Teaching Assistance through Social Robotics for ASD - Toy robot as Speech Buddy and Mini-Drone as Exercise Partner

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***Abstract*— Socially Assistive Robotics (SAR) is rapidly gaining importance in regular teaching. In this paper, we wish to extend SAR beyond usual schools and aim to design interventions for meeting the Individualized Educational Program (IEP) objectives of Children with Autism Spectrum Disorder (CwASD). Adoption of SAR in ASD is challenging because (a) existing studies are often confined to *humanoid robots* resulting in high costs, and (b) the nature of such interventions poses a considerable technological barrier for Special Educators (SE). We study the use of non-humanoid, non-biomimetic COTS robots, *Cozmo* and *Tello*, as providing Teaching Assistance through SAR (TSAR). A TSAR intervention is a Triadic Interaction between a SE, a robot and an autistic child. We present *Speech Buddy Cozmo* which helps students in verbal communication, specifically targeting contingent response, receptive and expressive language, turn-taking in conversation and use of non-native language. *Exercise Partner Tello* is used in another TSAR intervention, which aims to help students in exercise lessons focusing on posture, bilateral coordination, linear movement, and visual-motor skills. Not only did the interventions help in improving learning outcomes, but SEs were comfortable in using the TSARs. Adding to the expected TSAR intervention outcomes, certain benefits were also observed in a few participants like improvement in neck posture and self-motivated writing tasks. Our results show that TSAR based interventions can have a significant impact on dealing with ASD.**

I. INTRODUCTION

Autism Spectrum Disorder, or ASD, is a developmental disorder that not only affects communication and interaction but also motor skills and co-ordination [1]. Language impairment can be a significant contributor to communication challenges in ASD. These lead to problems such as echolalia, difficulty in spontaneous speech and contingent responding, using isolated words, unable to take turns in a conversation [2]. Motor abnormalities is another challenge for children with ASD (CwASD) with varying degrees of dyspraxia, a deficit in gross and fine motor skills, postural instability and can affect the daily living skills of CwASD with some of them requiring regular occupational or physical therapy interventions [3], [4].

CwASD have been found to express affinity towards technological interfaces owing to their preference towards structured and predictable environments [5], [6]. Due to this, tablets and computer interactive systems have been used in the past decade for various ASD interventions [7], [8]. However, it has been found that robots are a better interaction partner for CwASD as opposed to a computer screen [9]. Socially Assistive Robotics (SARs) is an emerging field of robotics that focusses on providing assistance to users through *social* interaction [10] and has been used to address developmental challenges in ASD like Joint-Attention [11], [12] Imitation [13], and Social interaction [14]. There has been growing interest in using SARs in Individualized Education programs [15]. [16] studies the impact of robots on communication skills of CwASD, listing encouraging improvements. However, the cost and complication of the robot were reported to be a limitation. Although low-cost robots such as a robotic toy, Keepon [17], and a robotic parrot, KiliRo [18], have been observed to improve learning outcomes among CwASD, such studies have been few. This work is a step in the same direction, where we focus on designing academic interventions using cost-effective robots. Furthermore, there has been no promising work other than [19] that address the efficacy of SARs in verbal communication intervention in autism, and only [20] provides a case study to enhance overall motor performances of CwASD using a humanoid robot. Thus, we target the less-researched areas of incorporating SARs in verbal communication and motor development.

In an academic context, every ASD child has an Individualised Education Plan (IEP) documenting the child's learning objectives for an academic year. It pertains to goals ranging from formal education to special needs such as social communication and motor skills [21], [22]. To date, existing research does not explicitly study the adoption of SARs in IEP curricula of CwASD.

Thus, we propose TSAR (Teaching Assistance through SAR) interventions - triadic interaction between a SAR, SE and the autistic child, to aid during academic lessons. We focused on the following broad questions:

1) How should the TSAR interventions be designed?
2) Can a non-humanoid toy robot be used in TSAR intervention for verbal communication lessons?
3) Can a mini-drone be used in TSAR intervention for motor development lessons?

