Improving Rhythm Perception Using Rock Paper Scissors

CS 6465 Robots & Humans

Final Project Report - Group 8

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1 Introduction

Rhythm perception plays a significant role in our daily lives. While the impact of rhythm may go unnoticed, we subconsciously use rhythm estimation to perform a plethora of everyday tasks - singing songs, playing music on an instrument, dancing to a beat, clapping together in a social environment, the list goes on. *Beat Deafness* [6] is a recently identified form of congenital amusia, a condition which can be defined by a person's inability to perceive musical rhythm. This condition is extremely rare and incurable as of now. Even so, there exists a milder form of rhythm perception disorder which is common and generally affects kids and adolescents suffering from attention deficit hyperactivity disorder (ADHD) [8] and stutter [9]. However, unlike absolute beat deafness, this milder form of rhythm imperceptibility can be treated with appropriate rhythm training.

The traditional game of *Rock Paper Scissors* possesses a salient property relating to rhythm synchronization. It is a game between two players, where in each round, both the players can choose either rock, paper, or scissor. According to Game Theory [1], this game's optimal strategy is a random strategy, i.e., there is no optimal way of winning this game. If played perfectly randomly, each player has a one-in-three chance of winning. However, there is a way in which a player can win this game 100% of the times - if they draw after their opponent. Obviously, such moves are invalid, and this brings us to the salient property of this game relating to rhythm synchronization - each player must serve their moves at the same time.

Leveraging on this property of the game, we build a human-robot interaction (HRI) system using the *NAO* robot capable of playing the Rock Paper Scissors game with a human player. Our system will actively track the user's rhythm and gesture landing time and give feedback when the user is not moving on time. Moreover, our system will also have a configurable rhythm setting so as to allow the user to play the game of Rock Paper Scissors at different speeds in order to better train the rhythm perception ability of the human.

By gamifying the entire experience, we build a system which can be both enjoyable while also allowing for rhythm improvement. For the purpose of our study, we form the following hypotheses:

Hypothesis 1 (H1): *people lacking rhythm perception will find it difficult to accurately play the Rock Paper Scissors game since it requires the user synchronize their moves.*

Hypothesis 2 (H2): *repeatedly playing our proposed Rock Paper Scissors game can effectively help improve rhythm perception.*

2 Related Work

B´egel et al[4] have studied on a similar region of rhythm training for beat perception enhancement in 2018. They devised a protocol with a tablet music-based serious game called Rhythm Workers targeted to the training of rhythmic skills. The protocol was designed into two versions. The tapping version required a synchronized motor response to the given beat rhythm, while the perception version required a perceptual judgement of the given beats. After training for two weeks, participants in the experimental groups showed high performance in the game comparing to the control groups that did not receive any training. The game appeared to be a motivating and efficient way to train rhythmic abilities in healthy young adults and with possible applications for training these skills in people with rhythm disorders.

Another related work in rhythm training is that of Patscheke et al.[7], who focused on effects of rhythm and pitch training for phonological awareness enhancement. In the experiment, preschoolers were randomly assigned to a music training condition and a non-music training condition. After 16 weeks training, the group with music training condition (pitch training) showed a positive effect in phonological awareness, while the rhythm training group and the control group showed no significant differences in phonological awareness before and after training. Though rhythm elements appear to have less impact than pitch elements on phonological awareness, Patscheke's work provided an explicit framework of training and evaluation for our work.

In the area of rhythm training for rehabilitation, Simone Dalla Bella et al.[3] have studied the effects of musically cued gait training in Parkinson's disease. The result of the experiment showed beneficial effect of musically cued gait training gait performance, perceptual timing, and sensorimotor timing abilities in PD patients. They concluded that with the hypothesis that gait disorders in PD are rooted in timing deficits, by asking PD patients with to synchronize steps to a given rhythmic sound cues, gait performance of the patient can be improved with benefits. The work exhibited a potentially broader usage of rhythm training in rehabilitation region.

3 System Design

Our system consists of four main modules: gesture recognition, rhythm estimation, robot movement control, and network synchronization. The first three modules work independently and collect all the necessary data. Data captured by the first three modules are then sent to the network synchronization module in real-time for results computation.

3.1 Gesture Recognition

ArUco fiducial markers are employed for gesture recognition. We use three small 15mm × 15mm ArUco marker cutouts, each of different IDs, and individually attach them to velcro strips to form a ring. Each ring is worn on the index, middle, and ring finger, respectively, and based on the number of ArUco markers detected, the gesture is classified as Rock, Paper, or Scissor. A sample result of the gesture recognition module is illustrated in Figure 1.

