Brain-inspired robots for autistic training and care

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An increasing number of projects world-wide investigate the possibilities to include robots as a part of assessment and therapy practices for individuals with autism. There are two major reasons for that: the special interest of the autistic people in robots and electronic tools and the rapid developments in the multidisciplinary studies on the nature of social interaction and on autism as atypical social behavior.

Evidence from several branches of the social and neurosciences, which aim to understand the social brain, advocates the perspective that social behaviors (e.g. shared attention, turn taking and imitation) have evolved as an additional functionality of a general sensory-motor system for action. The basic feature of this system is the existence of a common representation between perception for action and the action itself. An extended social brain system facilitates processing of emotional stimuli, empathy, and perspective taking.

This book chapter will describe a research line that builds on this perspective and incorporates theories from social- and neuro- sciences. Within this perspective, movement is modeled or generated as basic behavior that will further determine some aspects of social interaction. Typical and atypical (as seen when observing persons with autism) movement patterns are simulated in the sensory-motor system for action, as the difference is assumed to be caused by processing that takes place in Superior temporal sulcus - Parietal areas of the brain. As a result different movement patterns emerge within a robot simulation. These are to be used in games for behavioral training of autistic people with robots and tools with sensory-motor features.
The difference in movement patterns by typical and autistic persons has been investigated in goal-directed movements. Motor imitation is the most studied social behavior that is associated with goal-directed movements. We assume that there is a relation between the difficulties of the autistic people to imitate and their goal-directed movement patterns. We create social games that promote imitation and other social behaviors. A robotic system that will measure and give feedback on motor imitation and social behavioral patterns of autistic people is a subject of our research.

Robot imitation is inspired by the studies on motor imitation and on detecting motor intentions i.e. intentions directed towards inanimate objects. A more general ‘social perception’ system processes emotionally-rich facial expressions, bodily postures, and actions of others, and triggers appropriate emotional responses. The recognition of the emotional movements is the next level in our research on incorporating human social movements and responses in behavioral training of children with autism.

This Chapter is organized as follows. In Section 1 we introduce the findings about the atypical motor behavior of people with autism that possibly contributes to the known shortcomings in their social behavior as expressed in imitation and emotional movement behaviors. We introduce the most plausible theories for neurological causes of the atypical autistic behavior and propose a neural model that simulates typical and autistic behavior followed by a simulation of grasping behavior on a robot. In Section 2 we explain how the social skills can be enhanced by training motor behaviors through games and playful interaction scenarios. We also outline how to include robots that express basic motor and interaction behaviors for training social skills. Section 3 introduces the robotic platforms used in the experiments with autistic children that will be presented in Section 5. Section 4 introduces Laban movement analysis, a method that is needed for qualitative evaluation of the human movement behaviors and for generation of expressive (qualitatively distinctive) behaviors of robots. Section 5 features several game scenarios and Section 6 puts the work in perspective.

1  Enhancement of social skills with robots

1.1 Action, imitation, and social behavior

The ability to understand and respond to other persons’ actions is a core component of social behavior. In this respect, goal oriented grasping, imitation of
actions, and expression of emotional attitude in the action has been studied extensively through animal and human experiments. Across the spectrum of autism-related disorders, in which impairments in social development are typical, the cognitive functions that are embodied by action appear to be most affected [101]. While communication skills based on gestures, facial expressions and eye movements are underdeveloped by autistic people, those abilities that are less dependent upon integration with actions, such as certain sensory, mathematical and mnemonic abilities may be enhanced. Therefore, the mechanisms that underpin different movement behaviors such as goal oriented action, imitation, self-other matching and motor expression of emotional attitude through physical behavior are fundamental to our understanding of autism.

After thorough analysis of the existing literature Leary and Hill [54] pointed out that the importance of the motor impairments in autism have been overlooked. Others [12,20,55,92,96] indicated that the motor functions of people with autism differ or are impaired. Leary and Hill [54] provided an explanatory analysis of the bibliography on movement impairments in autism, aiming to show how some of the socially referenced characteristics of autism might be based on neurological symptoms of movement disturbance. Moreover, the authors argued that the application of social context to the observed behaviors may divert the attention from the neurological explanations for the same behaviors. They proposed that a shift in focus to a movement perspective may provide new insights, which could result in the development of useful tools for future diagnosis and rehabilitation.

The most characteristic abnormal motor behaviors exhibited by people with autism are as follows. First, there are repetitive and stereotypical movements of the body, limbs and fingers. Second, people with autism exhibit unusual gait patterns such as poorly coordinated limb movements and shortened steps, as well as ‘toe walking’ [20,96]. And third, poor performance of motor imitation tasks and the failure to use gestures for communicative purposes have been found in many studies that compare autistic and typical behavior (for a review see [85]).

In this chapter we focus on the last group of motor abnormalities. Studies on visuomotor priming consider actions, especially goal oriented actions such as grasping, as inseparable from sensing, seeing and recognizing these actions by others [25,75]. During observation of graspable objects and tools, motor cortical areas have been shown to code the object in terms of one or more potential actions with these objects [62,74]. Craighero et al. [19] suggested that motor preparation not only involves premotor cortical areas, but also evokes a representation of the prepared action in visual terms (p. 498), located in the posterior parietal region and STS. Because of the motor involvement during
observation of actions and objects, actions are internally simulated by the observer, as shown by different studies from neurosciences, such as those based on single cell recordings [25,75,93]; brain imaging methods [21,51,75,77]; and transcranial magnetic stimulation [34,89]. In addition, behavioral methods such as transfer paradigms [45,97,98]; and stimulus-response compatibility paradigms [85], have shown concordant results as well.

The above mentioned studies identify a mirror neuron system that is comprised of three main cortical areas: the premotor cortex (F5), the inferior parietal lobule (PF), and the Superior Temporal Sulcus (STS). This system creates an affordance to first implement goal-oriented tasks, such as grasping. This system has further evolved to dynamically represent the sensory and the motor correlation of an action in the same brain structure. In this way, perceiving and performing an action exploit the same representation, i.e. the action of the conspecific represented in the acting agent. Correspondingly, the mirror neuron system can facilitate imitation functionality as a natural addition to the goal-oriented actions. Because individuals with autism have difficulty communicating socially and understanding the emotions and intentions of others, the hypothesis that people with autism have a dysfunctional mirror neuron system has received a lot of attention in literature, following a number of studies that reported weak mirror neuron system responses in individuals with autism. Such a straightforward explanation that a system of 3 brain areas can embody all the reasons for abnormal action preparation, action understanding and action imitation is very tempting, especially if one aims at a computational model that can be implemented on a robot. However, there is recent counter evidence about the dysfunctional mirror neuron system in autism [24]. Dinstain and colleagues [24] showed that mirror system areas of individuals with autism not only responded strongly during movement observation, but did so in a movement-selective manner such that different movements exhibited unique neural responses. The mirror system responses of individuals with autism were, therefore, equivalent to those for controls. It will be most interesting to closely follow future research into the mirror system hypothesis.

