Children with autism social engagement in interaction with Nao, an imitative robot

A series of single case experiments

Adriana Tapus[1], Andreea Peca[2], Amir Aly[1], Cristina Pop[2], Lavinia Jisa[2], Sebastian Pintea[2], Alina S. Rusu[2] & Daniel O. David[2]
[1]ENSTA-ParisTech, France / [2]Babes-Bolyai University, Romania

This paper presents a series of 4 single subject experiments aimed to investigate whether children with autism show more social engagement when interacting with the Nao robot, compared to a human partner in a motor imitation task. The Nao robot imitates gross arm movements of the child in real-time. Different behavioral criteria (i.e. eye gaze, gaze shifting, free initiations and prompted initiations of arm movements, and smile/laughter) were analyzed based on the video data of the interaction. The results are mixed and suggest a high variability in reactions to the Nao robot. The results are as follows: For Child2 and Child3, the results indicate no effect of the Nao robot in any of the target variables. Child1 and Child4 showed more eye gaze and smile/laughter in the interaction with the Nao robot compared to the human partner and Child1 showed a higher frequency of motor initiations in the interaction with the Nao robot compared to the baselines, but not with respect to the human-interaction. The robot proved to be a better facilitator of shared attention only for Child1.

Keywords: human-robot interaction; assistive robotics; autism

1. Introduction

Autism Spectrum Disorders (ASD) refers to a group of neurodevelopmental disorders characterized by impairments in social interaction, deficits in communication and restricted and repetitive behaviors and/or interests (A. P. Association 2000). Some of the striking social impairments that are widely described in the autism literature are the deficit of imitating the others (Pennington 1991; Williams 2004), the incapacity of reading other's emotional expressions (Hobson 1986; Celani 1999), and the limitation in initiating (Charman 1997) and responding to joint attention behaviors (Leekman 1997).

Interaction Studies 13:3 (2012), **315–347.** DOI 10.1075/is.13.3.01tap
ISSN 1572–0373 / E-ISSN 1572–0381

Existing studies from the literature show that children with ASD have a great affinity with mechanical components, computers, and robots (Hart 2005). Both computer-based virtual environments (Parsons 2004) and embodied robots have therefore been proposed for facilitating social interactions in children with autism. An active area of socially assistive robotics (SAR) (Feil-Seifer & Matarić 2005) is studying robots as tools in socialization therapy for children with ASD, where robots have been shown to have great potential (Duquette & Michaud 2007; Salter & Michaud 2010; Scassellatti 2005a; Michaud & Laplante 2007; Kozima 2009; Dautenhahn 2009; Dautenhahn 2006).

Several projects are exploring ways of using robots as agents for therapeutic interaction. The European project AuRoRA (Dautenhahn 2006) uses simple mobile robots to help guide children with autism toward more complex social interactions. One of the experimental test-beds used during the project is the humanoid doll, called Robota. Different experiments were designed with Robota that had a general scope of encouraging imitation, joint attention, and social interaction skills in children with autism (Robins & Billard 2005). In a study conducted by Dautenhahn and Billard (2002), Robota was involved in an imitation game between the robot and 14 children with autism. The robot was programed to imitate gross motor movements of the children and also to perform movements on its own in order to encourage the children to mirror its movements. The results were inconclusive, and the study was considered to have some important drawbacks: (1) the children were required to sit still at the experimental table, facing the robot, and to move their arms in a very distinctive manner due to limitations in the vision system that cannot identify subtle movements; (2) the interaction involved a great amount of verbal prompting from the teacher and therefore the spontaneous initiations were limited; and (3) each child was exposed to the robot only once and hence children may have been reticent to interact with a novel partner. Based on these results, Robins et al. (2005) designed a longitudinal study for analyzing the reciprocal imitative interaction between children and Robota. This time, they decided to use a much more unconstrained setup, to expose the children to multiple interaction sessions, and to reduce as much as possible the prompting from the therapists in order to facilitate a more spontaneous interaction. The results indicate that the imitation and the touch behaviors increased considerably in the last trials. These results are important, but there is still a need for comparison between human-robot interactions and the same interactions performed in a human-human context. This comparison would reveal whether robots can bring any improvement in teaching social skills or in facilitating social engagement behaviors in children with autism disorder.

More recently, a new minimally expressive robot called Kaspar was developed (Dautenhahn 2009b). The authors in (Wainer 2010) use Kaspar in a dyadic game so as to determine whether a humanoid robot-child with autism collaborative interaction would influence the human therapist-child collaborative interaction in the same context. Another interesting and simple robot design is Keepon (Kozima 2009), used to establish a triadic interaction between a child, itself and the therapist. Kozima et al. (2009) conducted a longitudinal study (a year and a half – 500 child-sessions) and they noticed that Keepon played the pivot role in the triadic interaction. Moreover, in (Duquette & Michaud 2007 and Salter & Michaud 2010) different robotic designs (e.g. spherical ball, elephant toy) are explored in playful interactions with children with autism. Furthermore, in (Feil-Seifer & Matarić 2011) a new method for automatically determining whether a child is interacting positively or negatively with a robot is described, thus giving rich information about the state of the child with respect to the robot. Another robot that was tested as a therapeutic tool for children with autism is Probo. In (Vanderborght 2012) the Probo robot was compared to a human as a social story telling agent so as to see which of the two is a better facilitator of performance in a series of social tasks. The results suggest that Probo was better at improving the social interaction, motivation, and communication skills of children with autism.

Imitation plays a very important role in child development, being one of the precursors of social cognition. According to Nadel, preverbal children use synchronic imitation as a means to communicate (Nadel 2004). Some studies argue that there are imitation deficiencies in autism (Rogers 1999; Williams 2004). Moreover, the authors in (Stone 2006) identified motor imitation as a valid discriminating factor between children with autism and children with severe mental disabilities, hearing impaired, and language impaired children, while other studies argue that the relation between imitation and autism is mediated by the level of cognitive development (Charman 1994). Even though some children with autism imitate spontaneously and other children with autism can learn to imitate, the dynamics of imitation (i.e. the role-reversal behaviors, turn taking, initiation of new behaviors, adapting its own behavior to the other's behavior) is affected in the large majority of cases (Tomasello 1999; Carpenter 2005; Nadel 1999). Hence, if typically developing children usually have no problem imitating the behavior of others, children with autism show a deficit in this ability (Vivanti 2008), therefore causing serious consequences for their social interaction and communication. Improving the imitation skills of children with autism through specifically designed treatments based on imitation may yield to an improvement in social development. Many clinical studies have shown the effectiveness of adults imitating children with autism and vice-versa (Dawson & Adams 1984; Dawson & Galpert 1990; Nadel 1982 and Nadel 1986) in play situations by enhancing imitation, recognition of being imitated, and nonverbal communication (Nadel 2004).

For example, Dawson and Adams (1984) argue that children with autism and with a low level of imitative ability were more socially responsive, showed more eye contact, and played with toys in a less perseverative manner when their behavior was imitated by the experimenter. In another study, Nadel and colleagues (2000) used a modified version of the "Still Face Paradigm" to investigate whether children with autism form expectancies for human behavior after being imitated by another person. The results showed that in the second still face session, a series of social behaviors (e.g. looking at person, negative facial expressions, positive social gestures, close proximity, and touch) were significantly higher, suggesting a violation of the expectancies the children have developed. Moreover, Nadel (2004), in a study on imitation recognition in children with autism, found that there was a significant correlation between the level of imitation and the level of imitation recognition. Some children with autism recognized they were imitated and tested the intentionality of the imitator through strategies like changing the rhythm of activity, or changing the object used, or stopping the current action while gazing at the experimenter. On the other hand, those who did not test the experimenter, but increased the attention and positive affect towards the partner, may indicate an awareness of being imitated but do not understand the intentionality of the partner. These findings are explained by the theory of Active Intermodal Mapping (AIM) proposed by Meltzoff and Moore (1995, 1997) that addresses how infants become connected to the social world. This theoretical model claims that starting from birth, children are involved in active, simultaneous matching of sensory input, and proprioception. This coupling of the observation and execution of human acts is mediated by a "supramodal" representation of acts (Meltzoff & Moore 1997). The observed increase in the overt social behaviors when being imitated may be the consequence of the detection of the contingency between own and the other's movements, leading to an awareness of being imitated. Even though children with autism seem to understand that they are imitated, they seem to initiate less testing behaviors, which may be indicative of a lack of intentionality understanding or as a lack of motivation to communicate. Klin (2009), in a research work focusing on the preference for biological versus nonbiological movement, obtained data indicating that children with autism have impaired detection of biological motion, and are highly sensitive to non-social physical contingencies that occurred within the stimuli by chance. Two studies found increased imitation speed to robot models in comparison to human models (Bird 2007; Pierno 2008), suggesting that individuals with ASD might benefit from tasks that involve imitating robots in comparison to imitating humans (Diehl 2012). As Diehl and colleagues (2012) stated, it is unclear whether the findings are the result of cognitive factors related to imitation or an affective preference for the robot over the human.

Based on the results of Nadel (2000, 2004) and Dawson and Adams (1984), in this study, we want to investigate whether children with autism show more testing behaviors when being imitated while interacting with a non-social agent. Building on results of Bird (2007) and Pierno (2008), we expect that the motor acts of Nao robot to be better facilitators of the child's own motor acts, and based on the results of Klin (2009) we expect that the robot's movements, perceived as physically contingent, to be preferred and more adequately processed compared to the socially contingent ones. Therefore, in this study, we investigate whether children with autism show initiations more often and more social engagement behaviors when their actions are being mirrored by the Nao robot compared to a human partner in a motor imitation task. In this context, we expect that the robot, contingently mirroring the child's arm movements, will act as a natural reward system, increasing the children's motivation to enhance the rate of motor initiations and increasing their smiling/laughter and eye gaze behaviors. We describe a Wizard of Oz (WoO) technique for children's upper-body imitation with the robot. The system is tested with the mini-humanoid Nao robot.

