Development of Robot-enhanced Therapy for Children with Autism Spectrum Disorders

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DREAM

Development of Robot-enhanced Therapy for Children with Autism Spectrum Disorders

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. D2.3.1 Tasks for social robots (supervised autonomous version) on developing social skills

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PP	Restricted to other programme participants (including the Commission Service)	
RE	Restricted to a group specified by the consortium (including the Commission Service)	
CO	Confidential, only for members of the consortium (including the Commission Service)	

Contents

Executive Summary

This deliverable D 2.3 Tasks for social robots (supervised autonomous version) on developing social skills is based on the results from studies carried out in task T2.1, in which we have tested the effectiveness of RET using a supervised autonomous version. The effectiveness of RET is being tested for: joint attention, imitation, and turn-taking skills. The principal results in this deliverable are the parameters and parameter values that characterize the child behaviors identified in deliverable D1.3. In this deliverable (D 2.3) we will present: the theoretical background, objectives, design, procedure, environmental setup, preliminary results from the experiments carried in task 2.2, conclusions and discussions.

Principal Contributors

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Revision History

Version 1.0 (26-03-2017)
First draft, describing the methodology without the results.
Version 2.0 (31-03-2017)
Second draft, results included.

Introduction

Autism Spectrum Disorder (ASD) is a neurodevelopmental disorder defined by persistent deficits in social communication and social interaction and restricted, repetitive patterns of behavior, interests, or activities (APA, 2013). Difficulties in social interaction skills such as imitation, joint-attention and turn-taking are very common in ASD. Children with autism show an impairment in imitation (e.g. Rogers, Hepburn, Stackhouse, & Wehner, 2003). An imitation training can improve this ability, but also can facilitate the recognition of peers and caregivers as "social others", the hand-eye coordination and the later development of communication skills (Ricks & Colton, 2010). Imitation also enables the child to learn new information from his/her social environment (Cabibihan, Javed, Ang, & Aljunied, 2013).
Another social ability impaired in children with autism is joint-attention (Dawson, Toth, Abbott, Osterling, Munson et al., 2004). This social attention ability refers to the capacity of focusing on the same object with a social partner. It is particularly important for perceiving the social others, for a successful learning (Ricks et al., 2010) and for the acquisition of language (Dawson et al., 2004). A deficiency in turn-taking, has also been associated with autism. This ability plays a fundamental role in regulating conversations (Ricks et al., 2010, Cabibihan et al., 2013) and social interactions. Thus children with autism have difficulties sustaining a conversation or playing a game in which the partners' roles constantly alternate.
The use of a social robot in the therapy of children with autism has received a lot of attention in the last years. Like any other intervention, a robot-enhanced intervention addresses the difficulties displayed in autism. The most common targeted behaviors in such interventions are: imitation, eye-contact, joint-attention, turn-taking, emotion recognition and expression, self-initiated interactions, and triadic interactions (Cabibihan et al., 2013). Even though the results are promising, there is a still a lack of investigations that include different interventions groups which are then compared in terms of their efficacy (e.g. standard intervention with a therapist vs intervention with a robot).

The main aim of this study is to the test the efficacy of robot-enhanced therapy in children with ASD. We investigate if a social robot can improve the social abilities of children with ASD, and we will test if robot-enhanced therapy produces similar or better results than a standard intervention with a therapist. The social abilities targeted by our intervention program are: imitation, joint-attention and turn-taking.

Methods

Design

The present study is a randomized controlled trial. The children enrolled in the study are distributed in two groups: one group receives the intervention from a therapist and the other group receives the intervention from the Nao robot. The intervention protocols for the groups are identical, with the exception of the interaction partner who offers the intervention: in one case a therapist and in the other case a humanoid robot.

Inclusion and exclusion criteria

Participants included in the final study are 40 children with a diagnosis of ASD between the ages of 3 to 6 years old. A psychological examination will take place before the intervention to evaluate the presence of autistic symptoms. A diagnosis will be given based on scores obtained at *Autism Diagnostic Observation Schedule (ADOS),* corroborated with the scores

form *Social Communication Questionnaire (SCQ)* and a previous diagnosis. The children with scores that are not in a clinical range will be excluded.

