Proceedings of the 27th IEEE International Symposium
on Robot and Human Interactive Communication,
Nanjing, China, August 27-31, 2018

Dyadic Gaze Patterns during Child-Robot Collaborative Gameplay in a Tutoring Interaction

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Abstract - This study examines patterns of coordinated gaze between a child and a robot (NAO) during a card matching game, 'Memory'. Dyadic gaze behavior like mutual gaze, gaze following and joint attention are indications both of child's engagement with the robot and of the quality of child-robot interaction. Eighteen children interacted with a robot tutor in two settings. In the first setting, the robot tutor gave clues to assist children in finding the matching cards, and in the other setting, the robot tutor only looked at the participants during the play. We investigated the coordination between child and robots' gaze behaviors. We found that more occurrences of mutual gaze and gaze following made the children aware of the gaze hints given by the robot and improved the efficacy of the robot tutor as a helping agent. This study, therefore, provides guidelines for gaze behaviors design to enrich child-robot interaction in a tutoring context.

Keywords: Mutual gaze, Gaze following, Dyadic interaction, Joint attention, Child-robot interaction, Social cognition, Theory of mind, Observational analyses.

I. INTRODUCTION

To improve child-robot interaction outcomes in tutoring and other persuasion tasks, the design of intuitive interactions between robots and users is crucial. The use of verbal or nonverbal communicative cues by a social robot can improve task performance and learning [2, 4, 21, 22], provide positive experience including engagement [27, 28]; promote emotional bonding [7], enhance compliance during an activity [9], and help regulate human-robot collaboration [11, 12, 13]. Gaze behavior, in particular, has paramount importance in the field of non-verbal human-robot interaction [1, 6, 25]. Gaze facilitates many social functions in human communication [14, 15, 17, 29]. One primary role of gaze is to act as a pointer (i.e. referential gaze) both in human-human communication, [15, 19] and in human-robot interaction [22].

Prior work on gaze in the context of child robot tutoring and autism therapies has mainly focused on whether children can read and follow the gaze cues exhibited by a robot [20, 26]. We argue that since dyadic gaze interaction involves sequences of intertwined and coordinated looking behaviors between child and robot, further investigation on these dyadic patterns are needed. In particular, our specific interest is on mutual gaze, gaze following and joint attention which is of substantial importance for a natural human-human and human-robot interaction (HRI) as well as for the developmental robotics [8, 19]. Joint attention is a particular sequence of look at behaviors leading to sharing of attentional focus on an object of interest to ensure a shared understanding. Such gaze sequences are known to be very important in children's language development [17]. Moreover, gaze following and joint attention are shown to be the foundation of social cognition processes including the theory of mind and perspective taking [3]. It is also suggested that deficits in eye gaze interaction in either dyadic or triadic joint attention abilities are some of the core communicative deficits associated with autism spectrum disorder [3, 10].

The results of mutual gaze following experiment between human and a robot (Kompatsiari et al. [18]) suggests that people are sensitive to the mutual gaze of an artificial agent, and they feel more engaged with the robot when a mutual gaze is established. Mwangi et al. [22] showed that this gaze sensitivity can be used in tutoring applications. The study showed that that gaze hints made the task completions significantly easier and the robot's gaze hints were recognized significantly more often than the human tutors' gaze hints. In the follow-up study Mwangi et al. [23] showed that children also improve their leaning performance when tutored by a robot and this performance improves when the robot tutor uses more gaze cues.

The primary research goal of the current study is to further examine the dynamics of the – mutual gazing patterns between a child and a robot in a tutoring task. The present study aims to identify the occurrences of mutual gaze and coordination of gaze direction patterns and to assess how child-robot coordinated gaze behavior can improve the performance and the subjective experience during a tutoring game activity. Looking at these patterns we aim to investigate whether children can read/interpret and attribute intentions to gaze hints exhibited by a humanoid robot in a play situation. Gaze is shown to be a good indicator of attention [15, 17, 19], and therefore examining the coordinated eye gaze behavior of children could contribute to promoting more accurate interventions and thus further educational gains.

