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

Dorothée François[1], Stuart Powell[2] & Kerstin Dautenhahn[1]

[1]Adaptive Systems Research Group, School of Computer Science, University of Hertfordshire/[2]School of Education, University of Hertfordshire

This paper presents a novel methodological approach of how to design, conduct and analyse robot-assisted play. This approach is inspired by non-directive play therapy. The experimenter participates in the experiments, but the child remains the main leader for play. Besides, beyond inspiration from non-directive play therapy, this approach enables the experimenter to regulate the interaction under specific conditions in order to guide the child or ask her questions about reasoning or affect related to the robot. This approach has been tested in a long-term study with six children with autism in a school setting. An autonomous robot with zoomorphic, dog-like appearance was used in the studies. The children's progress was analyzed according to three dimensions, namely, Play, Reasoning and Affect. Results from the case-study evaluations have shown the capability of the method to meet each child's needs and abilities. Children who mainly played solitarily progressively experienced basic imitation games with the experimenter. Children who proactively played socially progressively experienced higher levels of play and constructed more reasoning related to the robot. They also expressed some interest in the robot, including, on occasion, affect.

Keywords: Human–Robot Interaction, Robot-Mediated Therapy, Robot-Assisted Play, Non-Directive Play Therapy, Assistive Technology, Autism, Children

1. Introduction

This study is part of the Aurora Project, (Aurora, 2009) an ongoing long-term project investigating the potential use of robots to help children with autism overcome some of their impairments in social interactions (Dautenhahn & Werry, 2004, 2000).

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Autistic spectrum disorders can appear in various degrees and refer to different needs and abilities (Powell, 2000; American Psychiatric Association, 1994). Detailed diagnostic criteria for autistic spectrum disorders are provided in the Diagnostic and Statistical Manual of Mental Disorders (1994). The main impairments highlighted by the National Autistic Society[1] are: impairments in communication, social interaction and imagination. As a consequence, children with autism often seem to operate in a world of repetitive patterns and some of them tend to restrict play to solitary play. Besides, it can be argued that children with autism have a relative potential for play but often encounter obstacles to actualize this potential, the causes of which are still under investigation. Difficulties in socio-emotional inter-subjectivity, joint attention and theory of mind (compare e.g. Baron-Cohen et al. (1985); Hobson (1993); Baron-Cohen (1997)) impair interactions in general and, more specifically, imply a lack of spontaneous and social reciprocity during play. Those impairments, in addition to the potential deficits in higher order representation, may explain the difficulties encountered in symbolic and pretend play (Chaillé & Silvern, 1996).[2] Yet, play is a vehicle for learning (Chaillé & Silvern, 1996). Through play, children can develop skills in many areas (e.g. logical memory and abstract thought, communication and social skills). Moreover, play is a medium for self expression (Boucher, 1999). From the perspective of this study that aims at supporting robot-assisted therapy for children with autism, we thus decided on an emphasis on play whereby the robot should facilitate play and adapt to each child's needs and abilities.

The use of robots for robot-assisted play and therapy is a growing area of research (see section on 'Related Work'). Until now, many approaches of robot-mediated play and therapy for children with autism have mainly explored the use of specific games, such as imitation (Robins, Dautenhahn, Boekhorst, & Billard, 2005) or chasing games (Werry & Dautenhahn, 1999) and only recently started to involve the experimenter in the play sessions, qualifying his/her role as "passive participant" (Robins, Dautenhahn, 2006). The study presented in this paper shows a different perspective on robot-mediated therapy, which is not primarily task-oriented. It draws inspiration from non-directive play therapy (Axline, 1946, 1947; Ryan, 1999; Josefi & Ryan, 2004) and, importantly, expands and *formalizes* the role of the experimenter in robot-assisted play. In this novel approach, the experimenter strongly encourages the child's proactivity and initiative-taking with respect to the choice of play, the rhythm of play and verbal communication. While a task-oriented approach might expect the child to complete a specific task, such as, for instance, performing imitative movements, our approach enables the child to proactively experiment with various situations of play, from simple exploration of the robot's features and capabilities to more complex situations of play. Those situations can, for instance, involve an understanding of the notion of causality or the ability to take on a specific role in play. Furthermore, at any moment, the child can appeal to the experimenter's participation, thus enabling the child to experience triadic play.

Besides, beyond inspiration from non-directive play therapy, the approach presented in this paper introduces a *regulation process*. This process notably enables the experimenter to regulate the interaction in order to guide the child towards other play styles when needed or modify slightly the rhythm of play if she feels the child is "standing still". The study presented in this paper explores the potential of this novel methodological approach for robot-assisted play through a case-study evaluation of a long-term study with six children with autism. This study should be regarded as a preliminary exploration of the feasibility of such a technique in the context of robot-mediated therapy for children with autism. Several research questions are addressed:

a. Does such an approach of robot-mediated therapy, inspired by non-directive play therapy, help the child experience higher levels of play and enable him/her to develop new play skills?
b. Does this approach encourage the child to play socially?
c. Might this approach be appropriate for children who play solitarily and speak mostly by using onomatopoeia?[3] Might it help him/her experience social play? If not, what might be the additional requirements necessary for such experience?

2. Non-directive play therapy

This section summarizes the core ideas of non-directive play therapy as mainly developed in Axline (1947) and explained and illustrated by case studies in Ryan & Wilson (1996).

Non-directive play therapy has its roots in Rogerian client-centred therapy with adults (Rogers, 1976), adapted to child therapy with a focus on play as the principal medium of communication (in contrast to verbal exchange). Rogerian theory[4] relies on the idea that all human beings have a drive for self-realisation; it means that any human being tends to develop towards maturity, independence and self-direction. The individual needs to completely accept himself/herself as well as be accepted by others.

In non-directive play therapy, the child, rather than the therapist, chooses the type of play and the activity in general in the playroom. This contrasts with other play interventions. We shall cite Axline who primarily developed the method of non-directive play therapy (Axline, 1947): "Non-directive play therapy is not meant to be a means of substituting one type of behaviour, that is considered more desirable by adult standards, for another 'less desirable'. It is not an attempt to impose upon the child the voice of authority that says 'You have a problem. I want you to correct it'." Few limitations in the behaviour of the child are set, which refer to safety and security reasons.

A relationship is progressively built up between the child and the therapist. This relationship enables the child to share his/her inner world with the therapist and, "by sharing, (the child) extends the horizons of both their worlds" (Axline, 1947). Ryan et al. state that this relationship, with the help of the therapist, progressively facilitates the child to choose freely the feelings he/she wishes to focus on as well as the way in which he/she wants to explore them (Ryan & Wilson, 1996). Three mediums may be used for communicating these feelings: action, language and play.

The therapist participates in the therapy. She observes, listens to and answers the child. The therapist is reflecting the child's feelings or emotionalized behaviours in order to help him/her build a better understanding of himself/herself. The therapist's role has been characterized by eight basic principles set out by Axline (Axline, 1947), see Fig. 1.

Note that in the study presented in this paper the experimenter was not trying to engage in therapy; the study only drew inspiration from non-directive play therapy, thus the context may be a therapeutic one, but the experimenter, a human–robot interaction researcher, was not behaving exactly like a therapist. The experimenter was not applying strictly the eight principles set out by Axline (Axline, 1947), see Fig. 1. She very much drew inspiration from Axline's principles 1, 2, 3, 5 and 8, but she was not dealing with the fourth one; and, concerning principles 6 and 7, she was considering these principles with more flexibility. It is worthy of note here that this study is a first step towards a proof-of-concept and required significant robotics expertise; however, in future, play therapists may use this approach.

3. Related work

3.1 Non-directive play therapy for children with autism

Non-directive play therapy has been largely used for children and adolescents with a wide variety of emotional and behavioural problems (Ryan, 1999; Ryan & Needham, 2001). Only recently have researchers started to investigate the feasibility of such techniques with children with autism. A pioneering case study was presented in 2004 in Josefi & Ryan (2004) involving a 6-year-old-boy with severe autism. The child attended 16 non-directive play therapy sessions of an hour a 5-month period in the child's special school. The room was empty except for specific materials selected for their "expressive, imaginative, relaxing and interactive properties". Results were analysed both qualitatively and quantitatively. Results showed an increase in the child's autonomy and initiative-taking and the child developed an attachment to the therapist. According to Josefi et al. (Josefi & Ryan, 2004), it was shown that non-directive play therapy itself may provide children with autism with the basis[5] for therapeutic progress as stated in play literature (Axline, 1947). Also, the child's concentration increased and his repertoire of play

1. "The therapist must develop a warm, friendly relationship with the child, in which good rapport is established as soon as possible."
2. "The therapist accepts the child exactly as he is."
3. "The therapist establishes a feeling of permissiveness in the relationship so that the child feels free to express his feelings completely."
4. "The therapist is alert to recognize the *feelings* the child is expressing and reflects those feelings back to him in such a manner that he gains insight into his behavior."
5. "The therapist maintains a deep respect for the child's ability to solve his own problems if given an opportunity to do so. The responsibility to make choices and to institute change is the child's."
6. "The therapist does not attempt to direct the child's actions or conversation in any manner. The child leads the way; the therapist follows."
7. "The therapist does not attempt to hurry the therapy along. It is a gradual process and is recognized as such by the therapist."
8. "The therapist establishes only those limitations that are necessary to anchor the therapy to the world of reality and to make the child aware of his responsibility in the relationship."

Figure 1. Eight basic principles set out by Axline for practice of non-directive play therapy: quotations from Axline (1947)

expanded over the sessions. The games involved progressively more joint attention and direct social interaction and verbal communication with the therapist increased; symbolic play emerged more and more verbally with the therapist.[6] However, repetitive and obsessive behaviours were not considerably reduced. As a conclusion, Josefi et al. (2004) stated that non-directive play therapy with children with autism may be complementary to behaviour therapy, non-directive play therapy is likely to be more efficient in the child's gaining autonomy, taking initiative, showing joint attention and developing social and symbolic play, while behaviour therapy could be more efficient in reducing ritualistic and obsessive behaviours.

3.2 Robot-mediated therapy and education

Robot-mediated therapy is an area of research in assistive and rehabilitation robotics that aims at using robots in the therapy of patients in a variety of domains, e.g. in stroke rehabilitation (Loureiro et al., 2003). Robot-mediated therapy, and in particular the use of robot-assisted play in therapy or education, is a growing research field. It has been shown that robots, compared to simple toys, elicit a range of behaviours in children with autism that are more desirable in the light of encouraging and/or teaching children with autism social behaviour and communication. Werry and Dautenhahn (Werry, Dautenhahn, & Harwin, 2001; Dautenhahn & Werry, 2004) showed that children with autism exhibited more eye gaze and more attention directed towards an autonomously operating mobile robot compared to a non-robotic toy. Later, Stanton et al.'s studies compared interactions of children

with autism with an Aibo robot (Sony) and a simple mechanical toy (Stanton et al., 2008). Their results show that the children spoke more words to the robot and more often showed certain behaviours towards the Aibo including verbal engagement, reciprocal interaction, and authentic interaction. Such comparative studies provide the main motivation of our approach to use robots (and not other non-robotic toys) to investigate their potential in the therapy and education of children with autism.

A fully comprehensive review of the literature would go beyond the scope of this paper, and we therefore focus below on selected research that is particularly relevant to the present work.

Long-term studies with the seal robot Paro have shown that specific everyday life situations exist in which human–robot interaction can have a positive effect on the well-being of human beings (Shibata et al.,2005); they may even be a significant factor of performance in therapy[7] (Marti et al., 2005).

Outside the therapeutic context, in the broad field of child–robot interaction, Tanaka et al. led a long-term study in a school in order to identify principles for realizing long-term interaction (Tanaka et al., 2005, 2006). This study notably showed that the children's views of the robot evolved: they progressively considered the robot (in this case, the humanoid robot QRIO) as a peer rather than as a toy.

Within the Aurora Project, Robins et al. carried out long-term studies analyzing, on the one hand, the role of the robot as a mediator (Robins, Dautenhahn, & Dubowski, 2005) and, on the other hand, the role of the experimenter (Robins & Dautenhahn, 2006) which they described as that of a "passive participant" who responds to the children if they initiate interaction with him/her. There was no autonomous reaction from the robot to the child's interactions in their study. Moreover, child–robot interaction situations taking place during these trials were mainly concerned with encouraging imitation of gestures (position or movement of arms and legs). In Robins et al.'s experiments, children interacted with a remotely controlled robotic doll by imitation of gestures.[8]

In different studies, Werry et al. encouraged free-play with a mobile rectangular autonomous robotic platform, Labo-1, equipped with infrared sensors (Werry & Dautenhahn, 1999; Werry, Dautenhahn, Ogden, & Harwin, 2001). The play situations were approach and avoidance games whereby turn-taking emerged from the child–robot interactions (Dautenhahn, 2007). The experimenters did not take part in the games; they only responded to the child when the child initiated communication or interaction with them (Dautenhahn & Werry, 2002).