2. Experimental platform and system design

2.1 Test-bed robot

The experimental test-bed used in this study is the humanoid Nao robot (see Fig. 1) developed by Aldebaran Robotics.[1] Nao is a 25 degrees of freedom robot, equipped with an inertial sensor, two cameras, eyes eight fullcolour RGB LEDs, and many other sensors, including a sonar which allows it to comprehend its environment with stability and precision.

Figure 1. Test-bed: Nao robot

2.2 System design

In addition to the robot, we used a Kinect sensor. The depth data coming from the Kinect camera is used by the PrimeSense middleware in order to perform skeleton tracking. The users that are within the view range of the camera are detected and the position of their bodies is tracked. The skeleton data (i.e. joints and rotation positions) is transmitted to a Nao robot which is mirroring the user upper-body position. Our system needs a short period of time for calibration and we need the user to remain in the view range of the camera. The skeleton tracking is done for the first calibrated user that is currently visible to the sensor. When multiple persons appear in front of the Kinect camera, no interferences will appear and the tracking will still be done for the initial calibrated person. More information can be found in the OpenNI/NITE documentation.[2]

Our clinical psychologist collaborator indicated to us that it would be very difficult for the children with autism participating in the experiments to stay still for the calibration process. Therefore, we were constraint to use the Wizard-of-Oz (WoO) technique and to split the room in two parts as explained in the subsection 3.5 (see Fig. 3), in order to be able to focus on the goals of this study.

An example of an interaction between the child and the robot with the corresponding depth image and the extracted skeleton is shown in Fig. 2.

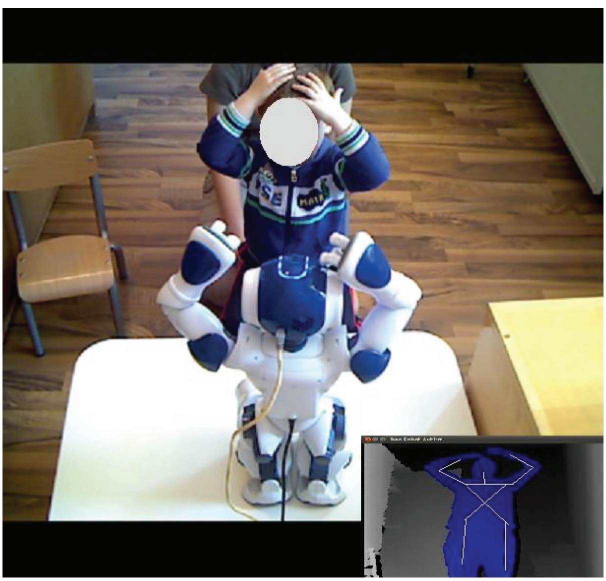

Figure 2. Child2 interacting with Nao robot and the corresponding depth image of the helper (the person staying on the other side of the room). Please see Fig. 3 for a more detailed description

3. Method

3.1 Participants

Five children with a DSM-IV (A. P. Association 2000) diagnosis of autism, and one child with elements of autism, all boys, ranging in age from 2 years and 8 month to 6 years (*M* = 4.2, *Sd* = 1.67), were recruited from the Autism Transylvania Therapy Center (ATTC), Cluj-Napoca, Romania. The inclusion criteria were the following: (a) a medical diagnosis of ASD confirmed by a clinical psychologist using the Childhood Autism Rating Scale (CARS) (Schopler 1980); and (b) an average ability to imitate gestures on demand according to the gestures subscale from the Motor Imitation Scale (Stone & Littleford 1997). We used additional data about the children's cognitive and language level of development, assessment made by an experienced clinical psychologist using the Carolina Curriculum for Preschoolers with Special Needs (CCPSN) Assesement Profile. One participant had to be excluded from the study due to their unavailability for all the phases of the experiment. The entire study was carried out under IRB procedures at Babes Bolyai University. Informed consent for participation was obtained from the parents. All the consent forms were reviewed with each family involved in the study and all questions were answered before consent was obtained and before the experiments took place and data was gathered.

3.2 Participants description

- **Child1** is 4 years and 6 months old and has a moderate level of autism (CARS assessment). According to a trained clinical specialist, his language abilities are equivalent to those of a 2-year old child, and his cognitive level of a 3-year old. His imitative abilities are well developed but the dynamic of imitation is disrupted (i.e. turn taking, initiation). Child1 has a very low rate of initiations in interaction and most of the time he is unmotivated to interact with other persons.
- **Child2** is 2 years and 6 months old and has a medical diagnosis of delays in language development and elements of autism (CARS assessment). His social interaction abilities are relatively high (e.g. he uses pointing and signs to explain situations and to compensate the deficits in language). His gesture imitation abilities are good. His language abilities are equivalent to those of a 1.5-year old child, and his cognitive level of a 2-year old. He suffers from poor development in symbolic/representational play and has some motor and verbal stereotypes. He enjoys and understands social interaction with people if these are simple.

– **Child3** is 6 years old and has a moderate level of autism (CARS assessment). His cognitive abilities are equivalent of a 3-year old child and his language abilities of a 2-year old child. Child3 seeks the presence of other persons, but prefers physical interaction to any other kind of play. He is hyperactive, his attention span is very low, and if he is not involved in some structured activities, he continuously gets involved in self-stimulatory behavior.
– **Child4** is 4 years old and has a medical diagnosis of severe autism and epileptic modifications (CARS assessment). His cognitive abilities are equivalent of a 1.5-year old child and he is nonverbal. He is extremely resistant to change and he actively resists interaction with people. The ability to imitate on request has been intensively trained in the therapy at the ATTC, and therefore the motor response to someone else's initiations is relatively good when a strong reward is granted, even if the gestures lack precision.

3.3 Environmental setup

The study was conducted in a 4m x 4m testing room (see Fig. 3). The room was split into two areas by a false wall. The left part of the room featured a table and one chair for the child. The child interacted directly with the robot that was positioned on the table (see Fig. 4). In the right part of the room the operator controlled the robot's movements by using the Kinect sensor and by observing the child's movements on a computer connected to a webcam.

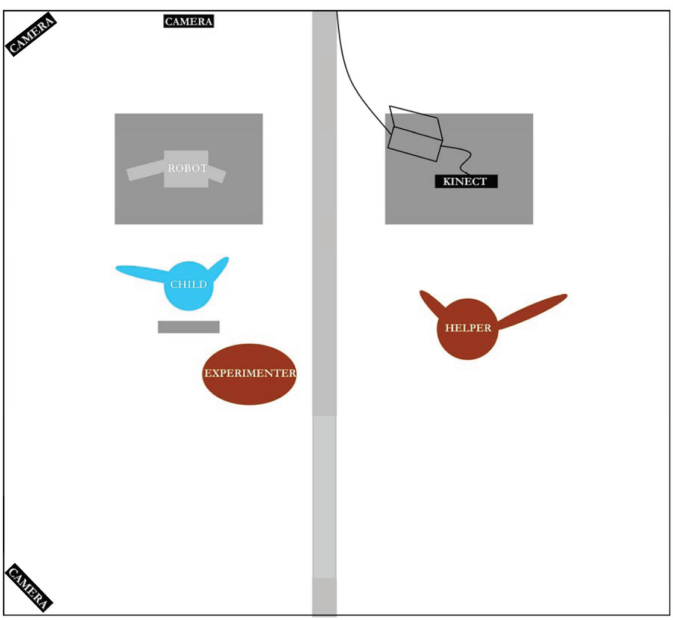

Figure 3. Description of the experimental room

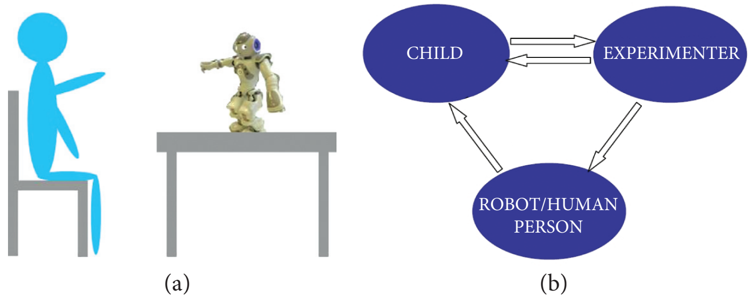

Figure 4. Interaction setup: (a) Positioning of the child and Nao robot platform; (b) Description of the triadic interaction. The arrows represent the flow of interaction

Three video cameras were placed in the experimental room, one camera behind the robot so as to capture the facial expressions of the children as they interacted with the robot, one in a fronto-lateral position, and the last one in the back of the room, in order to catch the prompting behavior of the experimenter and to record an overview of the room.

3.4 Hypothesis

In this study, we aim to verify the following research hypothesis:

H1: Children with autism will show more initiations and more social engagement behaviors in the presence of the Nao robot compared to the human partner when exposed to a motor imitation game.

We formulate the following more specific predictions:

- We expect that the frequency of free initiations (without prompt) to be higher in the Nao-interaction phase compared to the human-interaction phase.
- We expect that the frequency of total initiations (with and without prompt) to be higher in the Nao-interaction phase compared to the human-interaction phase.
- We expect that the duration of the eye gaze to the partner to be higher in the Nao-interaction phase compared to the human-interaction phase.
- We expect that the duration of smile and/or laughter to be higher in the Nao-interaction phase compared to the human-interaction phase.
- We expect that the frequency of gaze shifting between the two partners to be higher in the Nao-interaction phase compared to the human-interaction phase.

