# Improving Visual Focus of Attention of Children with ASD during Prompted Task Execution using NAO Humanoid Robot

by

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# Abstract

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# Chapter 1

# Research Objectives

## 1.1 Overall Goal and Approach

Our overall goal is to increase child with ASD's engagement level during COACH prompting and task execution, and thus improving prompt compliance and task completion rate. Our approach is:

1. to incorporate a half body humanoid robot, NAO T14 (see Figure 1.1) by Aldebaran Robotics, into the current COACH setup, capable of delivering verbal and gesture prompts and attention grabbers.

2. to automatically track the VFOA of child for more effective maintenance of child's attention. For example, by being able to recognize whether child is looking at the robot, the robot can call out child's name with a waving gesture or blink its LEDs for getting child's attention before prompting.

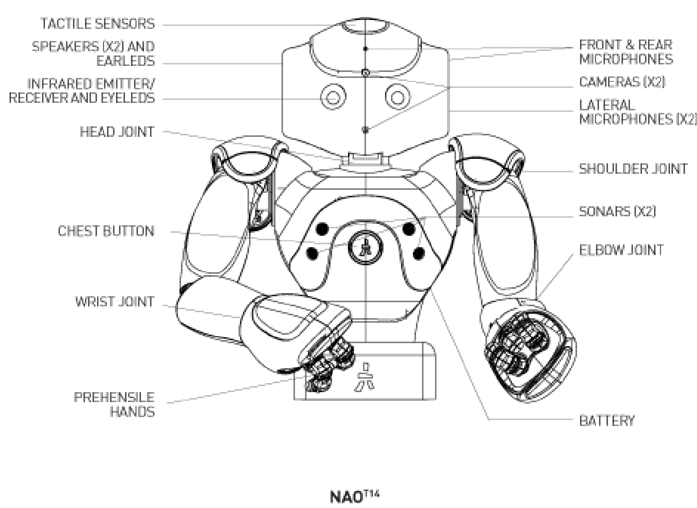



Figure 1.1: The Half-Body Version of Humanoid Robot NAO

## 1.2 Central Hypothesis

We hypothesize that the incorporation of an embodied agent, such as the humanoid NAO, is sufficient in better engaging child and better capturing and maintaining attention during prompting and task execution, and ultimately yields higher prompt compliance and task completion rates when assisting child with ASD through ADLs such as hand washing.

## 1.3 Specific Objectives

**Our objectives are:**

1. To investigate if a prompting system using NAO is able to guide child with ASD through hand-washing.

2. To explore the different modes of interactions between NAO and child when prompting hand-washing steps using a Wizard of Oz setup, focusing on verbal, gestures, and gaze for the modes of interactions

3. To implement a real-time algorithm for tracking child's VFOA

**Our hypotheses are:**

1. The humanoid robot, NAO, is able to independently assist child with ASD through hand-washing, and child exhibits greater engagement level, higher prompt compliance rate, and better task completion when prompted by NAO than by parent.

2. Gestural, gaze, and verbal are the essential modes of interactions present in the hand-washing prompting scenario between child with ASD and the prompting agent NAO.

3. Using 3DMM and ALR for estimating head pose and eye pose, and using the Kinect camera, a classification rate of more than 80% is achieved for estimating child's VFOA on NAO, monitor screen, soap, towel, tap region, hands, and idling.

# Chapter 2

# Wizard of Oz

One major objective of this thesis is to investigate the impacts that using a humanoid prompting agent has on the visual attention, prompt compliance, and task performance of children with ASD during hand-washing activities.

This is the first research of its kind in the field of humanoid robot prompting agent guiding children with ASD through an activity of daily living. Therefore, it is wise to begin with a pilot study, the purpose of which is to show plausibility of the key underlying assumptions of our hypotheses, and to probe what questions are important to be answered later in a more rigorous randomized control trial. For this reason, the pilot study should be exploratory in nature, having a flexible experiment design, and relatively low experiment setup cost.

## 2.1 Wizard of Oz Experiment Design

The Wizard of Oz (WoZ) is an experiment design widely used in Human Computer Interaction (HCI) and Human Robot Interaction (HRI) researches[REF]. In a typical WoZ study, there is an interactive agent that is not yet fully autonomous, and is remotely controlled by a human wizard (operator), and this fact is concealed from the user being tested until after the study. The wizard may control one or many parts of the agent, such as speech recognition and understanding, affect recognition, dialog management, utterance and gesture generation and so on [REF]. The advantage of a WoZ study is that it does not require a large amount of work spent in implementing the artificial intelligence (AI) behind the agent – it is taken care of by the wizard. This is great for testing hypotheses early on in the design loop, enabling us to obtain feedbacks from users, learn, and iterate through design cycles faster. Of course, care needs to be taken to ensure the mocked up part of the AI is implementable in the near future, since the real purpose of the mock up is to have an early knowledge of the real design constraints, not trying to provide a less constrained solution.

The characteristics of a WoZ study fits our pilot study requirements, where we want to learn early the important design questions regarding building an effective ADL prompting robotic agent for the children with ASD population. Therefore, we will conduct a WoZ study, in which a humanoid robot whose motions and speech are preprogrammed, but the decision and timing of their executions are controlled remotely by the researcher. This is mocking up computer vision algorithms that understands the child with ASD's actions, speech recognition algorithms that recognize the child with ASD's verbal interactions, and the AI decision making algorithms that decides what prompts to deliver and when to deliver them.

During each WoZ study trial, the child with ASD will be asked to complete the hand-washing activity in the washroom with the supervision of one of his/her parents, with the help of the NAO robot, or with the help of both the parent and the robot. The researcher, and the parent if the child is to be assisted only by the robot, will be in an adjacent room out of the child's view to observe his/her hand-washing activity. However, the parent may enter the washroom if the child needs physical assistance to complete a step. A controlling interface running on a laptop, connected wireless to the robot, will be used by the researcher to remotely control the robot, as well as to monitor the progress and responses of the child through the video feeds of the cameras installed in the washroom.

## 2.2 Recruitment

Participants will be recruited from a previous autism study who indicated that they would be interested in participating in future studies related to the development of the COACH prompting system.

Participants will be children between the ages of 4 to 15 with a diagnosis of ASD, and their parent. Six children will be recruited. This sample size is typical for studies of this nature for children with ASD. For example, a pilot study by Bimbrahw et al. [REF] and a Wizard of Oz study by Bhargava et al. [REF] both involved a similar sample size of the children with ASD in their studies. Another reason we chose six children for this pilot study is to equally explore the two permutations of experimental conditions (i.e. A-A-B-B-C-C and A-A-C-C-B-B, see Section 2.5.2). Participant demographics will be recorded and will include age, sex, and the Social Responsiveness Scale (SRS) test results. The SRS is a commonly used tool to identify the presence and estimate the severity of ASD [REF]. The results of the SRS will allow the research team to substantiate a diagnosis of an ASD for the child participants before proceeding with the study.