Figure 1: A Sample Result of the Gesture Recognizer

3.2 Rhythm Estimation

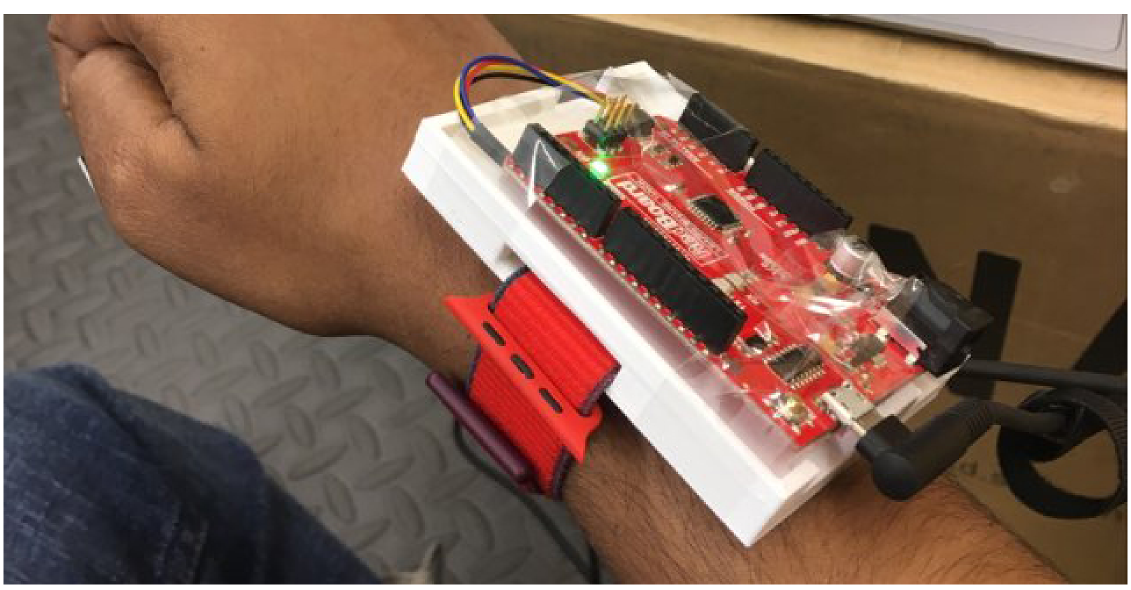

Figure 2: Rhythm Estimation Hardware

We use an Arduino Uno board along with a Sparkfun 9-DOF IMU for measuring the acceleration in the y-axis of the user's right arm to estimate the rhythm. After performing initial tests, we realize that upon moving the hand up-and-down as in playing Rock Paper Scissor, there are clear crests and troughs in the y-axis accelerometer readings of the hand motion. Therefore, we wrote a threshold-based signal processing algorithm to count every up-and-down hand movement, and once three consecutive motions are detected, the time gaps between the three crests is calculated and an average value for the crests per minute is estimated (which is equivalent to the beats per minute, or BPM). In order to make this setup easily wearable, we 3D print a base for the microcontroller which also supports a wearable strap, as illustrated in Figure 2.

3.3 Robot Movement Control

The Robot movement control, implemented with Python SDK developed by SOFTBANK ROBOTICS, has two major functions: show sample rhythm and play the game. The module is controlled by the server and receives configurable parameters from the server. The robot's movement has two modes - sample rhythm mode, and gaming mode.

For sample rhythm mode, the module takes the BPM value from the server, then the robot performs the beat in specified BPM by moving its arm up and down for five iterations. This action allows the users to perceive the rhythm at which the robot will be playing the game to allow them to synchronize their movements.

In gaming mode, the robot plays the Rock Paper Scissor game for 5 rounds. For each round, the robot first informs users about the start of the game, then it performs the beat three times and serves its move at the last drop. The move is randomly select at runtime and sent to the server simultaneously along with the system clock. After each round, the robot receives information from the server about the current round. Information sent to the robot includes the winning agent, the user's BPM delay, the user's move delay, and whether the round is valid. Based on the results of the current round, the robot informs the users about the results and the quality of the user's movements. To reduce repetitive feedback and make the interaction more natural and smooth, we provide a set of feedback phrases for each result that the robot randomly chooses from. One sample feedback is *"Haha I win. Speed up your rhythm a little."* After 5 rounds, the robot says the number of times the user wins, loses, and the number of times the game is a draw.