The contributions of this paper are summarized as follows:

- We describe design guidelines for TSAR interventions for IEP curriculum (sec. II).
- *Speech Buddy Cozmo* (sec. III-A) shows how a toy robot, Cozmo, aids verbal communication lessons.
- *Exercice Partner Tello* (sec. III-B) shows how a mini-

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drone, Tello, assists in motor development lessons.

- We find that TSAR interventions not only improves the desired learning outcomes but have additional benefits.

The TSAR interventions are conducted at ASHA[1].

II. TSAR INTERVENTION DESIGN STRATEGY

Social robots in a triadic partnership with the SE and autistic child for assisting in IEP curriculum have not been studied before. Furthermore, we use cost-effective COTS[2] robots which are not necessarily meant for this purpose. Thus, we needed a lot of field-testing and subsequent discussions to design TSAR interventions.

In case of TSAR intervention for verbal communication, a pilot free-form interaction with the robot and 20 CwASDs was conducted to gauge reactions and identify participants. The language objectives in their IEPs were perused and 4 target areas were identified. Post discussions with the SEs, the role of the robot was decided to be a co-learner or a co-instructor for each of the target areas taking into account the robot capabilities. Interface for controlling the robot interaction was designed for ease of use by the SE. Positive reinforcement and redirection were programmed in the robot to reduce participant's dependency on SE for the same.

Similarly, in TSAR intervention for motor development, a "follow-the-drone" pilot study (refer sec. III-B.7) was conducted with 55 CwASDs to screen children based on their response and compliance. Post-screening, the exercise lessons from their IEPs were extracted and mapped to drone maneuvers. This process was iterated until there was consensus amongst the SEs that the drone exercise lessons were easy to follow while also being challenging for the participants to measure improvement.

Our findings from above can thus be summarized as guidelines below, for future TSAR intervention design:

- The goals of the TSAR intervention should match with CwASDs IEP objectives.
- The social robot should be able to enhance motivation while also guiding the interaction.
- The TSAR intervention should define a triadic interaction between the social robot, SE and the CwASD.
- The robot should be capable of soliciting spontaneous behaviour from the CwASD.
- The robot should be easy to control for the SEs and be cost-effective to be deployed in special education institutions.

III. METHODOLOGY

A. Speech Buddy Cozmo

In this section, we describe the adoption of a robot Cozmo (refer section III-A.5) in TSAR intervention targeting communication challenges.

[1]ASHA - Academy for Severe Handicaps and Autism is one of the oldest and largest special education institution in Bengaluru, India

[2]Commercially Off The Shelf

1) Goals of the Intervention:

Contingent Response: It is the act of providing an appropriate response to questions asked by another person, which can be difficult for CwASD [23]. We study whether the CwASD show contingent response to Cozmo.

Turn-Taking in Communication: CwASD are averse to taking turns during verbal communication [24]. Robots have been used for non-verbal turn-taking activities [25], but in our study, we observe if turn-taking capabilities of CwASD during conversation improves with Cozmo as a partner.

Communication in non-native Language: From our discussions with SEs, we found they resort to native-language to elicit response from some CwASD. Although, robots have been deployed in elementary schools for teaching non-native language [26], the same hasn't been studied for ASD population. Thus, we study whether CwASD respond to Cozmo in their non-native language, English.

Receptive and Expressive Language: Receptive Language is the ability to perceive information, while Expressive language signifies the ability to convey thoughts in words. Robots have been used in Social Stories Intervention [9], where the questions asked are based on a story aimed to teach social interactions. We adopt a similar approach but our target is academic lessons, i.e., the stories taken from their IEPs. We study whether CwASD show receptive and expressive language when questions are asked by Cozmo.

Spelling Recall: CwASD have been reported to experience difficulty in producing accurate spellings [27]. In this study, we try to find if CwASD show improved spelling recalling when instructed by Cozmo.

2) Research Hypotheses:

We formulate following hypotheses inspired by the broad questions we listed in section I:

H1 : Participants will show improvement in contingent response without SE's help.