Dinstain and colleagues support the theory that noisy neural responses may cause the environment to be perceived as inconsistent and noisy, making it difficult for the child to cope with the outside world, and driving him/her to develop autistic behavioral symptoms in response. Both the opponents and the supporters of the contribution of the mirror neurons system to the specificity of the autistic behavior (see for instance Iacoboni [47]) agree that there is a much larger system that is involved in action preparation, understanding, and imitation. We base our experiments on the understanding that the action perception, execution, and imitation are in the core of the autistic behavior. In particular, we simulate the
effect of cue delay by multisensory integration on the global behavior which is not in contradiction with either of the mentioned theories. Motor imitation represents one of the earliest forms of reciprocal interaction observed between infant and caregiver [63]. It is foundational for an infant’s emerging ability to detect the correspondence between self and others [58]. The early opportunity for an infant to detect similarities with others leads to later understanding of other’s intentional behavior and to the development of a theory of mind. The system for social interaction embodies also emotional aspects of the imitative or reciprocal behaviors. The studies of human emotion that are related to observable human behavior in terms of postures and movement, such as [1,22,29,79] place the amygdala at the core of a network of emotional brain structures. The amygdala and STS are directly connected and involved in the recognition of emotional body language. The amygdala decodes the affective relevance of sensory inputs and initiates affective behaviors via its connections to the motor systems [29]. To extend the already suggested network to an even more complex neural structure that involves brain structures and mechanisms that relate to emotional processing is a challenging task. Instead we propose to include the common coding principle of behaviors that include emotional content as an addition to the typical movement, which is involved in imitation or other reciprocal social behaviors.

The role of the social interaction system therefore extends from motor control (for instance in goal-directed grasping) to imitation that is the basis for developing social communication skills, such as theory of mind, empathy, and emotional body language. Different motor behavior of people with autism may lead to differences in motor learning, which we are going to further explore.

1.2 Simulation of grasping behavior by autistic and typical people

After a thorough analysis of the bibliography on movement impairments in autism, Larry and Hill [54] outlined how deficits in movement preparation and execution could lead to many of the behaviors exhibited by individuals with autism. Difficulties in planning and executing simple discrete movements can lead to problems in learning to coordinate diverse muscle groups into a unitary movement pattern. Moreover, when a person is unable to respond to another’s action in a timely fashion, he or she will miss the positive reinforcement associated with interpersonal interaction.

Behavioral evidence of human perception and action indicates that organisms make use of multisensory stimulation. Under normal circumstances, multisensory
stimulation leads to enhanced perceptions of, and facilitates responses to, objects in the environment (e.g., [15,86,90]). However, literature shows that imprecise grasping or other motor or executive dysfunctions observed in autistic patients are caused by a disturbance in a dynamic mechanism that involves multisensory processing and integration. This can be caused by discrepancies between stimuli that are normally concordant. In these circumstances, multisensory stimulation actually leads to inaccurate perceptions and responses, regarding location, identity, and timing. Temporal binding for instance is identified as a dynamic mechanism that is disrupted and likely implicated in the perceptual and higher-order deficits observed in autism [16]. In other studies, atypical processing is specifically associated with enhanced sensory processing or discrimination in various modalities [61,66]. Some studies argue for a broader neurological problem such as an executive function deficit in the coordination of sources of information from different modalities [65,67].

All these works suggest that the dynamic aspects of integration of multisensory input influence the formation of coherent perception, planning, and coordination of action. Even more concrete, many studies assume that simple motor planning is intact, but the use of externally guided visual feedback is diminished, affecting the quality of motor performance, postural stability, and the lack of effective sequencing of actions [56,26,85,88]. Therefore, perceptually challenging tasks that require smooth integration of visual with vestibular–proprioceptive information may be particularly difficult to perform and could result in poor quality of motor performance on complex tasks.

We test this assumption by simulating the dynamic mechanism of temporal multisensory integration to investigate how the atypical formation of coherent perception might influence the coordination of action and compare the results with experimental studies by typical and autistic patients. Temporal multisensory integration has previously been discussed in the context of autism [16,49] in attempts to obtain a clear understanding of the underlying biological mechanism of interaction and to simulate it in the robotics setting [6,11], and implicitly in many other robotic studies. Masterton and Biederman [56], in particular, have shown that a proper interplay between integration of distal (visual) and proximal (proprioceptive) cues is essential by grasping.

For the purpose of simulating grasping behavior on robots we simulate the integration of these cues first. We expect that by varying the parameters for forming grasping behaviors, we can approximate autistic and typical behavior. Emulating typical and autistic behaviors on robots and gaining sufficient understanding in the differences will make it possible to include these in
behavioral training of autistic people through games and training scenarios. In particular, many studies conclude that people with autism rely more on proprioceptive than on visual information. By appropriate game scenarios, we can try to motivate them to use their visual information more often by letting them play games that include reaching and imitation movements that depend on the visual feedback, and not on proprioception.

This section will feature three experiments, presented in subsections 1.2.2 to 1.2.4, after a brief introduction of the model in subsection 1.2.1. In the first experiment, described in section 1.2.2 is elaborated that integration of robots visual and proprioceptive cue simulates grasping behavior. The impact of delays in each of the sensory modalities is investigated in subsection 1.2.3. The experiments are made with a simulated e-puck robot, and aim to find the proper parameters for the experiments with the physical robot, and the abruptness of the changes that delays in different cues will cause. This second experiment shows the effect of change of heading direction of the robot with tuned weighting parameters of the neural field model in the cases of no delay, delay for the visual cue, and delay for the proprioceptive cue. This experiment shows how close a Dynamic Neural Field (DNF) model can approximate grasping by humans. The parameters of the DNF model found in these experiments and the effects of the delay of sensory cues on the integration are used in the third experiment with an e-puck robot described in subsection 1.2.4.

1.2.1 DNF model for generation of human like movements

The integration process that causes the movement behavior is approximated by a dynamic mechanism. Proper modeling of dynamic (temporal) integration mechanisms requires a dynamic neural model. Erlhagen, Iossifidis, Schöner and colleagues [32,50,83] have adapted the dynamic neural field model of Amari [5] for controlling mobile robots and robot manipulators and producing close-to-human behavior.

The DNF model has been proposed as a mathematical model for neural processing [5,83,32]. The main characteristics of this model are its inherent properties for stimulus enhancement and cooperative and competitive interactions within and across stimulus–response representations.

Recently, Erlhagen and Schoner [32] formalized the extension of the theoretical model to the dynamic field theory of motor programming, explaining how it could be used for robotics and behavioral-modeling applications. The DNF model has been used in robotics for navigation and manipulation of objects [33,50,82],
multimodal integration [81], and imitation [87]. Applications feature biologically convincing methods that can optimize more than one behavioral goal, contradictory sensory information, or sensory-motor tasks that require common representation. Thelen et al. [91] have modeled the dynamics of the movement planning by integrating the visual input and motor memory to generate the decision for the direction of reaching.