3.5 Procedure

The study took place over a 4-week period. Each child had two intervention sessions per day: one for the dyadic interaction and one for the triadic interaction, separated by a 10-minute break.

A single-subject ABAC design (Kazdin 1982; Tawney & Gast 1984) with replication across the four participants was employed. This research design is commonly used in clinical settings, it can prove whether an intervention is functionally related to an outcome data, and it can measure the magnitude of the outcome changes (Janosky 2009; Riley-Tillman 2009).

The independent variable is the type of interaction agent: robot versus human person. The dependent variables measured were: frequency of free initiations (without prompt), frequency of total initiations (with and without prompt), duration of eye gaze to the partner (robot/human), duration of smile and/or laughter, and frequency of gaze shifting between the two partners.

Moreover, due to the different duration of the trials, in order to minimize the errors, all the variables measured were normalized by time.

We defined the measured variables as follows:

- **Free initiations** refer to the gross motor actions the child performs without prompt, while gazing at the interaction partner (robot/human).
- **Initiations with prompt** refer to the gross motor actions the child performs, which are triggered by a soft physical prompt (i.e. softly touching the elbows of the child for one second) or by a modeling prompt in triadic interactions (i.e. the experimenter performs the action as a demonstration).
- **Eye gaze** refers to the duration the child gazes at the interaction partner's face or arms area.
- **Gaze shifting** refers to the shifting gaze between the two interaction partners.
- **Smiling/Laughter** is measured as duration.

3.5.1 Condition – A(1)

The baseline procedure A(1) consisted of a motor imitation interaction game between the experimenter and the child. The experimenter had several free play sessions with the children before the beginning of the procedure. The baseline was measured for each child over a one-week period in sessions with an average of 5 minutes in duration.

The child and the experimenter were seated on two opposite chairs with a small table separating them. The procedure consisted of a series of imitative turn-takings between the child and the experimenter. We tried to develop a bidirectional imitation game that has the dynamics of a natural interaction game a child and another partner usually play. The experimenter produced several motor acts (e.g. gently hitting the table alternatively in the left and right top-corners, simulating playing the piano, moving the arms laterally), waiting after each behavior for the child to initiate a motor act in response, and mirroring this movement when it appeared. If the child did not produce any motor act in a 10-second period, the experimenter produced another motor act.

3.5.2 Condition – B

The B phase was composed of several conditions: Familiarization; Modeling; Dyadic Interaction; and Triadic Interaction.

Each condition is described below:

- **The familiarization** phase lasts between 5 and 10 minutes, depending on the child's reaction towards the robot. The experimenter and the child enter the room together. During this phase, the Nao robot is introduced to the child. When the child seems comfortable enough in the presence of the robot the following scenario is introduced:
  - The child is prompted to wave hello and bye bye at the beginning and at the end of the interaction, respectively and the robot responds with a similar gesture;
  - The child is encouraged to ask the robot its name and the robot answers back;
  - The robot's eyes color changes several times at the child demand;
  - The robot nods its head yes or no according to some questions the child or the experimenter asks.
- **The modeling** condition lasts 1 minute. During this period, the experimenter interacts with the robot in order to show to the child what Nao robot can do. The child is asked to sit on a chair next to the experimenter and to watch the experimenter-robot interaction. The experimenter sits in front of the robot and performs a series of motor acts: Rising left/right arm vertically; Rising both arms vertically; Rising left/right arm horizontally; Rising both arms horizontally; and Simulating flight. Contingently with the experimenter's movements, the robot mirrors the movements of the arms.
- **The dyadic interaction between the child and the robot** is the third condition. The duration of this phase is between 2 and 5 minutes. The child is placed on a chair in front of the robot. The experimenter stands behind the child, offering at first several physical prompts (on average 4–5 prompts) and then retreating behind and waiting for the child's reactions. If the child has no motor initiation, the experimenter offers minimal intrusive physical prompts by touching the child's arms approximately every 30 seconds.
- **The triadic interaction between the child, the experimenter and the robot** is the last phase of the procedure. This phase lasts between 2 and 5 minutes with an average duration of 3 minutes. The child, the experimenter, and the robot sit in a triangle. The experimenter is a demonstrator of the motor actions.

Each time, he initiates one movement, he waits in position for several seconds offering the child an opportunity to initiate and then comes back to the initial position. The robot only mirrors the child's motions (see Fig. 4). If the child initiates a gross arm movement, the robot and the human person mirror it immediately.

3.5.3 Condition – A(2)

The second A(2) implied the same experimental procedure as the first baseline and it also lasted one-week.

3.5.4 Condition – C

The C phase consisted of an interaction similar to the one presented in phase B, except that the robot was replaced with a specially trained human person that the children were not familiar with. This person was instructed to mirror only the gross motor gestures of the child's arms, therefore simulating the behavior of the robot. Furthermore, this person sat on a small chair, so that the height of the person was similar to that of the robot (from phase B).

This phase also had the same conditions as phase B: Familiarization; Modeling; Dyadic Interaction; and Triadic Interaction.

All sessions were finished when children manifested the desire to leave the place. We used open-ended sessions as we considered that a strictly standardized procedure would not correctly capture the spontaneous movement initiations of the children.

4. Results

Over all sessions with the four participants, we recorded a total of 186 minutes of experiment time that involved human-robot interaction (phase B), and a total of 377 minutes of experiment time including the ABAC conditions. Not all children interacted for the same amount of time with the robot and per session (see Table 1).

Table 1. The number of sessions per child for each phase of the ABAC design model

	Child1	**Child2**	**Child3**	**Child4**
1. Baseline A(1)	**7**	**4**	**4**	**4**
2. B (Nao robot)	**7**	**8**	**8**	**13**
– dyadic	4	5	4	10
– triadic	3	3	4	3

(*Continued*)

Table 1. (Continued)

	Child1	Child2	Child3	Child4
3. Baseline A(2)	**4**	**6**	**9**	**6**
4. C (person)	**8**	**7**	**2**	**2**
– dyadic	3	3	1	1
– triadic	5	4	1	1
Total	**26**	**25**	**23**	**25**

For the analysis step, the videos were manually annotated by 3 clinical psychologists, trained to correctly identify the target behaviors (see Table 2) according to the definitions of the variables. We performed a quantitative analysis. We also presented a series of additional observations that describe the children behavior in the modeling and familiarization phases, and capture some particular behaviors of the children that are not transparent in the quantitative analysis.

Table 2. The data extracted during manual video annotation

Video extracted data
Frequency of free initiations/second
Frequency of physical prompt/second (in dyadic condition, in B and C phases)
Frequency of modeling prompt/second (in triadic condition, in B and C phases, and in baselines)
Percentage of smile/laughter from the total duration (in all the phases of the experiment)
Percentage of attention (eye gazing) to the partner (robot/human) from the total duration (in all the phases of the experiment)
Experimenter prompts without success (in all the phases of the experiment, physically or modeling)
Frequency of shared eye gaze/second (in B and C phases)

For the quantitative analysis of the data, we used IBM SPSS (Statistical Packages for the Social Sciences)[3] version 16. The Mann-Whitney test was used to analyze the difference between all the phases of the experiment. The Mann-Whitney test was considered appropriate because it is a distribution-free test and because we have a small number of scores in each condition. The dependent variables were measured by coding the entire interaction in each phase of the experiment. The level of all the outcomes across the four phases of the experiment, for each child, is presented in Figures 5–8.

