Playful interaction with Teo, a Mobile Robot for Children with Neurodevelopmental Disorders

Andrea Bonarini
DEIB - Politecnico di Milano
Piazza Leonardo da Vinci,32
Milan, Italy
andrea.bonarini@polimi.it

Francesco Clasadonte
DEIB-Politecnico di Milano
Piazza Leonardo da Vinci,32
Milan, Italy
francesco.clasadonte@polimi.it

Franca Garzotto
DEIB-Politecnico di Milano
Piazza Leonardo da Vinci,32
Milan, Italy
franca.garzotto@polimi.it

Mirko Gelsomini
DEIB-Politecnico di Milano
Piazza Leonardo da Vinci,32
Milan, Italy
mirko.gelsomini@polimi.it

Maximiliano Romero
Dip.Design-Politecnico di Milano
Milan, Italy
maximiliano.romero@polimi.it

ABSTRACT

Teo is a mobile robot that has been designed for children with NeuroDevelopmental Disorder (NDD). Teo's behavior can be remotely controlled by the caregiver or autonomously activated by effect of internal sensors or an external depth sensor. Teo's body is soft and sensible to different types of touch (e.g., hugs, punches, or slaps); it can move freely on the floor and can manifest emotional reactions (through light, sound, and movement effects). The robot can be used for goal-oriented therapy-driven activities as well as free play. The latter involve spontaneous interaction with and exploration of the robot's affordances, to facilitate children's familiarization with the robot and to promote socialization, positive emotions, and self-expression skills. The paper describes the design of Teo and examples of the wide gamut of free play activities that can be performed with the robot. We also report the main results of the exploratory studies involving eleven NDD children at two therapeutic centers, highlighting the benefits of free play with Teo.

CCS Concepts

•**Human-centered computing** → **Field studies; Empirical studies in collaborative and social computing; Accessibility systems and tools;** *Empirical studies in accessibility;* •**Social and professional topics** → **People with disabilities;**

Keywords

Human-centered Design, Human-Robot Interaction, Accessibility, Autism, ASD, Robot Design

1. INTRODUCTION

DSAI '16 December 1-3, 2016 - UTAD, Vila Real, Portugal
© 2016 ACM. ISBN 978-1-4503-2138-9...
DOI: 10.1145/1235

The Neurodevelopmental Disorders (NDD) are a group of conditions with onset in the developmental period. They are characterized by a range of developmental deficits that frequently co-occur and vary from very specific limitations of learning or control of executive functions to global impairments of social skills or intelligence, producing impairments of personal, social, academic, or occupational functioning. The use of robots has been proven successful in many cases of subjects with different Neurodevelopmental Disorders, e.g., intellectual disability, attention-deficit, hyperactivity disorder (ADHD), or Autistic Spectrum Disorder (ASD) [4], [9]. Still, given the wide range of NDD conditions and the specific characteristics of each single subject, there is space for new exploratory experiences involving robotic interaction to enlarge the set of success stories and identify new forms of therapeutic and educational interventions for this target group.

In many existing researches, the experiences with the robot are shaped as games, especially for children, and the robot is static and cannot be personalized by the users, limiting the range of opportunities that robotic interaction can potentially offer to NND subjects Our robot Teo overcomes some of these limitations. It has been designed to be used as a play tool for children of different ages and with different NDDs, enables a wide range of game-based experiences, and supports a number of play dimensions that are largely unexplored with this target group, such as (joint) movements in space, physical manipulation, and robot personalization. Teo is emotional, huggable, mobile, and customizable. Teo is also holonomic, free of moving on the floor in any direction at a speed similar to that of humans in indoor environments. Its "natural" mobility has the potential of making the robot more easily accepted by NDD subjects and enables them to explore spatial relationships during robotic interaction. Teo can exploit several interaction modalities in ways that are completely customizable to the needs and preferences of each specific subject. Its soft body includes a set of sensors that detect various forms of body manipulation, such as hugs, caresses, slaps, and punches, that trigger Teo's emotional reactions, expressed by means of sound, light effects, or body movements. Coloured LEDs and sound speakers are embedded in the body. Sound speakers support verbal communication. LEDs are not used for representation purposes (e.g., to represent eyes or mouth), but to provide a stimulation channel where light intensity, color, and rhythm can be modulated and explored. Teo also wears a set of large buttons on its hat that enable intentional touch interaction, analogously to what done by existing robots used with NDD subjects. The set of stimuli offered by Teo contribute to create fun, to build an emotional bond with the robotic companion and to develop the awareness of cause-effect phenomena. Stimuli can be either controlled by the therapist or triggered automatically by effect of interaction (to relieve the caregiver from an attentionally intensive control of the child). Teo can be integrated with an external depth sensor (such as Kinect) that senses both the human player and Teo itself, to support shared activities involving full-body interaction in the space. Teo can be used alone or in combination with virtual worlds and characters on an external digital display (e.g., a TV screen or a projector) [12], which enlarges the gamut of activities that can be played with the robot.