**The inclusion criteria for enrolling in the study are as follows:**

- Boys and girls between the ages of 4-15
- Parent report of a clinical diagnosis of an ASD to be confirmed through administration of the Social Responsiveness Scale (SRS)
- Has difficulty independently completing self-care activities, specifically hand-washing
- Has the ability to follow simple, one-step verbal instructions
- Ethical consent granted by parents or primary guardian
- Does not exhibit severely aggressive behavior

Each participating family will be given a $200 honorarium per child subject upon completion of the study (please see Appendix K Study budget sheet). All participants will be able to withdraw from the study at any time. The honorarium will be adjusted to be proportionate to the number of visits completed (e.g. completing 3 visits means the participated child will receive $100 ($200 * 3 / 6 = $100)). This will be made clear to participants at the time of consent.

## 2.3 Humanoid Robot NAO

We chose the half-torso version of the commercially available humanoid robot NAO from Aldebaran Robotics as our robotic prompting agent. NAO is a humanoid robot about half a meter high in full torso [FIGURE of full torso NAO]. It is designed by Aldebaran Robotics to primarily serve in educations for children and in academia research in robotics. Because of this, NAO is designed to have a very likable appearance – one with baby like facial features. Also, NAO is equipped with the state of the art mechanical, electrical, embedded, control, and local network communication systems. It also has cameras and sonar sensors for computer vision algorithms for scene understanding, path planning, and obstacle avoidance. The software development kit (SDK) provided is very easy and powerful to program with. Also, an even easier graphic user interface (GUI) for robot behavior programming, the Choreographe software, is also available. One caveat of using NAO for SAR HRI researches is that it is only equipped with a single degree of freedom finger dexterity, though other joints in its body are much more mobile. It is more than enough for doing simple pointing and other non-contact gestural prompts in sync with verbal interactions. It just cannot perform detailed hand gesturing. This makes NAO less capable in demonstrating a hand-washing step in high detail.

From a HRI research perspective, Aldebaran Robotics took care of designing the intrinsics level of HRI, where NAO has a likable appearance and child like neutral gender voice, although it's incapable of facial expressions. The design decisions we face when using NAO for this thesis is on the behavior level of HRI. Design decisions such as voice intonation choice, verbal prompts, motion gestures and gaze, and eye blinks using LEDs in eye regions are made in this thesis. The objective of this thesis is then to ultimately find out if the lower two levels of design decisions made are able to cumulate to the child with ASD perceiving NAO as a role model / supervisor / assistant during hand-washing.

For our pilot study, we use the half-torso version of NAO because we do not require any mobility from NAO – it is fixed on the sink table top [FIGURE]. The relevant functionalities of NAO we will utilize for delivering prompts include:

- Verbal prompting through its bilateral loud speakers on the head and speech synthesis functionality
- Body gesturing through its moving head and arms (although its fingers are not capable of hand gesturing)
- Flashing LEDs on the eyes and ears

### 2.3.1 Verbal Prompts

We used the text-to-speech engine from NAO to synthesize the verbal prompts. The pitch of NAO's voice is changed to a lower one than default for the verbal prompts to give a more authoritative feeling. The reward verbal prompt remains the default pitch, though, to give an exciting praise. The verbal prompts are worded as short, three or four word phrases, such as "turn on the water" or "rinse your hand", and a pause is put between the action and the subject so that the prompts sound clearer and is easier to understand to children with ASD.

### 2.3.2 Gesture Prompts

There are several kinds of gesture prompts NAO needs to perform:

- **Attention grabber (AG)**: When prompting is needed but child is not looking at NAO, NAO waves at child to grab the childs attention.
- **Motion demonstrating prompt (MoDemo)**: NAO demonstrates to child the motion of interaction (e.g. turning tap, scrubbing, rinsing, etc.).
- **Object pointing prompt (ObjPt)**: NAO points to the physical object of interaction.
- **Reward (REW)**: After a task is successfully completed, NAO flashes LEDs as a positive reinforcement.

The gaze behaviour of NAO during gesture prompts is also important and is grouped as: looking at child (when delivering AG, MoDemo, REW), and looking at object (AR, ObjPt). The gesture and gaze motions can be programmed using NAO's software, Choregraphe.

### 2.3.3 Wizard of Oz Remote Control

The WoZ experiment setup involves controlling the robot remotely behind the scene by a human operator, the wizard. A touch screen laptop will be used as the user interface for the operator, and the behaviors of the robot are presented as buttons on the screen, with the camera views displayed along side. Keyboard accelerators are also implemented for faster access to robot actions.

## 2.4 Surveys

entrance survey, SRS, post intervention survey for parent, for child, exit survey

## 2.5 Protocol and Setup

### 2.5.1 Entrance Survey and SRS

Prior to their first HomeLab visit, the parent will be asked to complete the Social Responsiveness Scale (SRS) [REFsection]. If the child meets the SRS score (minimum of 76 T-score), the same parent will then be asked to complete the entrance survey before their first visit of the HomeLab. This is to capture the childs demographics, his/her hand-washing ability level and to gather information to help the research team configure the system to the childs preferences [REFsection]. The same parent who has completed the entrance survey should accompany the child through all the HomeLab visits.

### 2.5.2 Protocol Overview

Each child will visit the HomeLab on the 12th floor of Toronto Rehab Hospital once a week with a total of six visits with his/her parent. The six visits will be evenly divided into three phases. The three phases are the baseline phase (Phase A) and the intervention phases (Phase B and Phase C). In Phase A, the child will be asked to wash hands by him/herself as independently as possible. The parent will be instructed to provide assistance to the child when the parent sees necessary (as outlined below). In Phase B, the child will be assisted by both the robot NAO and the parent during hand-washing. The parent remains in the washroom and assists NAO in its prompts. In Phase C, the child will be assisted by NAO alone. The parent is out of view in the room adjacent to the washroom, and comes into the washroom to prompt when the parent sees necessary.

It will take about an hour to an hour and a half for each visit. The child will be asked to wash his/her hands eight times for every visit, for a total of forty-eight trials per child. The child and his/her parent may take short breaks after each hand-washing trials. The break may last as long as the child needs until he/she is willing to continue the trial. If the parent feels the need, they may leave and come back to finish the rest of the day's trials another day. They will not be withdrawn from the study unless requested.

The participating subjects will be randomly assigned one of the two phase orders (i.e. the phase conditions listed in the order of the six visits): A-A-B-B-C-C and A-A-C-C-B-B. This will reduce the confounding effect of learning when we compare between phase B and C.

### 2.5.3 Experiment Setup

-todo

### 2.5.4 Specific Protocol

The hand-washing activity will be broken down into seven tasks: turn on the water, wet your hands, get some soap, scrub your hands, rinse your hands, turn off the water, and dry your hands. These tasks are modified based on Bimbrahw et al. pilot study [REF]. These constitute the same tasks as Bimbrahws except that the first (i.e. turn on the water and wet your hands) and the last task (i.e. turn off the water and dry your hands) are now four individual tasks to ensure that each task only involves one action.

**Phase A (Baseline Phase)** The first two visits will be the baseline phase and will include sixteen trials of hand washing with eight trials for each visit. The child will be asked to complete the hand-washing as independently as possible. During this phase, the parent will be present in the washroom while the child is completing the hand-washing tasks. The parent will verbally and/or physically assist and give positive reinforcements to the child whenever the parent feels necessary.