Randomization

Until now we have enrolled in our study 17 children with ASD and we have randomized them in two groups: one group that benefits from the intervention with the therapist and one group that benefits from the intervention with the robot. An independent research using a digital random number generator carried out the randomization. The information regarding the allocated condition for each child was communicated to the research team, which has subsequently informed the parents.

Procedure

Participants were recruited form different organizations and institutions, which provide educational and/or psychotherapeutic services to children with autism, most of them in the city of Cluj-Napoca. An informed consent was obtained from parents/caregivers for each child. Then the children were randomized to an intervention with a therapist or intervention with a robot group. The protocol for each group is made of 12 sessions: 2 evaluation sessions (before intervention), 8 intervention sessions and 2 evaluation sessions (after intervention). Each session lasted 45 minutes and took place twice a week.

Protocol description

Sessions 1 and 2 are designed for doing a comprehensive psychological evaluation and for setting the baseline level of the three abilities. The *Autism Diagnostic Observation Schedule (ADOS)* and *Raven's Progressive Matrices (RPM)* are administrated to assess the social and communicative behavior associated with autism and respectively the general cognitive ability. The screening instrument for autism called Social Communication Questionnaire (SCQ) will be fulfil by the children's parents/caregivers.

The baseline levels of imitation, joint-attention and turn-taking abilities are determined. This is accomplished using the similar subtasks designed for the intervention part, which have different levels of difficulty (see below). After this evaluation, the level of each ability is determined for every child.

Sessions 3 to 10 are used for training the imitation, joint-attention and turn-taking abilities.

Sessions 11 and 12 explore the level of the three abilities after the interventions. This means that the targeted behaviors are preceded by a stimulus but not followed by any feedback or prompting. Moreover, a psychological evaluation using the same instruments (ADOS, RPM, SCQ) is conducted to determine if the benefits of the interventions will generalize.

Task description

Imitation. During the imitation task the child and the therapist are sitting at a table. If the robot provides the intervention, then the robot will be placed on a table in front of the child. In this task the child has to imitate the actions made by the robot.

- level 1 of difficulty: imitation with objects (e.g. moving a car, pretending to drink from a cup)
- level 2 of difficulty: imitation of gestures (meaningful movements) (e.g. waving one hand and say bye-bye)

- level 3 of difficulty: imitation of movements without a meaning

Joint-attention. On a big touch-screen incorporated in a table are displayed simultaneously 2 pictures: on the left side and the other on the right side. In this task the child has to look at the picture indicated by the robot/therapist. There are different ways to indicate one of the two images displayed:

- level 1 difficulty: simultaneously looking at one picture, pointing to that picture and saying: Look!;
- level 2 difficulty: simultaneously looking at one picture and pointing to that picture;
- level 3 difficulty: looking at one picture.

Turn-taking. The turn-taking sub-tasks are designed to be implemented on a big touch-screen tablet (Sandtray), incorporated in a table.

- sharing information: On the screen of the tablet are displayed simultaneously 5 pictures. In this task the child has to choose a picture from a series of 5 pictures displayed on a touchscreen (when it is his turn) and wait when the robot chooses a picture (when is robot`s turn).
- categories level 1: On the screen of the tablet are displayed simultaneously 3 pictures (two of them represents categories and the third one is the item that has to be categorized). In this task the child has to categorize the items (when it is his turn) and wait when the robot categorizes (when is robot`s turn).
- categories level 2: On the screen of the tablet are displayed simultaneously 10 pictures (two of them represents categories and the rest of eight are the items that have to be categorized). In this task the child has to categorize the items (when it is his turn) and wait when the robot categorizes (when is robot`s turn).
- patterns level 1: On the screen of the tablet are displayed 6 pictures (2 of them in the middle of the screen and the rest of them arranged in a string). The child has to continue the pattern illustrated by the string (when it is his turn) and wait when the robot adds a picture to the string (when is robot`s turn).
- patterns level 2: On the screen of the tablet are displayed 10 pictures (4 of them in the middle of the screen and the rest of them arranged in a string). The child has to continue the pattern illustrated by the string (when it is his turn) and wait when the robot adds a picture to the string (when is robot`s turn).