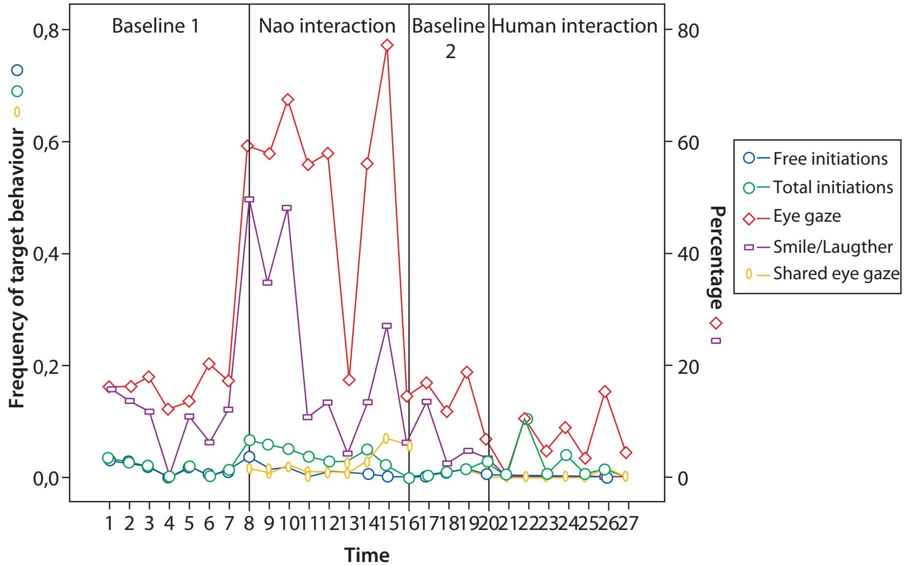

Figure 5. The outcome data for Child1

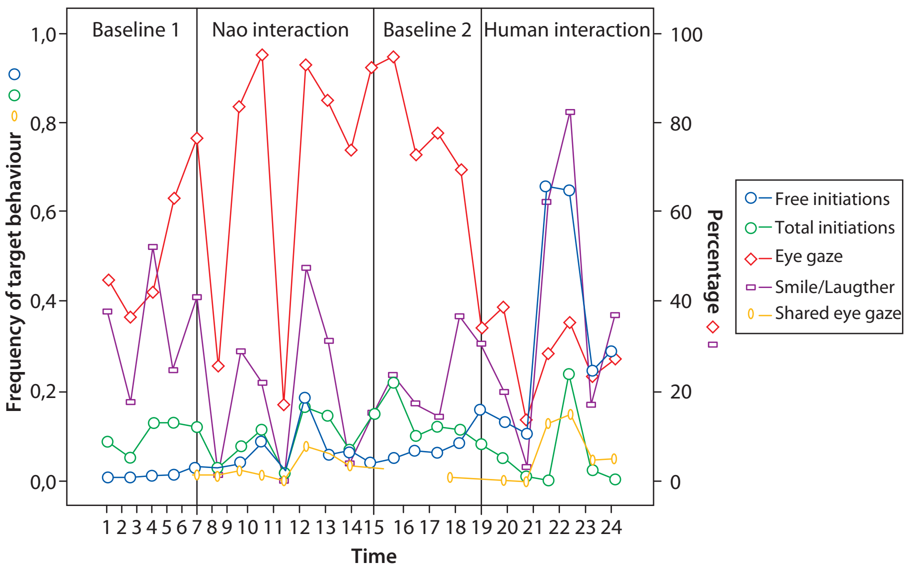

Figure 6. The outcome data for Child2

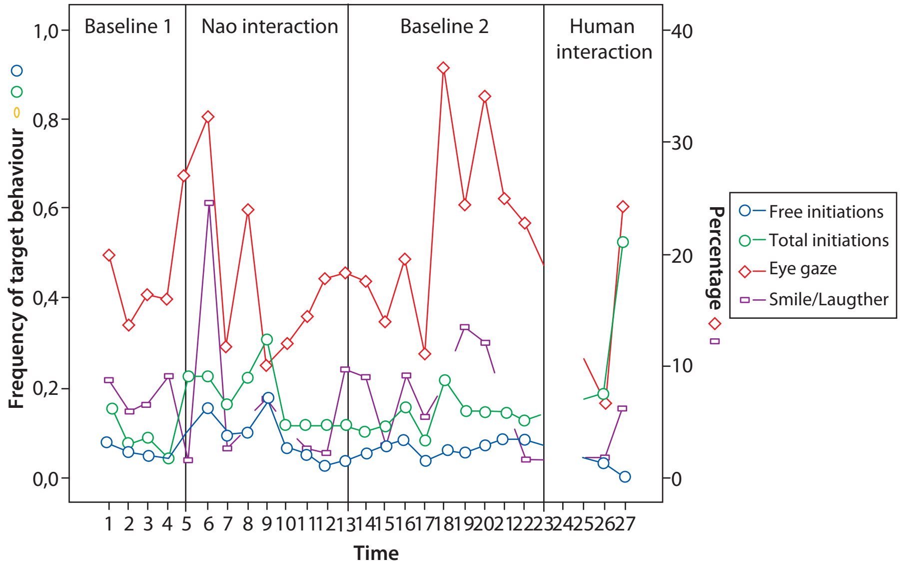

Figure 7. The outcome data for Child3

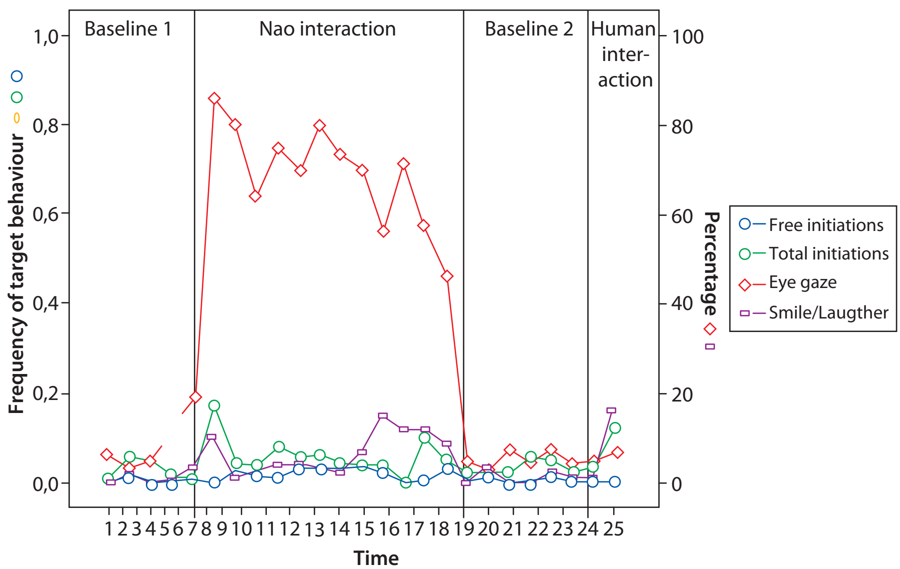

Figure 8. The outcome data for Child4

In the analysis of the data, we mixed the data from the dyadic and triadic interaction procedures in the same pool of data. This decision was based on the fact that the physical prompting offered in the dyadic phase and the modeling prompting offered in the triadic phase had a similar impact on the initiation rate.

Moreover, regarding the shared eye gaze behavior, it can only appear when the child and the human have a shared object of interest. In our study, in the baseline, we only had two agents in the room, so that the child could not initiate shared eye gaze episodes. In the experimental B and C sessions (both dyadic and triadic interaction), we had three agents in the room: the child, the robot/the human and the experimenter.

In order to verify the reliability of the coding for the target variables, a subset (20%) of the video data was randomly selected for each of the children and coded independently by a second experienced clinical psychologist. In order to check the reliability of scoring, Cohen's Kappa Coefficient was used. The Kappa scores obtained in the test of the subset of trials for the children was 0.89, indicating a good reliability.

Below we will show a detailed data analysis for each child participating in the study.

4.1 Data analysis: Child1

4.1.1 *Visual and statistical analysis of the data collected during the baselines and intervention phases for Child1*

In each experimental phase, we performed several interaction sessions in order to capture a trend or a level of the dependent variables measured. We did not expect to reach stable values of the variables as the behaviors we measured typically fluctuate and the number of measurements taken is relatively low, as can be seen on the graphical representation of the data (see Fig. 5).

Total number of initiations with or without prompt: The visual analysis of this variable indicates a low value of the variable in the two baseline phases, an increase in the level of the variable in the phase B (Nao-interaction), and a stabilization of the data in the same phase. In the phase C (human-interaction), the level of the variable is lower than in phase B with only one exception.

The statistical analysis indicates a significant increased frequency of the target behavior in phase B (Nao-interaction) compared to the two baselines A(1) and A(2) (see Table 3), suggesting the superiority of the simplified procedure in facilitating initiations of motor actions, without finding a significant difference between the two interaction agents (robot vs human person).

Table 3. Statistical analysis with Mann-Whitney test for Child1: Comparison of the results of all phases

	A1 vs B	B vs A2	A2 vs C	A1 vs C	A1 vs A2	B vs C
Total Initiations	$Z = -2.66$ $p = .066$ $A1 < B$	$Z = -2.72$ $p = .066$ $B > A2$	$Z = -.72$ NS	$Z = -.35$ NS	$Z = -1.52$ NS	$Z = -1.79$ NS
Free Initiations	$Z = -.92$ NS	$Z = -.86$ NS	$Z = -1.56$ NS	$Z = -2.82$ $p = .005$ $A1 > C$	$Z = -1.53$ NS	$Z = -2.54$ $p = .011$ $B > C$
Eye Gaze	$Z = -3.00$ $p = .003$ $A1 < B$	$Z = -2.54$ $p = .011$ $B > A2$	$Z = -2.37$ $p = .017$ $A2 > C$	$Z = -3.00$ $p = .001$ $A1 > C$	$Z = -.37$ NS	$Z = -3.36$ $p = .001$ $B > C$
Smile/ Laughter	$Z = -1.50$ NS	$Z = -1.69$ NS	$Z = -2.84$ $p = .004$ $A2 > C$	$Z = -2.95$ $p = .003$ $A1 > C$	$Z = -1.13$ NS	$Z = -3.50$ $p = .000$ $B > C$
Shared Eye Gaze	– –	– –	– –	– –	– –	$Z = -3.07$ $p = .002$ $B > C$

Free initiations: The visual analysis of the graphical representation of free initiations reveals a stable low level of the variable across the four experimental phases. Even if in the first sessions of interacting with Nao robot, in the first few minutes, the child manifested some free initiations associated with laughter triggered in the moment the movement was mirrored by the robot, the graph (see Fig. 5) does not reflect that because the data represents relative frequencies. The duration of the Nao-interaction was longer than the duration of the other phases, and therefore the weight of the imitations with Nao diminished. The statistical analysis of the data indicates that in the case of the free initiations outcome, there is no significant difference neither between baselines A(1), A(2) and phase B (Nao-interaction), nor between the second baseline A(2) and phase C (human-interaction) (see Table 3). However, when comparing phase B and phase C, a significant difference favors phase B (Nao-interaction).