We designed a setting in which children interacted with a robot tutor in a card matching task [23]. NAO robot from Softbank robotics played the role of a tutor in the study under

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978-1-5386-7980-7/18/$31.00 ©2018 IEEE

two conditions according to the assistance given. In the first condition (Help), the tutor provides gaze hints to assist the child to find the matching card on the board to make a pair. The hint consisted of the robot looking at the selected card, then to the face of the participant and finally to the matching card on the board. In the second condition (No_Help), the tutor does not give gaze clues and continuously looks at the child. We hypothesize that occurrences of appropriate sequences of the dyad's gaze behaviors (i.e. mutual gaze, gaze following and joint attention) would facilitate the effectiveness of the robot tutor as a helping agent and consequently improve the performance of the child fulfilling the task

II. METHODOLOGY

A. Participants

Eighteen typically developing children, (Age: 4 -11 Yrs; Gender: Male: 10, Female: 8) took part in the study. Children were recruited from a daycare center in the Netherlands, and the children of the staff at the university. Most of the children were of European-Dutch and Asian backgrounds.

B. Robot

For this study, we used the humanoid NAO, which is a 58cm tall from SoftBank Robotics. NAO has simple facial features, and therefore suitable for use with children either in education tutoring or autism therapy. However, NAO has some gaze limitations, since it lacks articulated eyes and therefore relies on head turns to indicate gaze direction (e.g. shifting gaze between cards and the child's face). Prior to the experiment, we conducted a preliminary study to examine whether NAO head angles [24] can direct attention to different locations on the board game layout. The gaze hints are designed to lead the attention of the child to the matching cards. Fig. 1 shows the sequence of NAO gaze behavior. The study informed the arrangements of the cards on the table.

C. Study Design

The experiment followed a within-subject design with two conditions (*Help* and *No - Help*):

- *No _Help*: In this condition, the tutor (robot) does not provide gaze hints during the game. The tutor only looks to the child and remains silent during the entire duration of the game.
- *Help*: In this condition, the tutor provides gaze hints during the game. The robot gaze hints are designed to *point with the head/eyes direction* to the matching card. The robot tutor first looks at the card picked by the participant, then looks to the player, and finally to the matching card, to attract and draw the child attention to the matching card. As in the *No-Help* condition, the tutor remains silent during the entire duration of the game.

D. Experimental Set-up and Procedure

The child entered the experimental room (accompanied by either the teacher, the parent or the guardian). The robot was in a stand-init position on one side of a table, and the child sat on the opposite side of the table. A researcher who controlled the behaviors of the robot was also present in the experimental room. The researcher sat in the corner of the room not to be in the visual field of the child so she could not interfere with the flow of the game. In the room, there was also a facilitator present, whose role was to guide the children if they had any difficulties or to answer any questions they may have.

The facilitator provided the child with a brief introduction of the robot and the game. The game began with NAO robot introducing himself as a tutor and giving instructions to the child on how to play the game.The robot spoke either Dutch or English depending on the language the child was comfortable with. After providing instructions, NAO remained silent and performed its gaze behavior as designed for either the Help or the No_Help condition. While introducing the game in the Help condition, the robot tutor informed the child that it would help him/her, without revealing the modality it would use to help.

In the beginning, there were 14 cards (7 matching pairs) laid face down on the board. The child selected the first card and tried to find the matching one. If the cards turned face up were similar (a pair of matching cards), the child continued to make a new move; otherwise, the child turned the cards face down and made a new try/move. The goal of this game is to find all pairs in the smallest number of moves/tries, and shortest time, possible. The game ended when the child found all the matching pairs. Each child played the card game "Memory" in the presence of the robot tutor in both conditions of Help and No_Help as described in section C. The order of conditions was counterbalanced. After playing the first game, the child waited for a few minutes for the experimenter to rearrange the card game. At the end of every session, the robot thanked and congratulated the child for playing the game. After both sessions, the facilitator asked the child a few post-experiment questions on whether they noticed the help cues from the tutor , how they perceived the robot tutor in both conditions and the game as well.

Fig. 1 Sequence of gaze cues for NAO tutor robot in "Help "condition. The NAO tutor looks at the card picked by the child, moves its head to the face of the child, and then to the matching card.

