hot (red) or cold (blue) in relation to its target coordinate and announce the total distance to the destination. The participants needed to move the Sphero along the ground to the correct coordinate. Once the desired coordinate was reached, the game completed. The encouragement version of the game would tell users various messages including "Keep working together you guys got it!" and "If anyone is wearing black suggest a new way to solve the problem!". The non-encouragement version just changed the display color and told the users the overall distance.

3.5 Luminosity Algorithm

In this game the Sphero kept track of the value of the luminosity sensor and compared it to the threshold value needed for a win. Along the way the Sphero provides hints including "It sure is bright out here. I could use some sunglasses" and "Seriously I am getting a sunburn". These hints attempt to push the participants towards putting the Sphero in a dark location. There were various visual cues alongside the auditory ones such as a smiley face with sunglasses and a flashing red LED display. In the encouragement version the Sphero told the participants to work together and communicate in order to solve the task. The version with no encouragement just provided the light hints.

4 Methodology

We wanted to observe three primary features of group-robot interaction: 1) how robotic encouragement affects task performance time, 2) how a robot can affect group cohesion, and 3) how sentiment towards the robot changes when solving the task. To do so, we divided participants into groups of three to four individuals and had them complete four separate games involving the Sphero. Each game involved a Sphero with which the participants needed to interact with in specific ways to solve a puzzle. Each game had an encouragement mode and a non-encouragement mode to measure how encouragement affected task completion time. Each participant completed a survey before and after the study that measured willingness to work with robots and enjoyment of group based problem solving.

We believed that the encouragement from the robot would improve participants' task completion, increase their willingness to engage in group activity and have more positive sentiment towards the robot.

4.1 Data Collection

Our games were handmade for the experiment. Data collection occurred to tune the parameters used for the Sphero sensors. To do this we performed the experiment with the study designers in a test walk-through. During these test runs we tuned the parameters of the game run on the Sphero.

4.2 Participant Recruitment

Participants were recruited from close connections including roommates and fellow students. This was a form of convenience sampling, however, it made

Figure 2: Participants working together to solve the Obstacle game.

sense for our experiment as this was our target population. The participants were told that the experiment involved playing with robots. Additionally, they were told that they would be put in a group of strangers. The recruitment information was intentionally left vague to keep the experiment details hidden.

4.3 Software Design and Implementation

The specific algorithms for each game are discussed in further detail in the algorithms section and the implementations for each can be found in the Additional Materials section.

4.4 Parameterization

Parameterization of the Sphero Key Word game model occurred prior to running the experiment with participants. The parameters were tuned by running the experiment with the study designers. After trial and error the parameters that suited the experiment the best are listed below:

Shaking - 50 shakes/min with a $\pm$ 5 cm/s rate

Luminosity - 75

Coordinates - 1 coordinate with 10 cm radius

Obstacle - 10 steps for obstacle course

Figure 3: This is the Sphero Bolt that we used to perform our experiments.

4.5 Robot/Robot Hardware/Hardware and Software Design

The robot that we used was the Sphero Bolt. This is a non-humanoid, spherical robotic device with a diameter of about 73 millimeters, making it compact and highly maneuverable. The Bolt is a versatile robotic ball with a wide array of sensors and functionalities. Equipped with an accelerometer, pitch sensor, and gyroscope, it can measure acceleration, orientation, and angular velocity, providing stability and control. With the ability to measure velocity, distance, speed, and heading, it can precisely track its movements and orientation. The Sphero Bolt can estimate its location within a controlled environment, even though it lacks built-in GPS, making it suitable for path-following applications. Additionally, it can measure time elapsed, act as a compass, and respond to changes in ambient luminosity, making it a valuable tool for educational programming, navigation, and interaction in various settings. The Bolt can be programmed through the Sphero App using block code or JavaScript.

4.6 Experimental Design/Experimental Protocol/Validation Study

The three main questions that we attempted to answer in our experiments were: 1) how robotic encouragement affects task performance time, 2) how a robot can affect group cohesion, and 3) how encouragement affects sentiment towards the robot when solving the task.

We used groups of 3-4 participants, ideally who had never met each other. They tried to ”solve” the Sphero game as described in our algorithm.