Intervention

The tasks developed for the training of the imitation, joint-attention and turn-taking abilities follow a structured behavioral approach called discrete trial training (DTT). According to Smith (2001), DTT can be "useful for teaching new forms of behavior (e.g., speech sounds or motor movements that the child previously could not make) and new discriminations (e.g., responding correctly to different requests)" for children with autism. In this approach, the learning environment is highly structured and directed by an interaction partner, which in our study will be the Nao robot or a psychotherapist. All activities will take place at a table, which

in the case of joint attention and turn taking tasks will be a big touch-screen. Each behavior presented to the child is preceded by the partner's discriminative stimulus or instruction (e.g. ”Do like me!”) and followed by a contingent reinforcement (e.g. “Try again!” ,“Well done!”). The behaviors are presented over multiple and successive trials and explicit prompting is provided when the child doesn’t succeed to accomplish the targeted behavior after several trails.

The group that receives the standard therapy has as interaction partner a psychotherapist and the group that received the robot-enhanced therapy has as the main interaction partner the Nao robot. Partner’s stimulus, contingent reinforcement and prompting are used to train each targeted behavior/action (see Table 1, Table 2 and Table 3). Each action is repeated 3 times. For every child the intervention for each ability starts from the level determined in the first two sessions, but as the child improves his/her performance, we will move to the next level. We intend to reach the highest level possible for each ability for each child.

The imitation ability is trained though following sub-tasks: imitation with objects (e.g. moving a car, pretending to drink from a cup), imitation of gestures (meaningful movements) (e.g. waving one hand and say bye-bye) and imitation of movements without a meaning (Table1).

Table 1.
The structure of imitation task.

Instruction
Provided by the interactional partner (robot or human) “Do like me!”
Response
Provided by the child Moving arms/objects in similar ways as the interactional partner
Consequence
Provided by the interactional partner (robot or human) Depending on the child’s answer If the child executes the requested movement correctly, he/she receives positive feedback: “Well done!” If the child doesn’t execute the requested movement, he/she receives encouraging feedback: “Try again!”

The joint-attention ability is taught using a big touch-screen tablet incorporated in a table. The partner will indicate one of the two images displayed by different means: looking at one picture, pointing to that picture and saying: Look!. The task is presented to the child in a context (e.g. “Now, we will play another game. In this game I will show you the objects I’ve seen in an office.”) (see Table 2).

Table 2.
The structure of joint-attention task.

Instruction
Provided by the interactional partner (robot or human) "Please, pay attention to what am I looking!"
Response
Provided by the child Looking at the picture indicated by the robot
Consequence
Provided by the interactional partner (robot or human) Depending on the child's answer If the child looks at the picture indicated by the robot, he/she receives positive feedback: "Well done!" If the child doesn't look at the picture indicated by the robot, he/she receives encouraging feedback: "Try again!"

The turn-taking ability involves different activities during which the child and his partner have to play by taking turns. The sub-tasks were designed to be implemented on the Sandtray and include: sharing information, assigning items to categories and continuing repeating patterns activities. In the sharing information subtask the pictures appear after the robot/therapist asks questions such as "What is your favorite.. .(sweet, color, etc.)?". The categories used in categories level 1 sub-task are familiar to the children between the ages of 3 to 7 years (e.g. fruits vs. vegetables) and the items that has to be categorized appear one by one. The categories used in level 2 are more difficult and the child has to choose one picture at a time from more simultaneously displayed (ground vehicles vs. water vehicles). The repetitive pattern contains geometrical shapes. At level 1 the repetitive pattern contains two or three repetitive items and the only relevant criterion is the geometrical shape (e.g. rectangle, rectangle, triangle, rectangle, rectangle, ...). At level two, four items repeat and there are two relevant criterions: the geometrical shape and its color (e.g. green squire, star, orange squire, circle, green squire, star, ...; see Table 3).