A feature of the model that is interesting for us is that it possesses dynamic properties useful for multisensory and sensory-motor integration. We suggest that the dynamic characteristics of the model can be exploited for investigating the temporal aspects of multimodal integration. The temporal window for integration is shown to have an impact on the multisensory interaction, so we investigate the possibilities for its adaptation within the neural field model and its impact on the computational outcomes. The presentation of the sensory cues within the DNF model is in the form of Gaussian distributions. We tune the variance of these distributions according to the experimental findings, and experiment with the delay in the presentation of each cue in accordance with the realistic times of sensory processing of different modalities, while, of course, following the restrictions of the experimental platform.

1.2.2 Integration of robots visual and proprioceptive cue simulates grasping behavior.

At the period the experimental work was performed, we had only available a mobile robot lacking human arm appearance. Therefore, the action of the robot was defined as turning towards, and approaching a target object that is intended to be grasped. Our experiments are therefore restricted to a two-dimensional task of reaching a target.

Based on earlier findings [6,95] two complementary sensory cues, namely proprioception and vision are necessary and sufficient for reaching, as well as for precision gripping by the robot. Unbalance of the same two cues may cause the different grasping in autistic people, as explained in the previous sections. In this experiment, we assume that the robot always sees the target at a fixed direction that is located at some distance in front of it. Then, the robot has to move from the initial position by turning to the target direction and move to the target. The proprioceptive or self-motion information is the angular deviation of the head direction of the robot from the initial position. Vision data is used for spotting the landmark or goal direction. The parameters of DNF were tuned empirically, taking the suggestions from human experiments [95] into account.
Our hypothesis is that a delay in the activation corresponding to each of the sensory cues may cause or contribute to imprecise motor behavior. In the underlying system for action, the integration between the visual and proprioceptive information takes place in the parietal area, before the intention for the action has taken place. With the following experiment we are going to test the impact of the delay in the activation caused by each of the sensory modalities. We experimented with different delay intervals.

To test the effect of cue delay on the sensory integration, each cue signal was delayed by a different time interval when a goal finding task was performed. Several tests were made with a simulated robot that performs target-following tasks. In each test, after the robot determined a heading direction, the target was moved so that the heading direction of the robot changed by different angles. Figure 1 depicts trajectories with changes of the heading direction corresponding to 5 - 15 - 25 degrees and 15 - 30 - 50 degrees with no introduced sensory delays. Figure 1 (left) shows the output potential of the second trajectory, and Figure 1 (right) shows the two trajectories in polar coordinates. Polar coordinate representation was chosen because it corresponds to the actual movement of the robot from its egocentric perspective. Several trials were made to compare the effect of changing heading direction with no cue delay, with a delay in the

![Figure 1. Left: the output potential with heading direction changing with 15 - 30 - 50 degrees; Right: the trajectories of the robot in polar coordinates with heading direction changing correspondingly with 5 - 15 - 25 , and 15 - 30 - 50 degrees.](image-url)
proprioceptive cue, and with a delay in the visual cue. Figure 1 shows the response time for the robot to decide the direction of the movement. The visual cue delay has a more significant effect on response time than the proprioceptive cue. To get further information on the delay effect for each cue, the experiment of changing heading direction was carried out for three successive steps.

In every experiment, a delay in proprioceptive cue had less of an effect for generating the new heading direction. With equal cue delays, and with the neural field parameters constant for both cues, the experiments differed in the abruptness of changes in heading direction.

**1.2.3 Effects of cue delays on grasping.**

With this experiment we test whether the DNF model approximates properly the dominance of proprioceptive over visual information for autistic people. Autistic subjects were reported to use visual information in order to determine the location of the target slot; however, they relied on proprioceptive information for reaching.

A grasping of an object in a two-coordinate plane was simulated. The sensory models of the visual and the proprioceptive cues are based on the findings of Van Beers and colleagues [95]. Three objects were located in random positions in space. We assume that when a subject has to grasp an object, he has to turn in the direction of the object. This means that the object is always located in front of the subject at the moment of grasping. This assumption is used to design the robot simulation. Figure 3 shows the results of the simulation: For proximal grasping, the proprioceptive cue has more effect on the output potential than the visual cue. As shown in Figure 2, with the same delay time, the output potential takes relatively longer to be generated in the case of a delay for the proprioceptive cue.
Experimental data from [95] show that the precision of movement is affected differently in terms of depth and azimuth motion by the visual and proprioceptive cues. The proprioceptive cue is more precise when the depth (distant goal) is targeted, and vision is more accurate in proximal (moment to moment) movements. To simulate this effect, the Gaussian ratio and amplitude of both cues were tuned to correspond to the variances in movement accuracy as found by Van Beers et al. [95]. Figure 3 shows the change of heading direction of the robot with tuned weighting parameters of the neural field model in the cases of no delay, delay for the visual cue, and delay for the proprioceptive cue. This result is in agreement with the experimental studies [95], and shows that DNF model approximates rightfully the precision of movement when the parameters for the two cues are directly borrowed from experiments with humans.

1.2.4 Modeling grasping behaviors of autistic and typical people by a robot.

For the third experiment, an e-puck mobile robot was used [30]. The robot is equipped with infrared sensors (IRs) that were used to obtain the information about the turning angle of the robot, which we will refer to as proprioceptive information. The obstacle-free space determined the possible direction of the
robot for the next moment to moment movement. Vision was used to determine the target direction of the robot.

![Figure 3](image)

**Figure 3** Heading direction of the e-puck robot with and without delay when changing the target direction from 0 to 15 to 30 to 50 degrees. The 3 lines depict the change of heading direction after sensory integration without cue delays, and with a delay of 15 steps for each cue.

In the robot experiment, we can assume that proprioceptive or visual information has been delayed so the simulated movement will depend on the non-delayed cue. The influence of each sensory cue on the output behavior was tested after the experimental scenario was simplified by using only one obstacle in the arena. With this simplification the influence of any artifact on the outcome of the experiment is excluded. In the absence of sensory cue delays, the robot can avoid the obstacle and reach the target. When delay was applied to the proprioceptive or to the visual input, the robot took different trajectories. Depending on the distance of the obstacle and the speed of the robot, changing the delays had different effects. Figure 4 shows three sample trajectories of the robot: respectively, without delay, with delay for the proprioceptive sensory cue, and with delay for the visual cue.

Proprioceptive cue delay resulted in a collision between the robot and the obstacle. With a visual cue delay, the robot started to move in an arbitrary direction until the visual input was received, but nevertheless avoided the obstacle.
This result could be compared with autistic and typical behaviors. When both cues are timely integrated, a typical movement behavior occurs. When the visual cue is delayed, i.e. the robot relies more on the proprioceptive information, the proximal obstacle is avoided, but the handling of reaching the distant object is interrupted. This may resemble the inability of autistic people to combine simple movements to a global complex behavior, as suggested by [56,85,88].