Overview

- Our experimental design was mixed.
- The participants were told general guidelines about what NOT to do with the Sphero (ie. light on fire, throw at wall, etc.). However, they did not know everything that they can do to explore the Sphero. This was part of the group exploration of the Sphero.
- Each group took around 30 minutes and the total study with multiple groups running at a time in different rooms was a little over an hour.
- Participants were not assigned conditions.
- Our experiment space was an empty classroom and the participants had an empty space to explore the Sphero and solve the game. They were not given any other tools to aid in completing the tasks.
- The robot gave hints when appropriate and notified the participants when they had solved the game. Depending on what version of the game the participants were playing the robot provided encouragement during the game or play the game with no encouragement.
- Two surveys were conducted with participants to measure participants' affinity towards robots and group interactions before and after the study. Details of the study included in the Measures section.

Steps:

1 Participants were recruited and arrived for the experiment.

2 Participants filled out the pre-study survey.

3 Participants were placed into groups of 3 or 4 and each participant was given a Sphero Bolt. Participants in a single group did not know each other.

4 Participants were given a brief demonstration of what not to do when handling the Sphero for safety reasons. Other than that, they were left to explore the Sphero on their own.

5 Participants were told that they were trying to solve a total of four games using the Sphero and that performance times and video interactions would be recorded. Specific instructions for solving each Sphero were not provided to the participants, however the Sphero gave hints as appropriately determined by our algorithm.

6 Each of the four games were played in order, where performance time, whether encouragement was provided and video interactions were recorded.

7 Participants were given a post-study evaluation questionnaire.

4.7 Measures

Our study was centered on how encouragement affects performance across various tasks and how encouragement affects group cohesion and sentiment toward robots. Each group was assigned two encouragement and two non-encouragement games, evenly distributed between the four game types. In order to measure performance, we measured the time to complete each task for each group and whether or not the task was completed. For sentiment, we utilized surveys as well as post-study video analysis. The surveys were developed specifically for this study and did not rely on previous questionnaires. For post-study video analysis we took extensive recordings of the groups while they were solving the tasks. This ended up providing additional insight into the group learning process and areas participants enjoyed or were frustrated by during the study. The pre-study and post-study surveys can be found in the Additional Materials section.

4.8 Data Coding

Given that our project did not involve the training of AI systems, there was no requirement for annotated data for machine learning purposes. However, to understand the dynamics of human-robot interaction, we still needed to analyze the data qualitatively. This involved coding the recorded videos to capture participants' responses and behaviors during the interaction with the robot.

The coding schema was developed to categorize different types of interactions and responses. For instance, we defined number of different exploration types as the number of times that a group tried a unique method or sensor to solve the puzzle. Overall, each member observed the full recorded study session and counted the following: negative sentiment words, positive sentiment words, number of task pass-offs, number of different types of exploration, adherence to robot instructions, and ignoring robot institutions. Each of these categories was distinctly measurable in the videos.

To ensure the accuracy and consistency of our coding, negative sentiment words were characterized as words that directly criticized the robot or group. In contrast, the positive sentiment words were characterized as words that directly complimented the robot or group dynamics. As mentioned before, the exploration types were unique ways that a group tried to solve the puzzle in a given session. These measures helped us ensure that the data was not only reliably coded but also provided a solid basis for subsequent analysis. This analysis was crucial for our project's aim to explore the nuances of human-robot interaction without the complexity of AI training algorithms.

The coder agreement among categories was 82.5% agreement on negative sentiment words, 73.9% agreement on positive sentiment words, 92% agreement on the number of task pass-offs, 87% agreement on the number of different types

Performance Data												
Group	**Game 1**	**Time**	**Tries**	**Game 2**	**Time**	**Tries**	**Game 3**	**Time**	**Tries**	**Game 4**	**Time**	**Tries**
A	Shaking NE	95	1	Obstacle NE	300	3	Coordinate E	420	3	Luminosity E	33	1
B	Shaking NE	251	3	Obstacle NE	285	1	Coordinate E	314	3	Luminosity E	27	1
C	Shaking NE	102	1	Obstacle NE	420	3	Coordinate E	420	3	Luminosity E	27	1
D	Shaking E	320	3	Obstacle E	420	3	Coordinate NE	334	3	Luminosity NE	55	1
E	Shaking NE	217	2	Obstacle NE	420	3	Coordinate E	420	3	Luminosity E	28	1
F	Shaking E	420	3	Obstacle E	232	2	Coordinate NE	420	3	Luminosity NE	34	1

Key	
	Encourage
	Non Encourage
	Incomplete

Figure 4: Performance data from each group including total task completion time and rounds played.

of exploration, 95% agreement on adherence to robot instructions, and 100% agreement on ignoring robot instructions.