Eye gaze: Visual analysis of the eye gaze indicates that in the first baseline A(1), the level of eye gaze is low and relatively stable. In the condition B (Nao-interaction), the level of eye gaze increases considerably and is relatively stable with an exception. In the second baseline A(2), the level of the variable decreases to the first baseline level and again, remains steady at this level. Moreover, in phase C (human-interaction), the level of the variable is decelerating and remains steady at a lower level. Statistical analysis indicates that the eye gaze variable is significantly higher in phase B (Nao-interaction) compared to the two baselines A(1), A(2) and compared to phase C (human-interaction), which rather has a negative effect (see Table 3). Such a result suggests the superiority of the Nao robot in attracting the child's attention.

Smile/Laughter: Visual analysis of the positive affect variable shows a great similarity between the trend of smile/laughter behavior and the trend of the eye gaze directed to the interaction agent along the four phases of the study, while the level of positive affect variable remains constantly lower compared to the eye gaze variable. The graphical representation of the data indicates that in phase B (Nao-interaction), the target variable seems to increase its frequency from the first baseline A(1), but the increasing trend appears only in the first three measurements data. The non-parametrical comparison between the two phases proved no significant differences (see Table 3). This data seems to sustain the conclusion that the Nao-interaction procedure had a significant positive effect on the positive affect variable, but that the effect diminished after three sessions, possibly due to the habituation effect. The results graph, from the second baseline A(2) to phase C (human-interaction), seems to depict rather a decrease of the frequency of smile/laughter behavior, which is indicated by the non-parametric comparison as a significant one. The comparison between phase B (Nao-interaction) and phase C (human-interaction) indicates a significant higher effect of the Nao-interaction procedure.

Shared eye gaze: Visual analysis of the shared eye gaze graphical representation, confirmed by the statistical analysis, reveals a higher level of shared eye gaze in phase B (Nao-interaction), with a positive trend in the last two sessions, compared to phase C (human-interaction), where the shared eye gaze behavior was almost absent.

4.1.2 *Additional observations of the interation for Child1*

In the first baseline A(1), Child1 actively avoided looking at the partner and manifested a lot of stereotypical motor behavior.

In the phases B (Nao-interaction), in the first session, Child1 expressed an increased interest in the robot from the beginning, but his behavior was extremely cautious and fearful and he maintained physical contact with the experimenter, while continuously looking at the robot. He felt more comfortably when we placed the chair at a larger distance from the robot, and the distance was increasingly shortened during the familiarization phase. During this phase, the child was very attracted by the Nao's changing eye color, and he asked for different colors. He was also interested in the Nao robot's saying his name, and he shared his enthusiasm by gazing at the experimenter every time the robot said his name.

In the modeling phase, Child1 smiled and switched attention from the experimenter to the robot and back, as the two agents were involved in an imitation game. During the interaction with the robot phase, the child's attention was permanently oriented towards the robot. A few joint attention episodes were present, the child turning his head up to 45 degrees towards the experimenter that was sitting behind him, and smiling, in an attempt to share his enthusiasm as a reaction to the robot's acts. In the first 2–3 minutes of the interaction sessions, the child spontaneously initiated some motor acts and other initiations were triggered by minimal physical prompts (touching the arms of the child). Every initiation was accompanied by positive emotional reactions (smiles and laughter). In the next sessions, the child continued to respond to almost every minimal motor prompt by initiating movements and expressing positive emotions, but the intensity of his reactions was diminished.

In the second baseline A(2) and in the phase C (human-interaction), the values of the target variables decreased a lot, but the child remained seated and complied with the procedure.

4.2 Data analysis: Child2

4.2.1 *Visual and statistical analysis of the data collected during the baselines and intervention phases for Child2*

Total number of initiations with or without prompt: The visual analysis of the data did not depict major variations of the target behavior between baselines and the two intervention phases. The statistical analysis detected one single significant difference, the total initiations variable being significantly higher in the second baseline A(2) compared to phase C (human-interaction). Based on the results of the non-parametrical test (see Table 4), we can conclude that none of the two procedures had any effect for Child2.

Free initiations: The visual analysis revealed a stable low level of the variable in the first baseline A(1), followed by a similar trend in phase B (Nao-interaction) with two higher values in the middle sessions. In the second baseline A(2), we observed a slightly ascendant trend that continued also in phase C (human-interaction), the values in this phase changing a lot, with two higher values in the middle sessions. The statistical analysis revealed a significantly better performance in phase B (Nao-interaction) compared to the first baseline A(1). Moreover, the statistical analysis revealed a significantly higher performance in the second baseline A(2) and also in phase C (human-interaction) suggesting a learning effect in these two phases. No significant difference was found between phase B (Nao-interaction) and phase C (human-interaction) showing that the robot was not a facilitator of this target variable (see Table 4).

Eye Gaze: The visual analysis of the data show an ascendant trend for eye gaze variable in the first baseline A(1), followed by high fluctuations in phase B. In the

Table 4. Statistical analysis with Mann-Whitney test for Child2: Comparison of the results of all phases

	A1 vs B	B vs A2	A2 vs C	A1 vs C	A1 vs A2	B vs C
Total Initiations	Z = −.34 NS	Z = −1.17 NS	Z = −2.03 *p* = .042 *A2 > C*	Z = −1.70 NS	Z = −.98 NS	Z = −1.50 NS
Free Initiations	*Z* = −2.71 *p* = .007 *A1 < B*	*Z* = −.43 NS	*Z* = −2.89 *p* = .004 *A2 < C*	*Z* = −2.64 *p* = .008 *A1 < C*	*Z* = −2.44 *p* =. 014 *A1 < A2*	*Z* = −1.86 NS
Eye Gaze	*Z* = −1.35 NS	*Z* = −.14 NS	*Z* = −2.84 *p* = .004 *A2 > C*	*Z* = −2.45 *p* = .014 *A1 > C*	*Z* = −2.44 *p* = .014 *A1 < A2*	*Z* = −1.97 *p* = .049 *B > C*
Smile/ Laughter	*Z* = −.84 NS	*Z* = −.14 NS	*Z* = −.89 NS	*Z* = −.18 NS	*Z* = −1.41 NS	*Z* = −.81 NS
Shared Eye Gaze	– –	– –	– –	– –	– –	*Z* = −.17 NS

second baseline, the level of the target variable remained at a high level, but it was followed by a descendant trend and a lower level in phase C. The statistical analysis showed no significant differences between phase B and the two baselines A(1) and A(2), suggesting no effect for Nao-interaction phase. The performance in phase C is significantly lower than in all the other phases, suggesting a habituation effect (see Table 4).

Smile/Laughter: The visual analysis revealed a fluctuant trend for the positive affect variable, along the four phases of the study. The statistical analysis confirmed no significant difference between any of the four phases, suggesting no effect for Nao-interaction phase (see Table 4).

Shared eye gaze: The statistical analysis proved no significant difference between phase B (Nao-interaction) and phase C (human-interaction), suggesting no effect for the Nao robot as an object of shared attention (see Table 4).

4.2.2 *Additional observations of the interaction for Child2*

Child2 rapidly understood that the interaction partner was mirroring his actions and manifested vocalizations and positive affect as a consequence. In the first baseline, Child2 imitated some of the adult's behaviors, but the free initiation rate remained low. In phase B (Nao-interaction), he enjoyed the tricks Nao performed in the familiarization phase, especially the change of Nao's eye color, and shared his enthusiasm with the experimenter several times by shared eye gaze and pointing to the eyes of the robot. During the modeling phase, he rapidly understood the fact that the robot was mirroring the experimenter's movements and therefore he did not need the initial physical prompts to start initiating motor acts. It was interesting to see that the child was performing a motor act and systematically remained in that position, maintaining his attention towards the robot until the robot mirrored it. Several times the child tried some more complicated movements that the robot could not mirror due to mechanical constraints, but later he gave up and continued with the simple movements the robot could mirror. The child intentionally selected his own movements, a phenomenon also observed in studies performed with Robota (Dautenhahn & Billard 2002), and also outlined in (Nadel 2004).

Moreover, we observed that at the beginning of each session, he exhibited more initiations and interest towards the robot, but that after a few minutes, the interest diminished and also the rate of initiations decreased. In the second baseline A(2), he manifested more sequences of testing behavior, while maintaining his attention towards the interaction partner. It was interesting to observe that the behavior of the child became more complex, as the human partner had more flexibility in movement and could mirror complex motor acts. In the last phase, in the human-interaction phase C, the child manifested more initiations than in the other phases of the study, but the attention to the robot was much more reduced. This phenomenon suggests that the child initiated motor actions because he understood that this was the expected response and not because he was motivated to do so.

4.3 Data analysis: Child3

4.3.1 *Visual and statistical analysis of the data collected during the baselines and intervention phases for Child3*

The visual analysis of all the target variables reveals high fluctuation in the development of the data for all the outcomes measured that may have been augmented by the attention deficit and the hyperactivity of the child.

Total number of initiations with or without prompt: The visual analysis, supported by the statistical analysis, showed significantly higher values of the target variable in the phase B (Nao-interaction) compared to baseline A(1). This result suggests that the Nao robot facilitated the increase of the target variable. The data shows that the difference between phase B and the baseline A(2) is not significant, suggesting that the child transferred the behavior learnt in the interaction with the Nao robot to the interaction with the human person (see Table 5).

Table 5. Statistical analysis with Mann-Whitney test for Child3: Comparison of the results of phases A1, A2, and B

	A1 vs B	B vs A2	A1 vs A2
Total Initiations	$Z = -2.66$ $p = .006$ $A1 < B$	$Z = -1.78$ NS	$Z = -1.52$ NS
Free Initiations	$Z = -1.53$ NS	$Z = -1.51$ NS	$Z = -.84$ NS
Eye Gaze	$Z = .01$ NS	$Z = -.97$ NS	$Z = 1.41$ NS
Smile/Laughter	$Z = -1.27$ NS	$Z = -1.29$ NS	$Z = -.34$ NS
Shared Eye Gaze	–	–	

Free initiations: The visual analysis of the data indicated a stable low level of the target variable in the two baselines A(1), A(2), and a slightly higher level in phase B (Nao-interaction); the statistical analysis showed that the difference is not significant, suggesting no effect for the Nao-interaction phase in increasing the rate of free initiations (see Table 5).