**Phases B and C (Intervention Phases)** The rest of the four visits will be the intervention phases and will include thirty-two trials of hand washing with eight trials for each visit. The child will be asked to wash his/her hands with the help of NAO or of both NAO and the parent in the washroom. During each trial, NAO and the parent will wait for the child to start each task. If the child has trouble, an appropriate prompt will be delivered from NAO in order to help the child complete the task. If the child does not respond to NAO's prompt, an attention grabber will be delivered to capture the childs attention from the prompting agent. The attention grabber may be repeated for the second time to the child if he/she fails to respond to it. A verbal reward will be delivered to the child once he/she completes the task.

The parent's role in phase B and C differ in that, in phase B, the parent takes a more active role to prompt the child of what to do by standing next to the child. On the other hand, in phase C, the parent takes more of a back seat role, being out of view and coming in to prompt only for the purpose of reminding the child to listen to the robot, but leaves the specific step to be prompted by the robot. Of course, if the child doesn't respond to any of the prompts, the parent will need to physically intervene and complete the task together, just like in phase A. After the physical intervention, the parent will then instruct and encourage the child to continue the rest of the hand-washing tasks on his/her own by following the robot.

There are three prompt categories that the NAO robot will deliver when interacting with the child (please see [TABLE] for the specifics of each prompt used):

1. **Task Prompt** (to prompt the child through a hand-washing task):

   A verbal prompt will be delivered, such as Please [task name] (e.g. Please turn on the water.). Synchronous to the verbal, a visual prompt will also be delivered. This is a two-part gesture prompt of: first, demonstrating the motion of interaction while looking at the child (MoDemo); second, pointing to the sink object (e.g. the tap) while looking at the object (ObjPt). A maximum of two prompts will be given to the child. If the child does not respond to the second prompt or has started the task but does not complete the task within the task execution timeout, the parent will be asked to help the child complete the task.

2. **Attention Grabber** (to catch the childs attention to the NAO robot or the avatar):

   A verbal prompt will be delivered, such as Hi, [childs name]! Synchronous to the verbal, a visual prompt will also be delivered. This is an attention grabbing gesture of waving and looking at the child (AG). A maximum of two attention grabbers will be given to the child in order to get his/her attention to look at the robot/avatar. The parent will be asked to instruct the child to look at the robot/avatar if he/she does not respond to the second attention grabber.

3. **Reward** (to provide positive reinforcement when the child attempts a task without the help from his/her parent):

   A verbal reward (i.e. Great!) will be delivered while looking at the child and switching back and forth the colors of the light-emitting diodes (LEDs) on the eyes after successfully performing a task (REW).

For each trial, in addition to the three prompt categories stated above, the NAO robot will also deliver a short introduction before the start of each trial, a re-intro after the parent finished assisting the child through a task, and an outro at the end of each trial. The introduction is a two-part prompt. The first part is an attention grabber. The second part consists of a verbal prompt (i.e. Lets start washing hands.) with a simple conversational gesture. The re-intro is a verbal prompt (i.e. Lets continue washing hands.) with a simple conversational gesture. Same as the introduction, the outro is a two-part prompt. The first part consists of a verbal prompt (i.e. Good job, [childs name]!) with a gesture of fist pumping in the air. The second part consists of a verbal prompt (i.e. You are all done.) with a gesture signifying all the hand-washing tasks have been done.

### 2.5.5 Post-intervention Survey and Exit Survey

During the last visit, the same parent who has completed the entrance survey will be asked to fill out the post-intervention survey and the exit survey [REFsection], which will allow him/her to provide the research team with his/her feedback regarding the device. A variation of the post-intervention survey will be verbally administered by the researcher to the child participant to capture his or her views of the system [REFsection]. This information will be used by the research team to better understand which aspects of the system are effective, which are not, and how, if in any way, the system should be changed.

### 2.5.6 Data Collection

All phases will be video recorded by the overhead, the scene, and the Kinect cameras and will be audio recorded by the microphone from the scene camera. The overhead and scene video data will be reviewed and annotated by two annotators. The inter-rater reliability will be calculated using Cohens Kappa [14]. The overhead video data will be used to score the participants prompt compliance and hand-washing performance. The scene video data will be used to evaluate the participants engagement during the whole activity. The effect of embodiment on engagement, compliance, and performance will then be explored qualitatively and quantitatively.

The Kinect video data will not be annotated. Instead, it will be used to evaluate the automatic gaze estimation algorithm that we developed. Specifically, the Kinect video data will be used by the gaze estimation algorithm as input and the output predictions will be compared with annotations of the scene video data to derive the algorithms prediction accuracy.

### 2.5.7 Ethics

The WoZ is approved by the Research Ethics Board (REB) of University Health Network (UHN), belonging to which is the Toronto Rehab Hospital, where the study is conducted.

**Consent and Assent** Participants will be given a package of consent/assent forms prior to starting the study [REFsection]. One of the parents will need to provide their consent for their child and themselves to participate in the study. In addition, child participants will need to provide their assent to participate in their every visit of the study.

Interested families will receive an information/consent package (please see Appendices F to H) prior to starting of the study. This package includes consent/assent forms for participation in the study for the parent and child with ASD (these forms include study details and research contact information) as well as consent to be videotaped for the parent and child with ASD. Consent from the parent and assent from the child with ASD will be given if and when they feel comfortable that they understand the information presented. Potential participants of both parents and children will have up to a week to decide if they would like to participate, although they may consent to participate as soon as they feel comfortable doing so. Parents will need to provide their consent for their children (please see Appendix F) and themselves [REFsection] to participate in the study. In addition, child participants will need to provide their assent in their every visit of the HomeLab during the study (please see Appendix H) to participate. Parents will be required to consent to having their children and themselves videotaped during the study. The parents will be informed that they and their children may withdraw from the study at any time without penalty.

**Confidentiality** Each participating family (parent and child with ASD pair) will be assigned a code number when they sign the consent/assent. All data in the study will be labelled with these code numbers only - the names of the participants will appear only on the information and consent/assent forms and will be kept confidential. Consent forms will be placed in a secure and locked area in the PIs laboratory, with access exclusively restricted to the research team. All forms will be destroyed seven years after the study publication.

The information and data collected will remain strictly confidential and will not affect any of the participants (both the parent and the child) employment, care, or treatment in any way. A code number will be assigned to each parent and child participant when they give consent. This code number, instead of their name, will be used for all data collection and analysis. Direct quotes may be included in the final research paper but names will not be used in any report or publication. Privacy of participants (both the parents and the children) will be ensured by omitting all participant information from participant data, by employing data encryption, and by storing data on a secure server. If and only if participants consent, participants (both the parents and the children) video data may be presented for educational purposes. If any images or videos are used in presentations and publications, faces and other identifiable features will be masked.