The rest of the paper presents TEO and its set of integrated and configurable capabilities, and describes how it can be used for free play, according to the spirit of the LUDI COST project [1] we are taking part of. We also report about what happened in the exploratory studies performed at two therapeutic centers to elicit Teo's potential for NDD children, and discuss the measured benefits of free play with the robot.

2. RELATED WORK

In the last years, a large number of researchers have investigated the application of robots for NDD subjects, mostly focusing on ASD children (e.g., [7, 15, 4, 5, 6, 21, 18]), and have explored how robotic interaction can help these subjects to develop skills needed for independent living. NDD children, as most children, are attracted by technological devices, even more if these can react to their actions. One important trigger for this attraction is the recognition of previous happenings, which, in principle, could be supported by robots programmed to consistently react to stimuli. However, repeatability strongly depends on the reliability of the sensors as well as on the level of detail of the stimulus as perceived by the subject as trigger for the expected behavior. For this reason and, often, on therapists' explicit request, most of the robots used in NDD therapies are remotely controlled. This gives the complete control of the interaction to the caregiver, but requires that the operator dedicates attention to control, both to catch the triggering act, and to actually perform the expected action. A proper interaction may require another person to complement the therapist's activity, to prevent the therapist to lose the correct relationship with the subject. A support to achieve a proper interaction can come from the implementation of high-level behaviors that could be triggered by the therapist, leaving to the robot the burden of realizing the specific, possibly complex, actions needed to implement them. In most cases, the experiences with the robot focus on a single type of activity, such as imitation and the available activities are framed in a specific protocol to achieve a specific goal. Few of the robots developed for NDD subjects can sustain spontaneous, free user interaction. Even when the tasks with the robot include gamification features, the subjects are expected to follow a pre-defined path of interaction and stimuli, thus betraying the intrinsic nature of play: "a range of voluntary, intrinsically motivated activities normally associated with recreational pleasure and enjoyment" [10], which has a fundamental role for the child's physical, cognitive and social development [3], [17], [23].

Few cases explore long term robotic interaction through many sessions, and the complexity of maintaining and supporting the relationship between the robot and the user while following the evolution of the subject and thus adapting the robot's behavior and affordances accordingly [8].

Many different shapes have been explored for robots in NDD contexts, from abstract ones to cartoon-like, to simplified humanoids, to realistic human-like faces [15]. Taking into account Mori's conjecture about the uncanny valley [16], and the difficulty of NDD subjects to interpret the multiple signals expressed by realistic human faces and body, it might be preferable for this target group to provide abstract shapes rather than realistic representations, while it is certainly important that the subject could easily understand where the robot is facing and "looking at".

Very few of the robots used in NDD therapy can successfully exploit movements in space, since they are either fixed (e.g., Kaspar [20], Keepon [13]), manipulable (at least to a certain extent), but not mobile (e.g., Paro [14]), or have such a slow and clumsy movement (e.g., Nao [22]) that they easily become unbelievable and boring, so that children lose attention in a movement-related task. Interesting exceptions are IROMEC [19] and Labo-1 [5], which started to explore the possibility to define space-related activities with ASD children. However, both IROMEC and Labo-1 are differential drive robots, with a rigid shape, limited movement possibilities, and running at a speed not comparable with that of a child, so reducing the opportunities of full playful interaction in the physical space.

3. THE DESIGN OF TEO

3.1 Requirements

Teo's body and behavior have been co-designed by a team of two designers, four engineers and 15 therapists (psychologists, neuro-psychiatrists, special educators) from two different rehabilitation centers who have long-term, everyday experience of NDD subjects (children and adults). The NDD specialists, none of whom acquainted with robotics, have collaborated with designers and engineers along the entire development process. They regarded the robot as a possibly useful tool to improve their interventions with NDD children, and presented their wishful thinking while technical people worked to implement it. By analyzing together a sequence of progressive prototypes, we finally came to the current version, depicted in figure 1, which holds the main physical and behavioral affordances to meet the needs of the intended target group. The salient requirements on Teo's body and behavior are discussed below. Some of them match existing guidelines in the current state of the art in robotic interaction for ASD children; others are novel, especially those concerning the largely unexplored dimensions of physical manipulation and joint exploration of the space. Teo should play different roles while interacting with NDD children; as: *Rewarding agent* provides feedback and positive reinforcements to the actions performed by the child; *Facilitator* suggests what to do and when to do it; *Prompt* elicits behaviors enhancing the game play; *Emulator* promotes the imitative skills; *Mediator* mediates the social behavior between the child and his play companions (e.g., caregivers or peers); *Restrictor* limits the child's range of possible choices or constrains the possibilities of movement in the space.