Table 3
The structure of turn-taking task

Sharing information
Instruction
Provided by the interactional partner (robot or human) a. "First is your turn. What's your favorite ...?" b. "Now is my turn."
Response
Provided by the child a. The child chooses a picture that represents what he/she likes the most. b. The child waits his turn (doesn't move his hands above the touchscreen of the

tablet when is the partner's turn)
Consequence
Provided by the interactional partner (robot or human) Depending on the child's answer a. If the child chooses a picture from that shown on the touch-screen, he/she receives positive feedback: "You showed me very nicely what you like!" If the child doesn't choose a picture from that shown on the touch-screen, he/she receives no feedback b. If the child waits his turn (doesn't move his hands above the tablet), he/she receives positive feedback: "You have waited very nicely!" If the child doesn't wait his turn (he/she moves his hands above the tablet), he/she receives an encouraging feedback: "You have to wait! It's my turn."
Categories
Instruction
Provided by the interactional partner (robot or human) a. "Let's sort... First is your turn." b. "Now is my turn."
Response
Provided by the child a. The child categorizes the items. b. The child waits his turn (doesn't move his hands above the touchscreen of the tablet when is the partner's turn)
Consequence
Provided by the interactional partner (robot or human) Depending on the child's answer a. If the child categorizes correctly, he/she receives positive feedback: "You sorted correctly the picture. Well done!" If the child categorizes incorrectly, he/she receives encouraging feedback: "You sorted incorrectly. Try again!" b. If the child waits his turn (doesn't move his hands above the sand tray), he/she receives positive feedback: "You have waited very nicely!" If the child doesn't wait his turn (he/she moves his hands above the tablet), he/she receives an encouraging feedback: "You have to wait! It's my turn."
Patterns
Instruction
Provided by the interactional partner (robot or human) a. "Let's continue the string!" b. "Now is my turn"
Response

Provided by the child a. The child continues the pattern illustrated by the string. b. The child waits his turn (doesn't move his hands above the touchscreen of the tablet when is the partner's turn)
Consequence
Provided by the interactional partner (robot or human) Depending on the child's answer a. If the child continues the pattern correctly, he/she receives positive feedback: "You matched correctly the picture. Well done!" If the child continues the pattern incorrectly, he/she receives encouraging feedback: "You've matched incorrectly the picture. Try again next time!" b. If the child waits his turn (doesn't move his hands above the sand tray), he/she receives positive feedback: "You have waited very nicely!" If the child doesn't wait his turn (he/she moves his hands above the tablet), he/she receives an encouraging feedback: "You have to wait! It's my turn."

Primary outcomes

As primary outcomes we have: *child's performance to imitate*, *child's performance to make joint-attention* and *child's performance to wait his/her turn*. The child performance in the imitation task will be coded with score 1- if the child executes the requested movement correctly and with score 0- if the child doesn't execute the requested movement. Joint-attention performance is coded with score 1- if the child looks at the picture indicated by the interaction partner and with score 0- if the child doesn't look at the picture indicated. In the case of turn-taking, a score 1- will be given if the child waits his turn (doesn't move his hands above the touchscreen of the tablet when is the partner's turn) and score 0- will be given if the child doesn't wait his turn (he/she moves his hands above the tablet).

Secondary outcomes: engagement

Besides the primary outcomes we also have some secondary outcomes that are relevant for an ASD intervention. The secondary outcomes are: engagement in the task and verbal utterances Engagement in the task is defined as the child's interest and enthusiasm for performing the task and has two components: eye-contact and positive emotions. Verbal utterances are meaningful verbal productions of child, both initiations and contingent responses.

Statistical analysis

Fourteen participants (30% of the expected sample) were included in the following analysis. These children have undergone the initial evaluation of the outcomes and at least 1 session of intervention. Because of the small number and the unequal distribution between the two groups (9 in the human therapist intervention condition and 5 in the robot enhanced intervention condition) we have conducted the analysis using non-parametric statistics, which have permissive assumptions about the distribution of data. Also, there was variation in the number of sessions that each child has undergone until the present moment (between 1 and 4) and thus, as a preliminary analysis, we have decided to use the las observation available for each child (*last observation carried forward*/ LOCF approach). Only primary outcomes were analyzed at this point, namely imitation/IM performance, joint attention/JA performance, and

overall turn taking/TT performance. For TT, we also looked at the performance in the three specific tasks in which this ability was assessed, namely *sharing information*/TT-SI, *categories*/TT-CAT, and *patterns*/TT-PAT. We first checked for the equivalence of the two groups at pre-test, and then we compared changes in each of the two conditions (standard human therapy/SHT and robot enhanced therapy/RET) from pre-test to the last available scores (LOCF). We also compared the two conditions on the LOCF scores. Because of the small number of subjects and their unequal distribution, careful consideration should be given when interpreting inferential results described below. We used *Mann-Whitney U* tests for between-subjects comparisons, and *Wilcoxon Signed Ranks* test for within-subjects comparisons, using *2-tailed* asymptotic distribution for estimating significance level.