3.4 Network Synchronization

We employed a central controller server which was responsible for synchronizing the inputs from all the different components of the system and computing the results based on it. We used two computers in our system, one of which was connected to the NAO robot, while the other was running the controller server, gesture recognizer, and rhythm estimator. Since the controller server was directly connected to the rhythm estimator and gesture recognizer (via on-board camera and USB), there was no latency. However, there was significant latency between the robot controller and the main controller owing to two factors - difference in system clocks and network latency. In order to tackle this, we sent 1000 data packets from the robot controller system to the main controller and back, and then calculated the average of the time taken to transmit and receive the data packet. We used this value to correct the time-based value calculations such as rhythm and move delay, which are explained later in this paper.

4 Experimental Setup

The experimentation setup involved five steps: orientation, pre-game rhythm test, gameplay, post-game rhythm test, and then finally a survey, performed in the exact same order.

4.1 Orientation

Before starting with the experimentation, each participants were explained the rules of the Rock Paper Scissor game, the nature of the experiments, the hardware that they would be wearing on their right arms, and the process of hand-sanitization before and after the experiment in order to ensure COVID compliance. Participants were given the liberty to quit anytime they felt uncomfortable. Each experiment took about 40 minutes to complete. The participants were not compensated for their time. However, they received chocolates at the end of their session as a gesture of appreciation.

4.2 Pre-Game Rhythm Test

In order to gauge the sense of rhythm of the participants, each participants were needed to take an online rhythm assessment test *GotRhythm*[2]. This test required the user to press the *Space* button on the keyboard along with a beat that played over the speakers. The beat then got muted and the user had to keep pressing space keeping the rhythm intact until a timer stopped. At the end of the rhythm assessment test, the platform returned an overall score out of 1000 indicating the rhythm perception abilities of the participant, with a higher score indicating better sense of rhythm. We refer to this score as the *Pre-Game Test Scores* hereon.

4.3 Gameplay

This step involves playing the actual game of Rock Paper Scissor with the NAO robot. The game was subdivided into three rhythm speed categories: Easy/Slow Rhythm (60 BPM), Medium Rhythm (90 BPM), and Hard/Fast Rhythm (120 BPM). Each game setting involved 5 consecutive rounds of the game. One block of experiment consisted of a game (5 rounds) with slow rhythm, followed by a game (5 rounds) with medium rhythm, followed by a game (5 rounds) with fast rhythm. The experiment consisted of three blocks, therefore resulting in a total of 45 rounds of Rock Paper Scissor (5 Rounds $\times$ 3 Rhythm Settings $\times$ 3 Blocks). For each round, user's rhythm (in BPM) and move delay (in milliseconds) was recorded for further analysis. To maintain the timing constraints of the game, a soft and hard threshold were defined for both user's rhythm difference and move delay. If the user's move crossed the soft threshold, the robot would give appropriate feedback regarding the movement of the user, but the round would be considered as valid. However, if the hard threshold value was crossed, the round would be considered invalid. The values for the soft and hard threshold were defined empirically as:

$$Move\,Delay_{Soft} = 300ms \qquad Rhythm\,Difference_{Soft} = 5BPM$$
$$Move\,Delay_{Hard} = 500ms \qquad Rhythm\,Difference_{Hard} = 10BPM$$

4.4 Post-Game Rhythm Test

Similar to the pre-game rhythm test, the participants were needed to take the same online rhythm assessment test [2] after playing the Rock Paper Scissor game with the robot in order to gauge any change in the user's rhythm perception ability. We refer to this score as the *Post-Game Test Scores* hereon.

4.5 Survey

The final step requires the participants to take a small survey consisting of 8 multiple-choice questions and an optional feedback/opinion field. This survey aimed to gather a qualitative feedback of the users pertaining to their experience with the robot for questions.

5 Experimentation

The experimentation was conducted in two phases - a set of pilot studies followed by system re-tweaking based on the findings of the pilot study, and then the actual user study.

5.1 Pilot Study

Since the setup consists of multiple components interlinked together through network and serial communication, with each component being required to work in sync with the other, it was fundamentally important to have trial runs using actual participants to check if the system performed as per expectation and provided accurate judgement of user's rhythm and gesture. A pilot study was thus conducted using two participants (Both Female, Age Mean: 24 Years) before conducting the final user studies.

5.1.1 Findings from Pilot Study

The pilot study resulted in the following significant findings:

- The network and system clock latency adjustments need to be made at the beginning of every game session.
- Negative messages such as *"Discard/Invalidate Round"* upon not moving the hand in-sync with the robot makes the user more nervous and conscious of their movements, making it hard for them to play correctly.
- Users want a trial run of the game before starting the main game to get acclimated to the gameplay.