E. Behavioral System

Extending the behavioral coding scheme from our previous study [23] we built new components to explore the coordinated gaze patterns and the interaction in the situation of play. The coding system is divided in two categories: behavior units and dyadic patterns. The behavior units include

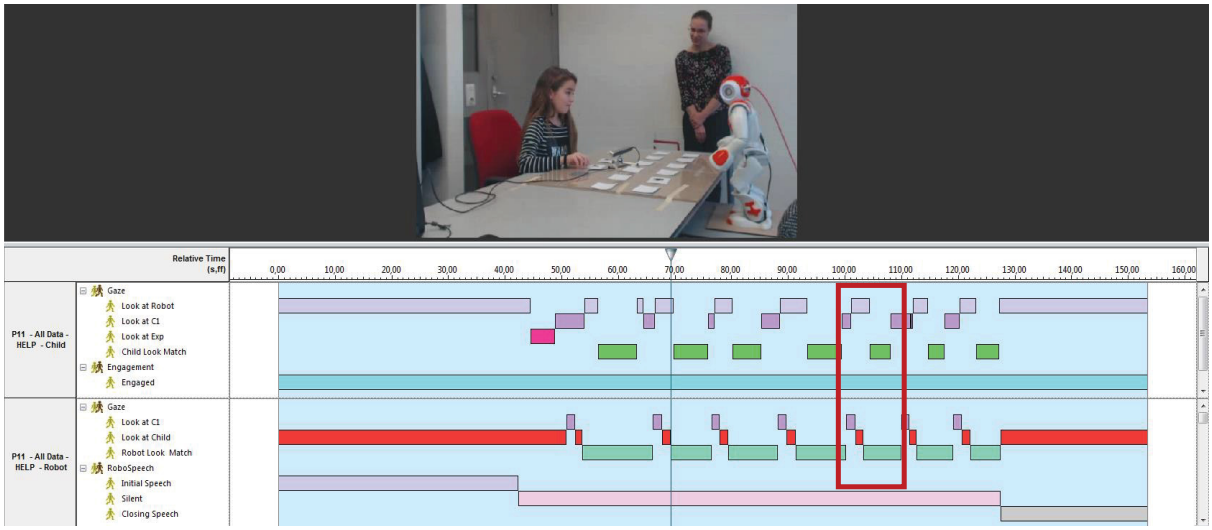

Fig. 2 Video footage and visualization of events plotted horizontally against a time axis of coded child and Nao behavior's units from one play session in the "Help" condition. The red rectangular bar denotes the co-occurrences of child robot behaviors.

Child and Robot's gaze behaviors and robot's verbal behavior, as can be seen in Table 1. The second category includes more complex sequences of coordinated gaze behaviors (dyad gaze patterns) as can be seen in Table 2.

TABLE 1: CHILDS' AND ROBOTS' BEHAVIORAL UNITS

Robots' gaze behavior
1.1. Look at the Child
1.2. Look at Card 1
1.3 Look at Matching Card
Robots' verbal behaviour
1.1 Initial Speech
1.2 Closing Speech
Childs' gaze behavior
1.1. Look at the Robot
1.2. Look at Card 1
1.3. Look at Card 2
1.4. Look at the Experimenter
1.5. Look Elsewhere

- Child - Robot Interactive Behavior Units

We defined the gaze and verbal categories for the same subject (Robot or Child) as mutually exclusive and exhaustive since the subject state is known at any time. The child and robots' gaze behaviors and robots' verbal behavior, can be seen in Table 1 above.

- Dyads' Coordinated Gaze Patterns

The purpose of the dyadic gaze analysis is to examine the interaction between the gaze behavior of the child and the robot. During the Help condition, we expected that children would notice the gaze hints from the tutor while the tutor was looking at different cards on the table and that they would follow the tutor's lead to the matching card. We focus on the following dyadic patterns as illustrated in Table 2:

Mutual gaze: The reciprocal gaze directed at the face region from one agent to the other [8].
Gaze following: Following the gaze direction of another [8] and look at the same target with the partner.
Joint attention: A sequence of behavioral patterns that includes mutual gaze and gaze following and a subsequent sharing of attentional focus on an object of interest [8].