1.2.5 Behavioral training with robot grasping

If we look back to the above experiments we can outline ways to deploy the gained insights. We applied the dynamic neural field model [5,32,83] to multimodal interaction of sensory cues obtained from a mobile robot in order to show the impact of different temporal aspects of the integration to the precision of movements. We speculated that temporally uncoordinated sensory integration might be a reason for the poor motor skills of persons with autism.

Even if this assumption is too simplistic approximation of grasping behavior by autistic people, the simulation gives a fair approximation of the actual autistic behavior. Using these results we can incorporate the behaviors in the humanoid robot or prepare games with the i-blocks platform, featured in Section 3.1, and use them in games that aim to train for better usage or integration of the visual cue.
The DNF model ensures human-like decision making and smooth motions when different external stimuli are present. However, the unreliable sensory information can result in totally different behavioral solutions when the robot starts from the same starting point in the same arena. Unrepeatable behavior may be caused by detection failure of the sensors or imprecise tuning of the parameters of the DNF model. This results in either the robot departing from the natural path or colliding with an obstacle. To fulfill our ambition of simulating the sensory integration process of autistic people we currently apply a 2D DNF on the humanoid robot NAO. The NAO robot can be involved in giving active feedback on the behavior of the autistic child and a comment (reflection) on its own behavior, if it is parameterized as autistic-like behavior.

2 Social skill enhancement with robot-mediated games.

We explore the hypothesis that social skill training by autism should have as basic component the training of motor skills. As it can be further elaborated from the reasoning in the previous section, training goal-oriented movements, such as grasping of an object, imitation of a movement, and permitting turn taking facilitates social interaction on a motor level. The social interaction context requires that the behaviors are not taken in isolation but are included in realistic scenarios.

Teaching social movement patterns can take many forms. Since we target children, we choose to design game scenarios. The most obvious value of games is enjoyment and sharing of social experiences with others [99]. In addition, play is widely used as a preferred educational activity for young children to acquire a variety of skills for life, such as motor-coordination, social and cognitive skills [72]. Malone and Lepper [59] have pointed out the importance of intrinsic motivation in games. Intrinsically motivating activities are those in which people will engage for no reward other than the interest and enjoyment that accompanies them. They identified factors such as challenge, curiosity, control, fantasy, competition, cooperation, and recognition. Note that the first four of these are individual factors whereas the other three are interpersonal factors.

Whereas traditional game design aims at creating a balanced mix of the seven factors identified by Malone and Lepper [59], assuming they all make a positive contribution to the attractiveness of the game, the role of the factors in this balance is probably different for children with autism. For the individual factors,
they could cope with even more demanding challenges. But the interpersonal factors are likely to be more challenging and at the same time less contributing to the intrinsic motivation.

In addition, children with autism feel comfortable with structure and clearly defined rules, which gives another incentive to use games to stimulate social interaction between them. The most important forms of play that make the relation between the motor and social development are as follows.

- Object play. Children with ASD explore objects less often and less thoroughly than their peers. Promoting early object-directed play is important for development of meaningful perceptual representation and later of functional, symbolic and social play [94].

- Functional play. Functional play relates to the ability to use an object in accordance with a socially designed function. Shortcomings in the functional use of objects may result from the motor difficulties addressed in Sections 1 and 2, and from the inability of a child to relate to people. Other people play a vital role in showing children how to use objects properly in a context of joint attention and imitation.

- Peer or social play. Social play is especially challenging to children with autism, because of their difficulties with imitation, sharing toys, taking turns, and understanding emotional expressions. Several reviews of imitation in autism indicated that most but not all studies show an early lack of imitation and later problems in imitation on demand [85,88]. Imitation by others, however, is effective in establishing social contact in autism [64].

All the above mentioned forms of play relate to physical play [14] and are based on the motor activities of the players. We add a new dimension to the play with physical objects that will promote social and the relevant motor skills, by using play objects that are behaving themselves, i.e. have sensors, actuators and can express some intelligent behaviors. We refer to such play objects as robots, although some of them (like the i-cube platform could be classified as tangible interaction tools). In the next sections we introduce the used robotic platforms and elaborate on how the play with robots can contribute to the behavioral training of children with autism.

3 Robotic platforms for grasping, imitation and social interaction games
Physical play [14] is based on the motor activities of the players. Robots, in addition to their appeal to the autistic children’s repetitive and controlled movements, raise the interest for nonverbal social communication, expressed via movement and postures. Robots have controlled and repetitive movements, which are features that are appealing to autistic children. In addition, the robots are intellectually challenging, and can stimulate the curiosity of the autistic children. Encouraging play using a robotic toy may foster individual development up to the child’s potential [60].

Visuomotor priming by robots has shown to be beneficial for people with autism [71]. In general, people with autism would perceive a movement behavior that is performed multiple times by a human actor differently, while for a typically developing person this is perceived as the same behavior. Because of that we suggest to involve robotic co-players in the games, since the robots can perform the same movement multiple times in the same or in a precisely controlled new way. In addition it has been shown that autistic children have affinity to robots and they find easier, less intimidating and even fascinating to have a robot for a play partner or a mediator of play.

In most of the studies that use robots in games with autistic children, the robot is used as a play partner, and in some as a mediator of play [7,9,10,78]. We propose that the robot has to encourage the social interaction in many ways, by explaining or demonstrating the rules of social interaction or by being a tool in a game that requires collaboration and tries to subconsciously persuade the children towards associative or collaborative play [9,10]. For these purposes, we first simulate simple robot behaviors such as grasping, pointing and waving for the expression of goal oriented and social behaviors. The simulations are based on a bio-inspired neural model of social interaction, which makes it possible to easily approximate autistic or typical motor behavior on the basis of changing the model parameters [11]. In addition we develop games and tools to measure or perceive the children’s body language by a robot or a tangible tool. We include these robots and tangibles in games and play scenarios that include motor imitation, turn taking, and emotional interaction and will eventually facilitate the enhancement of the social skills of the children.

To trigger more advanced forms of social play, we develop physical objects that have their own means to stimulate social interaction. These include: sensors so that the objects can record the changes in the surrounding world, some learning or adaptation mechanism that will facilitate decision making and insure a level of autonomy, and actuators so the objects can express behaviour. A physical object with such features is in a broad sense a robot independently of its shape or means of behaviour. We aim at a higher level of autonomy than the available robots have
at present. The difference by this new level of autonomy is in the robot’s ability to interpret human movement behaviour and to behave in such a way that is understandable to humans. Specifically, we aim at designing robots that can themselves express emotional behaviors, as well as understand emotional expressions in other agents. In this section, we give an overview of the available robot platforms. We present three platforms with increasing degree of complexity. In the conducted experiments, three platforms with different degrees of complexity have been used: the i-blocks, a multiagent platform of interactive blocks, e-puck, a wheeled mobile robot, and NAO, a humanoid robot.