4.9 Participants

We recruited 20 participants for the experiment, which we conducted over two sessions. Groups contained 3 or 4 participants, ideally who had never met each other. We targeted young adults aged 22 to 35, which mainly included university students and working professionals. There were no detailed requirements regarding the gender and ethnic distribution of the participants.

Our recruitment strategy was to recruit from the pool of people that we knew including roommates, classmates and friends.

5 Results

In this study we were able to analyze data from three key areas: performance time of task completion with an encouraging and non-encouraging robot, group cohesion and participation metrics from recorded surveys, and robot sentiment during the task completion.

5.1 Performance

The overall performance times are listed in Figure 4 and the average times listed in Figure 5. In the encouragement version of the Obstacle game, the total task completion time was less than with no encouragement. The encouragement version took users 5.43 minutes to solve on average whereas the non-encouragement

Performance Averages				
Game	Shaking	Obstacle	Coordinate	Luminosity
Average	3.9	5.77	6.47	0.57
Average NE	2.77	5.94	6.28	0.74
Average E	6.17	5.43	6.56	0.48
Analysis	Encourage takes longer	Non-Encourage takes longer	Encourage takes longer	Non-Encourage takes longer

Average NE Total	4.07
Average E Total	4.28

Figure 5: Average performance time for each game, across both the encouraged and non-encouraged version

Post-Experiment Analysis										
	ShakingNE	ShakingE	ObstacleNE	ObstacleE	CoordinateNE	CoordinateE	LuminosityNE	LuminosityE	AvgNE	AvgE
Negative words	2.1	6.3	3.7	4.3	4.8	12.9	0.2	0	2.7	5.875
Positive words	0	1.2	0.23	0	0	0	0	0	0.05	0
Task pass offs	3.8	5.6	4.9	3.6	9.7	13.8	1.2	1.2	4.9	6.05
Types of exploration	6.3	4.7	5.1	4.5	11.2	9.7	2.1	1.8	6.175	5.175
Adherence	3.3	3.3	4.5	3.6	8.2	9.3	2	2	4.5	4.5
Non-Adherence	1.3	1.8	3.4	3.1	2.8	7.3	0	0	1.875	3.05

Figure 6: Coded data from the recorded study sessions tracking metrics related to robot sentiment and group cohesion.

version took 5.94 minutes to solve. Similarly, in the Luminosity game the encouragement version took users 0.48 minutes to solve on average whereas the non-encouragement version took 0.74 minutes to solve.

However, for the two other games the exact opposite result was observed. The task completion time actually increased for the encouraged version of the game. The Coordinate game resulted in an average completion time of 6.56 minutes for the encouraged version whereas the non-encouraged version took 6.28 minutes. Likewise, for the Shaking game the encouraged version took 6.17 minutes to complete whereas the non-encouraged version took 2.77 minutes to complete.

With these results we can't conclusively draw any conclusions about performance time in relation to robotic encouragement in a team setting.

5.2 Group Cohesion and Participation

In the pre-study survey given to participants, 100% of participants said they find team based activities interesting or fun and similarly 100% of participants said they are willing to communicate with strangers in a group setting. In the post-study survey, 76% of participants responded that the robot positively affected team cohesion and collaboration (responding Agree or Strongly Agree), while the remaining 24% of participants disagreed. However, when asking participants whether the robot's encouragement influenced their willingness to work with strangers in a team the answers were significantly more mixed. 23.5% of participants strongly agreed with the statement, 35.3% agreed, 23.5% disagreed, and 17.7% strongly disagreed. This indicates that the encouragement and interaction with the robot during the study did not help with group cohesion but may have actually negatively affected it in many cases.