H2 : Participants will improve their turn-taking skills during communication.

H3 : Participants will respond to robot even without SE translating to their native language.

H4 : Participants will show improvement in Receptive and Expressive language to the questions asked by robot without SE's help.

H5 : Participants will improve spelling recall over time.

3) Speech Buddy Cozmo - Communication Lessons:

Based on the TSAR Intervention guidelines listed in section II, we formulate 4 communication lessons based on triadic interaction. The lessons are aligned to each participant's IEP.

Talk to me: Cozmo asks 7 self-introductory questions, each preceded by a model answer, e.g. "My name is Cozmo. What is your name?" to facilitate response.

Story Time: SE reads a story to the participant and Cozmo asks questions related to the story. Visual cue in the form of pictures was also provided for easier comprehension.

Spell it out: Cozmo asked the participant to spell words

from the story of *Story Time*. The participant could verbally answer or write the spelling and then pronounce.
Read with me: Cozmo reads out a line from a given script. The participant waits for his/her turn and reads the next line of the script and so on.
Table I summarizes the lessons along with the targeted goal and outcome measurements. The outcome metrics are defined in the next section.

Lesson Name	Target Behavior	Outcome Measures
Talk To Me	Contingent Response, Non-Native Language	Prompts,Accuracy Translations
Story Time	Receptive and , Expressive Language Non-Native Language	Accuracy, Prompts, Translations
Spell It Out	Spelling Recall	Accuracy,Initiations
Read With Me	Turn-Taking in Communication	Out of Turn Utterances

TABLE I: Verbal Communication Lessons

4) Evaluation Metrics:
Prompts: Prompts can be any verbal or non-verbal gesture made by the SE to elicit response from the participant.
Accuracy: Ratio of correct responses to the total number of responses by the participant.
Out of Turn Utterances: Number of times the participant speaks out of turn in *Read With Me* lesson. An utterance is considered out of turn, when either a) the participant reads out sentence to be read by Cozmo or b) the participant starts reading his own sentence before Cozmo has completed reading.
Initiations: Number of times SE reveals part of the ideal response to the participant in *Spell It Out* lesson.
Translations : Number of times SE translates the Cozmo's question to the participant's native-language.

5) Cozmo and Experimental Setup:
We used a COTS robot Cozmo [28] for our study. It is equipped with LED "eyes" that emote (figure 2), a camera, a speaker, and a programmable interface that was used to program the lessons. The intervention setup can be seen in Figure 1. Each such session comprised the 4 lessons which were performed in the same order as mentioned in III-A.3. Cozmo provides positive reinforcement (e.g. "Good Job!") or a redirection (e.g. "Let's try again") based on the participant's response. The SE uses prompts only if the participant does not respond to Cozmo. Each session lasted for about 20 to 30 minutes, depending on the response time of the participants.

A Wizard-of-Oz [29] method of operating the robot was used and audio was recorded to be annotated for analysis. For qualitative evaluation, each participant's SE made a note of progress at the end of every session.

6) Participants and Screening Criteria:
A pilot free-form interaction was conducted with 20 CwASD to see their reaction to Cozmo. We found most CwASD showing curiosity, initiating conversation with Cozmo, but some showed disruptive tendencies (e.g. wanting to hold/throw Cozmo). The screening criteria for a child to

Fig. 1: Experimental Setup

Fig. 2: (Top-left) Cozmo with happy expression, (Remaining) Ongoing Language Lessons with Speech Buddy Cozmo

be selected were: a) Verbal and has Cognitive thinking, b) Responsive to Robot Speech, c) Language present but not used for communication, d) Struggles with at least one of the language problem listed in section III-A.1. Five CwASD of 13 to 17 years, diagnosed with mild autism (mean ISAA [30] score of 85.6, S.D 8.3), were selected. All five were multilingual, and 4 had English as not the preferred language. Due to the nature of this study and given the small sample size of the participants, there was no randomization in the selection of students or activities in both intervention designs III-A and IV-B.