Results

On the average, at this point, the 14 children have received 1.60 sessions of intervention until this point. Means and standard deviations (SD) for each treatment condition at pre-test and LOCF are available in Table 1.

Table 1.
Descriptive statistics form main outcomes for pre-test and LOCF scores for the two treatment conditions.

Outcome	SHT ($N = 9$)		RET ($N = 5$)	
	Pre-test	LOCF	Pre-test	LOCF
IM performance	.33 (.35)	.42 (.36)	.35 (.40)	.51 (.48)
JA performance	.86 (.33)	.83 (.33)	.63 (.25)	.50 (.20)
TT performance	.33 (.31)	.54 (.31)	.39 (.34)	.57 (.33)
TT-SI	.28 (.40)	.54 (.38)	.20 (.45)	.44 (.43)
TT-CAT	.33 (.30)	.63 (.30)	.49 (.44)	.68 (.08)
TT_PAT	.38 (.35)	.51 (.36)	.62 (.30)	.68 (.11)

Note: values in parenthesis represent SD; SHT = human standard intervention; RET = robot enhanced intervention; IM = imitation; JA = joint attention; TT = turn taking; TT-SI = turn taking sharing information task; TT-CAT = turn taking categories task; TT-PAT = turn taking patterns task.

Equivalence at pre-test

Mann-Whitney U test indicated that the two groups were equivalent in pre-test on all the primary outcomes (no significant differences were found): for IM, $U = 17.00$, $Z = -.16$, $p = .876$, for JA, $U = 8.50$, $Z = -1.68$, $p = .092$, for TT (overall), $U = 20.00$, $Z = -.33$, $p = .738$, for TT-SI, $U = 18.50$, $Z = -.62$, $p = .534$, for TT-CAT, $U = 18.50$, $Z = -.54$, $p = .589$, and for TT-PAT, $U = 9.50$, $Z = -1.11$, $p = .265$.

Within groups changes

Wilcoxon Signed Ranks Test comparing pre-test scores with LOCF scores in the SHT conditions indicated significant changes for IM, $Z = -2.02$, $p = .043$, and TT-CAT, $Z = -2.52$, $p = .012$. Ranks differences point to an increase from pre-test to the last observation. No differences emerged for the other outcomes: for JA, $Z = -1.00$, $p = .317$, for TT (overall), $Z =$

-1.72, p = .086, TT-SI, Z = -1.63, p = .104, and for TT-PAT, Z = -1.02, p = .310. For the RET condition, no significant changes were observed: for IM, Z =-1.60, p = .109, for JA, Z = -1.41, p = .157, for TT (overall), Z = -1.46, p = .144, for TT-SI, Z = -1.07, p = .285, for TT-CAT, Z = -.37, p = .715, and for TT-PAT, Z = .00, p = 1.00.

Based small sample size, interpretation of significant results reported here should also take into account that no type I error correction for multiple tests has been applied here. A Sidak correction lowering the threshold to α = .004 would make all results not significant.

LOCF comparisons

Between groups comparisons on LOCF showed a single significant difference favoring the SHT intervention, on JA, U = 5.00, Z = -2.13, p = .033. Comparisons on all other outcomes were not significant: for IM, U = 17.00, Z = -0.16, p = .877, for TT (overall), U = 20.50, Z = -.27, p = .789, for TT-SI, U = 19.00, Z = -0.48, p = .634, for TT-CAT, U = 18.00, Z = .00, p = 1.000, and for TT-PAT, U = 13.00, Z = -.51, p = .610. The significant difference found here also would not cross the significance threshold if error I correction is applied (α = .004). All results are graphically represented in Figures 1 to 6.