TABLE 2 DYADS' COORDINATED GAZE PATTERNS. IN PLAIN (TRANSITIONS), IN BLUE ITALICS (BEHAVIOR CONTINUITY- NOT A TRANSITION). JOINT ATTENTION IS DEPICTED AS COMPOSITE SEQUENCE OF BEHAVIORS.

Mutual Gaze	**Child**	Look at robot		
	Robot	Look at child		
Gaze Following	**Child**	Look at robot	Look at X	
	Robot	Look at X	*Look at X*	
Joint Attention	**Child**	Look at robot	*Look at robot*	Look at matching
	Robot	Look at child	Look at matching	Look at matching

F. Coding

The coding process was done by having the researcher watch the videos and record the behaviors observed according to the coding scheme. We used Noldus Observer XT 10.1 software to perform the coding. Fig. 2 depicts a game situation in the "Help" condition, of the coordinated interaction between the child and the robot and the corresponding sequences of mutual behaviors. The plot shows all the coded behaviors for the child at the top row and for the robot in the bottom row. On top row is a timeline of the interaction in seconds. The rectangular bar indicates the duration of occurrence of each event. In the figure we can see the mutual

relations between the behaviors – at the same time we see on the second row the child behavior and the corresponding robot behavior at the bottom row. Each behavior appears on the visualization if it is coded at least once in the system. The length of the boxes indicates the duration and the incidences of similar colored bar rectangles show the frequency of the occurrences of each behavior. A coordinated back-and-forth gaze alternation between the child and the robot gaze and the cards (card 1 or matching card) is a sign of a successful occurrence of joint attention, as illustrated in the visualization with a rectangle. Mutual gaze is the instances when the child (Look at the robot) and robot (Look at a child) behavior co-occur.

III. RESULTS

We analyzed thirty video observations of fifteen children (age 6 -11). Fifteen trials in the Help condition and fifteen trials in the No_Help condition. Three children were exempted from the analysis due to the following reasons: one of the children failed to participate in one of the sessions of the game and the other two were very young (below age 5) and could not play the game on their own.

A. Mutual Gaze

In the current setting, the mutual gaze is defined as the co-occurrence of the robot looking at the child and the child looking at the face region of the robot.

- **Effect of Help on Frequency and Duration of Mutual Gaze (MG):**

To highlight mutual gaze from the observations, we reduced the video observations to intervals when the behaviors - Child (Look at Robot) and Robot (Look at Child) behaviors co-occur as shown in table 2 using the observer XT. We examined the frequency and duration of mutual gaze (MG) patterns in both the Help and No_Help conditions. To examine the impact of Help, we conducted a repeated measure ANOVA in SPSS, with Help Type (Help vs No_Help) as the within-subject factor. We analyzed the results of 15 participants, for a total of 15 trials in the Help condition and 15 trials in the No-Help condition. We found a significant difference in the number of occurrences of the mutual gaze between the Help and No_Help conditions (p=0.001). We also found significant differences in duration of mutual gaze (MG) in Help condition and No_Help condition (p=0.004).

TABLE 3 FREQUENCY AND DURATION (SEC) OF MUTUAL GAZE BEHAVIOUR IN HELP AND NO _HELP CONDITIONS

	Help Condition (N=15)		No_Help Condition (N=15)	
	Mean	**SD**	**Mean**	**SD**
Frequency	5.20	3.12	1.73	1.10
Duration(s)	32.43	1.10	12.98	12.18

- **Mutual Gaze & Awareness Of Tutors' Hints:**

From the post-experiment interview, eight out of the fifteen children said they noticed the gaze hints from the tutor while the rest stated that they did not see the help gaze cues.