3.1 i-blocks - a multiagent platform of interactive blocks

We developed a multiagent platform of interactive blocks [9,10,2], where the blocks can be classified either as robotic entities, since they can sense the environment and react on it by expressing different behaviors, or as tangibles, since they are embodied objects with sensors and actuators, that invite interaction with users through simple and natural physical interaction metaphors (Figure 5). The blocks emit colored light and interact when positioned in each other’s vicinity. Depending on the algorithm that is loaded on each block at this moment they express a different set of local interaction behaviors that cause emergent collective behaviors.

The blocks can be used to make constructions with regular forms and precise positioning, which is appealing to the autistic children. The fascination of the autistic children for patterns and regularity makes the blocks an interesting toy for them. The emergently changing behavior of the i-blocks stimulates their explorative behavior of the autistic children [10]. We have chosen blocks with cubic shape and a size that can easily be grasped by a child, but still big enough to prevent single child to “occupy” all the blocks. This may encourage children to join their efforts in building patterns together or at least make the child allow others to add to his construction, like another child or a caregiver.

The overall behavior of the system depends on the local interactions, and therefore it forms an embodied multiagent system [10]. The complexity of the emerging behaviors depends on the complexity of the individual behaviors of the blocks. The technical details of the first stage of the development of this platform are described in [2]. In a further development of the platform a built-in accelerometer is used to record the children’s hand movement and to facilitate a number of imitation games. The complexity of the internal organization of the blocks is similar to that of the commercial mini-robots, with sensors, microcontroller, and controllable LEDs; so we define them as robotic agents,
whose motor behavior is expressed not through motion, but through changing color and intensity of light (Figure 5).

We distinguish between the platform and the specific games. By platform we mean the hardware, including form, sensors, actuators, microcontroller, and the programming environment, which allows different behaviors to be simulated. By game we mean the specified rules as coded by the embedded program to make the blocks behave, together with the explanation of the rules to the players. The game/platform distinction makes it easier to develop several games and compare different games on the same platform.

The blocks were specially designed to fit the play habits and the patterns of thinking of the autistic children. Initial user tests as reported in [7,10] have shown that children find them very engaging and pleasurable. In general, the advantage of these blocks is as follows: (1) Direct manipulations of tangible objects can exactly be registered; multi-modal feedback can be provided. (2) i-blocks are suitable for training goal directed actions such as grasping and object manipulation. (3) i-blocks are relatively simple and reliable technological tools and can easily be connected to computers, robots and other media.

![Figure 5](image)

**Figure 5** The developed multi-agent system of interactive blocks (i-blocks): (a) internals of the block platform and (b) example of emergent light patterns when the blocks are put in each other’s vicinity.

### 3.2 The e-puck mobile robot

E-puck (http://www.e-puck.org) is a small mobile robot measuring 70 mm in diameter and 55 mm in height (Figure 6). It is equipped with infrared distance sensors that are located around the body at 10, 45, 90, 270, 315 and 350 degree with respect to the heading direction of the robot. The robot was controlled by a personal computer using a Bluetooth interface. A rectangular arena was
constructed for the robot which measured about 100 cm 70 cm. The arena was fenced by cardboard walls which were about 10 cm high. The robots movements were filmed by a Logitech QuickCam camera (http://www.logitech.com) suspended about 160 cm above the floor of the arena. The camera captured the entire arena using 320 x 240 pixels at 10 Hz. The floor of the arena was white. The robot was fitted with a black cap for maximal contrast so that tracking the robot while it moved was easy. All image processing and tracking of the location of the robot was done using RoboRealm software (http://roborealm.com). Processing the images of the camera included correcting for radial distortion. The tracking software provided the approximate location of the center of the robot in each camera frame. Furthermore, the tracing software provided a measure of the movement of the robot. Processing of the images and tracking the robot was done in real-time by the same personal computer that ran the software for controlling the e-puck robot.

![Four e-puck robots.](image)

**Figure 6** Four e-puck robots.

This robot has the advantage that it is relatively easy to control and many ideas can be easily tested. For instance the integration of proprioceptive and visual information using the DNF model for a humanoid robot will need a computationally more expensive 2D DNF model, while the parameter tuning would be the same. For the actual experiments with users, however, 2D DNF model can be simplified.

Another advantage of the e-puck robot is its abstract shape. We conduct experiments where solely the effect of movement on the children has to be
evaluated. This is the case of testing the ability of autistic and typically developing children to classify emotional expressiveness of movements.

3.3 The humanoid robot NAO

The commercially available humanoid robot NAO, is illustrated in Figure 7. The robot has 25 degrees of freedom, 5 in each leg and arm, and 1 in each hand. Further it has 2 degrees of freedom in its head and one in the pelvis. The platform contains 2 color cameras with a maximum resolution of 640x480 pixels at a speed of 30 frames per second. The platform contains an embedded AMD Geode 500MHz processor and is shipped with an embedded Linux distribution. A software library called NaoQi is used to control the robot. This is an easy to use C++ interface to the robot’s sensors and actuators. Due to this library it is relatively easy to control the robots actuators and make use of advanced routines that let the robot move and talk using text to speech conversion.

![Figure 7 NAO robot.](image)

The advantages of the humanoid robot are as follows. It can interact with humans on physical and social level. Since autistic people find humans intimidating, many
successful experiments showed that robots are less threatening to the autistic children, but human-like interaction can be trained with such a robot. Current developments in robotics permit robots to be programmed by demonstration and imitation. Therefore NAO can, with certain restrictions, learn to imitate behaviors in natural interaction. Since autistic people like predictability and being in control, the repetitive and simplified movements of NAO can be beneficial for training. Pierno et al. [71] have shown that interaction with robots has an effect on visuomotor priming processes, and that priming by a robot has a better effect on autistic persons than priming by a human. That is because an autistic person will interpret the details in the same human action as novel, and experiments with humanoid robots can be constant or changed in a controlled manner.

4. Laban movement analysis for emotional dialog between robots and humans.

In addition to social interaction conveyed by instrumental movements, emotional body language plays an important role in evaluating play behaviors with humans and robots. Making a robot to understand or express emotional body language requires an appropriate description framework. Laban movement analysis (LMA) is a method for describing the expressive (qualitative) features of the movements and posture. It was created by Rudolf Von Laban, a dance theorist, as a practical method for recording all forms of human motion. While Laban first refers to his notation, as well as to other systems as choreography, for its final form he introduced the term kinetography and initially published it as “Schrifttanz” (written dance or script-dance) [53].

LMA emphasizes the processes underlying motor actions rather than the resultant motor action. Using the motion determinants that a body takes in space, LMA gives a way to noticeably differentiate expressive and emotional actions. For instance, the difference between punching someone in anger and reaching for a glass is slight in terms of body organization —both rely on extension of the arm. However, the attention to the strength of the movement, the control of the movement and the timing of the movement are very different. This example shows how the three qualities, namely weight, flow, and time, respectively, help characterize the emotional load of movements.