B. Exercise Partner Tello

In the sections that follow, we describe the design of a fully autonomous TSAR intervention for introducing a Drone Inclusive Physical-Therapy Sessions (DIPTSs) using mini-drone Tello (refer sec. III-B.5).

1) Goals of Intervention:
Extrinsic motivation for physical therapy: In this study we focus on how mini-drones could aid in creating a stimuli for CwASD and reinforce it to elicit a targeted motor behaviour. We aim to tackle the fundamental problem to motivate the CwASD to participate in physical therapy

through DIPTS. We target a specific set of rudimentary exercises for our intervention design and observe how DIPTS benefit the participants.

Effective exercising through DIPTS: With increased participation and compliance during DIPTS, we also aim to observe subtle improvements of certain innate physical traits, such as posture, bilateral coordination, linear movement and visual-motor skills amongst others [31].

2) Research Hypotheses:

We formulate the following hypotheses inspired by the broad research questions listed in section I.

H1 : The novel interaction due to the mini-drone in DIPTS would be an extrinsic motivation for increased participation, which was otherwise absent during regular exercise lessons.

H2 : Participants will attempt these exercises spontaneously, i.e., we would observe significant reduction in the efforts of the SEs to assist the participants perform the exercise lessons.

3) DIPTS - Exercise Lessons:

Each DIPTS was a structured triadic interaction between the SE, Mini drone and the participant. A structured interactive session ensured safety through a controlled intervention setting. Further discussions regarding safety are presented in subsection III-B.6. The physical intervention tasks comprised of four rudimentary exercise lessons: *Arm raise*, *Bilateral Arm raise*, *Squats*, *Sprinting*. These exercises were a subset of regular occupational and physiotherapy sessions from the participant's IEPs. DIPTS should ideally enhance the below innate physical traits.

1. Adaptive response
2. Auditory
3. Auditory Perception
4. Bilateral Coordination
5. Bilateral Integration
6. Body awareness
7. Directionality
8. Linear Movement
9. Postural Adjustments
10. Vestibular
11. Visual motor
12. Visual Spacial Processing skills.

Exercise	Target physical traits	Outcome Measures
Arms Raise	1, 2, 3, 4, 10, 11	Prompts
Bilateral Arm Raise	1, 4, 5, 7, 11, 12	and
Squats	1, 6, 8, 9, 10, 11	Ranking
Sprinting	1, 6, 7, 8, 9, 10, 12	Performance

TABLE II: Exercise Lessons in DIPTS

The exercise lessons along with the target physical traits and outcome measures are summarized in table II. The outcome measures are defined in the next section. Each exercise listed was mapped to a unique set of synchronised drone maneuvers. Using these maneuvers as a cue, the SEs instructed and guided the participants to perform the required exercise lessons. All the Drone maneuvers were programmed to function autonomously.

Arms raise: The Drone takes off from a given location and varies its altitude between from 1.5m to 3m off the ground. The SEs instruct the participants to raise the arms up and down synchronously with the Drone's position. (Repeated over two rounds with eight counts in each round)

Bilateral Arm raise: The Drone takes off and alternatively sways from left to right. The SEs instruct the participants to raise their respective arms synchronously with the Drone's position. (Repeated over two rounds with eight counts in each round)

Squat: The Drone alternates between takeoff and land with a fixed time delay between each actuation. The SEs instruct the participants to squat and stand-up synchronously with the Drone's actuation. (Repeated over eight counts)

Sprinting: The Drone raises to an altitude of about 3m and traverses along the perimeter of a rectangle (7m×3m). The SEs instruct the participants to sprint and follow the Drone along its path. (Two rounds of sprinting along the perimeter)

4) Evaluation Metrics:

The following set of metrics was observed and recorded in real-time by a professional clinical physiologist at the school where the intervention took place. A pre-determined set of ratings (High, Moderate, Low) were defined for each metric below:

Prompts: The average number of times the SE issues a verbal or non-verbal cue to the participant.