Consequently, the necessary changes were made to ensure latency adjustment before beginning each game session, removal of the negative feedback from the robot and change it to a more friendlier responses, and allow participants to have a trial run of the game at medium rhythm speed before starting the main game.

5.2 User Study

The final user studies were performed with eight participants (4 Male 4 Female, Age Mean: 23.5 years). All the participants were friends and acquaintances of the experimenters. Participants were required to self assess their rhythm based activities and perception abilities through the post-game survey, the results of which are illustrated in Figure 3.

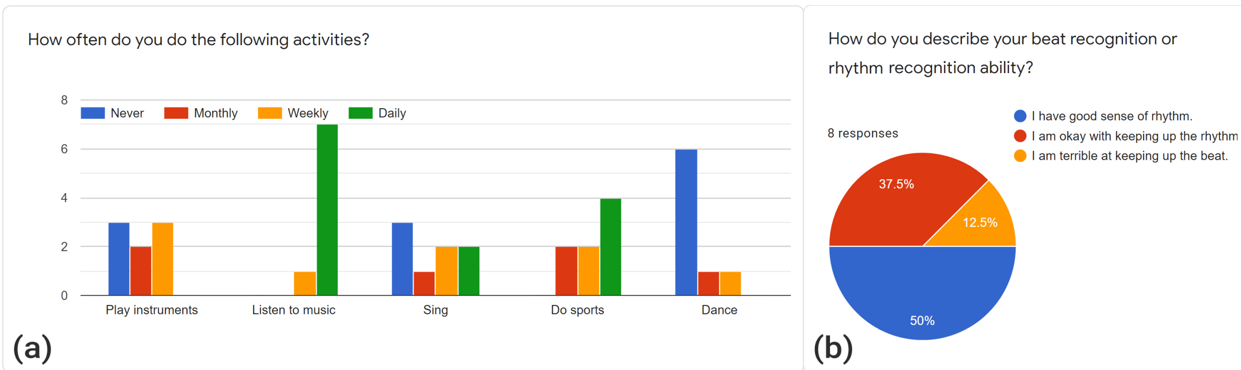

Figure 3: Participant Demography Information. (a) Participant Rhythm-Based Activity Habits, (b) Participant's Assessment of Self Rhythm Perception

6 Results

6.1 System-Level Metrics

We measure two system-level metrics - the accuracies of our gesture recognizer and rhythm estimator. We observed that the accuracy for gesture recognition heavily depends on the user's hand orientation and whether the user's hand is in the camera frame. If the user's hand is properly positioned, then the recognition is very accurate in classifying the user's hand gesture since the recognition is done via ArUco tracking markers. In addition, determining the ground truth of gesture recognition accuracy require us to videotaping the entire interaction and manually label each move, which is unrealistic given the time and resource constraints. Similarly, for rhythm estimation, we do not have any pre-available ground truth and manually estimating it would require us to videotape entire interactions and manually count each frame of data, which is unrealistic given the constraints. Therefore, instead of quantitatively measuring the ground truth accuracy of the gesture recognition and rhythm estimation, we focus on the accuracy perceived by the users through the post-game survey. The results of this qualitative analysis is illustrated in Figure 4.