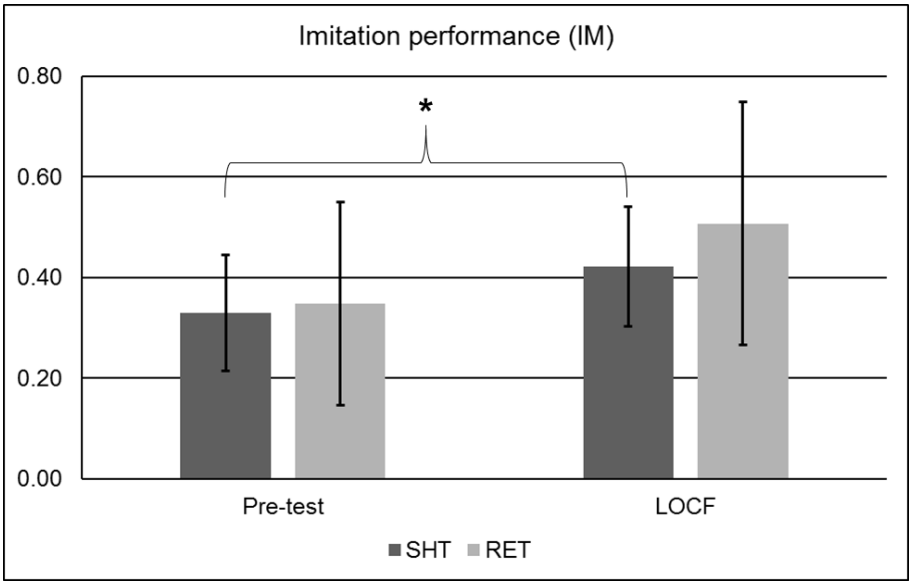

Figure 1. Results for imitation performance (IM). Error bars display standard errors of the mean (SE). Significant differences are marked with "*".

Conclusion

The efficacy of the robot enhanced intervention/RET, delivered by a supervised semi-autonomous robotic agent, is tested in a rigorous design (a randomized clinical trial/RCT) following the standard procedure in evidence-based psychotherapy. The primary outcomes are standard in the field and comprise imitation, joint attention and turn taking performance. These outcomes reflect key abilities that are trained by therapeutic interventions for ASD children. These outcomes will be measured objectively by an autonomous coding system developed in the consortium in the previous phases. Also, the RET intervention will be compared with an active and standard therapeutic condition delivered by a human agent,

which will allow us to offer a clear answer regarding its efficacy (by comparing it to thec current standard of practice).

Thirty five percent (35%) of the expected sample size has been recruited, assessed, and has undergone at least one intervention session. Due to the small sample size, the unequal distribution of the participants in the two conditions (resulted from the blind randomization process) and the small number of session, the preliminary results present in this deliverable do not allow us to formulate any clear predictions about the final results. Speculating on the observed trends we can see that groups have equivalent baseline levels indicating that the randomization process was efficient until this point and will likely result in comparable groups in terms of pre-test scores. The SHT intervention has already lead to significant improvements on imitation and one of the sub-tasks forming turn taking. Indeed, the stability of this result might be questioned because of the low numbers of participants and intervention sessions. For the robot condition we can see improvements as well on the same outcomes, but the lower number of subjects in this condition affect the statistical power and this might have reduced the chance to identify a statistically significant effect. In fact, both groups show signs of improvement (based on the descriptive and graphical data) on all outcomes, except for joint attention. This is a curious results and it is hard to find an explanation in this preliminary phase. This is also the outcome on which the SHT condition appeared to be superior to the RET condition, based on LOCF scores. However, given that there was no improvement in any of the conditions on this outcome, it is hard to interpret this results in a meaningful way. This outcome will be carefully monitored and more children and sessions might change it in the expected direction or at least they might offer more clues about its causes.