Outside the Aurora Project, Kozima et al. used a small dancing creature-like robot, Keepon, in a long-term study with children with autism, in relatively unconstrained conditions (Kozima et al., 2005). Keepon was manually controlled by the experimenter who was not part of the trials. Children and carers were involved in the trials which highlighted the role of Keepon as a pivot in triadic interaction by facilitating the emergence of joint attention. Another study conducted by Duquette et al. (2007) showed the potential of the robot Tito to elicit shared focused attention[9] (visual contact, physical proximity) in a large range of imitation games. This study also pointed out the impact of the robot in imitation games and showed its potential to foster imitation of facial expression but also, in this specific context, its limits for encouraging e.g. imitation of gestures.

These results reinforce the idea that child–robot interaction may be valuable for children with autism with respect to being a medium towards possible social interactions. It also shows the relevance of investigating new approaches in how to design and conduct robot-assisted play for children with autism.

4. Method

4.1 Participants

All the children taking part in the experiments have a diagnosis of autism and are from the same school based in the UK. This school welcomes children between 4 and 11 years old with moderate learning difficulties. In particular, an Autism Base provides extra care and a specific education program for children with autism to start within the school. When the child gets older or when he/she has made sufficient progress (especially if he/she has improved in social skills) he/she can be integrated in a more general class for children with specific needs and abilities including children with autism. Six children were selected by the teachers to take part in the current study. For purposes of clarity and simplicity, a consistent naming of the children will be used in the whole paper, starting with A and then, alphabetically, in order of appearance in the text.

Two boys from the Autism Base, Child A (seven years old) and Child B (eight years old) were invited to take part in the experiments. Both of them find it hard to express themselves verbally and their behaviour often includes using onomatopeia and repetitive gestures. According to the teachers, Child A often shows apprehension towards dogs and doors and Child B has a fascination for computers. Child C took part in the experiments who is a seven-year old girl. During the experiments, she was part of the Autism Base but in the process of being integrated into another class with children with moderate learning difficulties including children with autism. She therefore started to follow part-time the education program of this class and the rest of the time stayed in the Autism Base. She masters verbal communication pretty well and teachers describe her behaviour as proactively social, as far as play at playtime is concerned.

Three older children took also part in the experiments. All of them are integrated in classes for general moderate learning difficulties. Child D, ten years old,

is described by his teacher as a solitary child. In the classroom the position of his desk, fairly isolated from the others, gives him his 'own' space. Child D understands pretty well when one addresses him verbally but mostly speaks by using onomatopeia. At school, he often uses the computer to do exercises, especially exercises on words and writing. Two other children, Child E, ten years old and Child F, nine years old, took also part in the study. They communicate verbally and are not described as solitary children.

Note, other details, such as mental age of the children, were not available. The study was carried out with approval of the University of Hertfordshire Ethics Committee. The parents of all the children who took part in this study gave written consent, including permission to videotape the children and utilize photos in publications.

4.2 Artifact

The main artifact is a white robotic mobile autonomous dog, the Sony Aibo ERS-7 (Fig. 2). It is equipped with a great variety of external sensors, and particularly, five tactile sensors: the head sensor, the chin sensor and the three back sensors. Aibo's control programming was achieved using URBI (Baillie, 2005). A laptop endowed

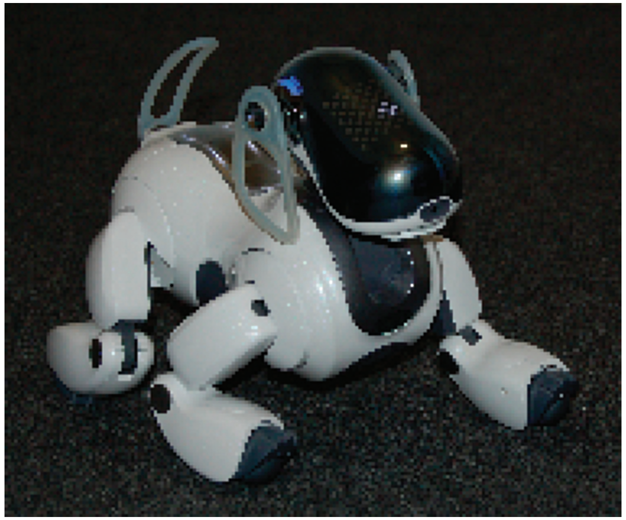

Figure 2. Aibo ERS-7. Aibo ERS-7 weights approximately 1.65kg and measures approximately 180(w) x 278(h) x 319(d) mm

the robot with specific behaviour-modes through a wireless connection. Once the robot had been endowed with a specific behaviour-mode, it reacted autonomously to the activation of its sensors.

4.3 Procedures and measures

4.3.1 *Procedures*

Experimental setup. The experiments took place once a week in the school. Each child participated in a maximum of ten sessions. Not every child could take part in 10 sessions because some of them may have been away for a day. Note that an exception was made for one child who showed some apprehension towards the robot: for him, experiments were stopped after 5 sessions and only restarted in the last session when he proactively came to the trial.

The rooms used for the experiments changed several times due to circumstances at the school (Fig. 3). In each case, the child could have encountered possible distractive objects, like toys or mirrors (Fig. 4). Thus, these experiments took place in a context of possible distraction.

Each trial involved one child with autism, the experimenter[10] and sometimes another researcher from the Aurora project with whom the children were familiar. The latter helped the experimenter film the trials and occasionally took part in a verbal communication process by answering a child's question directly addressed to her.

The duration of the sessions was variable. The child was free to play as long as he/she wanted with the following restrictions: (i) the upper limit of time was 40 minutes (so that the child did not miss too much of his/her courses at the school); (ii) if the child had an obligation due to his/her schedule, then the session was shortened.

The Aibo robot was programmed in order to show simple behaviours, tailored progressively by immersion according to each child's needs and abilities. Note that 'tailored by immersion' means here that the repertoire of appropriate robot behaviours with respect to each child's specific needs, abilities, dislikes and preferences was progressively refined as the experiments progressed. The mapping between the sensors and the reactions of the robot (also called behaviour-mode) could therefore vary from one session to the other and also during a session in order to meet as closely as possible the needs, abilities and demands of the child at a given moment (Fig. 5 includes examples of the robot's behaviours). The robot reacted autonomously to the activation of its sensors, with respect to the specific behaviour-mode it had been endowed with. The switch between various behaviour-modes was done manually by the experimenter through a wireless connection with a laptop. The laptop was located in the same room as the children, and thus constituted an additional source of distraction for the children.

Room	Description	Dimensions	Furniture in the room	Objects in the room
R 1	Small room	Approx. 10feet * 8feet	-small longitudinal window on the very top (children can't see through it), -cupboard, -low rectangular table, -2 children's chairs, -decoration on the wall (a clown's head drawn on a paper board).	Regular objects: - game with individual letters to form words, reflective blue metallic support, - coloured cubes (25mm*25mm) - rectangular paperboard 3D decoration, 1m*30cm*20cm , vertically in a corner. On occasion: man's like face drawn on a paperboard that children could hold in front of their face.
R 2	Small room in the Autism Base	Approx. 10feet * 12feet	-big window on a wall, -second internal window (semi-transparent, semi-reflective) with view on another classroom; -vertical mirror, children can see their whole body by reflection -shelves on the very top, children can't access -table & small chairs (session8 only)	- games in open boxes on the shelves (e.g. a doll); children can see them but can't access them.
R 3	Large meeting Room: library, kitchen and living room corners. Experiments took place in the living room corner.	-room: Approx. 35feet * 40feet; -living room corner, approx. 10feet * 12feet	-Large windows on two walls -2 sofas made of joint comfortable chairs -4 comfortable additional chairs -rectangular dinner table, 6 chairs -2 low coffee tables -shelves (at the entrance) -kitchen corner	-magazines on the coffee table -on the shelves, objects such as cloth samples in open boxes -small calculator -small alarm clock
R 4	Classroom; experiments took place in the library corner	-room: Approx. 30feet * 30feet; -library corner: approx. 10feet * 7feet	Library corner: -2 shelves separating the library corner from the rest of the classroom -small children's bench	Library corner: -books

Figure 3. Description of the school's rooms used for the experiments

Session	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10
Room	R1	R1	R1	R1	R1	R3	- Child C : R3 - Other children : R4	- Child C: R3 - Other Children: R2	R2	R2

Figure 4. List of the school's room(s) used for each session

Behaviour Mode / Sensor	1	2	3	4	5	6
Chin sensor	Wag the tail	Wag the tail	Emit "bark" sound while open-closing the mouth	Wag the tail	Open-close the mouth	Emit "bark" sound while open-closing the mouth
Head sensor	Open-close the mouth	Open-close the mouth	Move the head (head tilt oscillations)	Open-close the mouth	Wag the tail	Move the head (head tilt oscillations)
Back front sensor	Wag the tail	Wag the tail	Wag the tail	Walk forward, turn right, stand, turn left, walk backwards	Walk forward, turn right, stand, turn left, walk backwards	Walk forward, turn right, stand, turn left, walk backwards
Back middle sensor	Turn head (head pan oscillations)	Turn head (head pan oscillations)	Turn head (head pan oscillations)	Turn head (head pan oscillations)	Turn head (head pan oscillations)	Turn head (head pan oscillations)
Back rear sensor	Move the neck (oscillations)	Emit "bark" sound	Emit "drum" sound while wagging the tail	Emit "bark" sound and move the neck (oscillations)	Emit "drum" sound while wagging the tail	Emit "drum" sound while wagging the tail

Figure 5. Examples of Behaviour-Modes for the robot. Mapping between the external tactile sensors of the robot and its behaviours

Methodology of the approach. During the session, the child was invited to play with the Sony robotic pet Aibo. The experimenter took part in the experiment. The child was the major leader for play: the child was free to choose the game to focus on, the pace of play and he/she could engage in free-play (unconstrained play) with the robot and/or the experimenter; he/she was also free to engage in communication with the experimenter whenever he/she wanted. If the child appealed to the experimenter's participation, then the experimenter did take part in the game. If the child initiated verbal or non-verbal communication (e.g. smile, eye gaze) with the experimenter then the experimenter answered 'appropriately', e.g. (i) if the child smiled to the experimenter, then the experimenter smiled back at the child, (ii) if the child looked at the experimenter the experimenter looked at the child (eye contact) and (iii) if the child initiated verbal communication, the experimenter answered appropriately, using words the child could understand, to facili-ate social interaction. With respect to verbal communication, the experimenter tried to answer every question of the child and rewarded him/her verbally whenever appropriate (e.g. at the end of each play session, the experimenter told the child he/she played very well with Aibo and congratulated him/her.). Note that this approach is mainly child-centred, relies strongly on the child's capabilities of designing his/her own trajectory of progression and on total respect and consideration towards the child from the experimenter. In this sense, this approach draws inspiration from non-directive play therapy.

Beyond inspiration from non-directive play therapy, this approach adds a regulation process under specific circumstances which are detailed below:

a. *to prevent or discourage a repetitive behaviour*: If the child was starting or about to start a repetitive behaviour, the experimenter intervened and tried to help the child play a different game;[11]
b. *to help the child engage in play*: if the child did not engage in interaction with the robot, then the experimenter encouraged him/her to play with the robot, verbally and/or non-verbally (e.g. by stroking the robot and encouraging verbally imitation);
c. *to give a better pace to the game if already experienced by the child*: If the game was "standing still" but the child had already experienced it and had shown that he/she was capable of playing this specific game, then the experimenter could intervene straight away to confer a better pace to the game;
d. *to bootstrap a higher level of play*: if the child was about to reach a higher level of play but still needed some bootstrapping (some light guidance), the experimenter could provide it; note that the different levels of play are described in a Play Grid that is presented in the next subsection;
e. *to proactively ask questions related to affect or reasoning*: the experimenter could proactively ask the child simple questions related to affect or reasoning such as: "Do you think Aibo is happy today?" or "Do you like playing with Aibo?".

Note that (e) enables (i) testing the ability of the child to answer and/or (ii) showing the child a specific point for reasoning. We shall give several examples of levels of reasoning:

1. technical issue: show the child how to change the battery of the robot so that he/she can do it next time in a context of cooperative task;
2. ask the child if he/she thinks Aibo is happy;

3. help the child reason on causal effect: stimulation of a sensor implies a specific reaction of the robotic dog;
4. show the child that a reaction can be interpreted: e.g. if I press this specific button, then Aibo wags the tail; and wagging the tail can mean that Aibo is happy; thus if you press this button, you can show that Aibo is happy.

4.3.2 *Measures*

Each session was filmed unless the child explicitly asked not to be filmed which rarely happened. First, the experimenter viewed the video recordings and wrote down notes on the events constituting each session. These notes described the events in detail and contained as few interpretations as possible. As a second step, the experimenter analysed the data in terms of more abstract criteria that would enable her to identify, for each child, both the profile according to the three dimensions (Play, Reasoning and Affect) and the progress made over the 10 sessions. This methodology allows the researcher to first gather as much information as possible before deciding on the specific criteria; it has the advantage of not restricting the analysis to predefined criteria which might a posteriori turn out to be less optimal. This is especially relevant in the case of an exploratory study. This procedure follows the one described by Schatzman & Strauss (1973), stating that: "the researcher requires recording tactics that will provide him with an ongoing developmental dialogue" (p. 94). Schatzman & Strauss (1973) underline the importance of recording observations from the very beginning of research. They also suggest taking notes separately, categorizing notes into three different packages: (a) observational notes based on events, without interpretation; (b) theoretical notes representing an attempt to confer or denote the meaning from an observational note; (c) methodological notes dedicated to methodological comments.