Figure 6 shows the coded results from the recorded study sessions. In the results we can see that encouragement from the robot results in increased task pass-offs between participants, an indicator of how well groups are collaborating. When the robot is encouraging a group on tasks, participants in the group pass off the task an average of 6.1 times vs 4.9 times in the non-encouraged versions of the games.

5.3 Robot Sentiment

Robot sentiment was measured before and after the study in the survey. In the pre-study survey 82% of participants either agreed or strongly agreed that robots can make good team members. In the post-study survey the same percentage of participants, 82%, either agreed or strongly agreed that they can collaborate effectively with robots.

In the coded video analysis we further examined the sentiment towards the robot during the study. We found that on average, the negative sentiment words actually increased for an encouraging robot. This was especially true in the Coordinate game, which was the most difficult task to solve. The average number of negative sentiment words was 5.9 for the encouraging version of the robot whereas it was only 2.7 for the non-encouragement version. Additionally, the groups ignored the robot's instructions more for the encouraged version than the non-encouraged version. The average number of times the groups ignored the robot's instructions was 3.1 for the encouraged version but only 1.9 on average for the non-encouraged version.

These findings indicate that participants sentiment towards the robot actually worsened when given encouragement, especially the more difficult the task was that they were trying to solve.

6 Discussion

Our study ventured into the intricate dynamics of robotic encouragement within team settings, drawing upon various modalities of speech to endow a robot with slightly anthropomorphic qualities. Contrary to our working hypothesis, the findings reveal that robotic encouragement does not wield a universal positive influence on team performance. This phenomenon was particularly evident in the Coordinate and Shaking games, where teams exposed to encouragement exhibited slower task completion rates. Additionally, the encouragement from the robot, specifically on complex tasks, negatively affected the sentiment from the study participants towards the robot. However, the robotic encouragement did lead to an increase in group cohesion, incentivizing participants to work together.

Contributions: Our study demonstrates that encouragement in and of itself does not necessarily lead to performance gains and can potentially negatively affect how teams view robots in these settings. Additionally, our findings indicate that while performance may not be positively affected by robotic encouragement, group cohesion is. These findings highlight important considerations for robot design choices, specifically when a robot is tasked with working in a team-based setting.

Observations: A key observation from our study is the potential for encouragement to generate counterproductive persistence in incorrect strategies. Phrases intended to motivate, such as "almost there," inadvertently led participants to continue with ineffective methods. Moreover, while encouragement initially elicited positive engagement in the Coordinate game, it eventually evolved into frustration, suggesting that the efficacy of encouragement may wane over time or as task difficulty escalates.

Implications for Design: These insights bear significant implications for the design of collaborative robots in professional settings. There is a delicate balance to strike in terms of when and how robots provide encouragement to human teammates. Our results advocate for a more adaptive approach, where the robot's behavior is tailored to the group's dynamics and the task's complexity.

Future Work: Our study's constraints pave the way for future inquiries. Examining how different groups respond to robotic encouragement, given diverse task complexities and individual predispositions, will enrich our understanding of effective human-robot interaction. Longitudinal studies could also unravel how perceptions of robotic team members evolve with prolonged exposure and interaction.

7 Conclusion

The results of our research paint a complex picture of encouragement in group dynamics involving robots. We discovered that encouragement is not a one-size-fits-all booster of team efficiency; rather, its influence is nuanced and context-dependent. Interestingly, despite the mixed efficacy of encouragement, participants retained a favorable disposition towards teamwork, indicative of a societal readiness to collaborate with robots. As the landscape of professional interaction with robots grows, our study underscores the need for a nuanced approach to robotic behavior that is attuned to human teamwork dynamics.