Both the video and audio data will be stored temporarily on the touchscreen laptops hard drive during each childs visit. The data will be encrypted and transferred to the TRI servers as soon as after each childs visit. The portable devices, such as USB sticks, will be used to transfer the data to the TRI servers. All files stored in the portable devices will be password protected and encrypted. The data on the laptops hard drive and the portable devices will then be purged immediately after transfer.

**Data Storage** All soft (electronic) data will be encrypted before any transfer is made. All data will be password protected and be stored on the TRI servers with access restricted to the research team. The laptop used for the study will be password protected so that only the research team has the access to it. All computerized data will be password protected. All survey data will be stored in a locked cabinet different from where the consent forms are stored. Access to all the data will be restricted only to the supervisor and researchers involved in the project.

After the study is completed and the results of the study are published, data will be stored for at least seven years from study closure. All data will be destroyed seven years after the study closure. Data contained on paper material will be destroyed by shredding the material. Data contained on electronic media will be destroyed by erasing or other removing the data in such a way that it cannot be retrieved.

## 2.6 Measures

### 2.6.1 Video Data Measures

To evaluate the effectiveness of the robot prompts, to measure the child's compliance to the prompts, and to investigate their relationships with the child's engagement level during hand-washing, the following metrics are calculated and analyzed from the video data annotations:

#### Prompt Effectiveness

- Total Number of Incomplete Tasks
- Total Number of Parent Prompts

#### Responses to Prompts

- Compliance Rate
- Not Affected By Prompt Rate

**Engagement and Visual Attention**

- Total Number of Times Child Smiles
- Total Number of Times Child Murmurs
- Looking at Prompting Agent Rate

The specific definitions for each measure will be discussed further in the analysis section 2.8.3.

## 2.7 Video Annotations

In order to calculate the final measures outlined above, intermediate measures need to be extracted from the video data. This is the process of video annotation.

### 2.7.1 Annotation Framework

Only the scene camera videos will be annotated, since this view alone suffices in informing both the progress of the child in hand-washing steps and the child's response to prompts.

Each video file usually contains one hand-washing trial, sometimes two. The annotator needs to scroll through each video until the scene of the child entering the washroom, marking it as the start of a trial. The child leaving the washroom marks the end of a trial.

A trial contains many hand-washing steps, and for each step, the parent and/or the robot may give several prompts. For consistency and convenience, the annotator divides the video into segments we call "prompt sections", and describe each prompt section using a 3-part scheme. The first part describes the child's actions before any prompts, the second describes the prompting agent's prompts, and the third describes the child's actions after the prompts. The intermediate measures to be annotated in each part of the prompt section are shown in Table 2.1.

| Intermediate Measure | Type | Description |
|---|---|---|
| Step | Nominal | Prompting step, 0 no step, 1 intro, 2 turn on water, 3 get soap, 4 scrub hands, 5 rinse hands, 6 turn off water, 7 dry hands, 8 all done, 9 wet hands |
| **Child's Action Before Prompts** | | |
| Time Start | Ordinal | Time stamp for start of prompting section |
| Time Stop | Ordinal | Time stamp for end of prompting section |
| Attempted Step Before Prompt | Nominal | |
| Attempted Step Successfully Executed Before Prompt | Ordinal | 0 incomplete, 1 complete but low quality, 2 complete with high quality |
| **Prompting Agent's Prompts** | | |
| P Verbal | Ordinal | Parent verbal prompt, 0 no verbal prompts, 1 prompt for compliance to robot, 2 prompt for step |
| P Gesture | Ordinal | Parent gestural prompt, 0 no gesture prompts, 1 quick point, 2 sustained point, 3 motion demonstration, 4 motion demonstration and point, 5 nudge, 6 guide arm, 7 do step fully |
| P Reward | Boolean | Does parent give reward |
| R Verbal | Ordinal | Robot verbal prompt, same coding as P Verbal |
| R Gesture | Ordinal | Robot gestural prompt, same coding as P Gesture |
| R Attention Grabber | Boolean | Does robot give attention grabber |
| R Reward | Boolean | Does robot give reward |
| **Child's Action after Prompts** | | |
| C Looks At P/R | Nominal | Child looks at the prompting agent, 0 no looks, 1 looks at parent, 2 looks at robot, 3 looks at both |
| C Smiles | Boolean | Does child smile |
| C Murmurs | Boolean | Does child make a verbal sound |
| Attempted Step After Prompt | Nominal | |
| Attempted Step Successfully Executed After Prompt | Ordinal | Same coding as Attempted Step Successfully Executed Before Prompt |
| Attempted Step Is Correct Although Different From Prompt | Boolean | Is this one of those times that the prompts are wrong or ambiguous and child's actions make sense despite different |
| Number of Prompts Till C Executes Correct Step - Parent | Cardinal | Count number of prompts as any distinct actions performed by the parent before child executes the correct step. |
| Number of Prompts Till C Executes Correct Step - Robot | Cardinal | Same as above, but counting robot prompts |

Table 2.1: The intermediate measures annotated from the videa data

A hand-washing step could have multiple prompt sections. Take for example the following scenario: The child executes the wrong step before prompts, so the parent prompts the correct step, but the child ignores the prompt and continues the wrong step. This constitutes one prompt section. Then the parent prompts again, and the child finally follows the prompt and executes the correct step. This constitutes then another prompt section. For this example, because the parent prompts a second time without waiting for the child to stop his/her current action, the second prompt section should have a blank for the Child's Action Before Prompts.

A hand-washing step could also have multiple prompt sections because of the step's nature. For the "extended steps" (i.e. scrubbing, wetting, rinsing, and drying), even when the child is executing the correct step, the prompting agent may deliver more prompts to encourage the child to keep doing the same step for an extended period of time. This is in contrast to the non-extended steps (e.g. turning on the water), where a single action from the child marks the completion of that step. An example of an extended step with multiple prompt sections is: The child starts rinsing before prompt, then the parent tells the child to keep rinsing. The child continues to rinse. The parent says again "keep rinsing", and the child rinses more and then decides to stop. This constitutes one prompt section. Then, the parent prompts to rinse more again. The child follows. After a while, the parent decides this is enough and prompts for the next step. This marks the end of the second prompt section. For the first prompt section, it contains two prompts from the parent. This is intentional, for the purpose of convenience – we group any consecutive prompts (can be from either the parent, the robot, or from both) resulting in the same actions from the child as one prompt section. This grouping does not affect any of our measures for Prompt Effectiveness or Responses to Prompts, since those measures count the number of tasks or prompts, not prompt sections. However, this grouping does affect the measures in Engagement and Visual Attention, since these measures count the number of prompt sections instead.

### 2.7.2 Annotation Tools

The videos are played back by the software Media Player Classic - Home Cinema (MPC-HC 64-bit v1.7.8), where timestamps of millisecond resolution can be obtained. The annotations are recorded onto Microsoft Office Excel spreadsheets, and each sheet exported to CSV files to be analyzed.