Eye gaze: The visual analysis, confirmed by the statistical analysis, revealed a high fluctuation trend in the development of the data, with no significant difference between the phases of the study. The analysis of the data suggests no effect of the Nao-interaction procedure in facilitating the eye gaze of the child (see Table 5).

Smile/Laughter: Visual analysis of the target variable showed a great similarity between the development of smile/laughter behavior and the development of the eye gaze directed to the interaction agent, with a constantly lower level for the smile/laughter variable compared to the eye gaze variable. As in the case of eye gaze, the statistical analysis showed no significant difference between phase B (Nao-interaction) and the two baselines, suggesting no effect for the Nao-interaction procedure in facilitating the positive affect behaviors (see Table 5).

Shared eye gaze: There was no shared eye gaze behavior neither in phase B (Nao-interaction), nor in phase C (human-interaction) suggesting that the Nao robot did not facilitate the shared attention behavior for Child3.

4.3.2 *Additional observations of the interaction for Child3*

During the four sessions in the first baseline, Child3 got involved in a lot of stereotypical behaviors, especially sounds, that were not mirrored as our experiment involved only motor imitation of gestures. In phase B (Nao-interaction), he had less self-stimulatory behaviors, especially sounds that were almost absent.

In the first session, he enjoyed the interaction a lot, but he was also searching for the human presence for tactile stimulation. During the familiarization phase, the child touched the robot repeatedly, and he was especially interested in the robot's changing eye color, a behavior that elicited a smile and captured his attention. In the modeling phase, the child looked attentively at the Nao robot's movements, and twice switched attention from the robot to the person, to check for the synchrony of their movements. This kind of behavior was observed also in the interaction phase. The contingency between some of the mirroring movements of the robot and the eye gaze of the child suggest the fact that the child was aware of the fact that his movements were mirrored by the robot. Also, in several instances, the child looked at the robot as he was performing the free motor movements suggesting that he was anticipating the robot's response. The motor initiations of the child remained restricted to one movement, respectively raising his arms, no other variations in movement being tested, suggesting a limited ability of testing the imitation intention of the partner. In the second baseline, again, the frequency of stereotypical sounds produced was higher than in the Nao-interaction phase. In the last interaction phase, phase C, the child was giving strong signs that he did not enjoy the interaction and he refused to sit in the experimental setting for the first three sessions. We could not perform a statistical analysis for the last phase because we had only two measurements available.

4.4 Data analysis: Child4

4.4.1 *Visual and statistical analysis of the data collected during the baselines and intervention phases for Child4*

Total number of initiations with or without prompt: The visual analysis of the data reveals a constant low level of the target variable and the absence of major variations of the target behavior between baselines and the B phase (Nao-interaction). The statistical analysis confirmed no significant differences between any of the phases of the study. These results indicate that the Nao-interaction procedure did not facilitate the emergence of increased initiations for Child4 (see Table 6).

Free initiations: The visual analysis of the data showed a relatively low variance of the data throughout the phases of the experiment, with a very low frequency of the target behavior. The statistical analysis of the data shows that there are no significant differences between baseline A(1) and phase B (Nao-interaction). The comparison of phase B (Nao-interaction) and the baseline A(2) reveals a significant difference, indicating a tendency of the Nao-interaction procedure to be a better facilitator of free initiations (see Table 6).

Table 6. Statistical analysis with Mann-Whitney test for Child4: Comparison of the results of phases A1, A2, and B

	A1 vs B	B vs A2	A1 vs A2
Total Initiations	$Z = -.67$ NS	$Z = -1.31$ NS	$Z = -.21$ NS
Free Initiations	$Z = -1.58$ NS	$Z = -2.02$ $p = .043$ $B > A2$	$Z = -.01$ NS
Eye Gaze	$Z = -2.62$ $p{-}.009$ $A1 < B$	$Z = -3.42$ $p = .001$ $B > A2$	$Z = -.01$ NS
Smile/Laughter	$Z = -2.79$ $p = .005$ $A1 < B$	$Z = -2.81$ $p = .005$ $B > A2$	$Z = -.25$ NS
Shared Eye Gaze	–	–	

Eye gaze: The visual analysis of the data indicated a clear difference between the level of the target variable in the baselines and in phase B (Nao-interaction), with a significant increase in the level of the eye gaze variable and a relatively stable trend in phase B, compared to the baselines. Statistical analysis indicated that the eye gaze variable has a significantly higher level in the phase B (Nao-interaction) compared to both baselines A(1) and A(2). These results indicate that the Nao-interaction procedure is superior to the baselines in terms of increasing the child's motivation and interest towards the interaction partner (see Table 6).

Smile/Laughter: The visual analysis of the data indicated a low level of the target variable in the first baseline, followed by an increase in phase B (Nao-interaction), and a decrease in the baseline A(2) phase. The statistical analysis confirmed the difference to be a significant one, suggesting that the child enjoyed interacting with the robot more than with the person (see Table 6).

Shared eye gaze: There was no shared eye gaze behavior neither in phase B (Nao-interaction), nor in phase C (human-interaction), indicating that the Nao robot did not facilitate the shared attention behavior for Child4.

4.4.2 *Additional observations of the interaction for Child4*

In baseline A(1) the interaction game was very difficult to perform as the child avoided the interaction, manifesting rejection behaviors like turning his back to the person, closing his eyes, shouting, manifesting motor stereotypes and visual stimulations, leaving his chair in order to look at the video cameras that were placed in the room.

In phase B (Nao-interaction), the child paid attention to every behavior the robot performed in the familiarization phase. In the modeling phase, the child's attention was focused on the Nao robot, while ignoring the behavior of the experimenter. During the interaction with the robot, the child was extremely attentive to the robot, he was very quiet for all the duration of the session, the frequency of stereotypical acts was very much reduced compared to the baseline level, he did not leave the chair and at the end, he resisted leaving the room. Because the child was very compliant to the procedure, we had 13 measurements in this phase, but only 3 triadic interactions because the child also rejected this kind of interaction by turning his back to the human. In the second baseline A(2), the child also manifested rejection behaviors toward the human, but they were not very intense. In phase C (human-interaction), we took only 2 measurements of the target behavior because the child became frustrated, manifested violently, and refused any kind of interaction with the person. For this reason, we could not include this data in the statistical analysis.

5. Conclusion and discussions

Based on the observation of the interaction, we can draw some conclusions: all children were interested in the tricks Nao robot performed in the familiarization phase, especially its changing eye colors. In the modeling phase, two of the children switched attention between the experimenter and the robot, as the two agents were involved in a synchronous interaction. This behavior suggests that they understood the connection between the movements they performed. In the interaction phase, at first, all children manifested interest towards the robot, but the intensity of the positive emotions was greater in the first minutes of the interaction and tended to diminish towards the end of each session. Child1 and Child2 manifested an increased frequency of free initiations in the first 1–2 minutes of interacting with Nao and maintained their arms in position until the robot imitated the movement, showing strong signs that they understood the fact that their movements were being mirrored by the robot. Child3 and Child4 had a lower rate of free initiations in the first interaction with Nao robot, but each time they were prompted to initiate a motor act, they were paying attention to the robot and smiled when that happened. In the case of Child4, the most severely affected child, even if the child was not initiating free acts, several times he took the adult's arms and used them as a tool for initiation, a typical behavior for children with autism.

The quantitative results are mixed and suggest a high variability in reactions to the Nao robot. We expected that the frequency of total initiations (with and without prompt) to be higher in the Nao-interaction phase compared to the human-interaction phase. The results suggest that for Child1, the interaction with the Nao robot was a better facilitator of the initiations compared to the baselines, but in the case of the comparison with the human that was not significant. For Child3, the interaction with the Nao robot was also a better facilitator than the first baseline, but not the second one, while the comparison with the human-interaction phase was not possible due to the limited number of measurements. On the other hand, Child2 and Child4 show no difference in the frequency of initiations between the phases of the experiment.

We also expected that the frequency of free initiations (without prompt) to be higher in the Nao-interaction phase compared to the human-interaction phase. The results indicate that the robot was not a facilitator of the target variable for Child3. For Child1, the Nao-interaction phase was a better facilitator of initiations compared to phase C, but not with respect to the baselines. In the case of Child4, the Nao-interaction procedure was a better facilitator of free initiations compared to the second baseline A(2), but not with respect to the first baseline A(1). In the case of Child2 the Nao-interaction was a better facilitator of initiations compared to the first baseline A(1), while in the second baseline and in the C phase, the frequency of free initiations was higher than in the interaction with the Nao robot. However, taking into account that this child enjoys simple interaction games with humans, this result might be representative for children with mild autism. Contrary to our expectations, the results indicate a general low level of free initiations both in the robot and human condition. This result may indicate a trait of children with autism (Lord & Hopkins 1986), but also may have been augmented in our study by the use of non-meaningful gestures in the experimental task. Moreover, both in the case of total initiations and free initiations, there is some effect favoring the Nao robot in comparison to the baselines for some children. However, since in some cases, we lack data from the C phase (human-interaction) and in other cases, the baseline does not return to its initial level after phase B (Nao-interaction), it is difficult to draw some firm conclusions.