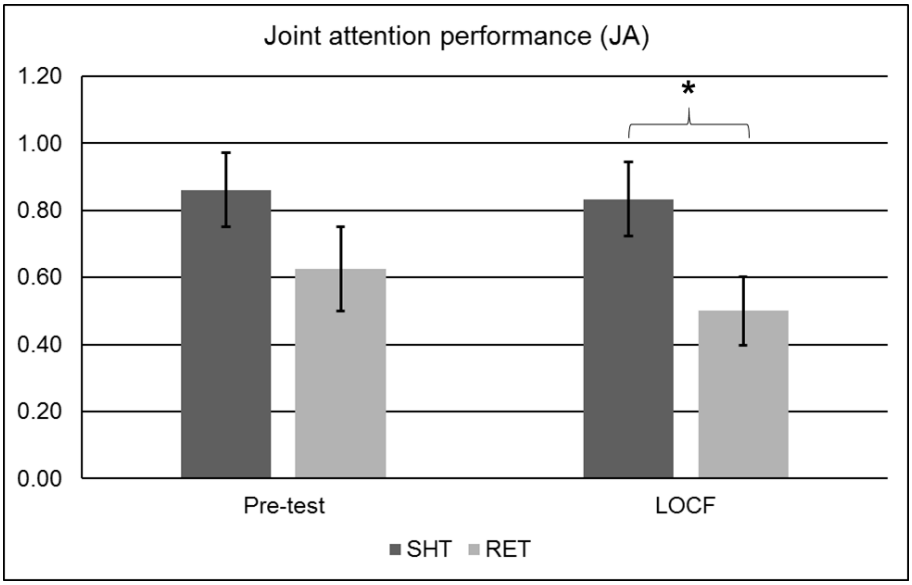

Figure 2. Results for joint attention performance (JA). Error bars display standard errors of the mean (SE). Significant differences are marked with "*".

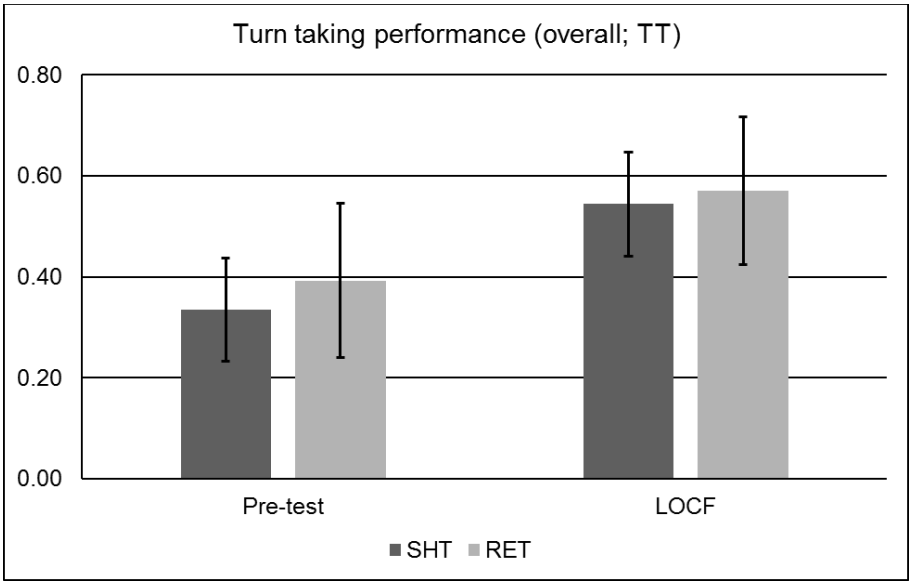

Figure 3. Results for turn taking (overall; TT). Error bars display standard errors of the mean (SE).

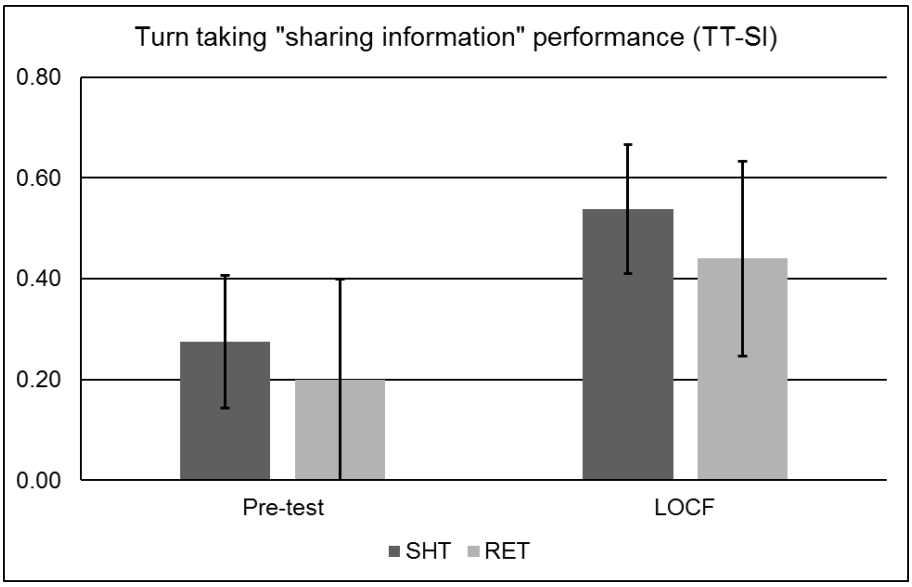

Figure 4. Results for turn taking "sharing information" (TT-SI). Error bars display standard errors of the mean (SE).