The interaction with Teo should be multimodal and include both physical manipulation(which, according to embodied cognition theories [24], plays a fundamental role in the development of sensori-motor capabilities as well as cognitive skills) and joint movements (to exercise perception and awareness of the physical space). In response to child's interaction, Teo should offer different types of stimuli, both one-by-one and in a multisensory combination. Clear feedback should be provided by the robot to answer to users' communicative actions, to support the development of cause-effect understanding, and to engage the children. Teo's behavior should be consistent with some positive experiences already done by the subjects, to reduce the distress caused by unknown phenomena that is typical of NDD subjects. In particular, the shape of the robot should remind familiar shapes, possibly something that the subject likes, such as cartoon characters. The physical aspect, interaction modalities and behavior of the robot should be strongly customizable, to adapt the interactive experience to the specific needs of each child. In particular, it should be possible to add or remove physical elements reminding human face or body, since they might be disturbing for some subjects. If the children themselves can do some customizing activities, this may help to improve the relationship and confidence with the robot, which comes to be perceived as a creature of the subject.

3.2 Teo's body

The whole structure of Teo is about 60 cm high, a size that makes subjects (from 3 years old up to adults) confident to control and manipulate it. The structures is composed by the base and teh body. The base consists of a robust, triangular, holonomic (omnidirectional) base, only 10 cm high (diameter 40 cm), and contains motors, batteries, electronics, a coloured LED stripe, infrared and sonar distance sensors. The base can move at a speed of up to 1.2 m/sec. This gives Teo the possibility to perform unconstrained movements on the floor, which resembles the movement capability of human beings who have no problems in moving laterally or changing direction. Teo's kinematics, widely adopted in many applications overcomes the limitations in speed, dexterity, and robustness intrinsic in existing humanoids (such as Nao [22]) and differential drive robots (e.g., IROMEC [14]) adopted in robotic research in the ASD arena.

Attached on the base there is a soft body, made of a cloth sack, about 50 cm high, filled by polystyrene micro balls. The color of the body is pastel yellow, selected to be enough attractive, but at the same time not too strong to disturb sensible subjects. Being the body just a sack, it is relatively easy to make it in different colors, would this be needed to adapt Teo to the visual needs of a specific subject. This soft body can be manipulated in a way similar to what is done with many pet toys (plush), thus enabling tactile experiences similar to others already known by the subjects. A set of 400 mm long, single-zone Force Sensing Resistors (FSR) optimized for use in human touch control is embedded in Teo's back skin, to enable it to distinguish different types of touch. A Bluetooth speaker is embedded in the body to enable Teo's sounds or vocal output.

Teo wears a changeable hat that can have both a quite recognizable shape (like a cylinder hat), which rises expectations about having a face on the body, or a more neutral hemispheric cap shape, thus leaving the subject free to interpret it either as a hat (possibly making a face below it) or just as a component of a neutral body. The hat holds a set of big push-buttons used for specific interaction activities. They can be personalized by inserting either colored tags, PCSs (Picture Communication Symbols) commonly used in AAC - Augmented Alternative Communication interventions [11] or realistic images. The hat buttons enable children to express choices, to answers to questions or simply to trigger Teo's behaviors.

The final shape of the sack is a kind of ovoid, so that Teo can be considered as "just an object", or something that resembles what children might have been seen in popular cartoons such as Minions or Barbapapa, so matching the therapists' requirement that the robot should be recognized as something familiar (see Figure 1). Based on Mr.Face (a tool commonly used in NDD therapy), a sheet of magnetic material is fixed on the front: face components like eyes, eyelids, or mouths can be attached to it to create a personalized character. With the addition of these physical components Teo can easily become more similar to cartoon-like characters. This activity is a form of free play that helps children to familiarize with the robot and promotes the capability of emotion representation, emotion recognition, and self-expression, which are underdeveloped in most NDD subjects.

Figure 1: A first version of Teo, smaller, with cap and velcro-attached eyes, and the final one, with hat and magnetic pad.

3.3 Teo's interactive behavior

Teo supports three main forms of full-body interaction: *Robot manipulation* , *Robot + Child interaction at the distance* , and *Joint (Robot + Subject) Virtual World interaction* .

Robot manipulation involves the tactile contact with Teo's body. Teo's sensorized skin can produce signals that are classified according to the intensity and dynamics of the body deformation induced by the physical contact. As anticipated in the previous section, it is possible to distinguish among caresses, hugs, and two levels of violent punches or slaps, each one triggering different types of *emotional multimodal ex-*

pressions, described in the following. *Happy*: when its body is softly caressed or touched, Teo "is pleased" and replies by vibrating, rotating itself cheerfully, and moving around, while a green coloured light LED strip slowly blinks. *Angry*: when its body is hit with moderate force, Teo becomes "angry" and moves sharply towards the child, suddenly turning on all the LEDs in red; *Scared*: when its body is brutally hit, Teo becomes "scared" and slowly retreats itself, while LEDs become yellowish and pulse slowly.

In *Robot + Child interaction at the distance*, the child and the robot move together in the space; the user's movements or position trigger Teo's emotional effects that are similar to the ones above mentioned and depend on the mutual distance, or the speed and direction of relative movements. As the distance sensors on Teo provide poor information, most of the needed data come from an external depth sensor (Kinect) that detects the presence and movements of the child and Teo when they are in the sensor's field of view.