Results of the experiments were analyzed according to three (intertwined) dimensions, respectively Play, Reasoning and Affect.

Play This study aims at testing the feasibility of this approach to encourage the child to learn new play skills and enable him/her to experience more and more complex play situations with respect to the following main criteria:

a. social aspect of play,
b. proportion of symbolic and/or pretend play,
c. understanding/use of causality,
d. ability to handle the pace of a specific play and possibly the chronology or the transitions between two logical segments of play.

That is why, concerning the dimension of play, what particularly matters is (1) to extract information qualitatively about play situations that the child has experienced

in each session, and (2) to see if the child really experienced a large repertoire of play and more complex levels of play gradually over the sessions.

For this purpose, a Play Grid was built (after the play sessions) based on the children's play observed during the experiments. This grid is exhaustive with respect to the variety of play situations which took place at least once during the experiments for at least one of the children. Besides, the different play situations were classified into 6 sets, each set denoting a specific level of complexity of play (Level 1 being the lowest and then gradually incrementing the level of complexity until Level 6). The level of complexity is defined according to four criteria:

a. social play,
b. proportion of pretend and/or symbolic play,
c. exploration of the use of causality/reaction,
d. chronology and/or number of different phases in the play, e.g. a simple reaction to a sensor is constituted of two phases while a search and rescue game involves many phases to handle chronologically: (i) initial situation, (ii) search phase, (iii) rescue phase, (iv) final situation.

The level of complexity is then deduced from an average evaluation over the four components which explains that the same level may contain play situations with a predominant component of '(d)' and others with a predominant component of '(b)'.[12] Consequently, within the same level of complexity, the different play situations are not ordered since they may be very different in nature. Ideally, the child would experience higher levels of play over time and, within the same level of complexity, play situations that are different in nature.

The systematic analysis with the grid for each child and each session shows the trajectory of each child (i.e. the profile of the child). Each cell in the grid is filled in if and only if it corresponds to a play situation experienced by the child at least once during that specific session; and the content depends on the play situation being acted proactively (i.e. child's own initiative) or reactively (i.e. the child was gently guided towards this play situation by the experimenter).

However, this grid is very enlightening with regard to children who manage to play socially and manage to diversify their play. For those who do not interact much with the robot and, when playing, tend to experience mainly solitary play through the exploration of the robot's features and behaviours, an additional tool to evaluate their progress was used. That evaluation was quantitative and relied on measuring for the whole duration of each session:

1. the total time spent in interaction with the robot,
2. the duration for each single uninterrupted phase (period) of pure interaction (note that the total duration is the sum of the duration of each single uninterrupted phase of play),

3. the amount of gestures imitated by the child and the number of gestures explicitly asked by the experimenter to be imitated.

Reasoning Through play, children can notably construct some understanding of social situations and gain experience of some situations they encountered while playing. If a child can reason about abstract concepts, infer mental states and make a sense of social rapport, it will be easier for him/her to play symbolically. Conversely, while the child experiences symbolic play, he/she manipulates abstract concepts such as inferring an emotion or handling social rapport. Both play styles and reasoning are therefore intertwined and both viewpoints should therefore be used to analyse the results of the experiments carried out for this study. Note that with respect to "Reasoning", what is particularly relevant is that both questions and answers emerg from play situations. The context of play enables the use of imagination, whereby Aibo may be assigned a specific role by the child, and it allows the child to attribute specific capacities to the robot such has having mental states (e.g. it enables him/her to imagine that Aibo is taking on a specific role and to make further assumptions on its mental state or its social status). Thus, the context of play enables the robotic pet to be attributed with mental states as well as a social role, and possibly moral standing. In this way, it is possible to explore the reasoning part of the coding manual developed by Kahn et al. (2003) for the analysis of children's conception of the Aibo robot, by exploring the four following categories used in Kahn et al. (2003): "Essence", "Mental States", "Social Rapport" and "Moral Standing". According to Kahn et al. (2003), those categories "reflect a 'quadrology' of children's conceptions of Aibo and Shanti".[13] For each of those four categories a list of related questions can be formulated (Kahn et al., 2003) that is provided in Fig 6.

Entity	Questions related
Essence	Does the child consider Aibo as an artifact or a biological entity?
Mental States	Does the child attribute mental states to Aibo? Does the child consider that the robot develops in terms of age for instance? Does the child consider Aibo has a personality? Does the child consider Aibo could live autonomously?
Social rapport	How does the child position Aibo relatively to himself/herself?
Moral standing	Can Aibo be physically or morally hurt? Can Aibo be held responsible for something? Can Aibo be punished when necessary? Could Aibo be praised?

Figure 6. Four categories proposed in Kahn et al. (2003) for the analysis of children's conceptions of Aibo. This table presents questions related to the four entities

Note that Kahn et al.'s coding manual has been developed in a different context: they targetted typically developing preschool children who only encountered Aibo once and afterwards immediately answered specific questions about "reasoning" (Kahn et al., 2003, 2006) – while answering questions, children could however carry on interacting with the robot. The context used in our study is different since the succession of sessions enabled the child to progressively build some reasoning and understanding, along with the progressive building of a shared space of expressions and routine activities between the child and the experimenter. Therefore, the reasoning related to the robot can be enriched. Besides, "reasoning" here is part of play in itself. In the study presented in this article, the context of play is actually used to enable the child to explore issues such as mental states or social rapport, and the robot in itself is a support for embodying such issues through the imaginary context that comes with play. Moreover, since the experimenter takes part in the experiments, not only social rapport between the child and the robot should be considered, but also the child's view on the notion of social rapport between the robot and the experimenter and between himself/herself and the experimenter. Consequently, here, the dimension of "Reasoning" is analysed as follows:

1. The main features of the four categories ("Essence", "Mental States", "Social Rapport" and "Moral Standing") are extracted from Kahn et al.'s coding manual (Kahn et al., 2003);
2. The issue of whether and how the child addresses those features is investigated for each child, in a perspective of questioning through play rather than giving firm answers.

Note that since the experimenter is not a therapist, and since the behaviour of children with autism might sometimes be interpreted differently from typically developing children, in the analysis we only consider events which are as much as possible objectively and reliably identifiable. Verbal events are particularly reliable events; they can be statements or questions arising from the child (major events) or answer to the experimenter's question (minor events). Below are some examples: (a) Essence: "He's a robot, he is a robot dog", "He has short teeth, he doesn't bite. Robot dogs don't bite, do some do?"; (b) Mental states: "Aibo is happy", "How old is Aibo", "Aibo, answer me, do you like toys?"; (c) Social Rapport: "It is your robot"; (d) Moral standing: the child accidently kicks the robot and apologizes verbally to the robot directly. Besides, in many cases, as already explained, reasoning and play are intertwined; for instance, when the child and the robot's relative social position in an enacted situation of pretend play is well-defined by the child (e.g. a competition with two participants, the child and Aibo), then the notion of social rapport is certainly addressed. Another example is a play situation of asking the robot about its mental states and answering with the activation of a sensor.

As a further step in reasoning, the child may tackle a more general issue related to his/her mental states for instance, or to social rapport, concerning himself/herself or even the experimenter. This is a relevant point for this study: it would show the potential reuse in another context of skills the child may develop or practise through reasoning about the robot during play.

Affect The 'Affect' dimension represents any expression indicating whether the child likes the robot or not, or if the child makes an assumption about the robot liking him/her. Here, only obvious signs (verbal expressions) of likes/dislikes are considered, (see Fig. 7 which provides the table of criteria for the coding of events related to affect). This is made in order to ensure that events considered as related to affect are clearly identifiable. For instance, a gentle stroke is not classified as an

1. Proactive (major) event related to affect: (i) Child's statement or question referring directly to himself/herself liking the robot or the robot liking him/her. No hug or kiss from the child to the robot. Examples: "I like Aibo", "Aibo likes me". (ii) Child's verbal compliment to/concerning the robot. No hug or kiss from the child to the robot. Examples: "good doggy", "nice dog", "he is a nice dog". (iii) Child's hug to the robot, clearly identifiable, accompanied by a kind word from the child to/concerning the robot or verbal statement qualifying the hug. Example: the child hugs the dog and asks the experimenter to hug the dog: "Put your hands and hug, hug, hug!" (iv) Child's kiss to the robot, clearly identifiable, accompanied by a kind word from the child to/concerning the robot. Example: the child gives a kiss to Aibo after saying "Goodbye Aibo, have a good sleep"
2. Reactive (minor) event related to affect: (i) Child's answer to a question about himself/herself liking the robot or the robot liking the child. Example: the experimenter asks the child: "Is it a nice robot?" and the child answers "Yes". (ii) Child's answer to a question about himself/herself being happy to play with the robot. Example: the experimenter asks the child: "Are you happy playing with the robot?" and the child answers "Yes". Note, reactive events related to affect are considered very cautiously in this study; they are not considered as sufficient to make firm deductions about the child addressing the notion of "Affect".

Figure 7. Criteria for coding events related to Affect. An event is related to 'Affect' if it corresponds to one of the items provided in the table; in some of the following figures, events related to affect are qualified by a corresponding code: the code of an event related to affect is given by its corresponding item's index, e.g. "I like Aibo" is [1i]

event related to affect in this study, neither a gesture such as a kiss or a hug, if it is not accompanied by an appropriate child's statement.

4.4 Coding and reliability

Inter-rater reliability testing was carried out for each of the three dimensions: play, reasoning and affect. A second coder who was not familiar with the aims of the study re-coded part[14] of the data. Good reliability was shown: (a) on play, 80.75% agreement (13*min*50*s* of videos coded divided among two children, Child E and Child C); (b) on reasoning, 80.35% agreement (18*min*24*s* of videos coded divided among two children, Child E and Child F); (c) on affect, 93.35% agreement (22*min* of Child C's videos coded).

5. Results

In the following we provide case study evaluations for each child.

Child A Child A showed some apprehension towards the robot and did not interact at all during the five first sessions. The experimenter therefore decided not to require the child to come for the following sessions and let the child proactively decide whether he wanted to take part in the further trials or not. In the last session (Session 10), Child A proactively came for the trial. In that session he engaged in an interaction with the robot with the help of the experimenter: one interaction event happened between the child and the robot, during which the experimenter showed the child how to stroke the robot and the child imitated (Fig. 8). Afterwards, the child showed both signs of light apprehension (he moved his body slightly backwards) and enjoyment (he smiled).

Child B Child B took part in 9 sessions (Fig. 9). Child B naturally showed attempts to play with the laptop rather than with the robot. It was a big challenge to get the child away from the laptop and get his attention focused on something else. The experimenter used a simple trick by hiding the laptop with a cloth. But for practicality reasons (e.g. to connect or reconnect Aibo during the session), the cloth had to be removed from time to time during the session thus introducing an important source of distraction for Child B. Progressively, the child seemed to have understood that he was allowed to occasionally have a look at the laptop (as part of his well-being) but that he should mostly engage in interactions with the robot. The table provided in Fig. 10 shows the average amount of time Child B spent engaging in play with the robot during each session. The tendency is clearly that the child

		1	2	3	4	5	6	7	8	9	10
L	*Solitary* Exploration										
1	"Imitation" of robot's bark										
	Solitary mirror play – look at oneself in the robot's reflecting face										
L 2	*"Pre-social" or basic-social* exploration – stroke Aibo immediately after the experimenter (possibly basic imitation of the gesture)										P
L	*Social* exploration (social play)										
3	Simple Bite/Save or Give/Food - no use of the sensors										
	Position or locomotion game – with verbal qualification of the game										
	Cooperative technical task: change the battery, or turn on/off Aibo										
	Verbal order towards Aibo: e.g. "sit", "walk", "wake up"										
	Basic pretend & social play – imitate Aibo's snoring & verbal comment										
	Basic play on affective gestures – give/receive a kiss and/or a lip to/from Aibo										
	Repeat after me - ask the experimenter to repeat verbal expressions										
	Look at Aibo through the camera (Possibly stroke Aibo & look at its reaction through the camera)										
	Speak French with Aibo - e.g. "Hello" or "Bye-Bye" in French										
	Show Aibo to other children (social play) Express verbally the willing/intention to show Aibo to the other children										
	Simple play with accessory (symbolic play)										
	Social Mirror play (social play) - look at oneself (and possibly at the experimenter) in the robot's reflecting face & express verbal comments, e.g. "Look at my arm!"										
	Social Hug – hug Aibo & ask the experimenter or the second researcher to hug Aibo										
L 4	*Complex* Give Food/Drink (cause-reaction play & symbolic play & social play) - use of sensors										
	Complex Bite/Save (cause-reaction play & pretend play & cooperative play) - use of sensors										
	Complex turn off Aibo to sleep (symbolic play)										
	Speak directly to Aibo about Aibo's feeling (symbolic play)										
	Cause-reaction play & mental states: Ask a question to Aibo (e.g. identity, feeling), answer with a sensor										
	Cause-reaction play, Aim at a physical reaction of the robot, show it with a sensor										
	Cause-reaction play & basic pretend play, "caught on the act"										
	Telling a story										
L 5	Cause-reaction play and explicit Social rapport: Ask a question to Aibo, answer with a sensor (e.g. press the sensor which opens the mouth), translate verbally the answer for the experimenter										
	Symbolic & pretend play Complex play with an accessory										
	Symbolic & pretend play Complex nap with Aibo										
	Symbolic & extrapolation play: "RobotCat" - Speak about the idea of a robotic cat (possibly imagine how one would play with it)										
	Causal composition of plays: Bite/Save & Give Food/Drink										
	Causal composition of plays: Kiss & Bite/Save										
	Pretend play & causal reaction & social rapports: Ask verbally Aibo to act a situation, use of sensors										
L 6	Pretend play & focus on Aibo's mental states: Mimic Aibo's cry, and explain Aibo is never crying but pretending to cry										
	Pretend play & social rapports: Look after Aibo and set up rules										
	Pretend & symbolic & chronological play & social rapports: Search and rescue										
	Pretend & symbolic play & social rapport & cause-reaction play & chronological play: competition (drink fast) between the child or the experimenter and Aibo ; the non-competitor activates Aibo's sensor										