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1 Pierno et al. [71] have shown that people with autism respond better on visuomotor priming by robot than typically developing people through the following experiment. Participants were requested to observe either a human or a robotic arm model performing a reach-to-grasp action towards a spherical object. Subsequently, the observers were asked to perform the same action towards the same object. As a result the children with autism learned faster when primed by a robotic but not by a human arm movement. The opposite pattern was found for normal children.
LMA was used to evaluate fighting behaviors of rats [36], to diagnose autistic patients [37], to explain the differences in sexual behavior in Japanese macaques [38] and to analyze the quality of movement by recovery of stroke patients [61]. We use LMA for the description of the kinematic and non-kinematic movements made by human subjects that perform emotional actions. The reliability of the non-kinematic measures in LMA has been validated in previous studies [38,39]. We focus on effort [53] or dynamics, in an attempt to understand the more subtle characteristics about the way a movement is performed with respect to intention. LMA emphasizes how internal feelings and intentions govern the patterning of movement throughout the whole body. It provides a complex understanding of intention.

Similar to the common coding/mirroring paradigm LMA is useful to describe the interaction in the physical world, which is caused by physical robots that move or perceive movements of humans and other agents (robots). Therefore using Laban movement analysis gives many possibilities: to design a robot that understands the emotional state of a human player and responds in an adequate manner; to design robot behaviors that imitate, enhance or counteract an emotional state of a person; to design socially believable robotic (embodied) characters that provoke social interaction; to create constantly adapting interaction based on movement/emotional understanding of a robot.

In order to identify the contribution of body movements to the recognition of emotion, it is important to have a clear and suitable description of these movements. The LMA, however, does not provide a straightforward way to assign quantitative measures to the movement qualities. It provides descriptors for the content of human body movements in terms of the following categories: Body, Space, Effort, and Relationship. The Effort category relates to the dynamic and expressive characteristics of the movement. It is comprised of four movement qualities: weight, space (not to be confused with the Space category), time, and flow. Each quality represents a continuum between opposite polarities: weight varies between strength and lightness, space, between direct and indirect, time between sudden and sustained and flow between bound and free. Effort qualities usually appear in combinations called ‘‘states’’ or ‘‘drives’’. When two motion qualities are combined, it is called the inner attitude or incomplete effort. They are suitable for expressing mental states. When three motion qualities are combined, they form externalized drives.

According to [36], the Laban Effort parameters can be translated into low-level movement parameters such as curvature, velocity, and acceleration. We have
shown [7] that this relation is reciprocal, i.e. if the factors that are the components of the Passion drive (i.e. time, weight, and flow) are combined, a judgment about the emotional load of the movement is possible to be made.

Connecting the Laban factors to emotional states is a two stage process. First, the right correspondence between the Laban factors and emotions has to be established. Camurri et al. [17] and Fagerberg et al. [35], have independently used LMA to classify dance gestures in terms of basic emotions; anger, fear, grief and joy. Their analysis overlaps for 3 of these emotions, namely anger, fear, and joy (happiness). We use the coding that corresponds to the relation between Laban movement qualities and emotions as introduced by [17].

Second, since we work with partially subjective parameters a classification method that can deal with a sufficient degree of uncertainty has to be deployed. For this purpose we used variations of neural classifiers for both analysis and synthesis of emotional movement.

For the purpose of mediation of play between children, a robot that can engage in reciprocal social interaction through movement was used. In particular, we design behaviors to support collective games for the humanoid robot NAO [3]. The game scenarios that are constructed on the basis of this interactive behaviors aim to help children with autism learn to recognize emotional movements from a robot partner and to produce similar movements.

Recognition of the emotional behaviors is a challenging task by itself. A performer and certified Laban movement analyst was asked to enact waving behaviors with different emotional coloring, namely angry, happy, sad and polite. The waving was chosen for several reasons. First, it is a behavior that is used exclusively in a social context. Second, it can relatively easily be tracked by a single camera. Third, several emotional states can naturally be expressed through waving. In fact our goal is not to confine to the type of the movement, but the extraction of a dynamic primitives that are typical for a certain emotion.

Figure 9 depicts pairs of 4 emotional waving patterns recorded in an experimental scenario as shown in Figure 8, using color images of 640 x 480 pixels at a speed of 29 frames per second. The image processing consists of a combination of skin color and motion detection with the aim of tracking a single body part per person that can be associated with the emotional waving movement. The black rectangular regions capture the center and the boundaries of the skin color areas, green areas capture moving objects and the blue areas give a combination of a moving skin colored area.
Recordings of 20 seconds have been made where performers were asked to demonstrate happiness, anger, sadness, or politeness. In each plot the acceleration profile has been obtained by taking the second derivative of the central point of the tracked object. Examples for all four different emotional states are depicted in Figure 9. From this figure the following can be observed:

1. happy waving provides a regular waving pattern with a relatively high frequency.

2. anger demonstrates bursts with tremendous acceleration

3. sadness demonstrates a profile of low acceleration, its frequency is relatively low and appears to have a lower frequency compared to the other three emotions.

4. politeness that demonstrates a queen type of waving profile is a regular pattern with a high frequency that is obtained by using minimal energy.

In an average acceleration-frequency plot of the recorded movements four distinctive clusters are formed (Figure 10).
Figure 9. Waving patterns. a) shows typical acceleration profile for happiness, b) for anger, c) for sadness, and d) for politeness.

Figure 10. Distinct emotion profiles are revealed by average frequency and acceleration.
The plots in Figure 9 are distinctive for a robot observer, as seen from the clustering shown in Figure 10. This implies that the robot is able to classify the emotional states of a human based on the emotional primitives that are extracted by the observable motion.

5. Game scenarios for training autistic people

5.1. Training gross motor skills, imitation, and turn taking

We created a number of game scenarios that train imitation and turn taking skills. It is well known that the children with autism have problems with imitation. Different studies have established that autistic children would imitate either the goal of the imitation, or the particular movement behavior. Combining both, however has shown to be challenging for the children. In addition, facilitating turn taking is particularly important because of weak social responsiveness of the autistic children. Sensitivity to the contingencies involved in cooperative play may produce turn taking and variability in the partner’s play behavior.

Earlier research indicated that if the children with autism are asked to make a verbal description of the acted out target behavior before imitating it helped them to initiate and sustain cooperative play, which resulted in longer play episodes and more variation in play [48]. To address the problem of turn taking through the imitation of the goal of an action, we used a task similar to those of Jahr [48] where actors were demonstrating actions to the children. To minimize the stress levels of newness due to meeting actors that can behave differently every time we asked the same actor to demonstrate all the scenarios. The request for social interaction and the newness of the actor can both make it unnecessary stressful for the child to attend the training. To further reduce this stress, we created video scenarios instead of using a physically present actor, similar to Charlop-Christ and colleagues [18].