Joint (Robot + Subject) Virtual World interaction takes place when the robot and the child stay in front of a digital display or projection showing multimedia contents and characters. The depth sensor can detect the robot's and the user's position and movements, or the child's gestures, and the integrated system triggers the corresponding behaviors in the virtual world according to the logic of the ongoing activity. In addition, when no play activity is ongoing, Teo can exhibit two "social presence" states and associated behaviors: *Waiting* and *Invitation to interact*. In the *Waiting* state, Teo detects whether nobody is close enough. It manifests that it is waiting for someone to interact with by slowly turning left and right on place (as if it was looking around), while blue LEDs around the robot base are dynamically turned on and off to simulate an analogous light movement. In the *Invitation to interact* state, Teo detects that someone gets close, and it rotates towards the subject, verbally inviting him to play.

The execution of Teo's behaviors is performed in three modalities: *remotely controlled*, *autonomously reactive*, and *programmed*.

In *remote control* mode, the caregiver triggers the desired stimuli on Teo's body and drives the robot movements, states, and behaviors using a remote controller, as it happens for most existing robots used in therapeutic contexts. The remote controller can be a joy stick, a tablet, or a blue-tooth pen. With a tablet, the caregivers can actuate an additional form of verbal interaction, by selecting an utterance to be expressed by the robot (e.g., "Bravo!", or "Ehi!") from a built-in set, or by editing a text on the fly which is translated using a text-to-speech synthesizer. Still, a tablet makes the caregiver's role of control more evident and the experience less magic. A blue-tooth pen does not provide this verbal capability, but it can be easily hidden in the hand, giving the impression that Teo behaves autonomously. The remote control mode makes it possible to set up a countless number of experiences where the robot can act as a social play companion, without any apparent direct involvement of the caregivers who maintain their role of adult/therapist. Still, remote control is a demanding mode for the caregiver, who must pay a constant attention to the child and at the same time has to operate on Teo to maintain the emotional and cognitive connection between the child and the robot. Hence they must be able to control Teo in a believable and timely way, giving the impression that the robot is moving by itself and behaves consistently with the current context. This problem can be reduced by leaving the control of the robot to a third trained person.

As an *autonomously reactive* agent, Teo reacts to the presence of distant users, exhibiting a "Waiting" behavior or an "Invitation to interact' behaviors, as mentioned above.

As a *programmed* robot, Teo acts autonomously as a play companion in the goal oriented, "therapy-driven" structured activities and behaves according to its role as defined in the current game. Depending on the activity logic, the activity state, and the movements and positions of both Teo and the child, an external system drives the robot to specific areas, or activates light, audio, or vibration effects on Teo's body. At any time, the caregiver can turn the remote control "off", to make Teo act as an autonomous reactive agent and to relief the burden of controlling it, or "on", to create the best combination of stimuli for a specific subject and play context, modulating the multi-sensory stimuli that the experience with Teo may create.

4. PLAYING WITH TEO

A typical therapeutic session with Teo exploits all the above mentioned behaviors and interaction modes, and alternates moments of free play with the execution of structured play activities. *Free play* involves spontaneous manipulation of Teo, exploration of the robot's affordances, and joint exploration of the space, while the therapist provides support and outlines Teo's affordances when needed. *Goal-oriented structured activities* focus on the development of specific skills according to the therapeutic plan of each child; as such, they follow a pre-defined flow of tasks and stimuli.

While free play activities are mostly performed with Teo remotely controlled by the therapists, possibly inter-played with moments in which Teo acts as autonomous agent, goal oriented structured activities use Teo as a programmed robot (switching to remote control mode when needed). The description of goal-oriented structured activities are reported in [2]. The rest of this paper focuses on free play activities, framing them in a model of intervention for NDD children (depicted in Fig. 2) that has been defined in cooperation with the therapists consistently with their current theories and practices. The basic assumption of the model is that the learning process for NDD children unfolds along a set of mental and emotional states that involve relaxation, affection, and engagement (and a number of intermediate states) before achieving a condition in which the development of skills in the communication, social, affective and cognitive spheres can be actuated. Free play is mainly devoted to achieve relaxation and affection, and to autonomous skill development, while structured goal oriented activities focus on the development of specific skills, and both of them attempt to achieve a state of engagement.

Relaxation is an emotional state of low tension in which there anger, anxiety, or fear are absent. The deficits induced by NDD create a persistent state of insecurity, uncertainty, and inadequacy. This in turn originates anxiety, psychological rigidity, and resistance to any change in routine. Relaxation is fundamental to help children unlock these states. As the presence of Teo in the playground affected is potentially worrying, the child must be helped to learn that this "object" is predictable and safe, and become confident that it is good, harmless, and inoffensive. This can be achieved through forms of free play that help the children to famil-

Figure 2: Model of intervention

iarize with this new thing, like Teo. Free play may involve exploration and manipulation of Teo's body using all senses, the actuation of few light and sound stimuli, and the use of Teo as autonomously reactive agent. Even if children progressively relax, this state may remain episodic, unless a state of affection is reached.