### 2.7.3 Annotators and Inter-rater Agreement

- number of annotators - percentage of overlap - inter-rater agreement calculation (method, what's good enough)

## 2.8 Data Analysis and Results

### 2.8.1 Participants Recruited

Due to limitation of time, we were only able to recruit one subject. - report subject demographics: age, gender, ethnicity, hand-washing ability, other inclusion criteria fit, SRS score. General impression (verbal?, communicative?, interactions with parents, behavior trend)

### 2.8.2 Experiment Design Change

Because we only recruited one participant, we decided to go with the phase order A-A-C-C-B-B so that phase C (robot alone prompts) can be compared against both A (parent alone prompts) and B (robot and parent prompts).

At the third visit, however, after performing eight trials of phase C, we learned that the child responded very poorly to the robot. One reason was that the child did not follow the order of steps prompted by the robot. This meant the robot needed to change the order of steps being prompted on the fly quickly. However, due to the way its remote control was programmed, the researcher cannot change prompts quickly enough, resulting in the child growing impatient and ignored the robot prompts altogether. Another reason might be that the child did not know how to cooperate with the robot (i.e. did not understand that the robot was there to help, and one must wait for the robot to prompt and follow its instructions). Because of these two reasons, we implemented the following design changes:

First of all, the robot remote control scheme was changed from being inflexible in step order into one that the researcher can select the current prompting step on the fly. Also, instead of implementing a timer, and automatically issuing the prompt after a predefined seconds of waiting, the timing of prompt delivery is now decided by the researcher on the fly. This makes the robot behavior much more flexible and relevant for the child. We call the intervention phase using the new robot control scheme Phase C', repeating Phase C with a slight change.

Secondly, we decided to put most of the trials of Phase C' last, and put trials with parent and robot joint prompting in the middle. This way, the trials with parent and robot joint prompting can serve as a modeling phase for the child to learn what is the correct behavior expected when being prompted by the robot. We had some Phase C' trials interspersed during the modeling phase in an attempt to monitor child's progress. The interspersed trials themselves did not turn out to show much of a trend, thus during analysis, we decided to lump them together with the rest of the Phase C' trials.

The modeling phase had in fact three conditions. The first condition was the parent prompting the hand-washing steps, in competition with the robot. The common prompts used were verbal prompts for the step, pointing to the object needing interaction and demonstrating the motion of interaction in the air. The second condition was the parent prompting to follow the robot, complementary to the robot prompts. The common prompts were similar to those of the first condition except there was no verbal prompting of the step. Instead, the parent relied on the robot to prompt the step, and pointed to robot during prompts and verbally prompting to follow the robot. The third condition was the parent standing right behind the child, as opposed to beside the child in the previous two conditions. And the parent prompts the child to follow the robot by physically guiding the child's arm to execute the correct step after robot prompts. The first condition was scrapped after one trial, since we felt this condition doesn't serve the theme of the modeling phase – prompting the child to follow the robot. The other two conditions were left to the parent to decide in terms of the order and number of trials for each condition, so the parent had to assess whether the child would benefit more from a physical intervention or from a less intrusive one.

So the study roughly follows the phase order A-A-C-M-C', M being the modeling phase. The exact order and number of trials for the above mentioned phases are shown in Figure 2.1. Phase A is P Alone (16 trials), Phase C is R Alone (6 trials), Phase C' is R Alone Rep (11 trials), the modeling phase is constituted of R + P Step (1 trial), R + P Compliance (10 trials), and R + P Behind (6 trials).

Despite the experiment design changes, our hypotheses raised were still valid for testing under the

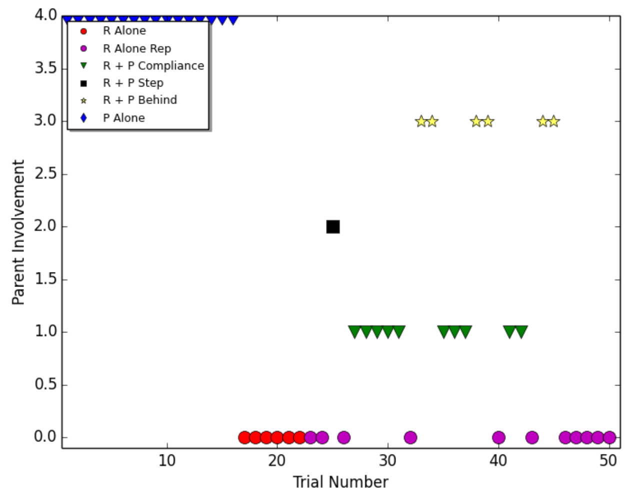



Figure 2.1: Hand-washing Trials Categorized by Phase Types

new design. The specific protocols for each phase still remained the same, and the experiment setup and data collection procedures remained unchanged. Because we only recruited one participant, instead of a comparison study with an adequate sample size, our analysis and discussion will be in more of a case study format and an exploratory nature.

### 2.8.3 Video Data Analysis and Results

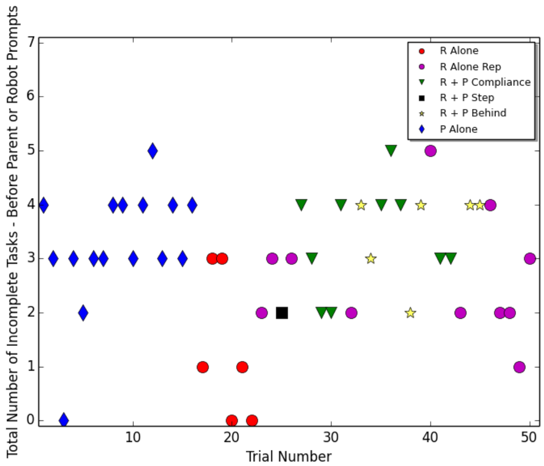
#### Analysis Method

#### Prompt Effectiveness

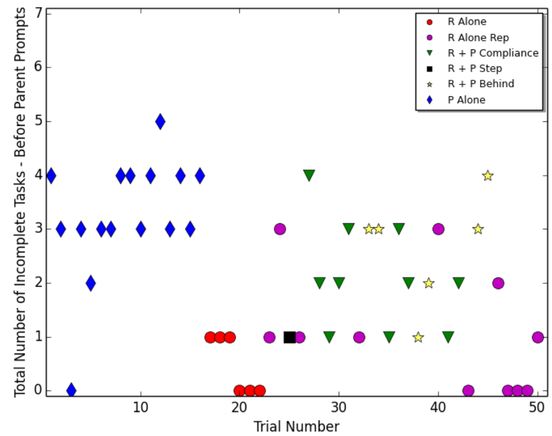
To reflect how effective our prompting system is, we show whether the system can reduce both the number of incomplete tasks and the number of parent prompts.

**Number of Incomplete Tasks** We assumed that prompts can be ordered by their level of authority over the child, with robot prompts the lowest level of authority, followed by parent non-physical prompts (e.g. verbal prompts and gestures such as pointing and motion demonstrations), and lastly parent physical prompts (e.g. nudging, guiding the arm, and completely executing the step for the child). Figure 2.2 shows a series of plots for the measure "Total Number of Incomplete Tasks", differing in the prompt levels threshold used to produce the figure. The prompt levels threshold defines what tasks were counted as incomplete when plotting the figures, e.g. Plot 2.2a ("before parent and robot prompts") counts any tasks that were prompted by either robot or parent as incomplete. These four plots show a progression of allowing more and more tasks to count as complete by removing lower prompt levels from the threshold. For example, the next Plot 2.2b ("before parent prompts"), allows tasks prompted by the robot to also count towards completed tasks, and Plot 2.2c ("before parent physical prompts") allows tasks prompted by parent's non-physical prompts to also count towards completed tasks, and lastly, Plot 2.2d ("overall") counts every completed tasks even if they were prompted by parent's physical prompts.