played longer with the robot in the last two sessions than in the previous ones and almost doubled his play time between the 9th and 10th session. If we consider in detail the duration of single phases of play, i.e. uninterrupted periods of time when the child continuously played with the robot, then, again, this table shows that the child experienced longer uninterrupted periods of play with the robot during the last sessions. Typically, two uninterrupted periods of play are often separated by an attempt of the child to play with the laptop. This shows that the child progressively learnt to focus more and more on the robot and on engaging in play with the robot. Nevertheless, the experimenter also often intervened to help the child carry on playing and keep focusing his total attention to the robot; this intervention usually happened in two ways: (a) encouraging and rewarding the child verbally, or (b) showing an example, e.g. stroking the robot and asking for the child to do the same. In this context, '(b)' is very relevant indeed since the child does not speak verbally and encouraging imitation is favourable for both relaunching the child's engagement in play and bootstrapping social play. It should be noted that in this specific context, imitation is very rudimentary: the experimenter either touches a specific sensor or gently strokes the robot (e.g. on the head) and explicitly asks the child to do the same. The child is considered to imitate the experimenter's gesture if he exhibits the same type of gesture within 10 seconds, i.e. either by touching a sensor or stroking, and if the gesture is applied on the same part of the robot's body; for instance, (i) the experimenter touches the head sensor and, within 10 seconds, the child presses the same sensor (with or without activation depending on the child's precision of touch) ; or (ii) the experimenter gives a gentle stroke on the back of the robot and, within ten seconds, the child gives a stroke on the back of the robot. Results show that Child B progressively experienced more situations of imitation. Besides, they also reveal that during the last session he imitated some gestures proactively, i.e. without being explicitly asked by the experimenter to imitate.

Figure 8. Child A. Play Grid. The first column describes the corresponding level of play, the second column details the various play situations for each level that the child experienced at least once; the following columns refer to the sessions, ordered chronologically. The table is then completed according to the following rules: (a) if the child did not experience the play situation during the specific session, leave the corresponding cell blank; (b) if the child experienced the specific play situation at least once during the session, then write "P" (if the child experienced it proactively only – i.e. it was his/her own initiative). Write "r" if the child never experienced it proactively (only reactively: the experimenter guided the child towards the play situation). Write "B" if the child experienced this play situation several times, sometimes proactively and sometimes reactively. Note that Child A did not take part in the play sessions 6, 7, 8 and 9

		1	2	3	4	5	6	7	8	9	10
L 1	*Solitary* Exploration	P	B	B	P	r			B	P	B
	"Imitation" of robot's bark										
	Solitary mirror play – look at oneself in the robot's reflecting face										
L 2	*"Pre-social" or basic-social* exploration – stroke Aibo immediately after the experimenter (possibly basic imitation of the gesture)								r	r	B
L 3	*Social* exploration (social play)										
	Simple Bite/Save or Give/Food - no use of the sensors										
	Position or locomotion game – with verbal qualification of the game										
	Cooperative technical task: change the battery, or turn on/off Aibo										
	Verbal order towards Aibo: e.g. "sit", "walk", "wake up"										
	Basic pretend & social play – imitate Aibo's snoring & verbal comment										
	Basic play on affective gestures – give/receive a kiss and/or a lip to/from Aibo										
	Repeat after me - ask the experimenter to repeat verbal expressions										
	Look at Aibo through the camera (Possibly stroke Aibo & look at its reaction through the camera)										
	Speak French with Aibo - e.g. "Hello" or "Bye-Bye" in French										
	Show Aibo to other children (social play) Express verbally the willing/intention to show Aibo to the other children										
	Simple play with accessory (symbolic play)										
	Social Mirror play (social play) - look at oneself (and possibly at the experimenter) in the robot's reflecting face & express verbal comments, e.g. "Look at my arm!"										
	Social Hug – hug Aibo & ask the experimenter or the second researcher to hug Aibo										
L 4	*Complex* Give Food/Drink (cause-reaction play & symbolic play & social play) - use of sensors										
	Complex Bite/Save (cause-reaction play & pretend play & cooperative play) - use of sensors										
	Complex turn off Aibo to sleep (symbolic play)										
	Speak directly to Aibo about Aibo's feeling (symbolic play)										
	Cause-reaction play & mental states: Ask a question to Aibo (e.g. identity, feeling), answer with a sensor										
	Cause-reaction play, Aim at a physical reaction of the robot, show it with a sensor										
	Cause-reaction play & basic pretend play, "caught on the act"										
	Telling a story										
L 5	Cause-reaction play and explicit Social rapport: Ask a question to Aibo, answer with a sensor (e.g. press the sensor which opens the mouth), translate verbally the answer for the experimenter										
	Symbolic & pretend play Complex play with an accessory										
	Symbolic & pretend play Complex nap with Aibo										
	Symbolic & extrapolation play: "RobotCat" - Speak about the idea of a robotic cat (possibly imagine how one would play with it)										
	Causal composition of plays: Bite/Save & Give Food/Drink										
	Causal composition of plays: Kiss & Bite/Save										
	Pretend play & causal reaction & social rapports: Ask verbally Aibo to act a situation, use of sensors										
L 6	Pretend play & focus on Aibo's mental states: Mimic Aibo's cry, and explain Aibo is never crying but pretending to cry										
	Pretend play & social rapports: Look after Aibo and set up rules										
	Pretend & symbolic & chronological play & social rapports: Search and rescue										
	Pretend & symbolic play & social rapport & cause-reaction play & chronological play: competition (drink fast) between the child or the experimenter and Aibo ; the non-competitor activates Aibo's sensor										

Figure 9. Child B. Play Grid. See Fig. 8 for a detailed caption. Note that Child B was away for Session 7

	Total duration of play (min: sec)	Repartition of the play time in single phases of play (min:sec and + between 2 single phases)	Aspects of imitation: In each single phase of play, numbers of gestures:		Verbal expression involving either the word 'dog' or 'robot'
			Imitated by the child	Explicitely asked by the experimenter to be imitated	
Session1	0:06	0:06	0	0	
Session2	1:30	1:00 + 0:30 (mostly looking attentively at Aibo)	0	0	
Session3	0:40	0:40	0	0	
Session4	Almost null	Almost null	0	0	'The little dog was easy'
Session5	0:15	0:15 the experimenter helps by holding the child's hand to show him	0	0	
Session6	0:00	0:00	0	0	
Session7	away				
Session8	1:05	1:05	1	2	
Session9	2:21	0:40 +1:16 +0:16	0 +1 +0	0 +2 +0	
Session10	5:24	0:20 +1:47 +0:18 +2:46	0 +3 +0 +3	0 +3 +0 +1	

Figure 10. Child B. Dimension of play: quantitative results. For each session, the following indicators are reported: (a) total duration of play; (b) duration for each specific single session of play ; (c) aspects of imitation with respect to (i) the occurrence of gestures (touch or stroke of the robot) that the child imitated and (ii) the occurrence of gestures that the experimenter explicitly asked the child to imitate; (d) verbal expressions including the word "dog" or "robot"

Concerning the "Reasoning" dimension, Child B did not address the issue verbally. Thus, no firm conclusions should be drawn. However, the detailed study of the child's gestures shows that the exploration of the child became progressively richer over the sessions. The child varied his position relative to the robot, from sitting to kneeling and lying, and thus looked at the robot from various viewpoints. Moreover, he progressively varied his way of touching the robot: during the first sessions, he progressively abandoned random-like touch to develop more targeted touch. Note that targeted touch can be, for instance, trying to touch a single sensor precisely or stroke the robot gently and then activate many sensors. Besides, during the last session, the child experienced proactively a combination of two previous sensor activations: first, he imitated the experimenter and stroked the back of the robot; then he imitated the experimenter again and touched the head; third, he simultaneously activated the robot's back and head sensors.

Concerning the third dimension, "Affect", no event that was related to affect (with respect to Fig. 7) was recorded.

Child D Child D was away for Session 3 and Session 6 and therefore took part in 8 sessions in total. The analysis of the Play Grid in Fig. 11 shows that Child D played mostly solitarily. He engaged largely in exploratory play which became progressively more and more enriched. Two main aspects objectively illustrate the phenomenon (a) a progressive change of position (from sitting orthogonal to the robot and not facing the experimenter to facing the robot and the experimenter) and (b) a more diversified way of touching the sensors. Moreover, the child practised "solitary mirror play" frequently. It consists of looking at one's own image in the robot's reflecting face. Child D experienced situations of looking at his image with other reflecting surfaces too, such as a window partially reflecting, or a mirror perfectly reflecting (room R2 contained a mirror). All of these play situations, consisting of looking at one's own image, were often fascinating for Child D, and sometimes prevented him from engaging in other kinds of play situations. Besides, Child D did not experience play involving explicitly causal reactions, such as showing a specific reaction of the robot through the sensors' activation.

However, progressively, Child D experienced situations with some components of social play. From a cooperative point of view, the child did take part, both reactively and proactively in cooperative technical tasks such as turning on the robot. Furthermore, Child D, who mostly speaks by using onomatopeia did develop some ways of expressing himself, by dancing in front of the mirror and/or the robot and even probably telling a story by not using proper words but onomatopeia. The situation described below, that Child D experienced, may actually be interpreted, with caution, as a storytelling situation: Child D chronologically (a) pressed the button to "wake up" Aibo (i.e. turn Aibo on), then

		1	2	3	4	5	6	7	8	9	10
L 1	*Solitary* Exploration	P	P		P			P	P	P	P
	"Imitation" of robot's bark										
	Solitary mirror play – look at oneself in the robot's reflecting face	P			P	P		P	P	P	P
L 2	*"Pre-social" or basic-social* exploration – stroke Aibo immediately after the experimenter (possibly basic imitation of the gesture)				P	P		P	B		
L 3	*Social* exploration (social play)										
	Simple Bite/Save or Give/Food - no use of the sensors										
	Position or locomotion game – with verbal qualification of the game										
	Cooperative technical task: change the battery, or turn on/off Aibo				P	P		B	P	P	B
	Verbal order towards Aibo: e.g. "sit", "walk", "wake up"										
	Basic pretend & social play – imitate Aibo's snoring & verbal comment										
	Basic play on affective gestures – give/receive a kiss and/or a lip to/from Aibo										
	Repeat after me - ask the experimenter to repeat verbal expressions										
	Look at Aibo through the camera (Possibly stroke Aibo & look at its reaction through the camera)										
	Speak French with Aibo - e.g. "Hello" or "Bye-Bye" in French										
	Show Aibo to other children (social play) Express verbally the willing/intention to show Aibo to the other children										
	Simple play with accessory (symbolic play)										
	Social Mirror play (social play) - look at oneself (and possibly at the experimenter) in the robot's reflecting face & express verbal comments, e.g. "Look at my arm!"										
	Social Hug – hug Aibo & ask the experimenter or the second researcher to hug Aibo										
L 4	*Complex* Give Food/Drink (cause-reaction play & symbolic play & social play) - use of sensors										
	Complex Bite/Save (cause-reaction play & pretend play & cooperative play) - use of sensors										
	Complex turn off Aibo to sleep (symbolic play)										
	Speak directly to Aibo about Aibo's feeling (symbolic play)										
	Cause-reaction play & mental states: Ask a question to Aibo (e.g. identity, feeling), answer with a sensor										
	Cause-reaction play, Aim at a physical reaction of the robot, show it with a sensor										
	Cause-reaction play & basic pretend play, "caught on the act"										
	Telling a story									P	P
L 5	Cause-reaction play and explicit Social rapport: Ask a question to Aibo, answer with a sensor (e.g. press the sensor which opens the mouth), translate verbally the answer for the experimenter										
	Symbolic & pretend play Complex play with an accessory										
	Symbolic & pretend play Complex nap with Aibo										
	Symbolic & extrapolation play: "RobotCat" - Speak about the idea of a robotic cat (possibly imagine how one would play with it)										
	Causal composition of plays: Bite/Save & Give Food/Drink										
	Causal composition of plays: Kiss & Bite/Save										
	Pretend play & causal reaction & social rapports: Ask verbally Aibo to act a situation, use of sensors										
L 6	Pretend play & focus on Aibo's mental states: Mimic Aibo's cry, and explain Aibo is never crying but pretending to cry										
	Pretend play & social rapports: Look after Aibo and set up rules										
	Pretend & symbolic & chronological play & social rapports: Search and rescue										
	Pretend & symbolic play & social rapport & cause-reaction play & chronological play: competition (drink fast) between the child or the experimenter and Aibo ; the non-competitor activates Aibo's sensor										

(b) stood in front of the wall mirror in the room, still watching Aibo "waking up"; (c) once Aibo had "woken up", the child started dancing and using onomatopeia in front of the mirror. At some point, the robot disconnected. During the whole process the experimenter told Child D many times that she thought he was telling a story and asked him if she was right. She got no answer. When the robot disconnected the child stopped dancing and the experimenter reiterated her question: "Was it a story that you were telling me? Yes or no?"and the child answered "Yes". Then she asked: "Can you tell me another story, yes or no?" and the child answered "yes". Then the child repeated the same succession of behaviours '(a)', '(b)' and '(c)' and she asked: "Is the story about a boy?" And he answered "Yes". It is worthy of note here that the child might have simply repeated the word 'yes' after each question without giving a 'real' answer to the questions. Nonetheless, that example shows how the child may have progressively opened up to more communication with his surrounding social environment for play (notably the experimenter).