Based on the presumption that children with autism are attracted by robots, we expected that the duration of the eye gaze to the partner and the duration of smile and laughter to be higher in the Nao-interaction phase compared to the human-interaction phase. The results indicate that only Child1 and Child4 manifested more of these behaviors in the presence of the Nao robot, while Child2 and Child3 had a high fluctuation pattern of attention and smiling. These results are limited by the fact that we used relative values. The systematic observations performed show that even in the case of the last two children, the eye gaze and smiling/laughter behavior was higher in the first part of the session, but decreased towards the second part of the session. Taking into account the fact that Child1 and Child4 are the children most affected by autism, that Child2 has only signs of autism, and Child3 shows attention deficit and hyperactivity, we suggest that for children with low functioning autism the Nao robot might have appealing characteristics for interaction. Our results are consistent with those of Robins et al. (2005) suggesting that some children with autism direct significantly more eye gaze and attention towards the robot.

We also expected that the frequency of gaze shifting between the two partners to be higher in the Nao-interaction phase compared to the human-interaction phase. This prediction was confirmed only for Child1. In the case of Child2 there was no difference between the two phases of the study, while in the case of Child3 and Child4 no manifestation was seen in neither of the two phases of the study. This lack of shared attention was expected for Child4 as he is extremely resistant to any interaction with people. Therefore, only the results of Child1 are consistent with those described in (Werry 2001) that illustrated the robot's ability to function as a mediator of shared attention for children with autism.

There were also some limitations of the study that should be outlined: (1) the robot is capable of imitating only gross arm movements; (2) the robot is not fast enough to assure a perfect contingency; (3) we may have introduced a habituation effect by having two interaction sessions a day in phase B and phase C, but not in the baselines; (4) the experimental setup is somehow rigid, the child has to sit on a chair and we used physical and modeling prompts and therefore we interfered in a certain way to the spontaneous behavior of the child.

To better investigate if children with autism manifest more testing behaviors while being imitated by a robot, a different study would have to be conducted involving contingent interaction between the child and the robot, in an object mediated interaction. We believe that by introducing objects into the task, this would become more meaningful and facilitate the initiations of children with autism by increasing their motivation to interact with the robot. Our presumption is supported by Nadel studies (Nadel 2004), that found evidence that those even low-functioning children with autism can produce spontaneous imitations when the actions are goal-directed and involve objects.

Overall, the results of the study are mixed, showing some effect in some children on some variables and in others on other variables, but not in all four children. The results indicate a high variability of reactions to the Nao robot. This finding has been outlined before in several studies (Robins & Billard 2005) and may indicate that the human-robot interaction may be beneficial only for a subgroup of children with autism (Diehl 2012). In future studies, greater consideration needs to be given to predictors that might account for individual patterns of response to robot-like vs. human behavior.

Notes

1. http://www.aldebaran-robotics.com/
2. http://openni.org/Documentation/
3. http://www-01.ibm.com/software/analytics/spss/

References

A. P. Association. (2000). Diagnostic and statistical manual of mental disorders (DSM IV). (4th Edn., text revision).

Behne, T., Carpenter, M., Call, J., & Tomasello, M. (2005). Unwilling versus unable: Infants' understanding of intentional action. *Developmental Psychology*, *41*, 328–337.

Bird G., Leighton, J., Press, C., & Heyes, C. (2007). Intact automatic imitation of human and robot actions in autism spectrum disorders. *In Proceedings of the Royal Society â€" Biological Sciences*, *274*, 3027–3031.

Celani, G., Battachi, M.W., & Arcidiacono, L. (1999). The understanding of the emotion meaning of facial expressions in people with autism. *Journal of Autism and Developmental Disorders*, *29*, 57–66.

Charman, T., & Baron-Cohen, S. (1994). Another look at imitation in autism. *Development and Psychopathology*, *6*, 403–413.

Charman, T., Sweettenham, J., Baron-Cohen, Cox, S.A., Baird, G., & Drew, A. (1997). Infants with autism: An investigation of empathy, pretend play, joint attention, and imitation. *Developmental Psychology*, *33*, 781–789.

Dautenhahn, K., & Billard, A. (2002). Games children with autism can play with Robota, a humanoid robotic doll.

Dautenhahn, K., Nehaniv, C.L., Walters, M.L., Robins, B.H., Kose-Bagci, N., Mirza, A., & Blow, M. (2009). Kaspar – a minimally expressive humanoid robot for human-robot interaction research. *Special Issue on Humanoid Robots*, *Applied Bionics and Biomechanics*, *6*(3), 369–397.

Dawson, G., & Adams, A. (1984). Imitation and social responsiveness in autistic children. *Journal of Abnormal Child Psychology*, *12*, 209–226.

Dawson, G., & Galpert, L. (1990). Mothers' use of imitative play for facilitating social responsiveness and toy play in young autistic children. *Diagnostic and Statistical Manual of Mental Disorders*, *2*, 151–162.

Diehl, J.J., Schmitt, L.M., Villano, M., & Crowell, C. (2012). The clinical use of robots for individuals with autism spectrum disorders: A critical review. *Research in Autism Spectrum Disorders*, *6*(1), 249–262.

Duquette, A., Michaud, F., & Mercier, H. (2007). Exploring the use of a mobile robot as an imitation agent with children with low-functioning autism. *Autonomous Robots*, *24*, 147–157.

Feil-Seifer, D., & Matarić, M.J. (2005). Defining socially assistive robotics. In *Proc. IEEE International Conference on Rehabilitation Robotics (ICORR'05)*, pp. 465–468, Chicago, Il, USA, June 2005.

Feil-Seifer, D., & Matarić, M.J. (2011). Automated detection and classification of positive vs. negative robot interactions with children with autism using distance-based features.

In *Proc. IEEE/ACM International Conference on Human-Robot Interaction (HRI'11)*, Lausanne, Switzerland, Mar. 2011.

Francois, D., Powell, S., & Dautenhahn, K. (2009). A long-term study of children with autism playing with a robotic pet: Taking inspirations from non-directive play therapy to encourage children's proactivity and initiative-taking. *Interaction Studies*, *10*(3), 324–373.

Griffith, E.M., Pennington, B.F., Wehner, E., & Rogers, S. (1999). Executive functions in young children with autism. *Child Development*, *70*, 817–832.

Hart, M. (2005). Autism/excel study. In *Proceedings of the ASSETS 2005: Seventh International ACM SIGACCESS Conference on Computers and Accessibility*.

Hepburn, S., & Stone, W. (2006). Longitudinal research on motor imitation in autism. In F., Volkmar, R., Paul, A., Klin, D., Cohen (Eds.), *Handbook of autism and pervasive developmental disorders*, 3th edition, New York: Wiley.

Hobson, R.P. (1986). The autistic child's appraisal of expression of emotion. *Journal of Child Psychology and Psychiatry*, *27*, 321–342.

Janosky, J.E., Leininger, S.L., Hoerger, M.P., & Libkuman, T.M. (2009). *Single subjects designs in biomedicine*. New York, USA: Springer Press.

Kazdin, A. (1982). *Single-case research designs*. New York, USA: Oxford University Press.

Klin, A., Lin, D.J., Gorrindo, P., Ramsay, G., & Jones, W. (2009). Two-year-olds with autism fail to orient towards human biological motion but attend instead to non-social, physical contingencies. *Nature*, *459*, 257–261.

Kozima, H., Michalowski, M.P., & Nakagawa, C. (2009). A playful robot for research, therapy, and entertainment. *International Journal of Social Robotics*, *1*(1), 3–18.

Leekman, S., Baron-Cohen, S., Perrett, D., Milders, M., & Brown, S. (1997). Eye-direction detection: A dissociation between geometric and joint attention skills in autism. *The British Journal of Developmental Psychology*, *5*, 77–95.

Lord, C., & Hopkins, J.M. (1986). The social behavior of autistic children with younger and same-age nonhandicapped peers. *Journal of Autisa and Developmental Disorders*, 16, 249–262.

Meltzoff, A.N. (1995). Understanding the intentions of others: Reenactment of intended acts by 18-month-old children. *Developmental Psychology*, *31*, 838–850.

Meltzoff, A.N., & Moore, M.K. (1997). Explaining facial imitation: A theoretical model. *Early Development and Parenting*, *6*, 179–192.

Michaud, F., Salter, T., Duquette, A., & Laplante, J.F. (2007). Perspectives on mobile robots used as tools for pediatric rehabilitation. *19*, 14–29.

Nadel, J. (1986). *Imitation et communication entre jeunes enfants*. Paris: PUF.

Nadel, J. (2004). Do children with autism understand imitation as intentional interaction? *Cognitive and Behavioral Psychotherapies*, *4*(2), 165–177.

Nadel, J., & Butterworth, G. (1999). *Imitation in infancy*. Cambridge: Cambridge University press.

Nadel, J., Croue, S., Kervella, C., Mattlinger, M.J., Canet, P., Hudelot, C., Lecuyer, C., & Martini, M. (2000). Do children with autism have ontological expectancies concerning human behavior? *Autism*, *4*, 133–145.

Nadel-Brulfert, J., & Baudonniere, P. (1982). The social function of reciprocal imitation in 2-year-old peers. *International Journal of Behavioral Development*, *5*, 95–109.

Parsons, S., Mitchell, P., & Leonard, A. (2004). The use and understanding of virtual environments by adolescents with autistic spectrum disorders. *Journal of Autism and Developmental Disorders*, *34*(4), 449–466.

Pierno, A.C., Mari, M., Lusher, D., & Castiello, U. (2008). Robotic movement elicits visuomotor priming in children with autism. *Neuropsychologia*, *46*, 448–454.