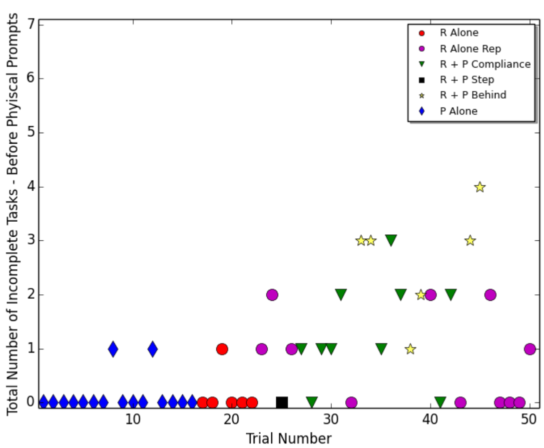
By comparing the plots from one to the next, the effects of each newly added prompt level is apparent. The most important comparison is between Plot 2.2a ("before parent and robot prompts") and Plot 2.2b ("before parent prompts"), demonstrating the effectiveness of the robot's presence. We see that P Alone phase was unaffected since robot wasn't present, but introducing the robot in the rest of the phases show effectiveness: R alone from 1.5 to 0.5, R + P Compliance from 3 to 2, R + P Behind from 3.5 to 2.5, and R Alone Rep from 2.5 to 1. Also, a more subtle observation is – by comparing the effect of the robot in R Alone Phase versus R Alone Rep Phase, we see R Alone Rep is more affected, suggesting



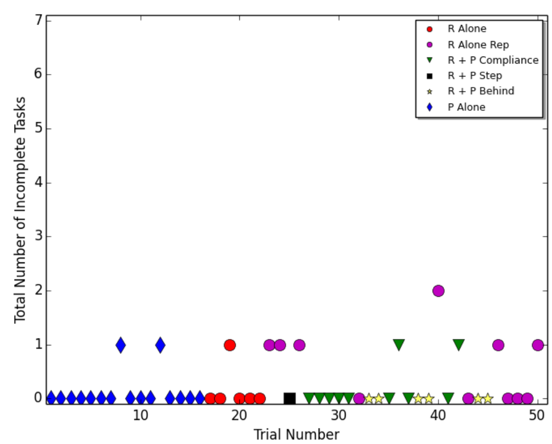

(a) Total Number of Incomplete Tasks - Before Parent or Robot Prompts




(b) Total Number of Incomplete Tasks - Before Parent Prompts



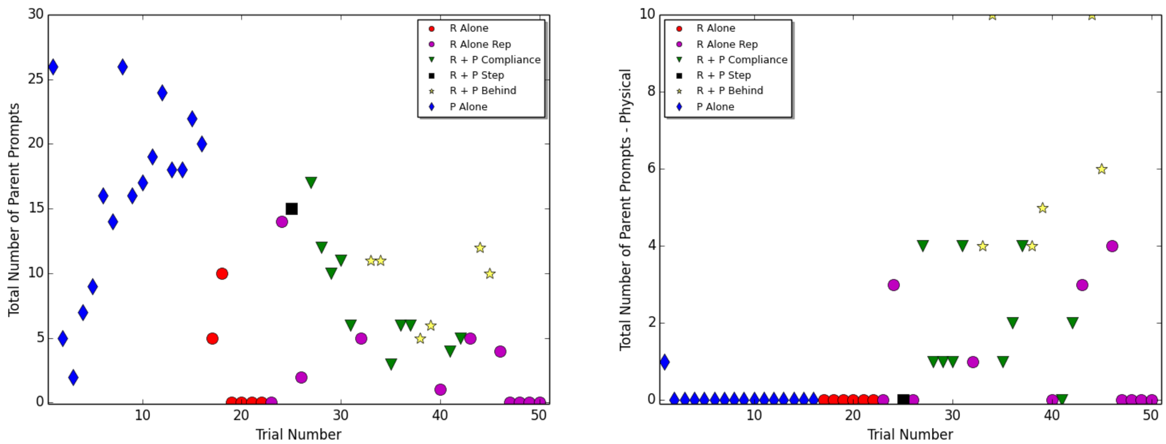

(c) Total Number of Incomplete Tasks - Before Parent Phyiscal Prompts




(d) Total Number of Incomplete Tasks - Overall

Figure 2.2: Total Number of Incomplete Tasks

**Number of Parent Prompts** The measure "Total Number of Parent Prompts" is plotted in Figure 2.3. Plot 2.3a is for the overall count (i.e. counting both physical and non-physical prompts). It shows that during P Alone phase, the measure has an average around 13 and a upward trend from 5 moving to 20. However, in R Alone and R Alone Rep phases, the levels are both at 2. In R + P Compliance phase, it averages around 10, with a downward trend from 15 moving to and settling at 5. In R + P Behind phase, the level is at 10. Comparing P Alone with the rest of the phases, we see that the robot's presence were effective in reducing the number of parent prompts, especially in R Alone and R Alone Rep phases. Plot 2.3b is for the physical prompt count. This plot shows when the parent resorts to a higher prompt level (e.g. nudging, guiding, and physically intervene) in order to get the child's compliance. We see that the level is mainly near zero for all phases except R + P Compliance (at 2.5) and R + P Behind (at 7). This means for these two phases, the previously observed small number of overall parent prompts was mainly due to a reduction in non-physical prompts, not physical.




(a) Total Number of Parent Prompts - Overall

(b) Total Number of Parent Prompts - Physical

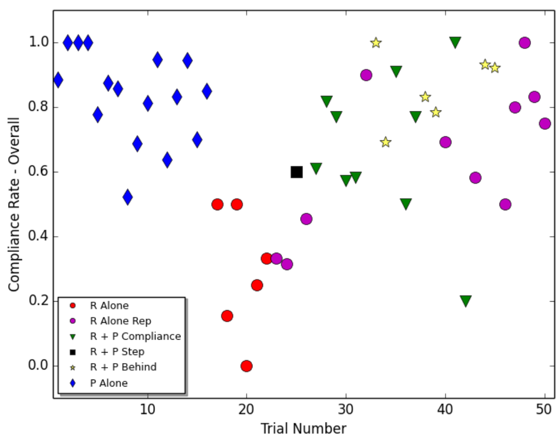
Figure 2.3: Total Number of Parent Prompts

### Child's Response to Prompts

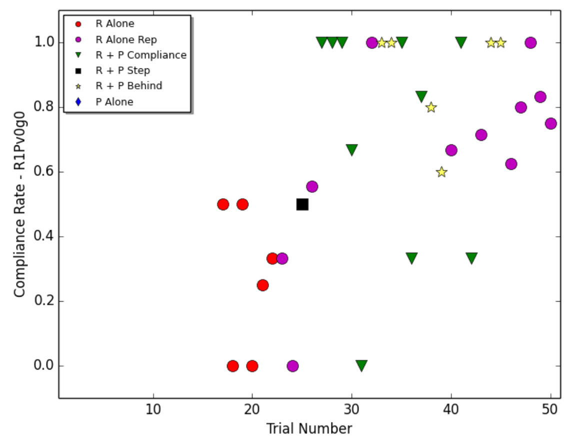
To illustrate the child's different responses to the prompts, we characterized child's responses into three categories: "compliance", "not affected by prompt', and others.