This storytelling situation took place in the last sessions while the child was starting to answer some questions about reasoning as well as using proactively verbal expressions to express intention. An in depth study of the verbal answers the child gave shows that over the first sessions, the child almost only answered "yes" or "no", whenever he answered. Then, progressively, the child answered some questions by repeating words from the question: e.g. in Session 4 the experimenter asked "Do you want to play with the robot or go back to the classroom?". The child answered: "play with the robot". And in the last two sessions, the child did use expressions to express his own intentions; for instance, the expression "sitting down" means that he wants to remain sitting down on the ground to carry on playing with the robot. In Session 9, the experimenter actually asked the child: "Do you want to go back to the classroom or play with him (the robot)?" and the child answered "play with him". Then later in the session, the experimenter asked the question "Shall we go back to the classroom now?" and the child answered: "Sitting down". During the last session, the child reused exactly the same expression ("sitting down") to answer the experimenter's question: "Would you like to go back to the classroom soon?".

Figure 11. Child D. Play Grid. The first column describes the corresponding level of play, the second column details the various play situations for each level that the child experienced at least once; the following columns refer to the sessions, ordered chronologically. The table is then completed according to the following rules: (a) if the child did not experience the play situation during the specific session, leave the corresponding cell blank; (b) if the child experienced the specific play situation at least once during the session, then write "P" (if the child experienced it proactively only – i.e. it was his/her own initiative). Write "r" if the child never experienced it proactively (only reactively: the experimenter guided the child towards the play situation). Write "B" if the child experienced this play situation several times , sometimes proactively and sometimes reactively. Note that Child D was away for Session 3 and Session 6

Regarding the analysis of the reasoning dimension, the child answered reactively very basic questions about Aibo's mental states, such as "Do you think Aibo is happy today?" or about his own mental state: "Do you like playing with the robot?" but there was no proactivity from the child with respect to mental states.

Concerning "Social rapport", the child progressively grasped the fact that Aibo belonged to the experimenter. In the first sessions, the experimenter had to explain many times to the child that he could not take the robot with him back to the classroom. In contrast, at the end of the last session, the child hesitated a short time and gave the robot back to the experimenter proactively. Apart from that, the child did not explicitly show any reasoning on "Social rapport" or on Aibo's "Moral standing".

The dimension of Affect has been mostly addressed indirectly (Fig. 12), through simple questions from the experimenter: in Session 4, the child answered affirmatively to the following questions: (a) "Is it a nice robot?" and (b) "Are you happy playing with the robot?". Later, in Session 9, the child answered affirmatively to the question "Do you think Aibo likes you?" And in Session 10, the child answered affirmatively to the question "You like the robot?". Note that since these inputs did not emerge proactively we should be careful with too much interpretation. Nonetheless, it should be underlined that most of the time the child said he preferred playing with the robot rather than going back to the classroom, which shows the child was having fun playing with the robot. Note, the experimenter is aware that the child may just have given a stereotypical answer.[15]

Child C Child C was away for Session 7 and thus took part in 9 sessions in total (note that in Session 6 she had a very limited time of play, approximately 10 minutes, because of a class trip). The Play Grid in Fig. 14 shows that Child C experienced more and more complex levels of play during the sessions (see Fig. 13). She experienced play situations involving the activation of a specific sensor to generate a precise reaction only a bit. She rather proactively experienced firstly play situations where "affect" is largely addressed (e.g. "Social Hug"). Secondly, she developed play situations where the robot embodied a character in a story she was telling. Finally, in a third and last phase, she initiated play situations where she was

Session	**Events objectively related to Affect** (ordered chronologically with respect to first appearance, event only mentioned once per session)
S1	
S2	· [2i] **"Do you like it?"** (Experimenter); **"Yes"** (Child D)
S3	
S4	· [2i] **"Is it a nice robot?** (Experimenter); **"Yes"** (Child D); ·[2ii] **"You are happy playing with the robot?** (Experimenter); **"Yes"** (Child D)
S5	
S6	
S7	
S8	
S9	· [2i] **"Do you think Aibo likes you?"** (Experimenter); **"Yes"** (Child D)
S10	· [2i] **"You like the robot?"** (Experimenter); **"Yes"** (Child D)

Figure 12. Child D. Events related to Affect. Events are separated by bullet points, and provided with their context (normal font) in the table. Events written in bold are coded according to Fig. 7 (the code is provided in brackets in front of the event); please note that when the child answers a question, the event in itself is the child's answer, but, in this table, in order to make it clear to the reader, the question that the answers refers to is also written in bold

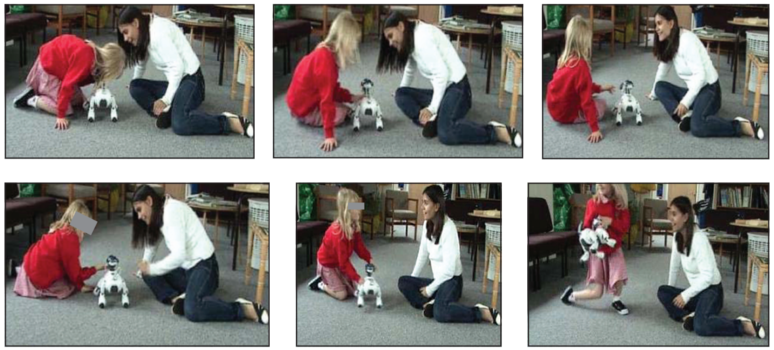

Figure 13. Child C involved in social play with the experimenter. Two sequences are displayed, one on each line. Each sequence is organised chronologically; on the first line, picture on the right and on the second line, picture in the middle, Child C is making eye contact with the experimenter

able to tackle issues on social rapport or mental states (Session 10: "looking after Aibo and set up rules" and "search and rescue" play situations).

The "looking after Aibo" game dealt with deciding that she and the experimenter would take care of Aibo, and Child C proactively suggested that, as a

		1	2	3	4	5	6	7	8	9	10
L 1	*Solitary* Exploration										
	"Imitation" of robot's bark				P	P			P		
	Solitary mirror play – look at oneself in the robot's reflecting face										
L 2	*"Pre-social" or basic-social* exploration – stroke Aibo immediately after the experimenter (possibly basic imitation of the gesture)										
L 3	*Social* exploration (social play)	P	P	P	P	P	P		P	P	P
	Simple Bite/Save or Give/Food - no use of the sensors						r				P
	Position or locomotion game – with verbal qualification of the game	P				P	P		P		
	Cooperative technical task: change the battery, or turn on/off Aibo		P	P	P		r		r	P	
	Verbal order towards Aibo: e.g. "sit", "walk", "wake up"		P	P	P				P	P	P
	Basic pretend & social play – imitate Aibo's snoring & verbal comment		P								
	Basic play on affective gestures – give/receive a kiss and/or a lip to/from Aibo			P	P	P	P				
	Repeat after me - ask the experimenter to repeat verbal expressions										P
	Look at Aibo through the camera (Possibly stroke Aibo & look at its reaction through the camera)				P						
	Speak French with Aibo - e.g. "Hello" or "Bye-Bye" in French										
	Show Aibo to other children (social play) Express verbally the willing/intention to show Aibo to the other children										
	Simple play with accessory (symbolic play)										
	Social Mirror play (social play) - look at oneself (and possibly at the experimenter) in the robot's reflecting face & express verbal comments, e.g. "Look at my arm!"										
	Social Hug – hug Aibo & ask the experimenter or the second researcher to hug Aibo			P							
L 4	*Complex* Give Food/Drink (cause-reaction play & symbolic play & social play) - use of sensors								B	B	P
	Complex Bite/Save (cause-reaction play & pretend play & cooperative play) - use of sensors										
	Complex turn off Aibo to sleep (symbolic play)										
	Speak directly to Aibo about Aibo's feeling (symbolic play)										
	Cause-reaction play & mental states: Ask a question to Aibo (e.g. identity, feeling), answer with a sensor						P				
	Cause-reaction play, Aim at a physical reaction of the robot, show it with a sensor						r		P		r
	Cause-reaction play & basic pretend play, "caught on the act"										
	Telling a story				P		P		P	P	
L 5	Cause-reaction play and explicit Social rapport: Ask a question to Aibo, answer with a sensor (e.g. press the sensor which opens the mouth), translate verbally the answer for the experimenter										
	Symbolic & pretend play Complex play with an accessory										
	Symbolic & pretend play Complex nap with Aibo										
	Symbolic & extrapolation play : "RobotCat" - Speak about the idea of a robotic cat (possibly imagine how one would play with it)										
	Causal composition of plays: Bite/Save & Give Food/Drink										
	Causal composition of plays: Kiss & Bite/Save										
	Pretend play & causal reaction & social rapports: Ask verbally Aibo to act a situation, use of sensors										
L 6	Pretend play & focus on Aibo's mental states: Mimic Aibo's cry, and explain Aibo is never crying but pretending to cry										
	Pretend play & social rapports: Look after Aibo and set up rules										P
	Pretend & symbolic & chronological play & social rapports: Search and rescue										P
	Pretend & symbolic play & social rapport & cause-reaction play & chronological play: competition (drink fast) between the child or the experimenter and Aibo ; the non-competitor activates Aibo's sensor										

Figure 14. Child C. Play Grid. See Fig. 11 for a detailed caption. Note that Child C was away for Session 7

consequence, she and the experimenter would have to define rules the robot would have to respect; and she enumerated the rules (among them, a detailed list of what the robot is not allowed to eat, and the statement: "dogs must go outside and must walk", followed by "I need to make him walk"). This game also gave rise to proactive inferences of state, the child even saying: "Look! He is smiling!" in the proper context. The social status that she took of taking care of Aibo led her to show the experimenter how to do specific things such as to make Aibo go forward: "You see, you must do like this, see".

Furthermore, this game was followed by a "search and rescue game" which was extremely rich in many ways:

a. The child led the rhythm, the pace, and the three steps of the play situation (chronologically):
   - step 1: initial situation where Aibo is lost, the goal of finding Aibo is stated,
   - step 2: the experimenter and the child are looking for the dog,
   - step 3: final situation: the experimenter and the child find the dog.
b. The child slightly extended step 2 over time so that she could deal with emotional states, particularly sadness: "You think we've lost him forever" said Child C; "Oh, that's sad" said the experimenter; and the child replied: "I think we're sad actually" thus conferring a socio-dramatic dimension to the current play situation.
c. During step 3, when the robot was found, the child introduced some reasoning about categories: she introduced the notion that it might be a robot other than Aibo that she and the experimenter had found; she introduced this reasoning step by step and she might not have been really at ease with these concepts, but the point is that she practised them through experiencing them: Child C's reasoning started with "Oh no, there are two Aibos here" and, after several steps in the reasoning, she drew the following conclusion: "No there are two dogs, only one Aibo. The clever one!" and she threw up her hands accompanied by a big smile. Again, what is illustrated here is that both "reasoning" and "play" dimensions are highly intertwined.

Concerning the notion of "Essence" for the Reasoning dimension, Child C mixed the use of artifacts and biological statements such as saying within the same session: "He's a robot, he's a robot dog" and "Nice dog", "He is a nice dog", "I love dogs", "A boy or a girl?" (Session 10).

Except in the last session, the notion of "Mental states", was addressed mostly reactively: the child answered questions asked by the experimenter such as "Do you think Aibo is hungry?" (which usually initiates the game "Give food/drink"). There were two exceptions: (a) the child proactively said that the robot liked her, and (b) the child could sometimes refer to mental states when telling stories she adapted from well-known children's books. During the last session, the child proactively referred to mental states of the robot as mentioned above in both "look after" and "search and rescue" play situations. During the "look after" play situation, she said: "We play, want to make the dog happy, make the dog feel pretty".

Moreover, as already mentioned above too, she experienced "Social rapport" a lot e.g. either simply by saying (in Session 9) "Look at Aibo, Aibo is your dog" or in taking on specific social roles in more elaborated play situations (e.g. in Session 10, during "look after" and "search and rescue" games).

Concerning "Moral standing", no objective event related to it happened.