Affection denotes a strong positive feeling of affective bond towards an entity. Children need to establish affection towards Teo in order to use it for a prolonged time and in a functional, goal-oriented way. While developing affection, children learn to feel emotions. Affection is thought to be an emotional trigger that helps children to further release remaining tensions and to fully embrace the challenge of "getting involved", so moving to the engagement state. To achieve affection, therapists typically stimulate and facilitate forms of free play with Teo that promotes trust in the robot and create controlled stimuli that increase Teo's attractiveness and the child's willingness to experience the various affordances of the robot. For example, caregivers may invite the child to hug Teo, to move it around, to talk with him, to follow it while it is moving in the room, while they trigger the appropriate stimuli using the remote controller.

Engagement is a state attitude of active, voluntary involvement in an activity and the willingness to act upon the associated objects maintained for a (relatively) prolonged time. In NDD children, this state can be achieved through forms of free play, alone or in group that promote pleasure, fun, and sense of control and ownership (agency). With normally developed children, engagement is typically regarded as a learning facilitator whereas, with NDD children, engagement is a form of learning per se, and a precondition for the execution of structured, goal oriented activities. To promote engagement, free play may involve the use, by the child alone or with peers, of the components that enable to personalize Teo's face. Children can create their own character, possibly matching the emotional expression they believe is appropriate for the current situation of play and social situation. This composition game is so open that often results into an amazing assembly of eyes, mouth and other components, without any realistic face composition. During this play activity, Teo can move on place, so that the children can explore its reactions and become acquainted with it.

5. EXPLORATORY STUDIES

We performed two exploratory studies at local therapeutic centers to investigate the potential of Teo as a tool to help NDD children learn through free play. Overall, the study involved 11 NDD subjects and 5 specialists. The total number of sessions with Teo was 43, each one involving in average from 10 to 15 minutes of free play. In each session, at least one therapist supervised the subject(s) intervening when needed, while two members of the technical team participated as non-intrusive observers. A dedicated room was instrumented in each center for the purposes of our studies. A textual report was produced by the therapist at the end of each session.

The first study took place at the rehabilitation center Sacra Famiglia (specialized in ASD children and adults), involving 2 therapists and 3 low functioning autistic children aged 3. Each child attended 9 sessions with Teo, on a weekly base, for a period of 2.5 months.

The second study took place at the rehabilitation center L'Abilità that serves NDD children aged 1-16. The participants were 3 specialists and 8 children aged 6-10 with different functioning levels (4 low-functioning, 3 medium-functioning, 1 high functioning) and various disorders (Down syndrome, intellectual disability, ASD, Prader-Willy syndrome and psychosis). Children were split in two groups: those with most severe cognitive deficits played alone while children whose socialization problems were more severe than cognitive impairments played with a peer. Each child attended two sessions with Teo in two subsequent weeks. All sessions were video-recorded.

5.1 Main results of Study 1

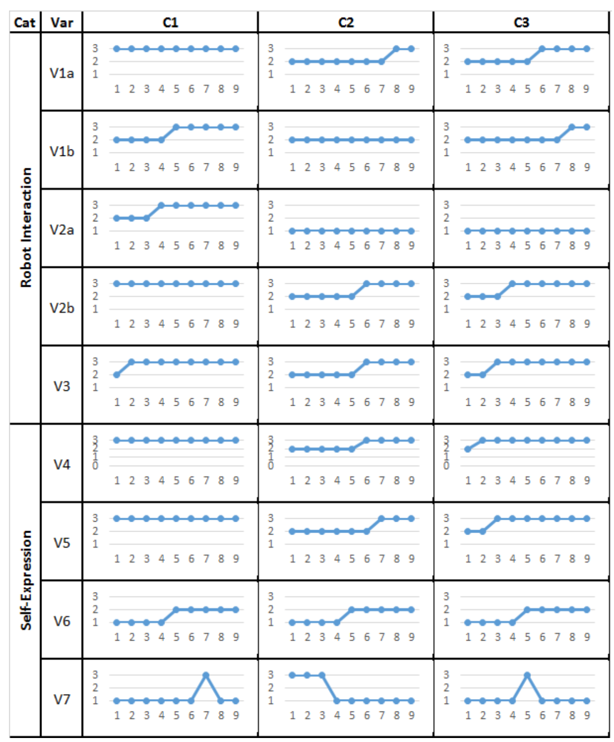

Figure 3: Key findings of Study 1

In study 1, the therapists defined a reporting protocol and filled the corresponding form during each session. The protocol includes variables and associated behavioral signals (as subset of which is described in Figure 4 that can be scored (1) for "absent", (2) for "emerging" and (3) for "present". The plots in 3 report the evolution of outcomes (y-axis)