Ranking performance: This provides a scale to show the average performance and involvement of the participant for each given exercise.

Overall Eye-gaze: This metric provides an estimate of the amount of eye contact the participant maintains with the Drone during an entire session.

5) Mini Drone and Experimental design:

We used a COTS mini Drone *DJI tello* for this intervention. It weighs around 100g with dimensions 98×92.5×41mm (L×B×H) and it fits in the palm of your hands (figure 3a). The DJI Tello is programmable through an SDK, therefore enabling autonomous maneuvering capabilities. The entire DIPTS was conducted in an indoor setting within the school premises inside a large hall of (20ft×30ft) dimensions. The Drone maneuvers were programmed with respect to the room dimensions. There were visual markings embedded on the floor of the hall (figure 4b) in-order to enforce a disciplined design for the intervention study.

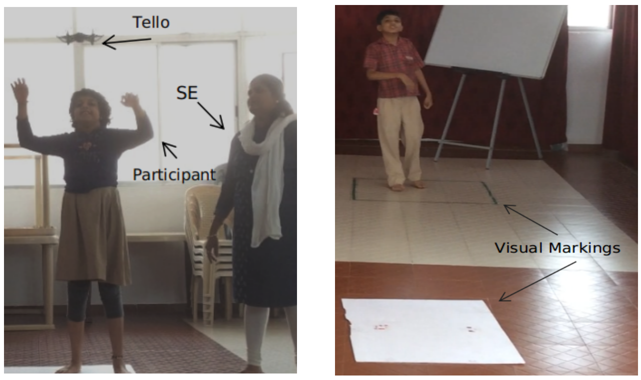
(a) Comparable size of the Drone

(b) DJI tello with retrofitted propeller gaurds

Fig. 3: COTS DJI tello Indoor Drone

6) Safety Precautions for DIPTSs:

Given the form-factor and lightweight properties of Tello, it poses no significant threat in any form. However, due to the eccentric and impulsive behavior of CwASD, propeller guards were retrofitted as a safety precaution (fig. 3b). This prevents the children from harming themselves or the Tello during DIPTS. Also, SEs are advised to strictly instruct the participating children to not physically handle the Tello anytime during the session. Conversely, the participants are also screened based on their compliance towards the SEs to preempt CwASD from bruising themselves or cause damage to the Tello. Although, Tello is relatively sturdy for its size to handle head-on wall collisions and hence cannot be damaged easily.



(a) SEs providing constant assistance

(b) Visual markings embedded on the floor

Fig. 4: Drone Inclusive Therapy Sessions (DIPTS)

7) Participants and Screening criteria: The final design for the physical intervention tasks was a sequel to the initial pilot study conducted. This study involved 55 participants. A simple pilot experiment was designed where each participant had to follow the Tello traversing in a definite path. The Tello was flown at a higher altitude to account for safety. The observation post the pilot experiment is presented in table III. The screening criteria for the final list of participants were: i) Children performing poorly in regular physical therapy sessions or Children with developmental delay. ii) Children observed with positive affect during the pilot experiment (Excited and Happy participants table III). Three participants P1, P2, and P3 of age 12 to 13 years were finally selected for a focused study. P2 and P3's motor skills fall in the age group of 4-5 years based on Normal Development Checklist [32]) while P1's is age-appropriate, only exhibits non-compliance to exercise lessons.

Participant reaction	Excited and happy	Mixed or diverted	Sensitive to noise	Unresponsive
Number of participants	23	18	6	8

TABLE III: Pilot Study Observations

IV. RESULTS AND DISCUSSIONS

A. *Speech Buddy Cozmo*

We conducted a short longitudinal study of 3 weeks, with two sessions per week. Session 1 was conducted without Cozmo (SE assumes role of Cozmo) and remaining 5 sessions with Cozmo (video). The participants are identified as P1 to P5 henceforth. For Spell It Out, only P1, P3 and P5 participated based on their language exposure. Figures 5 and 6 show the lesson specific outcome measures for each participant for the first and the last sessions, i.e., without and with Cozmo.