The dimension of "Affect" played an important role for the child (Fig. 16). In Session 1 already, she started saying "good doggy" with respect to the robot. Then, in Session 3 she introduced the notion of social hug (see Fig. 15), which consisted in asking the experimenter (or the second researcher present) to help her hug the dog: "Put your hands and hug, hug, hug" Child C asked. Later in the same session, as well as in Session 4, the child said, "The dog really likes me". Note that end of Session 3 is the first time she answered the question "Do you like it (Aibo)?" (she answered affirmatively). From that session onwards, the child confirmed several times the fact that Aibo liked her (e.g. Session 4 "The dog really likes me") and that she liked Aibo (e.g. in Session 10: "I love Aibo" and "Nice dog").

Figure 15. Child C's social hug to the robot. Photos ordered chronologically. The child brings the robot to a second researcher (who helped out during this trial) while saying "Put your hands and hug, hug, hug" and both of them hug the dog. In the third picture from the left, Child C makes eye contact with the researcher

Session	**Events objectively related to Affect** (ordered chronologically with respect to first appearance, event only mentioned once per session)
S1	· [1ii] **"Good doggy"** (Child C) while stroking the robot and looking at the experimenter (eye contact)
S2	
S3	· [1iii] **"Help me hug the dog: put your hands and hug, hug, hug"** (Child C) while bringing the robot near the assistant and showing how to hug · [1ii] **"Good doggy"** (Child C) · [1i] **"The dog really likes me"** (Child C). The experimenter answer "yes" · [2i] **"Do you like it?** (Experimenter). **"Yes"** (Child C)
S4	· [1ii] **"Good doggy"** (Child C), while stroking the robot · [1i] **"The dog really likes me"** (Child C) and she starts mimicking the noise that would do the dog by lapping her.
S5	· [1ii] **"Good doggy"** (Child C) and she looks at the experimenter; "yes very good doggy" (Experimenter).
S6	
S7	
S8	· [1ii] **"Good doggy"** (Child C) after the robot has "woken up" (i.e. is connected)
S9	· [2i] **Are you happy to see Aibo?** (Experimenter); **"Yes"** (Child C)
S10	· [1ii] **"Nice dog"** (Child C) · [1i] **"I love Aibo. I love Aibo"** (Child C) and she strokes the robot · [1ii] **"Good boy, good boy"** (Child C) and she strokes the robot · [1i] "Do you like the walk C, please tell me? (Experimenter); **"Yes, this is all about dogs like me"** (Child C) · [2i] **You like Aibo, right?** (Experimenter); **"Yes"** (Child C)

Figure 16. Child C. Events related to Affect. See caption of Fig. 12 for details

Child E. Child E took part in the 10 sessions of experiments. The Play Grid in Fig. 17 shows that Child E progressively experienced more and more complex levels of play over the sessions. During the first sessions, he attentively explored the reactions of the robot and in the following sessions, he experienced more and more simple causal reactions through the following games: (a) "ask about a feeling, answer with a sensor", e.g. in Session 10 the child asked: "are you happy?" and pressed the head button which made the robot wave the mouth as to say "yes". (b) "aim at a physical reaction, show it with sensors": e.g. the experimenter asked "Do you think Tornado (the name the child gave to the robot) can wag the tail today?" and Child E activated the right sensor at the first attempt and commented: "That's the tail one". Child E also proactively played the game of giving food or drink to the robot as well as a cooperative play situation of Bite/Save (see Fig. 18). Bite/Save play situation consisted of two chronological steps: (i) the robot bit the finger of either the child

		1	2	3	4	5	6	7	8	9	10
L 1	*Solitary* Exploration										
	"Imitation" of robot's bark										
	Solitary mirror play – look at oneself in the robot's reflecting face			P							
L 2	*"Pre-social" or basic-social* exploration – stroke Aibo immediately after the experimenter (possibly basic imitation of the gesture)										
L 3	*Social* exploration (social play)	P	P	P	P	P	P	P	P	P	P
	Simple Bite/Save or Give/Food - no use of the sensors						r	r			
	Position or locomotion game – with verbal qualification of the game	P		P					P		P
	Cooperative technical task: change the battery, or turn on/off Aibo	P	P	P	P	B	P	P	P	P	P
	Verbal order towards Aibo: e.g. "sit", "walk", "wake up"		P			P					
	Basic pretend & social play – imitate Aibo's snoring & verbal comment										
	Basic play on affective gestures – give/receive a kiss and/or a lip to/from Aibo										
	Repeat after me - ask the experimenter to repeat verbal expressions										
	Look at Aibo through the camera (Possibly stroke Aibo & look at its reaction through the camera)										
	Speak French with Aibo - e.g. "Hello" or "Bye-Bye" in French										
	Show Aibo to other children (social play) Express verbally the willing/intention to show Aibo to the other children										
	Simple play with accessory (symbolic play)							P			
	Social Mirror play (social play) - look at oneself (and possibly at the experimenter) in the robot's reflecting face & express verbal comments, e.g. "Look at my arm!"		P	P		P	P	P	P		
	Social Hug – hug Aibo & ask the experimenter or the second researcher to hug Aibo										
L 4	*Complex* Give Food/Drink (cause-reaction play & symbolic play & social play) - use of sensors						B	B	B	B	B
	Complex Bite/Save (cause-reaction play & pretend play & cooperative play) - use of sensors			P		B	r	P	P	P	P
	Complex turn off Aibo to sleep (symbolic play)							P			
	Speak directly to Aibo about Aibo's feeling (symbolic play)						P	P		P	P
	Cause-reaction play & mental states: Ask a question to Aibo (e.g. identity, feeling), answer with a sensor					r		r		P	P
	Cause-reaction play, Aim at a physical reaction of the robot, show it with a sensor			r		B			r		r
	Cause-reaction play & basic pretend play, "caught on the act"										P
	Telling a story										
L 5	Cause-reaction play and explicit Social rapport: Ask a question to Aibo, answer with a sensor (e.g. press the sensor which opens the mouth), translate verbally the answer for the experimenter						P		P	P	
	Symbolic & pretend play Complex play with an accessory										
	Symbolic & pretend play Complex nap with Aibo										
	Symbolic & extrapolation play : "RobotCat" - Speak about the idea of a robotic cat (possibly imagine how one would play with it)										
	Causal composition of plays: Bite/Save & Give Food/Drink							P			r
	Causal composition of plays: Kiss & Bite/Save										
	Pretend play & causal reaction & social rapports: Ask verbally Aibo to act a situation, use of sensors									P	
L 6	Pretend play & focus on Aibo's mental states: Mimic Aibo's cry, and explain Aibo is never crying but pretending to cry										
	Pretend play & social rapports: Look after Aibo and set up rules										
	Pretend & symbolic & chronological play & social rapports: Search and rescue										
	Pretend & symbolic play & social rapport & cause-reaction play & chronological play: competition (drink fast) between the child or the experimenter and Aibo ; the non-competitor activates Aibo's sensor							P			

Figure 17. Child E. Play Grid. See Fig. 11 for a detailed caption

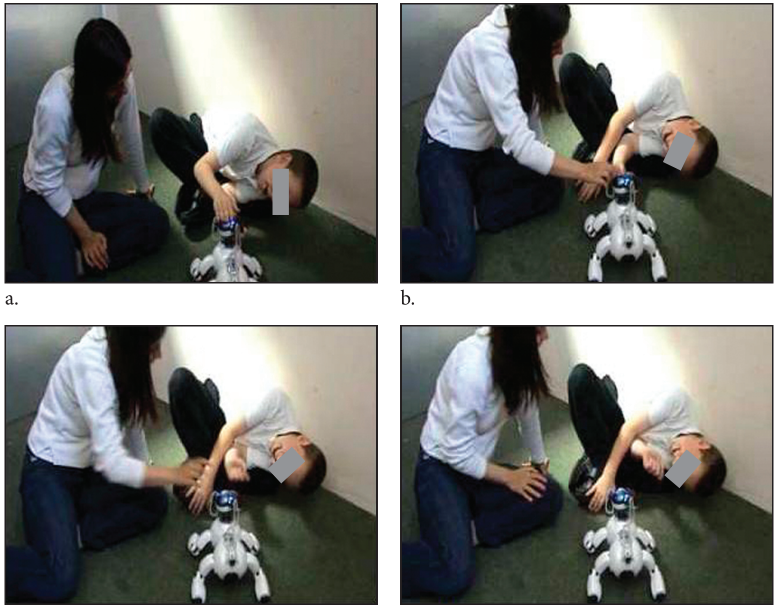

Figure 18. Child E playing the game 'Bite/Save' with the experimenter. Chronological order of the photos: from left to right and top to bottom. a) the child activates the head sensor of the robot which makes the robot open the mouth and enables the robot to 'bite' his finger. b) the experimenter brings her hand close to the head of the robot in order to activate the head sensor. c) the experimenter activates the robot's head sensor to make Aibo open the mouth in order to 'save' the child's finger; when the mouth opens, the child pulls of his finger (c and d)

or the experimenter (through the use of the sensors) and (ii) the person remaining (child or experimenter) saved the latter by freeing her/his finger: the freeing was done either by activating the sensor ("Complex Bite/Save") or by directly taking the finger out of the mouth of the robot ("Simple Bite/Save").

Furthermore, in Session 7, the child proactively combined 2 games, "Give food/drink" and "Bite/save" and said: "He (the robot) is saying: give me a drink or I bite your fingers".

Another interesting play situation the child proactively experienced in Session 7 consisted of a competition between the robot and himself: both of them had to drink as fast as possible their invisible drink; the robot could only drink with the help of the experimenter (the experimenter was asked to activate the sensor linked to the opening

of the mouth as fast as possible). At the end of the competition, Child E decided that the robot had won. Thus, in this play situation Child E experimented with:

a. dealing with rules of competition,
b. handling the temporal aspects of the game and the various chronological phases,
c. taking on the role of the participant (as a competitor) and the one of the organizer who announces the winner,
d. playing with abstract entities (invisible drink),
e. playing socially.

Concerning the reasoning dimension, it should be first noted that the child decided to rename the robot after the first session and call him "Tornado". Moreover, in the first sessions, most of his questions addressed the issue of the robot's technical capabilities and how to control the robot. In Session 2, for instance, the child said: "How is he doing that?" and "What's being on the head to make him walk?" (because when he touched the head and activated the head sensor, the robot walked). And later in the same session, while looking at the laptop he said "this must be the controller". Furthermore, in Session 3, the child said: "I found how he might open his mouth"; the experimenter asked "is he moving the mouth?" and the child answered: "yes, when I stroke on the head, you see". This example illustrates that the child actively developed technical and causal reasoning about behaviours and capabilities of the robot. This questioning can be related to the category "Essence" and shows that the child considered primarily Aibo (Tornado) as a proper robot. It should be noted here that the child invented the concept of "invisible drink" as well as the way of calling it (very logically): "invisible robot drink". This illustrates the ability of the child to make links with a real dog's life while adapting it correctly to the characteristics of robots.

The category "Mental state" was addressed during later sessions (from Session 5 onwards). In Session 5 the child actually said "he is wagging the tail"; the experimenter answered: "yes, that shows he is happy"; and the child replied "He likes me" and he stroked the robot. The experimenter reinforced the positive feeling: "yes, he likes you". That first step was expanded into the game "speak directly to Aibo about Aibo's feeling". In Session 6 and onwards, the child addressed proactively the question of emotions but he tended to deal with a restricted repertoire of emotions only, such as "being scared" or "being terrified" (e.g. Session 7 the child said: "You're scared Tornado, in fact you're terrified").

Child E dealt with "Moral standing" in Session 5 when he accidentally kicked the robot and, in return, apologized to it directly ("Sorry Tornado") and comforted it by stroking him.

Finally, Child E addressed indirectly the question of "Social rapport" through play. For instance, in Session 10, he conferred a specific role to the robot for the competition; the robot thus became his adversary, but on a very kind level, since the child decided at the end of the game that the robot had won the competition. Another example took place in Session 8 where the child asked directly questions to the robot (e.g. "Do you want to drink something Tornado?"). Then, he made the robot bark as an answer and the child "translated" the answer verbally for the experimenter: "He said yes". In this case, the child proactively played the social role of an intermediary position between the experimenter and the robot.

The dimension of affect (Fig. 19) appeared from Session 5 onwards where the child proactively said "he (the robot) likes me". And the experimenter replied "Yes he likes you. You like him?" The child then answered "Yes". Then later, in Session 8, the child said "he (the robot) is very happy". The experimenter agreed with him and then Child E added "Tornado likes me" and the experimenter reinforced the positive feeling: "Yes he likes you". In Session 9, Child E commented on the robot, qualifying him as "friendly": "Tornado is very friendly, isn't it?" and the experimenter agreed verbally.