The i-blocks platform is used in the game. There is one active block (which can change the colors of other blocks) and 5 passive blocks, that can be subject to a color change. There are sheets of colored paper at the 4 corners of the table. The task for the children is to match the color of the blocks to the pieces of colored paper positioned in front of the children. For example a colorless passive receiving block laying on red piece of paper should be colored red. This can be done by turning the active sending block to red and holding it close to the passive receiving block. Turning of the active block changes its color and this is the behavior that the child has to imitate. A child could explore the blocks by him- or herself and later color the blocks together with someone else.
Three scenarios have been performed and tested in the following way. First, the child and the coordinator view the video scenario on a computer or TV. After that the coordinator asks the child to describe what actions were performed by the actor. If the scenario is described correctly the child can start imitating the scenario, if not the video scenario is re-played until the child explains correctly the actions. The child plays the scenario with the coordinator. Snapshots of the 3 scenarios are shown in Figure 11.

In the first scenario, the blocks are placed in front of the actor, the passive blocks are on the colored pieces of paper, and the active block is in the middle. The actor picks up the active block and starts turning it until the block gets the color of the paper in front of him. The actor transfers the color to the passive block on the piece of paper. He does so for all the three paper-block combinations. The scenario is finished when all passive blocks are colored according to the underlying piece of paper.

The goal of this scenario is training of the gross motor skills and also that the child gets familiar with the interaction possibilities of the blocks and the concept of the game. By the second and third scenario complexity of the task increases, and imitation and turn taking behaviors between a child and a caregiver take place. Within the video modeling, the first actor colors a block and then shares the block with the second actor who, on his turn, colors his block. By the third scenario the active block is shared once more back to the first actor. Following the videomodelling, the coordinator and the child have to complete a longer scenario, where they share the blocks two times.

**Figure 11** Snapshots from scenario 3. a) Child colors 2nd block, b) Child shares a block (cooperates) c) Coordinator colors 2nd.
Two user tests were performed with groups of five autistic children. The first test was meant to optimize the concept and the experimental setting. The second, actual test, was done with children of 4 and 5 years of age. Two of them were diagnosed with PDD-NOS (P1, P2), one PDD-NOS or classic autism (P3), one classic autism and ADHD (P4) and for the fifth child there were no definite outcomes of the diagnosis (P5). All the children managed to finish two or three of the scenarios.

The children were prepared for the test by their development coordinator, who also was the turn-taking partner in the scenarios with the children who made a qualitative evaluation of the tests. 4 out of 5 children could do the imitation and turn-taking properly.

Most of the children could perform the imitation and turn taking behaviors (with one exception). Some individual achievements were as follows. A participant, who normally has trouble sustaining one on one play, was concentrated on the scenarios and followed the instructions. The participant who didn’t manage to complete the scenarios usually shows minimal group play and play variability – he plays every day with the same train. It was surprising that he followed the instructions and let the coordinator join in the game. He didn’t manage to complete the scenario, because he became heavily distracted.

With such a short-term exposure to the game, it is not possible to judge about the effect of the game on the general social behavior of the children, i.e. whether the children would be able to generalize the imitation and turn taking skills to a different real life situation. The usage of the blocks did not have distraction effect on the children during the imitation and turn taking tasks. In tables 1 and 2, the number of distractions of the children during the test with the first and second group is shown. Although the total distraction still varies widely per person the distractions by the blocks considerably decreased for the second test. The total number of distractions decreased with respect to the pretest that was conducted with different group of autistic children (table 1,2) due to better preparation of the children by the coordinator.
We implemented an accelerometer that makes the blocks sensitive to handling with a hand and has possibilities to implement and test many behaviors related to grasping, imitation and other interaction behaviors. In the future, we will test the children's ability of mimicry or 'blind' imitation, of goal imitation or of the overall process of imitation proper. At this study goal imitation was used to further facilitate turn taking. We showed that when all the actions are well understood by the autistic children, they performed willingly turn taking behaviors, which they normally do not do.

In another game scenario (Figure 12), aiming to encourage pairs of children to cooperate and imitate each other, mobile robots were used. As already shown in several studies, children with autism understand that they are imitated and find this experience rewarding and pleasurable. We use this finding to stimulate collaboration between pairs of autistic children. The children first observe a set of behaviors that have been performed by mobile robots. If the pair of children chooses to perform one and the same behavior the robots will start to imitate it. The robots can enhance or contradict the movement and in this way cause the children to start to negotiate for their possible actions to further control the robots.

Table 1 Number of disturbances by the pretest

<table>
<thead>
<tr>
<th>Participant</th>
<th>Total Disturbances</th>
<th>Disturbed by a robot</th>
</tr>
</thead>
<tbody>
<tr>
<td>P1</td>
<td>12</td>
<td>13</td>
</tr>
<tr>
<td>P2</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>P3</td>
<td>6</td>
<td>3</td>
</tr>
<tr>
<td>P4</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>P5</td>
<td>12</td>
<td>0</td>
</tr>
<tr>
<td>P6</td>
<td>19</td>
<td>14</td>
</tr>
</tbody>
</table>

Table 2 Number of disturbances by the final test

<table>
<thead>
<tr>
<th>Participant</th>
<th>Total Disturbances</th>
<th>Disturbed by a robot</th>
</tr>
</thead>
<tbody>
<tr>
<td>P1</td>
<td>7</td>
<td>2</td>
</tr>
<tr>
<td>P2</td>
<td>1</td>
<td>9</td>
</tr>
<tr>
<td>P3</td>
<td>2</td>
<td>9</td>
</tr>
<tr>
<td>P4</td>
<td>31</td>
<td>2</td>
</tr>
<tr>
<td>P5</td>
<td>1</td>
<td>9</td>
</tr>
</tbody>
</table>
In summary, the children were enthusiastic about playing with the blocks, and the mobile robots despite they normally do not show variation in play. The proposed method shows a potential in supporting autistic children in learning imitation and turn taking behaviors at a very early age, as summarized in the following observations. (1) Most of the children managed to imitate the play scenarios with the i-blocks and with the mobile robots. The children took part in turn taking by sharing the active block with the caregiver. (2) The video modeling showed to be a suitable way to teach the children understand and imitate the target behavior. (3) The stress levels of the children stayed lower than in actual social contact with new person, as observed by the coordinator and they could get well prepared for the upcoming scenario.

Earlier studies have shown that the basic principles of this method, namely using videomodeling and making the children verbalize the behavior that has to be imitated can improve the social skills of the children. We changed the setting by introducing multiagent system of tangible interaction blocks that were especially designed for autistic children and were tested to be perceived as very pleasurable and engaging. By using physical and engaging play objects training of relatively complex and untypical behaviors as imitation and turn taking was turned into a pleasurable game activity. Similarly, because of the engagement with the moving robots, the children willingly collaborated to make the same movement together. It is common for children with autism to choose the play objects based on the sensory stimulation that they provide, such as color, touch, sound, or smell. The color emitting lighting blocks, which emit pleasant dimmed light, as seen through the semi-transparent walls, has been well accepted by all autistic children that have been participating in different experiments with the blocks so far.
We plan a longitudinal study with an extended range of imitative and turn taking games that will aim at testing whether the children will be able to transfer the learned cooperative play behaviors to different, preferably real life situations. In the current research the play of child and a caregiver in a prepared environment has been observed. We would like to explore the effect of this method in natural environment and in realistic every day interactions, such as at school with autistic and typical children.