8 Additional Materials

8.1 Algorithms

Algorithm 1 Shaking Game Algorithm

```
slow ← 0.8g
fast ← 3.0g
failureCount ← 0
successCount ← 0
shakingIntensity ← 0
showGameInstructions()
while true do
    shakingIntensity ← shakingIntensity(NetAcceleration(AccelX, AccelY))
    if shakingIntensity < slow then
        showSlowMessage("I feel like a snail!")
        failureCount ← failureCount + 1
    else if slow < shakingIntensity < fast then
        failureCount ← failure count + 1
        while true do
            shakingIntensity ← shakingIntensity(NetAcceleration(AccelX, AccelY))
            if not (slow < shakingIntensity < fast) then
                successCount ← successCount + 1
            else
                break
            end if
            if successCount> 5 then
                showSuccessMessage("Mission complete!")
                return
            end if
        end while
        failureCount ← failureCount + 1
    else if high<shakingIntensity then
        showFastMessage("Oh dear, I am getting quite dizzy!")
        failureCount ← failureCount + 1
    end if
    if failureCount in (3, 8, 12, 18) then
        showEncouragementMessage()
    end if
end while
function NetAcceleration(X, Y)
    return √(X^2 + Y^2)
end function
```

Algorithm 2 Obstacle Course Algorithm

```
track ← [0, 0, 1, 1, 0, 1, 0, 1, 0, 0]
length ← 10
index ← 0
task ← ”shuffle”
score ← 0
while index < length do
    if track[index] = 1 then
        task ← ”jump”
        setLED(blue)
        spin(counterclockwise)
    else
        task ← ”shuffle”
        setLED(green)
        spin(clockwise)
    end if
    takeAction()
    index ← index + 1
end while
function TAKEACTION( )
    if task = ”jump” then
        playSoundEffect(boing)
    else
        playSoundEffect(running)
    end if
    while true do
        if squareRoot(AccelX^2+ AccelY^2+ AccelZ^2 ≤ 0.2 AND getElapsedTime() > 0.1 then
            if task = ”jump” then
                playSoundEffect(confirm)
                score ← score + 1
            else
                playSoundEffect(fail)
            end if
        end if
        if squareRoot(AccelX^2+ AccelY^2+ AccelZ^2 ≥ 5 AND getElapsedTime() > 0.5 then
            if task = ”shuffle” then
                playSoundEffect(confirm)
                score ← score + 1
            else
                playSoundEffect(fail)
            end if
        end if
```

Algorithm 3 Coordinate Game Algorithm

```
targetX ← 50
targetY ← 50
currentX ← 0
currentY ← 0
initialDistance ← calculateDistance(currentX, currentY, targetX, targetY)
while distanceToTarget(currentX, currentY, targetX, targetY) > 10 do
    currentX ← getCurrentX()
    currentY ← getCurrentY()
    distance ← distanceToTarget(currentX, currentY, targetX, targetY)
                                                ▷ Display distance feedback
    displayFeedback(distance)
    if getElapsedTime() > 180 then
        showGameOverMessage(”Time’s up! Better luck next time.”)
        exitGame()
    end if
    SayEncouragementMilestones()
    SayTemperatureWarnings(distance, initialDistance)
end while
playCelebration()
showSuccessMessage(”Nice job!”)
function DISTANCETOTARGET(x1, y1, x2, y2)
    return √((x2 − x1)^2 + (y2 − y1)^2)
end function
function SAYTEMPERATUREWARNINGS(distance, maxDistance)
    scaledDistance ← min(distance/maxDistance, 1.0)        ▷ Scale the distance
    redValue ← ⌊(1 − scaledDistance) × 255⌋       ▷ Calculate red component
    blueValue ← ⌊scaledDistance × 255⌋           ▷ Calculate blue component
    return [redValue, blueValue]
end function
function SAYENCOURAGEMENTMILESTONES()
    return Verbal Encouragement
end function=0
```

Algorithm 4 Luminosity Game Algorithm

```
dark ← True
ongoing ← True
start ← True
while ongoing = True do
    light ← detectLight()
    if start = True then
        rollAndPrompt()
        start ← False
    end if
    if getElapsedTime() ≥ 15 AND ongoing = True and getElapsedTime() ≥ 75
then
        hint1()
    end if
    if getElapsedTime() ≥ 25 AND ongoing = True and getElapsedTime() ≥ 75
then
        hint2()
    end if
    if getElapsedTime() ≥ 45 AND ongoing = True and getElapsedTime() ≥ 75
then
        hint3()
    end if
    if getElapsedTime() ≥ 60 AND ongoing = True and getElapsedTime() ≥ 75
then
        gameFail()
        ongoing ← False
    end if
    if dark = False then
        gameWin()
        ongoing ← False
    end if
end while
```