Child F. Child F was away for Session 5. Thus he took part in 9 sessions. Note that on his explicit demand, Session 7 and Session 8 were not recorded (the experimenter had permission from the parents to videotape the child but she decided to value the child's request); thus information from sessions 7 and 8 is missing in the corresponding columns in the Play Grid. The Play Grid (Fig. 20) shows that

Session	**Events objectively related to Affect** (ordered chronologically with respect to first appearance, event only mentioned once per session)
S1	
S2	
S3	
S4	
S5	· **[1i]** "Yes that shows he (the robot) is happy" (Experimenter); **"He likes me"** (Child E); "Yes he likes you" (Experimenter); · **[2i]** **"You like him** (the robot)**?"** (Experimenter); **"Yes"** (Child E)
S6	
S7	
S8	· **[1i]** "He (the robot) is very happy" (Child E) while making the robot bark; "Yes he is" (Experimenter)**, "Tornado likes me"** (Child E); "Yes he likes you" (Experimenter)
S9	· **[1ii]** **"Tornado is very friendly, isn't it?"** (Child E); "yes, he is"(Experimenter)
S10	

Figure 19. Child E. Events related to Affect. See caption of Fig. 12 for details

		1	2	3	4	5	6	7	8	9	10
L 1	*Solitary* Exploration										
	"Imitation" of robot's bark	P	P	P			P			P	
	Solitary mirror play – look at oneself in the robot's reflecting face										
L 2	*"Pre-social" or basic-social* exploration – stroke Aibo immediately after the experimenter (possibly basic imitation of the gesture)										
L 3	*Social* exploration (social play)	P	P	P	P		P			P	P
	Simple Bite/Save or Give/Food - no use of the sensors									P	P
	Position or locomotion game – with verbal qualification of the game	P			P		B			B	P
	Cooperative technical task: change the battery, or turn on/off Aibo	r		P	B		r			P	B
	Verbal order towards Aibo: e.g. "sit", "walk", "wake up"	P	P	P	P					B	P
	Basic pretend & social play – imitate Aibo's snoring & verbal comment										
	Basic play on affective gestures – give/receive a kiss and/or a lip to/from Aibo									P	P
	Repeat after me - ask the experimenter to repeat verbal expressions										P
	Look at Aibo through the camera (Possibly stroke Aibo & look at its reaction through the camera)			P	P		P			P	P
	Speak French with Aibo - e.g. "Hello" or "Bye-Bye" in French				r		B				r
	Show Aibo to other children (social play) Express verbally the willing/intention to show Aibo to the other children	P	P								
	Simple play with accessory (symbolic play)			P	P						
	Social Mirror play (social play) - look at oneself (and possibly at the experimenter) in the robot's reflecting face & express verbal comments, e.g. "Look at my arm!"										
	Social Hug – hug Aibo & ask the experimenter or the second researcher to hug Aibo										
L 4	*Complex* Give Food/Drink (cause-reaction play & symbolic play & social play) - use of sensors										
	Complex Bite/Save (cause-reaction play & pretend play & cooperative play) - use of sensors										
	Complex turn off Aibo to sleep (symbolic play)						P				P
	Speak directly to Aibo about Aibo's feeling (symbolic play)		P								
	Cause-reaction play & mental states: Ask a question to Aibo (e.g. identity, feeling), answer with a sensor		B	P	r		B				
	Cause-reaction play, Aim at a physical reaction of the robot, show it with a sensor		P	B	B		r			P	P
	Cause-reaction play & basic pretend play, "caught on the act"										
	Telling a story										
L 5	Cause-reaction play and explicit Social rapport: Ask a question to Aibo, answer with a sensor (e.g. press the sensor which opens the mouth), translate verbally the answer for the experimenter										
	Symbolic & pretend play Complex play with an accessory			P	P		P				
	Symbolic & pretend play Complex nap with Aibo				P						
	Symbolic & extrapolation play : "RobotCat" - Speak about the idea of a robotic cat (possibly imagine how one would play with it)									P	P
	Causal composition of plays: Bite/Save & Give Food/Drink										
	Causal composition of plays: Kiss & Bite/Save										P
	Pretend play & causal reaction & social rapports: Ask verbally Aibo to act a situation, use of sensors										
L 6	Pretend play & focus on Aibo's mental states: Mimic Aibo's cry, and explain Aibo is never crying but pretending to cry										P
	Pretend play & social rapports: Look after Aibo and set up rules										
	Pretend & symbolic & chronological play & social rapports: Search and rescue										
	Pretend & symbolic play & social rapport & cause-reaction play & chronological play: competition (drink fast) between the child or the experimenter and Aibo ; the non-competitor activates Aibo's sensor										

Figure 20. Child F. Play Grid. See Fig. 11 for a detailed caption. Note that Child F was away for Session 5 and, on his request, was not filmed during Sessions 7 and 8

Child F engaged in social play almost all the time. He used verbal language a lot and progressively experienced some more complex levels of play, notably pretend play with respect to "play with accessory". The first situations of "play with accessory" happened in Session 3. In this session, the child borrowed the mouse of the laptop and put it on the ground in front of Aibo at approximately 30 cm distance and asked the robot to touch the mouse with the paw. Then he activated the right sensor to make Aibo walk forward and approach the mouse. The child carried the robot for the 5 remaining centimetres separating the robot's paw from the mouse and finally the robot touched the mouse with his paw. Later, in Session 4, the child experienced further situations of "play with accessory" in two successive steps. As a first step, he proactively played very simply with an accessory. For instance, Child F used the face of a character drawn on a piece of cardboard that he held in front of his face and told Aibo: "Stay here Aivo, I've got something to show you". Note that the child slightly changed the pronunciation of the name of the robot and referred to Aibo as 'Aivo'. As a second step, later in the same session, the child proactively played a more complex accessory game with the robot, the "ghost dog". That play situation consisted in putting a cloth on top of Aibo and pretending Aibo was a ghost dog (Child F told Aibo: "You can be a ghost dog Aivo"); vocally, the child used classical onomatopeia mimicking a ghost's "voice and presence". Moreover, in Session 6, the child decided to make the robot wear clothes and this game was expanded by:

a. a series of questions on inferring states of the robot with respect to like/dislike,
b. a direct communication with the robot to explain to it what he was wearing (Child F told Aibo: "Look at you Aivo! You've got some paper on to be black");
c. a version of the game "aim at a physical reaction of the robot, show it with a sensor" (the experimenter asked "How do you make him walk with all these clothes?", the child replied "Walk?", and the child made the robot walk).

In addition to the accessory games, the child experimented with pretend play with the robot in a social context, e.g. pretending to have a nap with the robot (in Session 4) in a detailed (and complex) way resulting in

1. using a cloth as a blanket to cover both of them,
2. deciding on the duration of sleep and asking for the clock to be watched to respect the time predefined for the nap,
3. pretending to snore,
4. both of them waking up again.

Besides, another way of tackling pretend play as well as the robot's mental states happened in Session 10 when the child imitated Aibo's crying, and then argued that Aibo was not crying but pretending to cry. And this notion of pretending to cry for the robot was reused many times during the last Session (e.g. Child F said: "No, he's not crying, he is only pretending to cry.").

The reasoning dimension is an important component of the profile of Child F. Child F principally addressed three of the four components: "Essence", "Mental States" and "Social Rapport", and, to a lesser degree, "Moral Statement".

Concerning "Essence", the child really tackled the question of artefact or biological features, processes and categories. In relation to category, he often asked about the robot dogs' boundaries, e.g. in Session 2: "Have you seen dogs that are not robot dogs, yes or no?" he asked the experimenter, and later in the same session: "He has short teeth, he doesn't bite. Robot dogs don't bite, do some do?"

The part on "Mental States" component is very rich since the child addressed all the aspects defined in the coding manual of Kahn et al. (2003) except probably the "autonomy" one. Actually, he attributed "intentions" to the robot in Sessions 1 and 2. He explicitly considered the robot's "emotional states" in sessions 2, 4, 6 and 10. He also both tackled "emotional states" of the robot and his "personality" when he asked the robot questions about its likes/dislikes (e.g. Session 4: "Do you like toys Aivo, yes or no?"). Furthermore, he pretended the robot had some "cognitive abilities" and developed play upon it: in Session 4, for instance, he disguised himself with an accessory in order to "show" Aibo and thus presupposed -for the game- that Aibo could see. Later, in Session 6, again the child presupposed for the game that the robot could see and told it: "Look at you Aivo. You've got some paper on to be black". The last aspect of "mental states" is the notion of "development" of the robot. Child F asked about it throughout the sessions. More than the notion of development, the child seems to have been willing to build a biography for the robot (i.e. the past of the robot) and therefore asked questions to the experimenter such as: (a) in Session 1: "Where was this robot dog from?"; (b) in Session 2: "Where was he born?" and "Has he travelled in a car?"; (c) in Session3: "Where did you get him from?", "Where does he live?", "How old is he?", etc.

Concerning the part on "Social rapport", the child really investigated the social links between the robot and the experimenter, who was considered by the child as being the "mum" of the robot (Child F told the experimenter "it's your dog son", meaning that Aibo is the experimenter's dog, and that the experimenter, in a way, is considered as being Aibo's 'mum'). He also investigated the social links between the robot and himself, through situations of pretend play but also verbally. In Session 2 for instance, the child presupposed that there was a social rapport between the robot and himself since he told the robot: "When it is lunch time Aivo I got to go. And don't cry Aivo". Later, in Session 6, the child stated that the robot was his cousin: "Aivo is my cousin". And when the experimenter asked: "Aivo, do you like playing with F?[16] Can you tell me? Can you ask for his answer F?" then the child told Aibo: "Aivo do you like me? You're my cousin. I'm your cousin, Aivo". The child also investigated beyond social rapport involving Aibo and, for instance, asked the experimenter a few questions about her family: (a) in Session 4, the child asked about the experimenter's French accent:[17] "What accent do you speak?", which was further investigated in Session 6: "Why do you speak French?" and "Why were you born in France?"; (b) in Session 6, he asked her about her family: "What are your parents' names?"; he investigated further questions on the experimenter's family in Session 10.

On the "Affect" level (Fig. 21), the child expressed himself a lot, both by gestures (e.g. giving a kiss to Aibo after saying "Goodbye Aivo, have a good sleep" in Session 6) and verbal expressions (e.g. in Session 4 when he dressed up Aibo: "Put this on, Aivo, my dog, my friend, Aivo"). It is perhaps worthy of note here that it might be the case that some gestures relating to affect from a non-autistic perception (e.g. giving a kiss), do not have the same interpretation for a child with autism: for a child with autism, giving a kiss might, for instance, just be an imitated response. Concerning Child F, it might be the case that the child reproduced the gesture "giving a kiss" from a situation he had encountered or witnessed before; nonetheless it should be mentioned that his gesture was made proactively, with no previous reference from the experimenter to such a gesture.

Session	**Events objectively related to Affect** (ordered chronologically with respect to first appearance, event only mentioned once per session)
S1	· **[1ii]** **"Ooh he is a nice dog"** (Child F) and he strokes the robot
S2	
S3	
S4	· **[1ii]** Child F brings a towel to put on the robot : **"Put this on Aivo, my dog, my friend, Aivo"** (Child F)
S5	
S6	· **[1i]** **"Aibo, do you like me?** You're my cousin. I'm your cousin Aivo " (Child F) · **[1iv]** Child F gives a **kiss** to the robot on the muzzle after saying **"OK, Goodbye Aivo, have a good sleep"**
S7	
S8	
S9	
S10	· **[1iv]** Child F has covered Aibo with a coat; he gives the robot **a kiss** on the forehead and says **"Goodnight Aivo"**

Figure 21. Child F. Events related to Affect. See caption of Fig. 12 for details

6. Discussion

Results from these experiments show that the children progressed differently, and that their profiles according to the three (intertwined) dimensions *Play – Reasoning – Affect* are unique. This highlights how the experimental approach presented in this study allows many trajectories for progressing and, more specifically, how it can meet the child's specific needs and abilities.

Furthermore, concerning the dimension of play, and, more precisely, concerning the children's progression with respect to solitary vs. social play, three groups can be highlighted. The first one, group 1, consists of children who mostly played solitarily and possibly encountered rudimentary situations of imitation, but no further components of social play. This group includes Child A who encountered imitation in Session 10 and Child B. Note that both of them find it very hard to communicate verbally. For the children whose current play with the robot is mainly dyadic, it is particularly relevant to enable the robot to adapt automatically to their play styles in real time so that they can benefit from this dyadic play and progressively reach well balanced and potentially higher levels of play. The second group, group 2, consists of Child D who communicated mainly non-verbally yet progressively experienced situations of verbal communication and showed pre-social or basic social play during the last sessions. The third group, group 3, consists of Child C, E and F. Those children proactively played socially (i.e. in a triad including both the robot and the experimenter).

For those three groups, results shows that a) Child B (group 1) experienced progressively longer uninterrupted periods of play and engaged in basic imitation during the last sessions; (b) children from group 3 tended to experience higher levels of play gradually over the sessions and constructed more and more reasoning about the robot (and sometimes engaged in specific reasoning about real life situations as well). At a more basic stage, Child D (group 2) also experienced higher levels of play progressively. He started to reason about technical aspects of the robot as well, e.g. 'turning on/off' the robot and changing the battery. In the last sessions different elements suggested that he may also have experienced some reasoning about social rapport. Besides, the children's proactivity was encouraged, enabling them to take initiative and express intentions (cf. the proportion of proactive activities vs. reactive activities in the Play Grids).