Cat	Var	Description
Robot Interaction	V1a	Initial Interaction: The child looks and grabs the accessories
	V1b	Advanced Interaction: The child uses the accessories in an appropriate way
	V2a	Verbal social communication
	V2b	Non-verbal social communication
	V3	Ability of manual exploration
Self - Expression	V4	Interest for something new
	V5	Manifestation of positive emotions
	V6	Capability of externalize own needs (e.g., to ask for help)
	V7	Manifestation of negative emotions

Figure 4: Main behavioral variables of Study 1

along the 9 sessions (x-axis) for each child C1, C2, and C3 and for each behavioral variable. The results are not homogeneous, as it often happens with NDD children, because the enormous diversity of each individual condition even for subjects with comparable diagnostic profile, introduce many confounding variables that are difficult to control. Still, considering the number of sessions (9) and the duration of the study (2.5 months) the general trend is positive on most variables for all children. The plots clearly highlight that all variables denoting positive behaviors progressively increase for all children (remaining invariant in some case). The variable denoting negative emotions decreases in C2 and has a pick of increment in one session for C1 and C3 (which therapistsâĂŹ observations ascribe to a problematic health state of these children).

5.2 Main results of Study 2

The results of study 2 are elaborated from the analysis of video recordings and specialists' notes taken during or after each session. The coding scheme for video analysis was defined by the therapists using behavioral variables they adopt in their current practice. The diagrams in Figures 5 and 6 show the frequency of signals, calculated as the mean of the correspondent signals per minute. The diagrams allow to compare the behavior of each child in the first and the second session, and the behaviors of those playing alone (C1, C2, C3, C4) against those playing in pairs (C5, C6, C7, C8).

We can observe that robot Interaction (RI), decomposed into the sub-variables "Communication with Teo" and "Manipulation of Teo", increases for most of the children regardless the play modality. In particular C1, C3, C5 and C6 show a steep increase in robot communication. "Manipulation of Teo" variable decreases in session 2 for all children except C5, which can be ascribed to a more intense verbal interaction with Teo and peer-to-peer interaction which was observed by therapists. Self-Expression (SE) capability of both single and paired children increased in session 2. In single play sessions, C3 and C4 externalized more needs, and all children manifested higher positive emotion in session 2, which are both positive phenomenon since SE is one of the lacking capabilities in NDD subjects. None of the children manifested enhanced Creativity (C) except C2, a girl with Down Syndrome who is usually not interested at all to the activities proposed in regular session, and instead created a new free game with Teo. She ran away from Teo while pulling its tie, and then she waved the tie like a matador's cape to let Teo to catch it. Finally, she showed to other children how it was possible to play with Teo. In session 2, Stereotypes (S) decrease in all children who manifested them in session 1.