8.2 Pre-Survey Questionnaire

1. Name
2. Age
3. Gender
4. Occupation/Field of Study
5. What is your experience level with robots?
   Expert, Some experience, Very little experience, and No experience
6. What are your expectations regarding working with a robot during the study?
7. I am willing to communicate with strangers in a group setting
   Strongly Agree, Somewhat Agree, Somewhat Disagree, Strongly Disagree
8. I can collaborate effectively with robots
   Strongly Agree, Somewhat Agree, Somewhat Disagree, Strongly Disagree
9. I find team based activities interesting and fun
   Strongly Agree, Somewhat Agree, Somewhat Disagree, Strongly Disagree
10. I enjoy interacting and playing with robots
    Strongly Agree, Somewhat Agree, Somewhat Disagree, Strongly Disagree

8.3 Post-Survey Questionnaire

1. How would you describe your overall experience working with the robot during the study?
2. Did the robot's encouragement impact your team's performance? Please provide specific examples.
3. I found that the robot affected our team cohesion and collaboration.
   Strongly Agree, Somewhat Agree, Somewhat Disagree, Strongly Disagree
4. I found the robot's encouragement influenced my willingness to work with strangers in the team.
   Strongly Agree, Somewhat Agree, Somewhat Disagree, Strongly Disagree
5. I think robots can make good team members.
   Strongly Agree, Somewhat Agree, Somewhat Disagree, Strongly Disagree
6. Has your sentiment towards interacting with robots changed after this experience? Please explain.
7. What suggestions do you have to improve the interaction between humans and robots in a team setting?
8. Is there anything else you would like to share about your experience or the study in general?

9 Acknowledgements

9.1 Qidi

Code: I was responsible for developing the Shaking game for our experiment. I programmed the game scripts in JavaScript, creating both encouragement and non-encouragement versions.
Study: In the study phase, I actively recruited participants and recorded the experiments on both days of the study.
Data Analysis: I computed the timing performance metrics in a separate version, which was ultimately not included in the final paper.
Paper: I authored Section 6, Section 7, section 4.9, and the description of the Shaking algorithm.
Presentation: I created Slide 8 for our presentation.

9.2 Kelly

Code: I worked on the coordinate game for the experiment. I wrote the scripts for the games in javascript and wrote both an encouragement and non-encouragement version.
Study: For the study I actively recruited participants and helped run one room of the studies on both days that we held the study
Data Analysis: I calculated the timing performance metrics and formatted all the tables associated with the metrics
Paper: I wrote section 2, sections 4.5 and 4.6, and the coordinate algorithm. Lastly, I actively edited the entire report.
Presentation: I made slides 1, 3, and 4 for the presentation.

9.3 Tyler

Code: I created both the encouraged and non-encouraged versions of the obstacle game using JavaScript.
Study: I recruited several participants and led one of the rooms alongside Ryan for both days of our experiment.
Data Analysis: I analyzed several of the video recordings and helped define our findings.
Paper: I wrote the introduction as well sections 3.3 and 4.1. I also edited the entire paper, focusing on omissions and errors.
Presentation: I made slides 2 and 5.

9.4 Ryan

Code: I created both the encouraged and non-encouraged versions of the Luminosity game using JavaScript.
Study: I recruited several participants for the study and purchased necessary supplies for the study to run. Additionally, I helped run one of the rooms with

Tyler including recording all interactions and recording performance times.
Data Analysis: I primarily was responsible for the survey and video coding analysis. In the data analysis I looked for any statistical significant findings to draw conclusions from.
Paper: I wrote sections 4.2 - 4.2, 5 and edited the final document.
Presentation: I worked on the What We Learned slides in the final presentation (slides 6 and 7).

References

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[3] E. Short *et al.*, Robot moderation of a collaborative game: Towards socially assistive robotics in group interactions, *2017 26th IEEE International Symposium on Robot and Human Interactive Communication (RO-MAN)*, pp. 385-390, 2017

[4] Y. Tanizaki *et al.* Learning effect of robotic encouragement-based collaborative learning, *2017 IEEE International Conference on Fuzzy Systems (FUZZ-IEEE)*, pp. 1-6, 2017