These results are in agreement with Josefi et al.'s findings (cf. Section 'Related Work') who have shown that non-directive play therapy encouraged the child's initiative-taking (Josefi & Ryan, 2004). Further to this, Josefi et al.'s study has shown that non-directive play therapy may encourage symbolic play, which is an important finding of our approach too: In our study, children from group 3 progressively experienced situations of symbolic or pretend play. Note that, as already explained, the study presented here took place in a therapeutic context but the experimenter was not behaving exactly like a therapist.[18] Besides, we identified several advantages in introducing a robotic pet in the experimental setup:

a. the use of a robot allows us to simplify the interaction and to initially create a relatively predictable environment for play, thus facilitating the child's understanding of the interaction (e.g. by initially giving the robot a simple predictable behaviour) (Dautenhahn & Werry, 2004). Progressively the complexity of the interaction can be increased.
b. children tend to express interest in the robot, and occasionally affect towards Aibo, as our findings show;
c. here, one of the findings is that, in these experiments, with this new approach, through play with the robotic pet, children tend to develop reasoning, and make comparisons to real dogs' lives. Note that based on our findings we cannot claim that the children's reasoning genuinely developed as a direct result of our study – we observed, however, cases where reasoning skills were *expressed* increasingly during successive sessions. Thus, the robotic pet can be considered as a good medium for developing and/or expressing reasoning on mental states and social rapport upon, and for learning about basic causal reactions.

In the context of robot-assisted play, we have shown in Section 'Related Work' that research has, until now, mainly addressed task-oriented activities, such as chasing games with Labo-1 (Werry & Dautenhahn, 1999) or imitation with Robota (Robins et al., 2004). Nadel et al. have shown that imitation skills have a significant impact on the acquisition of social skills for children with autism (Nadel et al., 1999). However, focusing on imitation tasks only may not be sufficient when the child reaches some higher levels of play (cf. children from group 3 in the experiments presented in this study); Howlin and Rutter underlined the necessity of incorporating developmental aspects (Howlin & Rutter, 1987).

The study presented in this paper goes beyond these previous experiments, since it provides the child with a relatively highly unconstrained environment of play: due to the mobile and autonomous nature of the robotic pet, the child can engage in a larger repertoire of play situations (note that Robota was remotely controlled and fixed in place while Labo-1, while operating autonomously, had no tactile sensors) and notably experience causal reaction play and symbolic play. Imitation is used to bootstrap and initiate more complex situations of interaction or

to help the child re-engage in the interaction. Besides, in this approach the experimenter is both a "passive participant" and, under precise conditions, becomes an active participant, which expands and formalizes his/her role compared with Robins et al.'s study (Robins & Dautenhahn, 2006).

Moreover, in this study, we have adopted a qualitative approach for the analysis of each dimension, Play, Reasoning and Affect. We were actually interested in the emergence and in the specificities of the play styles, questions or statements related to reasoning and events that could be objectively related to affect, rather than in the occurrences or the duration of each of them. In particular, two similar games might actually happen to be different in the way the child experiences them, such as for example, the fluency, the rhythm, the coherence etc. Consequently, unlike a quantitative analysis which often relies on micro-behaviour analyses[19] (e.g. Dautenhahn & Werry (2002); Tardif et al. (1995)), this qualitative analysis here focused on a bigger scale, i.e. an intermediary scale.[20] This intermediary scale enabled us to consider events constituting a game as connected events and, in particular, to describe the structure of a specific play situation in possibly different (chronological) phases or identify in this play situation, the presence of social play, the proportion of symbolic or pretend play, and the use of causality.

This study is explorative in nature, and more research should be done to investigate more systematically the contribution of such an approach in the field of robot-mediated therapy for children with autism.

7. Future work

Looking back at the results, the existence of group 1 shows that some children remained playing mainly dyadically with the robot. The only situations of social play those children experienced were basic imitation. For those children, it is particularly crucial to develop basic play skills through this dyadic interaction first, in order to help them reach higher levels of play and ideally, experience later triadic situations of play with the experimenter and the robot.

As part of future work, the question should therefore be investigated as to how to further facilitate children's play with the robot, for the children who remain at the level of solitary play; in this case, the robot should be able to adapt appropriately to the child's needs and abilities and encourage the child to progress towards more complex play styles autonomously. This issue has been addressed in François et al. (2007, 2008) where the robot adapts its behaviour in real time and autonomously to specific play styles of the child in order to guide him/her towards more balanced interaction styles. Such an 'adaptive' robot might help the child e.g. experiment with simple cause-reaction play situations. In François et al. (2009) we implemented and evaluated such an adaptive robot that rewards well-balanced interaction styles (e.g. not too strong, not too frequent) in a study conducted with seven children with autism. A statistical analysis of the results showed the positive impact of such an adaptive robot on the children's play styles and on their engagement in the interaction with the robot. Such initial findings are promising and need to be extended in future larger-scale studies.

Ideally, at some point, the child would naturally move towards group 2 and be able to engage in simple situations of social play (with both the experimenter and the robot).

Another avenue for future research within the proposed approach is to include "theory of mind" (ToM) more explicitly in the experimental design. ToM was not specifically considered in the present work, but we observed children commenting on the robot's intentions and 'feelings', which may provide a starting point for more detailed ToM investigations. Children with autism's difficulties with "mindreading" have been reported widely (e.g. Baron-Cohen et al. (1985); Hobson (1993); Baron-Cohen (1997)) and its relevance to the employment of interactive robots in autism therapy has been discussed in Dautenhahn & Werry (2004). Thus, in the context of the approach presented in this article, future work could specifically include further aspects of ToM, e.g. concerning the children's abilities to read the experimenter's intentions, goals and beliefs, or to take his/her perspective during play. Also, future work in this area would benefit from an assessment of whether the skills – that the children developed and/or expressed during the play sessions according to our approach – will also generalize to other situations, e.g. involving other children or adults (instead of the experimenter), or involving other play and/or social interaction situations within and outside the school. Furthermore, in order to distinguish whether the skills expressed by the children in our sessions genuinely developed or whether our approach only helped them to better express them in successive sessions, an assessment and comparison of the children's skills prior and after the play sessions in different contexts are important. Such directions would benefit from a larger-scale research programme put together and carried out jointly by roboticists, autism researchers as well as therapists, teachers and possibly also involving the children's parents.

Generally, future work in this area could either encompass more parameters to test, e.g. include further specific aspects of ToM as discussed above, or it could concentrate in further depth on specific aspects such as the dimension of "Play" and e.g. investigate in great detail different levels and aspects of play.

8. Conclusion

This paper presents a more approach in the context of robot-mediated therapy with children with autism. This approach draws inspiration from non-directive play therapy, notably encouraging the child's proactivity and initiative-taking. Here, the experimenter participates in the play sessions and the child is the main leader for play. Beyond inspiration from non-directive play therapy, the approach introduces a regulation process: the experimenter can regulate the interaction under specific conditions; in brief:

a. to prevent or discourage repetitive behaviours,
b. to help the child engage in play,
c. to give a better pace to the game if it has already been experienced by the child,
d. to bootstrap a higher level of play,
e. to ask questions related to reasoning or affect.

A long-term study was carried out with six children which highlighted the capability of the method to adapt to the child's specific needs and abilities through a unique trajectory of progression with respect to the three dimensions, Play-Reasoning-Affect. In particular, each child made progress in at least one of the three dimensions progressively over the sessions. Moreover, in terms of play, and, more precisely, solitary vs. social play, children could be categorized into three groups. The children who managed to play socially experienced progressively higher levels of play and developed progressively more reasoning related to the robot; they also tended to express some interest towards the robot, including on occasions interest involving positive affect. This preliminary long-term study has therefore shown promising results for this new approach in robot-assisted play. It is a first study that potentially may be developed towards a new method in autism therapy.

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Notes

1. http://www.nas.org.uk/

2. It should be further noted that children with autism often tend to perceive objects in their parts and not as a whole, which is integral to the weak central coherence theory (Fritz, 1989). This frequent inability may also influence the way the child plays.

3. Onomatopoeia refers to using words that imitate the sound(s) associated with objects or actions, e.g. "buzz".

4. We focus on Rogerian theory in this article because of its strong ties with non-directive play therapy which is a key source of motivation for us. Our specific approach to robot-assistive play as outlined in this article is however not restricted solely to his theory. Other theoretical approaches such as those proposed by Jerome Bruner (Bruner, 1986, 1990) and Lev S. Vygotsky (Vygotsky, 1978) – both are indeed fundamental to other work in our research group related to development, narrative and learning – could be used for an extended theoretical discussion of this work that would however go beyond the scope of this publication.

5. "(i) emotional security and relaxation, (ii) an enhanced and attentive adult environment in which playing together is emphasized, and (iii) the acceptance by therapists of children's ability to instigate therapeutic change for themselves under favourable conditions". (Josefi & Ryan, 2004:545).

6. Note, the symbolizing capacities have similarities with, and may overlap with, capacities to learn language during normal development; conversely, it is very likely that learning a language requires some symbolizing capacities and processes.

7. The seal robot Paro was introduced in the Bobath protocol (http://www.bobath.org.uk/) in the context of a child with severe cognitive and physical delays. The Bobath protocol is a method used for the rehabilitation of physical functional skills (Knox & Evans, 2002). Results showed that the introduction of Paro may have strengthened, for this particular child, the efficiency of the Bobath protocol.

8. Those imitations concerned the position or movement of arms and legs.

9. In this study, focused shared attention refers to the child's eye gaze directed towards the mediator (alternatively a human or a robot). It does not include joint visual attention, i.e. looking at an object that the mediator is pointing at.

10. The experimenter was the first author of this paper.

11. Note, the ultimate goal of this approach is to prevent the child from exhibiting repetitive behaviour in the first place.

12. Different classifications of play coexist in play literature. Piaget's classification identifies four categories: practice play, symbolic play, games with rules and constructions (Piaget, 1945). Another taxonomy, given by Boucher (1999) emphasizes the importance of social play which is one category of the classification. Here, we take a slightly different perspective since we *describe (analyse)* each situation of play according to four criteria, which are, in this context of robot-assisted play for children with autism, of particular relevance to measuring progress in the expression of skills in social interaction, communication, reasoning related to the robot and imagination. A situation of play is analysed according to the four criteria. These criteria are not exclusive to each other. On the contrary, a situation of play should ideally contain several of these criteria.

13. Shanti is the name of the stuffed dog that was used in Kahn et al. (2003)'s study as a basis for comparison.

14. The recoded segments contained only high involvement of the children in interaction. High involvement is characterised by the fact that (i) children do not stop interacting for a period longer than a few seconds, and (ii) children experience many situations of play, reasoning or affect related to the robot. Therefore, the density of events to identify and code is very high in the recoded segments which makes the evaluation highly meticulous.

15. For instance, the experimenter did not ask the question: "Does the robot hate you?", to which the child might have said "yes" as well.

16. Child F is designated by F in the dialogue.

17. Child F mastered some French vocabulary.

18. The experimenter did not have any formal training as a therapist.

19. Micro-behaviour analysis is the analysis of videos based on the coding of low level behaviours such as eye gaze, eye contact, touch, etc.

20. To make a parallel with the notion of micro-analysis used in (Tardif et al., 1995), one could qualify our approach here as a mesoscopic approach or a meso-analysis. The prefix 'meso' comes from the Greek word 'mesos', meaning middle. "Mesoscopic" is an intermediary scale between "microscopic" and "macroscopic". Those terms are commonly used in physics and chemistry, and can be transposed metaphorically to our context. Applied to our context here, a mesoscopic approach means that we look at the events constituting an uninterrupted game as connected events, and as a whole.

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Author's address

Dorothée François
Adaptive Systems Research Group
School of Computer Science
University of Hertfordshire
College Lane
Hatfield, Herts, AL10 9AB
United Kingdom

Email:dorotheefrancois@hotmail.com

Stuart Powell
School of Education
University of Hertfordshire
College Lane
Hatfield, Herts, AL10 9AB
United Kingdom

Email:s.d.powell@herts.ac.uk

Kerstin Dautenhahn
Adaptive Systems Research Group
School of Computer Science
University of Hertfordshire
College Lane
Hatfield, Herts, AL10 9AB
United Kingdom

Email:k.dautenhahn@herts.ac.uk

About the authors

Dorothée François has a Ph.D. degree in Computer Science from the University of Hertfordshire, UK. Her research interests include Human–Robot Interaction, Robot-mediated Therapy and Education and Socially Adaptive Robots. She is involved in the Aurora Project and her Ph.D. research concerned facilitating play between children with autism and an autonomous robot. She has conducted play sessions in schools with children with autism for more than a year on a weekly basis, whereby she evaluated new approaches she designed for Robot-Assisted Play. In parallel, her research has addressed the issue of automatic real-time recognition of human–robot interaction styles.

Prof. Stuart Powell is Professor of Educational Psychology. His original research interests were in psychology and education, and he has published over a number of years in the area of special needs teaching with a particular focus on working with children with autism. More recently, he has published in the areas of special needs and higher education and advanced study skills.

Prof. Dr. Kerstin Dautenhahn received her Ph.D. degree from the Biological Cybernetics Department of the University of Bielefeld (Germany) in 1993. She is Professor of Artificial Intelligence in the School of Computer Science and coordinator of the Adaptive Systems Research Group at the University of Hertfordshire (UK). She has published more than 100 research articles on social robotics, robot learning, human–robot interaction and assistive technology. Prof. Dautenhahn has edited several books and frequently organizes international research workshops and conferences. She is involved in several European robotics projects and is Editor in chief of the journal *Interaction studies.*