TABLE 4 FREQUENCY AND DURATION (SEC) OF MUTUAL GAZE BEHAVIOUR WITH AND WITHOUT AWARENESS OF TUTORS' HINTS

	Noticed Gaze Hints (YES group) N=8				Did Not Notice Gaze Hints (NO group) N=7			
	Mean	**SD**	**Range**		**Mean**	**SD**	**Range**	
			Min	**Max**			**Min**	**Max**
Frequency	7.63	1.92	4	10	2.43	1.27	1	4
Duration (s)	40.62	17.34	24.47	78.93	20.27	18.46	1.00	56.27

The table above shows the descriptive statistics regarding the frequency and duration of mutual gaze patterns alongside gaze awareness of children. Gaze awareness refers to whether the subject/participant noticed the gaze hints from the robot tutor or not. We conducted an independent sample T-test using SPSS, to compare the (Frequency and Duration of mutual gaze), for participants who noticed gaze hints (reported as YES), and those who did not notice gaze hints (reported as NO.). There was a significant difference in the frequency of mutual gaze for those children who noticed gaze hints (YES group M=7.63, SD=1.92) and those who did not notice the gaze hints (NO group M=2.43, SD=1.27); p=0.001; 2-tailed, assuming equal variances. We also found a significant difference in duration of mutual gaze for those who noticed gaze (YES group M=40.62 Sec, SD=17.34) and those who did not notice the gaze hints (NO group M=20.27 Sec, SD=18.46); p=0.046; 2-tailed, assuming equal variances.

B. Gaze Following

Gaze following like mutual gaze is a key component cue of joint attention as illustrated in Table 2. Joint attention in literature, is a sequence of coordinated behavioral patterns that includes mutual gaze and gaze following that leads to sharing an attentional focus on an object of interest [9]. In this particular setting, such coordination implies that the child is looking at NAO, and NAO looks to the child, then NAO shifts to look at the matching card –referential gaze-, and subsequently, the child follows the gaze direction of NAO to look to the matching card as well.

To highlight gaze following from the video observations, we reduced the video observations to intervals when the following child and robot behaviors co-occur: Child (Look at Robot) and Robot (Look at Match): The pattern implies that the child is looking at the robot while the robot is looking at

the matching card. This co-occurrence is the key feature Joint attention and a subsequent shared view pattern Robot (Look at Match) – Child (Look at Match): The pattern implies that both the robot and the child are looking at the correct card match at the same time.

- **Gaze Following & Awareness Of Tutors' Hints:**

TABLE 5: FREQUENCY AND DURATION (SEC) OF GAZE FOLLOWING BEHAVIOUR WITH AND WITHOUT AWARENESS OF TUTORS' HINTS

	Noticed Gaze Hints (YES group) N=8				Did Not Notice Gaze Hints (NO group) N=7			
	Mean	SD	Range		Mean	SD	Range	
			Min	Max			Min	Max
Frequency	8.88	2.75	4	12	2.14	1.07	1	4
Duration (s)	22.43	14.95	9.60	55.67	4.20	3.63	1.00	10.33

We conducted an independent sample T-test in SPSS to compare the (Frequency and Duration of gaze following) see Table 5, for children who noticed gaze hints as robot trying to help (reported as YES), and those who did not notice the robot hints (reported as NO). We found significant differences in the frequency of gaze following related pattern for children who noticed gaze hints (YES group M=8.88, SD=2.75) and those who did not recognize the gaze hints (NO group M=2.14, SD=1.07); p=0.001; 2-tailed, assuming equal variances. There were also significant differences in duration of gaze following pattern for those who noticed the help through gaze hints (YES group M=22.43 Sec, SD=14.95) and those who did not notice the gaze hints (NO group M=4.20 Sec, SD=3.63); p=0.008; 2-tailed, assuming equal variances.

The box plots below show the frequency and duration of mutual gaze and gaze following pattern alongside gaze awareness of the children.

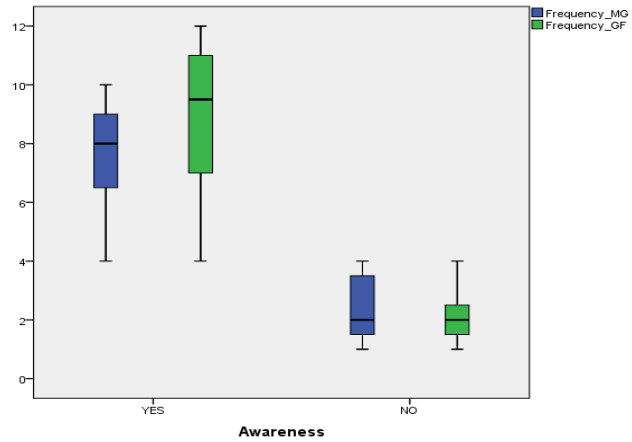

Fig. 3 Frequency of mutual gaze and gaze following patterns; Awareness YES: noticed gaze hints, NO: did not notice gaze hints.