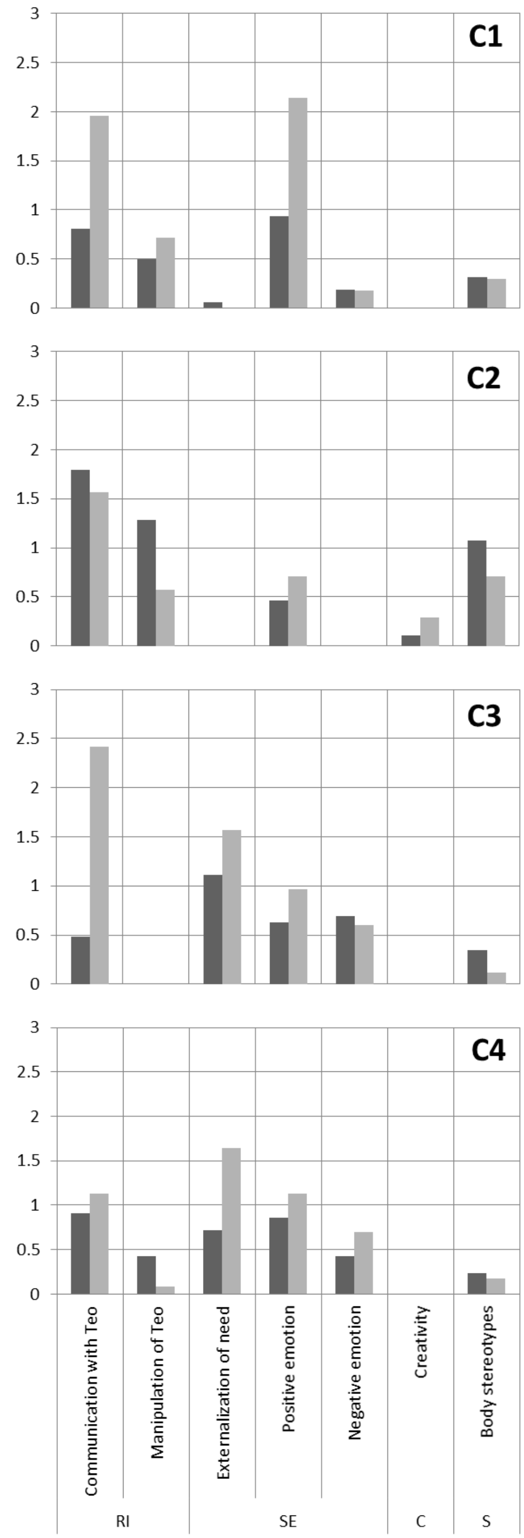

Figure 5: Children who played alone

Social Play (SP) increases in paired sessions, which indicates an enhancement of children's socialization capability, also confirmed by therapists' observations. For example, an autistic child explicitly called a mate to play with Teo: it was the first time he expressed the willingness to play in social mode. The "Mr. Face" activity performed in session 2 triggered a very impressive pre-verbal communication process between two medium functioning ASD children (C5 and C6) who did not speak with nor look at each other during regular sessions. Initially, they stuck expressions on different sides of the robot, working in parallel but ignoring each other. Eventually, C5 pushed down Teo, C6 decided to stick an angry face on Teo and showed it to C5 as depicted in figure 7. Therapists unanimously stated that this kind of pre-verbal communication is an extraordinary step ahead for these children. A final interesting observation concerns C1, a girl with severe Attention Deficit/Hyperactivity Disorder: she relaxed in few minutes after meeting Teo, and she was able to concentrate on, and perform different free play activities during 25 minutes, which was considered extremely positive by the therapists considering the nature of her disorder.

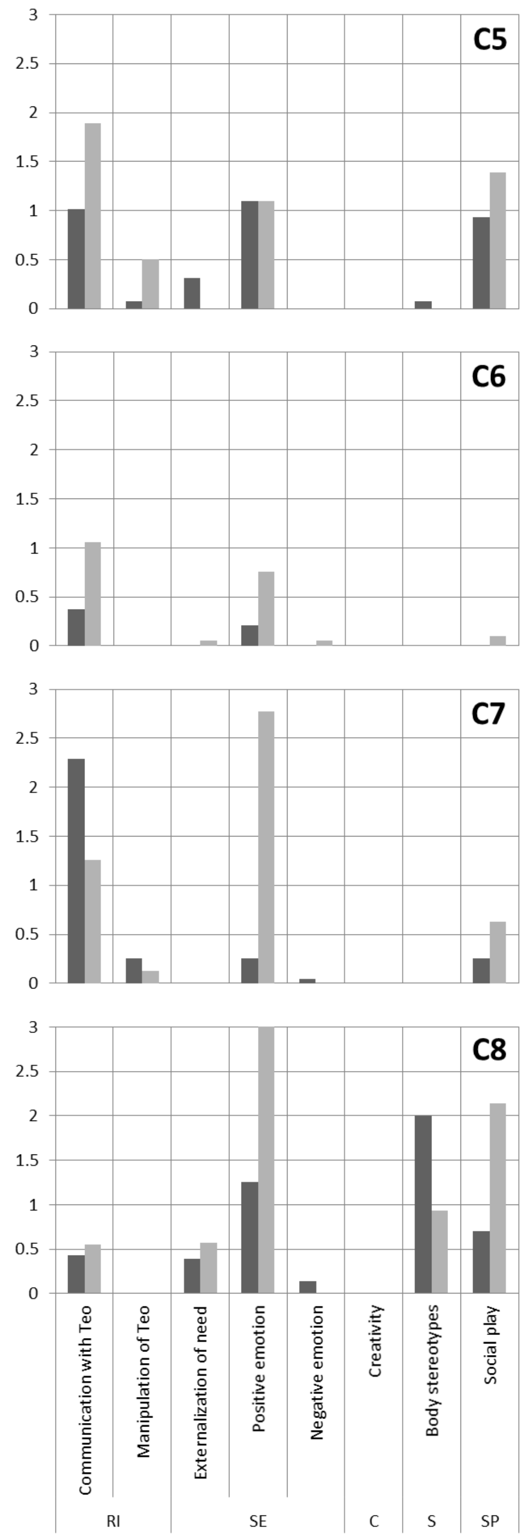

Figure 6: Children who played in pair

Figure 7: Pre-verbal communication enhancement between 2 autistic children

6. CONCLUSION

In this paper we have presented Teo, a robot that could freely move in space and react to touch interaction. In particular, we focused on the free play activities integrated in the the protocol we have followed in two different centers. Teo was co-designed by a team made of engineers, designers, therapists and psychologists in a higly interactive development process.

All therapists involved in our study agree that Teo can open new dimensions in the interaction and therapy with

NDD children. The possibility to freely move in the space, to have physical reactions and to interact in a natural way with the robot have been appreciated as new stimuli to improve interventions and free play experiences. Moreover, the integration of robotic and full-body interaction in the space opens new extraordinary opportunities in the NDD context: this technology elicits operational behaviors, social interaction, and emotional responses that normally do not occur using other methods, or that require a much longer time to be achieved.

7. REFERENCES

[1] V. Besio, Serenella & Stancheva-Popkostadinova and D. Bulgarelli, editors. *Theoretical models descriptive of play development of children with disabilities.* LUDI COST Action TD1309, 2016.