**Compliance Rate** A response is counted towards "compliance" if the child executes the correct step in response to the prompt. If the child was executing the wrong step before prompt, and is converted into doing the correct step due to prompt, we call this hard compliance. The compliance and hard compliance response rates are shown in Figure 2.4.

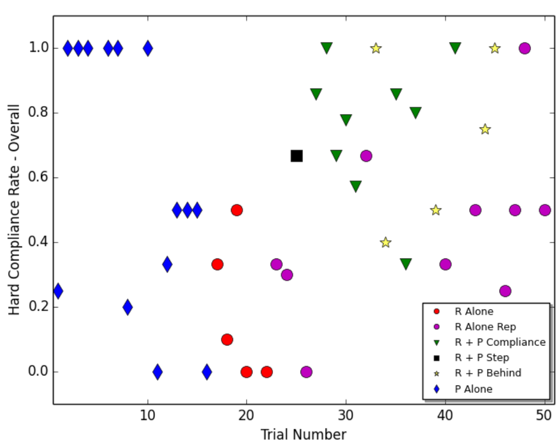
Plot 2.4a shows the overall compliance rate, with all phases leveling at 80% except R Alone phase leveling at 25% and R Alone Rep at 70%. We see that when the robot was first introduced in R Alone phase, the child did not comply to the prompts. However, by going through phases where the parent prompts for child's compliance to the robot, the child complies more readily in the R Alone Rep phase. We need to note that this plot includes prompts delivered by the robot, by the parent, and by them together. Even in R Alone and Rep phases, the parent still comes into the washroom and prompts when the child isn't complying to the robot. To see whether the robot alone can potentially guide the child through the whole hand-washing activity with minimal parent involvement, we plotted the compliance rate counted over only prompts delivered by the robot, shown in Plot 2.4b. This plot confirms the levels observed in the overall plot, validating the improvement of compliance rate seen in R Alone Rep phase. To investigate to what extent is the child compliant, the overall hard compliance rate is shown in Plot 2.4c, with P Alone phase split leveling at 100% and 30%, R Alone leveling at 20%, R + P Compliance and R + P Behind both leveling at 70%, and R Alone Rep leveling at 40%. This shows that joint prompting from parent and robot together is better able to change the child's mind than single agent prompting once the child starts a step. Looking at the robot prompts only Plot 2.4d, the R Alone level drops to almost 0%, while R Alone Rep maintains at 40%. The hard compliance rate overall and robot only both further confirm the improvement in compliance seen in R Alone Rep over R Alone phase.



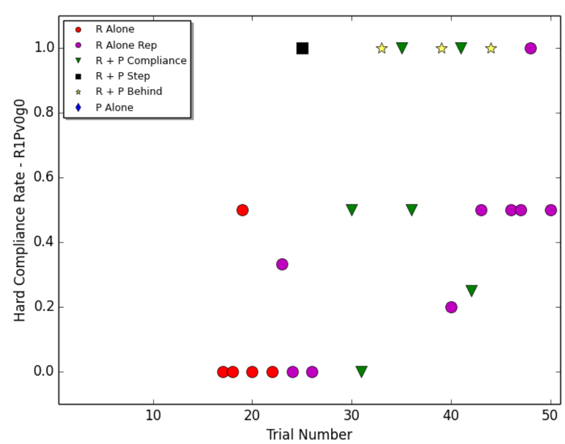

(a) Compliance Rate - Overall




(b) Compliance Rate - Robot Only Prompts




(c) Hard Compliance Rate - Overall




(d) Hard Compliance Rate - Robot Only Prompts

Figure 2.4: Compliance Rate

**Not Affected By Prompt Rate** A response is counted towards "not affected by prompt" if the child was executing a wrong step and did not change after the prompt or was idling and did not change after the prompt. The not affected by prompt rate is shown in Plot 2.5. We see that for most phases, it levels at 15%, but for R Alone phase it's particularly high at 30%, and for R + P Behind it's particularly low at 5%.

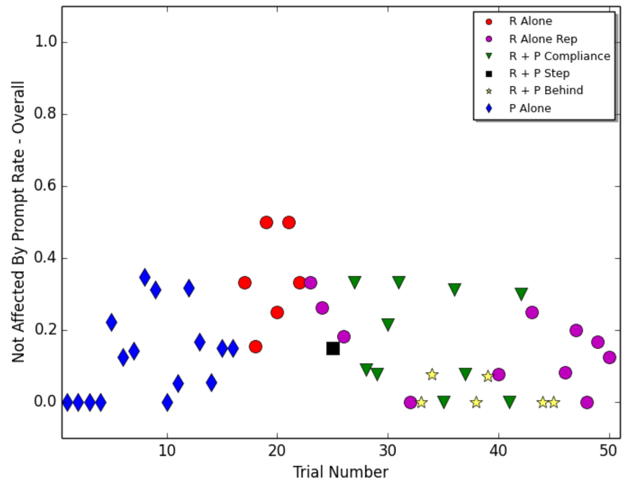



Figure 2.5: Not Affected By Prompt Rate

### Engagement and Visual Attention

To further characterize child's response to different prompting phases, we investigate how many times the child smiles and murmurs during task execution, and how often the child looks at the prompting agent during prompting and task execution.

**Number of Times Child Smiles** The measure "Total Number of Times Child Smiles" is shown in Plot 2.6. In it, P Alone phase levels at 2, R Alone and R + P Compliance both level at 1, R + P Behind and R Alone Rep both level at 4. It shows that the child smiles much more in later phases compared to earlier phases, and particularly, smiles more in R Alone Rep compared to R Alone.

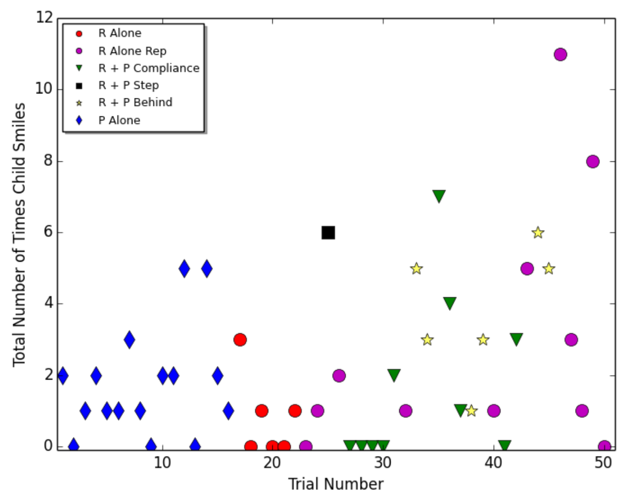



Figure 2.6: Total Number of Times Child Smiles

**Number of Times Child Murmurs** The measure "Total Number of Times Child Murmurs" is shown in Plot 2.7. In it, P Alone phase averages around 3 with upward trend starting at 1 moving to 3, R Alone levels at 0.5, R + P Compliance averages around 4 with downward trend starting at 5 moving to 2, R + P Behind levels at 3, and R Alone Rep levels at 1.5. It shows that the child murmurs much more often when the parent is present. Also, child murmurs more in R Alone Rep than in R Alone.