Riley-Tillman, T.C., & Burns, M.K. (2009). *Evaluating educational interventions. Single case design for measuring response to intervention*. New York, USA: The Guilford Press.

Robins, B., Dautenhahn, K., & Dubowski, J. (2006). Does appearance matter in the interaction of children with autism with a humanoid robot? *Interaction Studies*, *7*(3), 509–542.

Robins, B., Dautenhahn, K., te Boekhorst, R., & Billard, A. (2005). Robotic assistants in therapy and education of children with autism: Can a small humanoid robot help encourage social interaction skills?.

Rogers, S.J., & Pennington, B. (1991). A theoretical approach to the deficits in infantile autism. *Development and Psychopathology*, *3*, 137–62.

Salter, T., Michaud, F., & Larouche, H. (2010). How wild is wild? a taxonomy to categorize the wildness of child-robot interaction. *International Journal of Social Robotics*, *2*(4), 405–415.

Scassellatti, B. (2005). How social robots will help us to diagnose, treat and understand autism. In *Proc. of the 12th International Symposium of Robotics Research (ISSR'05)*, San Francisco, CA, USA, Oct. 2005.

Schopler, E., Reichler, R., DeVellis, R., & Daly, K. (1980). Toward objective classification of childhood autism: Childhood autism rating scale (cars). *Journal of Autism and Developmental Disorders*, *1*, 91–103.

Stone, W., Ousley, O., & Littleford, C. (1997). Motor imitation in young children with autism: What's the object? *Journal of Abnormal Child Psychology*, *25*, 475–485.

Tawney, J.W., & Gast, D.L. (1984). *Single subject research in special education*. New York, USA: Merrill Press.

Tomasello, M. (1999). *The cultural origins of human cognition*. Cambridge, MA: Harvard University press.

Vanderborght, B., Simut, R., Saldien, J., Pop, C., Rusu, A., Pintea, S., Lefeber, D., & David, D. (2012). Using the social robot probo as social story telling agent for children with asd. In *Interaction studies (accepted for publication)*.

Vivanti, G., Nadig, A., Ozonoff, S., & Rogers, S. (2008). What do children with autism attend to during imitation tasks? *Journal of Experimental Child Psychology*, *101*(3), 186–205.

Wainer, J., Dautenhahn, K., Robins, B., & Amirabdollahian, F. (2010). Collaborating with KASPAR: Using an autonomous humanoid robot to foster cooperative dyadic play among children with autism. In *Proceedings of the 10th IEEE-RAS International Conference on Humanoid Robots*, Nashville, USA, December 2010.

Werry, I., Dautenhahn, K., Ogden, B., & Harwin, W. (2001). Can social interaction skills be taught by a social agent? the role of a robotic mediator in autism therapy. In M. Beynon, CL., Nehaniv, K. Dautenhahn (Eds.), *Proceedings CT2001, the 4th international conference on cognitive technology: Instruments of mind, LNAI 2117* (pp. 57–74). Berlin Heidelberg: Springerâ€ Verlag.

Williams, I.H., Whiten, A., & Singh, T. (2004). A systematic review of action imitation in autistic spectrum disorder. *Journal of Autism and Developmental Disorders*, *34*, 285–289.

Authors' addresses

Prof. Adriana Tapus
Associate Professor
ENSTA-ParisTech, Cognitive Robotics Lab
828, Boulevard des Maréchaux
91762 Palaiseau Cedex, France

adriana.tapus@ensta-paristech.fr

Andreea Peca
Babes-Bolyai University
Department of Clinical Psychology and Psychotherapy, Cluj-Napoca, Romania

andreea.peca@ubbcluj.ro

Amir Aly
ENSTA-ParisTech, Cognitive Robotics Lab
828, Boulevard des Maréchaux
91762 Palaiseau Cedex, France

amir.aly@ensta-paristech.fr

Cristina Pop
Babes-Bolyai University
Department of Clinical Psychology and Psychotherapy, Cluj-Napoca, Romania

pop.cristina@ubbcluj.ro

Lavinia Jisa
Babes-Bolyai University
Department of Clinical Psychology and Psychotherapy, Cluj-Napoca, Romania

lavinia.jisa@ubbcluj.ro

Sebastian Pintea
Babes-Bolyai University
Department of Clinical Psychology and Psychotherapy, Cluj-Napoca, Romania

sebastianpin-tea@psychology.ro

Prof. Alina Rusu
Babes-Bolyai University
Department of Clinical Psychology and Psychotherapy, Cluj-Napoca, Romania

alinarusu@psychology.ro

Prof. Daniel O. David
Babes-Bolyai University
Department of Clinical Psychology and Psychotherapy, Cluj-Napoca, Romania

danieldavid@psychology.ro

Authors' biography

Dr. Adriana Tapus is an associate professor at ENSTA-ParisTech, France. She received her Ph.D. in Computer Science from Swiss Federal Institute of Technology, Lausanne (EPFL) in 2005 and her degree of Engineer in Computer Science and Engineering from "Politehnica" University of Bucharest, Romania in 2001. She worked as an Associate Researcher at the University of Southern California (USC), where she pioneered the development of socially assistive robotics, also participating to activity in machine learning, human sensing, and human-robot interaction. Her main interest is on long-term learning (i.e. in particular in interaction with humans) and on-line robot behavior adaptation to external environmental factors. Prof. Tapus is Associate Editor for International Journal of Social Robotics and in the steering committee of major robotics conferences. She received the Romanian Academy Award for her contributions in assistive robotics in 2010. Further details about her research can be found at http://www.ensta-paristech.fr/~tapus.

Andreea Peca received her M.S. degree from Babes-Bolyai University in Psychology in 2005. Between 2006 and 2007 she worked as a clinical psychologist at Autism Transylvania Association. In 2007, she founded Pasi Inainte Association, an NGO that offers assessment and early intervention services for children with autism. Since 2011, she has worked as a research assistant in human-robot interaction at Babes-Bolyai University, Department of Clinical Psychology and Psychotherapy. Her research interests include human-robot interaction, and the development of the prerequisites of social cognition in the first years of life with emphasis on the dynamics of imitation in autism.

Amir Aly received his first BSc Degree in control engineering from Benha University in Egypt. It was followed by a second BSc Degree in automation and signal processing from ENSISA in France. He worked on his MSc Degree in the image and sound processing department in the Pierre and Marie Curie University (UPMC-Paris 6) in France. He is currently doing his Ph.D. at ENSTA-ParisTech, and mainly focuses on understanding human activities and emotional internal states and generating a corresponding action through different modalities of interaction (para-verbal, verbal, and nonverbal).

Cristina Pop received her M.S. degrees from Babes-Bolyai University, in Psychology, in 2011. From October 2011 she is a Ph.D. student at Babes-Bolyai University, Department of Clinical Psychology and Psychotherapy. From 2008 to 2011 she worked at Autism Transylvania Association as a psychologist, and from 2010 she was the head of the Research Department of Autism Transylvania Association. Since 2011 she is involved in the project 'Using the social robot Probo in therapy for children with autism spectrum disorders' from Babes-Bolyai University in collaboration with Vrije Universiteit Brussel. Her research interests include human-robot interaction and improving social and play skills.

Lavinia Jisa got her master degree in Clinical Psychology at Babes-Bolyai University, Cluj-Napoca, Romania in July, 2012 (with a thesis on the topic of robo-therapy and autistic children-"Robonova and its virtual representation, an imitative interaction with children with ASD"). Currently she is working as a research assistant in the project – Exploratory research projects – PN-II-ID-PCE-2011-3, a collaboration project between Babes-Bolyai University, Romania and Vrije Universiteit Brussel, Belgium. She is interested in human-robot interaction and rehabilitation robots.

Sebastian Pintea received his M.S. and Ph.D. degrees from the Babes-Bolyai University, Romania in 2003 and 2006, respectively. From 2007 to 2008, he was Postdoctoral researcher in The International Institute of Advanced Studies in Psychotherapy and Applied Mental Health, Babes-Bolyai University and Albert Ellis Institute, USA. Now, he is Senior Researcher at the Department of Clinical Psychology and Psychotherapy, Faculty of Psychology and Educational Sciences, Babes-Bolyai, University. Some of the recent projects he has been involved in are in the domain of robot-assisted therapy and animal-assisted therapy for ASD children. He is the author of over 25 publications in the field of psychology. His scientific interests include advanced clinical research methods, entrepreneurial psychology and evidence-based therapy based on humanoid robots.

Alina S. Rusu received her Ph.D. degree from University of Zurich, in 2004, in Natural Sciences (Animal Behavior). From 2005 until now, she is Associate Professor at Faculty of Psychology and Sciences of Education, Babes-Bolyai University, Romania. She is the Director of the Biological Models of Psychopathology at the Department of Clinical Psychology and Psychotherapy (Babes-Bolyai University), and also, the President of the Romanian Association of Animal Assisted Activities and Therapy. She is the author of over 30 papers, book chapters and scientific reports. Her research interests include comparative psychology, human-animal and human-robot interaction.

Daniel O. David is the 'Aaron T. Beck' Professor of Clinical Psychology and Psychotherapy, and Head of Department of Clinical Psychology and Psychotherapy at Babes-Bolyai University, Cluj-Napoca, Romania. He is also an adjunct professor at Mount Sinai School of Medicine, NewYork, USA since 2008. He founded the International Institute for the Advanced Studies of Psychotherapy and Applied Mental Health and developed one of the most advanced Platforms for Robotherapy and Virtual Reality Therapy. Daniel David and his team published more than 60 international papers and book chapters.