Contingent Response - Talk To Me: We observe in figure 5 the number of prompts reduce with Cozmo for all participants. Accuracy also slightly improves, indicating hypothesis *H1* could be true.

Turn Taking communication - Read With Me: Figure 6 shows P1 has 0 out-of-turn utterances with and without Cozmo. P2 has lower out-of-turn utterances, when the reading partner is a human (SE), as P2 was reluctant without SE prompting in his native language, Kannada. For P4 to P5, out-of-turn responses decrease over time. Thus, *H2* may hold true for all but one participant.

Non-native Language Communication - Talk To Me and Story Time: In figure 5, we see 4 out of five participants needed no translations by the last session in *Talk To Me*, and for *Story Time*, translations decreased for all, remained at a low value for P4. Thus *H3* could be true.

Receptive and Expressive language - Story Time: Figure 5 indicates the prompts decrease, and the accuracy increases or remains constant for all participants, indicating *H4* could be true.

Spelling Recall - Spell It Out: As evident in figure 6, the number of initiations for P1, P3 decreased with Cozmo and P5 didn't need any. All of them showed perfect accuracy with Cozmo by the last session, with accuracy of P1 and P5 increasing. Thus *H5* could be true.

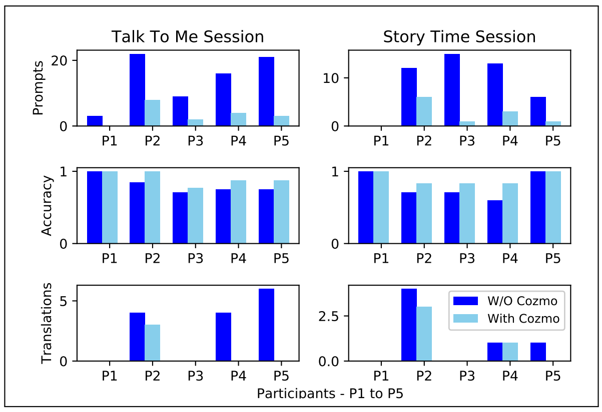


Fig. 5: Prompts, Accuracy, Translations for Talk To Me and Story Time Tasks

Following are the excerpts from the qualitative improvements, as reported by the SEs of the participants. **Improvement in Self-Introduction:** P5 was known to be verbal and had reading comprehension, but struggled in sentence construction. The *Talk to Me* lesson was specially beneficial to P5 as P5 tried to respond to Cozmo in full sentences.

Improvement in Repetition task - Spelling: P1, although

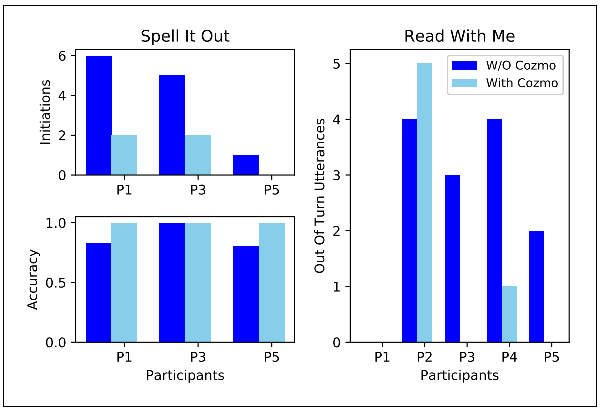


Fig. 6: Initiation, Accuracy for Spell It Out and Out of Turn Utterances for Read with Me tasks

verbal and capable of comprehension, struggled with repetitive tasks such as spelling. But in Spell it Out, P1 tried to recall and even wrote the spelling on receiving a negative feedback from Cozmo. The SE noted it can be extremely difficult to motivate CwASD to write and although, participants were never explicitly instructed to write (writing-pad was only placed in front of them), it was an unprecedented benefit of the intervention.