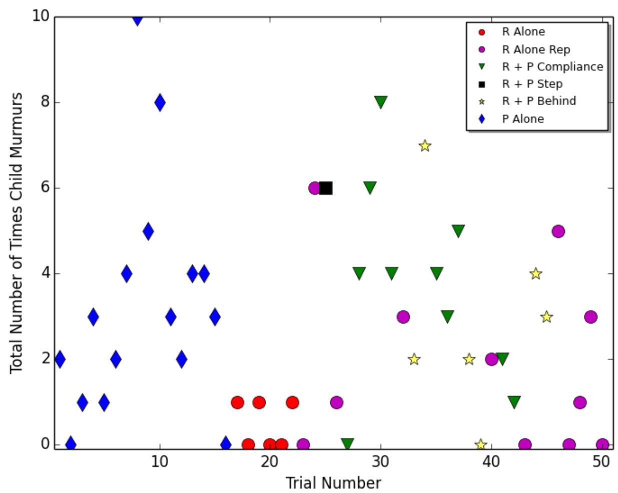
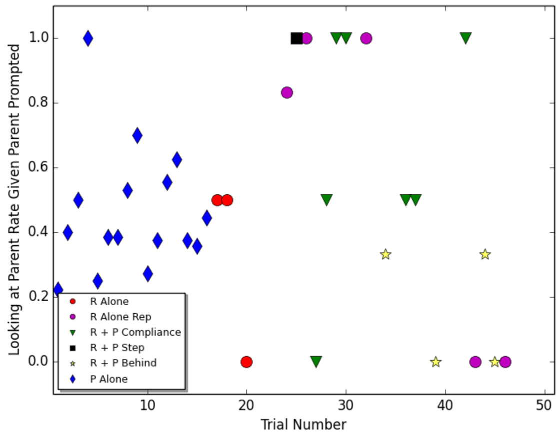
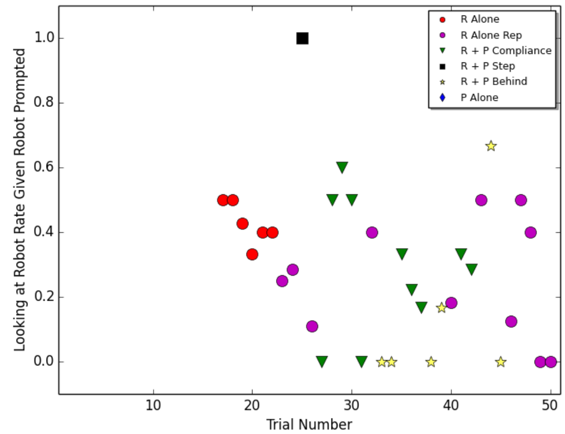



Figure 2.7: Total Number of Times Child Murmurs

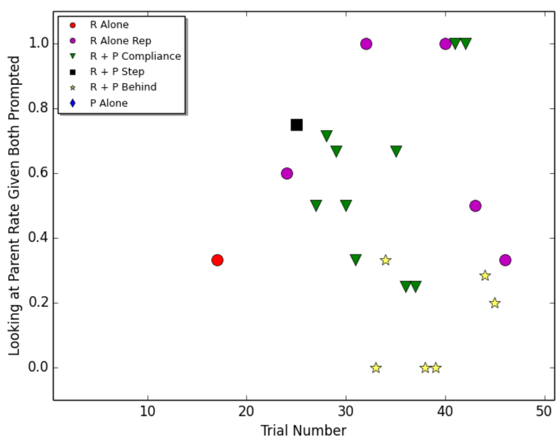
**Looking at Prompting Agent Rate** A prompt can be given by the parent, by the robot, or by them together. During prompting and during task execution, the child may turn and look at the parent and/or the robot. The gaze behavior of the child is shown in Figure 2.8 for all the cases above. Because not all cases have the same amount of data in all phases, we will only mention here the phases that have enough evidence. In Plot 2.8a, "Looking at Parent Rate - Given Parent Prompted" levels at 40% in P Alone phase. In Plot 2.4d, "Looking at Robot Rate - Given Robot Prompted" levels at 35% for R Alone phase, levels at 25% for both R + P Compliance and R Alone Rep, and levels at 10% for R + P Behind. We see that when the parent and the robot prompt individually, the parent has a higher chance of getting the child's visual attention. Although the robot had similar levels of attention when was first introduced as well as when R + P Compliance phase first started, it decayed as the study went on. In Plot 2.8c, "Looking at Parent Rate - Given Both Prompted" levels at 50% for R + P Compliance and levels at 15% for R + P Behind. In Plot 2.8d, "Looking at Robot Rate - Given Both Prompted' levels at 15% for R + P Compliance phase, and levels at 30% for R + P Behind. We see that when the parent and the robot prompt at the same time, the parent had a greater amount of visual attention. The reason why robot gets more attention during R + P Behind is because the parent is directly behind the child, making it awkward to give visual attention to the parent. Also, it's interesting to note that the parent had similar levels of visual attention when prompting alone and when prompting with the robot. The robot, however, experienced a decrease in visual attention level when the parent prompts with it.



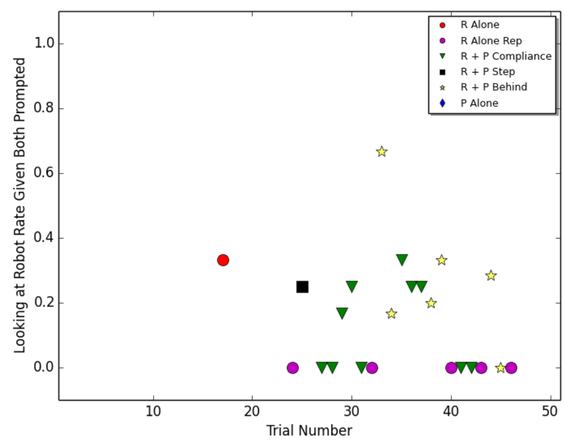

(a) Looking at Parent Rate - Given Parent Prompted




(b) Looking at Robot Rate - Given Robot Prompted




(c) Looking at Parent Rate - Given Both Prompted




(d) Looking at Robot Rate - Given Both Prompted

Figure 2.8: Looking at Prompting Agent Rate

### 2.8.4 Annotation Inter-rater Agreement Analysis and Results

- method - result

### 2.8.5 Survey Data Results

- method - result

## 2.9 Discussion

# Bibliography