[2] A. Bonarini, F. Garzotto, M. Gelsomini, M. Romero, F. Clasadonte, and A. N. Çelebi Yilmaz. A huggable, mobile robot for developmental disorder interventions in a multi-modal interaction spacen. In *Proceedings of the 25th IEEE International Symposium on Robot and Human Interactive Communication (RO-MAN 2016)*, page In press, New York, NY, USA, 2016. IEEE Computer Press.

[3] J. S. Bruner, A. Jolly, and K. Sylva. Play: Its role in development and evolution. 1976.

[4] J.-J. Cabibihan, H. Javed, M. Ang Jr, and S. M. Aljunied. Why robots? a survey on the roles and benefits of social robots in the therapy of children with autism. *International journal of social robotics*, 5(4):593–618, 2013.

[5] K. Dautenhahn, I. Werry, T. Salter, and R. T. Boekhorst. Towards adaptive autonomous robots in autism therapy: Varieties of interactions. In *Computational Intelligence in Robotics and Automation, 2003. Proceedings. 2003 IEEE International Symposium on*, volume 2, pages 577–582. IEEE, 2003.

[6] W. Den Brok and P. Sterkenburg. Self-controlled technologies to support skill attainment in persons with an autism spectrum disorder and/or an intellectual disability: a systematic literature review. *Disability and Rehabilitation: Assistive Technology*, 10(1):1–10, 2015.

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

[8] C. Ferrara and S. D. Hill. The responsiveness of autistic children to the predictability of social and nonsocial toys. *Journal of Autism and Developmental Disorders*, 10(1):51–57, 1980.

[9] T. Fong, I. Nourbakhsh, K. Dautenhahn, T. F. A, I. N. A, and K. D. C. A survey of socially interactive robots: Concepts, design, and applications, 2002.

[10] C. Garvey. *Play*, volume 27. Harvard University Press, 1990.

[11] F. Garzotto and M. Bordogna. Paper-based multimedia interaction as learning tool for disabled children. In *Proceedings of the 9th International Conference on Interaction Design and Children (IDC '10)*, pages 79–88, New York, NY, USA, 2010. ACM.

[12] F. Garzotto and M. Forfori. Hyperstories and social interaction in 2d and 3d edutainment spaces for children. In *Proceedings of the seventeenth conference on Hypertext and hypermedia (HYPERTEXT '06)*, pages 57–68, New York, NY, USA, 2006. ACM.

[13] H. Kozima, M. P. Michalowski, and C. Nakagawa. Keepon. a playful robot for research, therapy, and entertainment. *International Journal of Social Robotics*, 1(1):3–18, 2009.

[14] P. Marti, A. Pollini, A. Rullo, and T. Shibata. Engaging with artificial pets. In *Proceedings of the 2005 annual conference on European association of cognitive ergonomics*, pages 99–106. University of Athens, 2005.

[15] F. Michaud, A. Duquette, and I. Nadeau. Characteristics of mobile robotic toys for children with pervasive developmental disorders. In *Systems, Man and Cybernetics, 2003. IEEE International Conference on*, volume 3, pages 2938–2943. IEEE, 2003.

[16] M. Mori. Uncanny valley. *Energy*, 7(4):33–35, 1970.

[17] J. Piaget. *Play, dreams and imitation in childhood*, volume 25. Routledge, 2013.

[18] D. J. Ricks and M. B. Colton. Trends and considerations in robot-assisted autism therapy. In *Robotics and Automation (ICRA), 2010 IEEE International Conference on*, pages 4354–4359. IEEE, 2010.

[19] B. Robins, K. Dautenhahn, E. Ferrari, G. Kronreif, B. Prazak-Aram, P. Marti, I. Iacono, G. J. Gelderblom, T. Bernd, F. Caprino, et al. Scenarios of robot-assisted play for children with cognitive and physical disabilities. *Interaction Studies*, 13(2):189–234, 2012.

[20] B. Robins, K. Dautenhahn, R. Te Boekhorst, and A. Billard. Robotic assistants in therapy and education of children with autism: can a small humanoid robot help encourage social interaction skills? *Universal Access in the Information Society*, 4(2):105–120, 2005.

[21] B. Scassellati, H. Admoni, and M. Mataric. Robots for use in autism research. *Annual review of biomedical engineering*, 14:275–294, 2012.

[22] S. Shamsuddin, H. Yussof, L. Ismail, F. A. Hanapiah, S. Mohamed, H. A. Piah, and N. I. Zahari. Initial response of autistic children in human-robot interaction therapy with humanoid robot nao. In *Signal Processing and its Applications (CSPA), 2012 IEEE 8th International Colloquium on*, pages 188–193. IEEE, 2012.

[23] L. S. Vygotsky. Play and its role in the mental development of the child. *Soviet psychology*, 5(3):6–18, 1967.

[24] M. Wilson. Six views of embodied cognition. *Psychonomic Bulletin and Review*, 9(4):625–636, 2002.