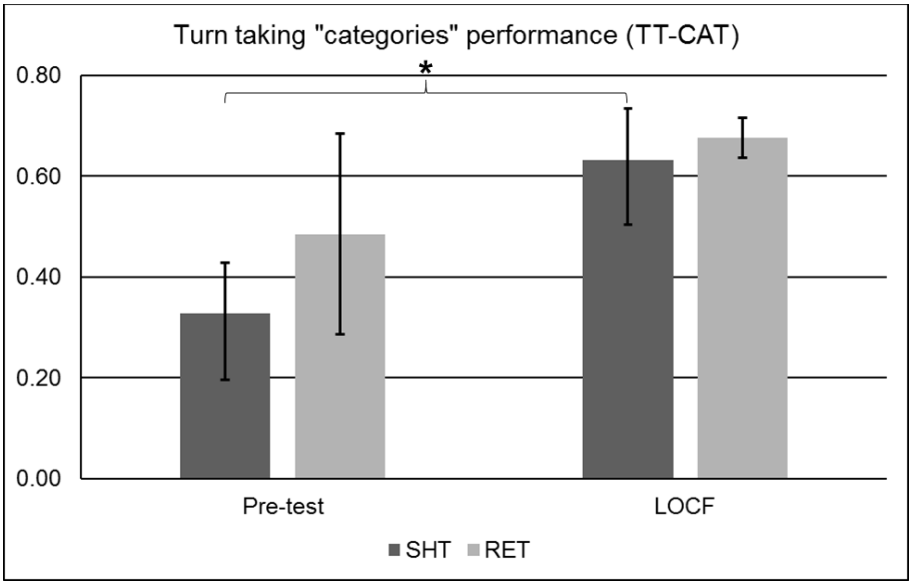

Figure 5. Results for turn taking "categories" (TT-CAT). Error bars display standard errors of the mean (SE). Significant differences are marked with "*".

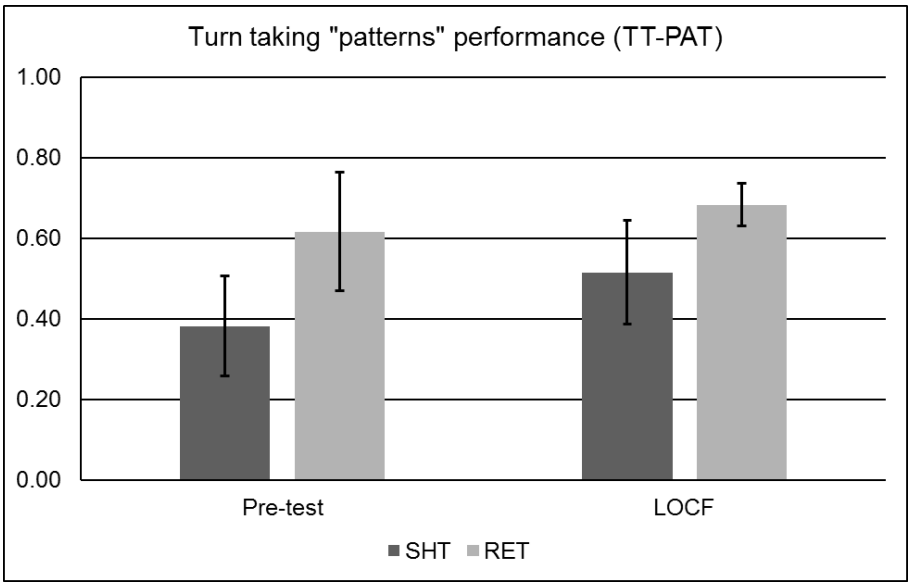

Figure 6. Results for turn taking "patterns" (TT-PAT). Error bars display standard errors of the mean (SE).

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