5.2 Understanding and imitation of emotional behaviors

In this section we aim to go beyond sensory–motor interaction in robotic models of embodied cognition by also including the interactive aspects of autonomy. This means that sensory–motor interaction has to be enriched with intentional, emotional and reward features. Specifically, we focus on the emotions that are conveyed by movement behaviors. Keltner and Kring [52] point out a highly dependent link between emotion and social meaning. They argue that emotions serve a set of functions that are critical for coordinating social interactions. These functions are: to provide information to the peers about the surrounding environment (e.g., fear may indicate the presence of a danger); to elicit both complementary and similar emotions in others, depending on the context; to be an incentive that promotes social relationships. This motivates us to pursue a more general social learning framework with robots that include emotional facial expressions, bodily posture and actions of others, and triggers appropriate emotional responses.

Although it is not shown that emotional resonance (response to perceived emotion) and emotion understanding and recognition are related components of the emotional system [64], teaching to just recognize emotions will be beneficial to children with autism [7].

For the purpose of mediation of play between children, a robot that can engage in reciprocal social interaction through movement was used. In particular, we design behaviors to support collective games for e-puck and the humanoid robot NAO [3]. The game scenarios that are constructed on the basis of these interactive behaviors aimed to help children with autism learn to recognize emotional movements from a robot partner and to produce similar movements.

The Laban movement guidelines as suggested by Camurri et al. [17] were used to design emotional behaviors on a mobile robot. Note that for this experiment we did not use directly the human emotional movement primitives.
To test solely the perceived emotion from the movement, the experiments with the e-puck [30] robot that had neither anthropomorphic nor zoomorphic shape were performed. A control user group of 42 typically developing children were asked to observe and categorize the emotional behaviors enacted by the robots. The outcome of the tests showed a good recognition of several basic emotions. The first row (light bars) of the chart in Figure 13 shows the recognition rate in percents of the designed emotional behaviors for each emotion. It is important to mention that the children were not provided with a list of possible emotions.

To analyze the robot behaviors we attached the Wiimote to the robot when it performed the emotional movements. The plots did not show the typical acceleration profile as by the emotional movements enacted by a human demonstrator, as shown in Section 4. The recording of the acceleration profiles from human motion patterns are a substantial step for redesigning the robot emotional behavior. The second row of bars (the dark red color) in Figure 13 shows the recognition rate in percentage by a group consisting of naive participants (children from different school), after we have redesigned the robot behaviors according to the findings from human recordings.

![Figure 13.](image.png)

**Figure 13.** The outcomes of the two user tests on perceiving emotional behaviors from robot movement. For the first test (the light bars) the robot behaviors are designed according to Laban theory guidelines. In the second test (the dark bars) we used human data, from which we extracted movement primitives. The emotional content of the movements were evaluated by independent certified movement analysts.

The emotional behaviors of the robots, based on human data were included in a game for promoting associative play [7] by children with autism. The emotional behaviors consist of robot sequence of movements that were shown to be perceived as expressing a certain emotion (Figure 13, the darker bars). To design
the game, the following shortcomings of the children were targeted: inability to share and socially interact, inability to understand expression of emotions and link them to context, preference to learn by examples and logic rather than by trial and error.

To account for these problems, a combined approach of a game that requires negotiations and working towards a common goal, together with recognition of emotional states was made. The game uses a storyline that describes various situations involving different emotions. When the children recognize the emotion described in the story they have to command a robot to either perform or contradict this emotion. The robot is commanded by the collective physical behavior of the children. At least two children have to step on one site of a large disk to make the disk tilt (Figure 14). The disk can be tilted in several directions denoted with colored LED-lighted arrows. Every tilt direction will provoke movement behavior of the robot that expresses particular emotion. The tilted disk will trigger a movement of a robot that expresses corresponding emotion. The LED arrows have the color that resembles the emotion in a similar way as the traffic light metaphor that was used in schools for autistic children to illustrate children’s emotions.
Figure 14. Fragments from game scenarios and flowchart of the game platform. The robot is drawn as a small object near the platform. The right side of the figure shows the information flow from the robot to the life-size disc through a notebook.

To change the robot emotional behavior, the children had to agree on their next position and move together. When conflicting views occur, it was an opportunity for the children to learn to negotiate and get aware that they need the help of others.

The two experiments in this section showed that expressing and interpreting emotions by humans and robots is done on the basis of the same signals. LMA was used for a qualitative evaluation of the human as well as the robot movements and the robot movement behaviors were incorporated in a simple game with e-puck robot. LMA, therefore, incorporate on a functional level the common coding (mirroring) principle. At present scenarios that involve recognition and simulation of emotional movements on the humanoid robot NAO [3] are created.

6 Discussion

Using robots for behavioral training of autistic children through games and interaction scenarios is a topic of growing interest. We have shown how using brain inspired and cognitive models to emulate human-like features on robots can add to this research line. Our hypothesis that training motor skills at early age can contribute to the development of social skills of autistic people was confirmed in several cases. Autistic children could play games that targeted imitation of behavior. In addition, they got involved in taking turns, by exchanging tangible objects. Both behaviors: imitation and turn-taking, are not typical in the everyday activities of the autistic children. The robots and the tangibles especially contributed to accomplishment of these behaviors. The engaging light emitting i-blocks that in addition trigger the curiosity and the logical thinking of the children are a powerful stimulation for accomplishment of the social interaction scenarios. Controlling mobile robots was another pleasurable activity for the children. Children willingly imitated each other’s movement patterns in order to control the robots. A step further is the negotiations that the children had to engage into in order to recognize the emotional pattern in order to change the robot mood (the experiment with the e-puck robot) or the open-ended play that made the children discuss the goal of the game, and thus communicate more often.
We simulated human-like behaviors on robots in two ways. First, we showed that neural models of sensory integration could approximate instrumental behaviors by autistic and typical people. Using the Dynamic neural field model we created a realistic simulation of autistic and typical behavior. Independently whether the delays in sensory integration is the actual mechanism that causes the atypical grasping behavior, the behavioral emulations on a robot showed realistic movement patterns that can be used for behavioral training. The difference in the autistic and typical grasping behavior is detected by the tangible devices, for instance by the i-blocks during the imitation scenarios. Further games that stimulate the usage of the visual cue can be created. The grasping behavior can be precisely emulated by a robot.

Second, for enacting and recognition of emotional body language by humans we used a method that finds correlations of signal parameters and qualitative analysis of emotional signals by certified Laban movement analysts. Based on these correlations we created emotional primitives that can be used for recognition as well as for emulation of emotional behavior by robots. Constructing robot behaviors based on this method showed much better recognition rate by the children than the behaviors that were build solely on the recommendation of the Laban guidelines. The constructed robot behaviors have been used in games with mobile robots. The scenarios that will use a humanoid robot NAO are under development in collaboration with autistic clinics.

References