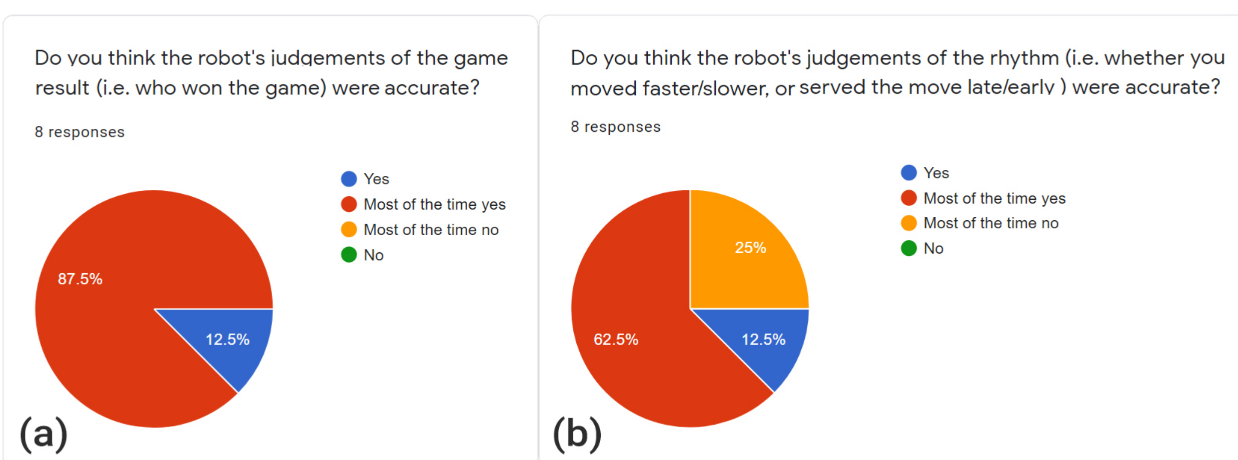

Figure 4: System-Level Metrics. (a) Perceived Gesture Recognition Accuracy, (b) Perceived Rhythm Estimation Accuracy

6.1.1 Gesture Recognition Accuracy

In the survey, we ask our participants to rate how do they think the robot's judgments of the game result (i.e who won the game) were accurate. From the result, 1(12.5%) participants reported that the gesture recognition was very accurate, and 7 out of 8 (87.5%) said that the gesture recognition was correct most of the time.

6.1.2 Rhythm Estimation Accuracy

From the survey response, 1 out of 8 (12.5%) thought that our system's rhythm judgment was very accurate, 5 out of 8 (62.5%) said that the judgment was correct most of the time, and 2 out of 8

(25%) reported that the rhythm judgment was not accurate most of the time.

6.2 Performance-Level Metrics

6.2.1 T-Test for Rhythm Test Score

Using the pre-game rhythm test score and post-game rhythm test score, we conduct one tail paired T-test(H_1 = post-game > pre-game). At significant value $p < 0.05$, the results from the pre-game (M = 769.6, SD = 93.8) and post-game (M = 810.8, SD = 84.9) rhythm test score indicate that after the interaction, users resulted in an improvement in rhythm synchronization test score, p = 0.040. In addition, using cohen's d, the observed effect size d is large, d=0.72.

6.2.2 Correlation of Rhythm Test Score and Valid Round Ratio

We compute the correlation between the user's pre-game rhythm test score and the user's valid round ratio. Results of the Pearson correlation indicated that there is a non-significant medium positive relationship between pre-game rhythm score and valid round ratio, ($r(6) = 0.46$, $p = 0.252$).

6.2.3 User's Qualitative Feedback

Interaction Enjoyment: On a scale from 1(least enjoyment) to 5(most enjoyment), the average interaction enjoyment score is 4.625. The result suggests that our participants have fun throughout the game.

Interaction Smoothness: On a scale from 1(least smooth) to 5(most smooth), the average interaction enjoyment score is 4.25. This indicates that the human and robot interaction was mostly smooth, but certain improvements can be made to improve the smoothness.

User's attention while playing the game Among the choices, 50% participants reported that they pay attention to the result of the game, 50% participants pay attention to their rhythm, 37.5% pay attention to landing time.

7 Discussion

Our system-level metrics suggests that our gesture recognition is able to correctly and robustly distinguish Rock, Paper, and Scissor gestures in real-time. In addition, most participants were satisfied and trust with the rhythm estimation feedback provided by the robot. However, for those that report negatively on the question, one participant pointed out that it might be the case that the differences were too small for the human agent to perceive, while large enough to trigger the invalid condition on the robot.

In our hypothesis one, we hypothesize that people with deficient rhythm perception will have a lower valid round ratio. However, we were unable to recruit participants that have such rhythm deficient, which leaves our hypothesis inconclusive. Given the fact that all of our participants were able to achieve a Rhythm Test Score higher than 600 and no correlation between the Rhythm test score and the valid round ratio was found, one possible explanation of this is the threshold theory[5]. Applying the threshold theory, there might be a minimum threshold of rhythm perception capability that users need to have to succeed in this game, and above that certain level, rhythm perception capability doesn't have much effect on gaming performance.

The paired T-test for pre-game and post-game test score suggests that the Rock Paper Scissor interaction improves the user's rhythm perception, which confirms our second hypothesis. Qualitative feedback suggests that users not only enjoy the game, but they are paying extra attention to their beat and rhythm, which might contribute to the improvement in rhythm perception improvement. However, we acknowledge that the learning effect might contribute to a statistically significant improvement of the test score.

8 Future Work

In future work, we can find participants who have deficient rhythm perception to test our hypothesis one. We should also include more participants, and eliminate the confounding variables to the best of our ability. Secondly, we can improve the accuracy of gesture recognition and rhythm estimation. To do that, we also need to collect the ground-truth value for users' gesture and their movement timing by manually analyzing the interaction.

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