Even in this short study, we see that the participants require fewer prompts from their SE for the communication lessons, indicating spontaneous response from CwASDs. Accuracy improvements could be due to repetitve bias since the same lessons were used for all the sessions. However, lessons such as *Talk To Me* were being practiced for a year before this study, and yet the SEs noted improvement in performance when Cozmo was introduced. One unanimous finding was that the participants looked forward to visiting Cozmo. The onus of providing motivation was shifted from SEs. Thus, we find that even a non-humanoid toy robot was effective in TSAR intervention targeting verbal communication.

B. Exercise Partner Tello

We opted for a longitudinal study of 10 sessions, spanning eight weeks. To determine the effectiveness of DIPTS, the participants were evaluated based on the qualitative findings *pre* and *during* DIPTS (video). We also provide results from three quantitative metrics recorded (III-A.4). We present our final results on three focused participants.

P1: P1 Portrayed a large sense of disinterest and lacked motivation with almost no participation in any regular exercise lessons. However, P1's intrinsic interest in technology acted as an extrinsic motivation for increased participation in DIPTSs, indicating *H1* could be true.

P2: P2 was found to consistently underperform due to a lack of focus in regular exercise lessons. Also, P2 exhibited abnormal gait and never attempted to sprint. P2 always actively looked forward to DIPTSs, showing *H1* could be true.

P3: P3 portrayed low levels of stimuli and compliance during regular exercise lessons. P3 always required prompt and physical aid from two SEs. P3 also exhibited poor neck posture and was often found slouching. During DIPTSs, there was a significant improvement in compliance and SE's efforts were largely mitigated, strongly indicating *H2* could be true.

We also observed a few unprecedented benefits associated with each of the participants during DIPTSs. The tech-savvy nature of P1 resulted in increased involvement which may not be limited to only DIPTS, but would translate to any TSAR intervention. For P2, through successive DIPTSs, the participant attempted to run behind the Tello during the *"Sprinting"* exercise. P3 never performed the necessary physiotherapy exercises to improve her overall posture. However, during DIPTS, P3's neck posture improved effortlessly while gazing at Tello. As the Tello provided a novel sense of stimuli for increased participation of the above participants, *H1* could hold.

Quantitative metrics: During subsequent sessions, all the participants show progress in performance, with a decrease in number of prompts. The targeted behaviour was reinforced through successive DIPTSs and we observe the gradual decrease in number of prompts for every exercise in DIPTS. This shows that *H2* could be true. The participants show consistency in performing each listed DIPTS as observed in Fig.7. P3's hesitancy to perform certain exercises could be due to the participant's hypoactivity or mood swings [33] while performing those particular exercises.

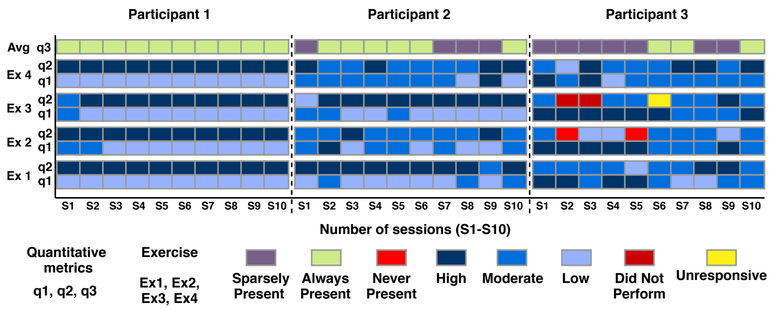


Fig. 7: Quantitative Metrics for DIPTSs (q1= Prompts, q2 = Ranking Performance, q3 = Overall Eye-Gaze)

V. CONCLUSION

In this study, we observe how social robots can be used as teaching assistants by the SEs in autism education. We defined how TSAR interventions can be designed. TSAR interventions using robot for verbal communication, and mini-drone for motor developments were conducted and the participants showed improvement in certain learning outcomes even within the small timeframe. However, our results are preliminary, limited by the small sample size, fewer sessions, and absence of post-study evaluation. Full-fledged long-term studies using TSAR interventions targeting a wider range of IEP objectives and for longer duration should be conducted to further validate our findings.

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