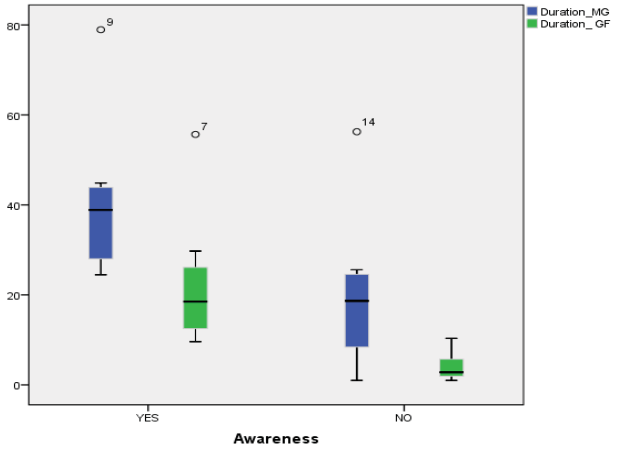

Fig. 4 Duration (S) of mutual gaze and gaze following pattern; Awareness YES: noticed gaze hints, NO: did not notice gaze hints.

IV. DISCUSSION & CONCLUSION

Gaze cues of robots have been a subject of recent study in social robotics, since it is shown to be a crucial factor in human robot interaction. Continuing the previous line of research in which we conducted an experiment with children playing a 'Memory' card game, with and without gaze hints from the robot. In our prior findings, we reported the impact of gaze hints on the performance of children which was measured based on how quick children finished the game regarding tries and time [23]. From the results, we found that there was no significant difference in time taken to complete the game; however, the number of tries that children used to finish the card matching game reduced significantly with gaze hints from the robot tutor(NAO) .

In the present paper, we examine the occurrences of repeating gaze patterns in the dyadic interaction between a child and NAO robot during gameplay. Specifically, we were interested to investigate whether children can read/interpret and attribute intentions to gaze hints exhibited by a humanoid robot in a play situation. We found significant differences regarding the frequency and duration of mutual gaze between Help and No_Help conditions. Children looked more frequently and significantly longer to the tutor when the tutor as helping gaze hints than when the tutor. During the Help condition, eight children out of the fifteen children reported noticing the gaze hints from the robot tutor, while the rest did not see the gaze hints. We saw significant differences in occurrences and durations of mutual gaze and gaze following pattern for children that recognized the hints from the tutor vs the ones that did not notice it. These findings suggest that more occurrences and higher durations of coordinated - mutual gaze and gaze following pattern - increased the children' awareness of the helping cues from the robot. In turn, when children noticed that the robot tutor tries to help with the gaze hints, they looked more to the robot to take advantage of its cueing.

From our observations, as soon as the child noticed the tutor

was helping with gaze hints, they waited until the robot showed them the matching card, even when they had an idea of where the matching card was. On a more conceptual level, the potential risk is that tutor's hints might induce slacking, inducing children to rely on his help even when it would not be necessary. However, this might be the result of the use of explicit, overt cues. It is possible that if more covert signals could give the help - e.g., with a gaze cueing that is effective even without reaching conscious awareness, but this needs further research. The conclusion based on these findings is that it is essential to design robotic behaviors to draw the attention of the children and thereby increase occurrences of mutual gaze and gaze following and the subsequent joint attention to foster interaction outcomes especially in robot-based educative interventions.

ACKNOWLEDGMENT

This work was supported in part by the Erasmus Mundus Joint Doctorate in Interactive and Cognitive Environments, which is funded by the EACEA Agency of the European Commission under EMJD ICE FPA no 2010-0012. We thank Kyra Fredrick's, for her support during the experiment, and all the children who participated, the teachers and all the parents/guardians who made this study possible.

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