Tangible Technologies for the Development of Play Skills in Autistic Children

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***Abstract*— In this paper we describe Game of Stimuli (GoS) an interactive tangible game for children and adolescents diagnosed with Autistic Spectrum Disorder. The system is designed to engage children in play scenarios addressing different stages of development from practice play to rule-based play. The objective of the game is to maintain the attention on a given task while filtering irrelevant stimuli. The study was developed adopting a research-through-design approach, a design method that uses prototypes in the real context of use to generate new knowledge and future visions. The study exploited the modularity of GoS to adapt play activities to the current level of development of autistic children, and to appreciate if the tool could support them in mastering different stages of play of increasing complexity, from practice play (initial level of child development) to rule-based play (a more advanced and skilled playful competence), in solitary and collaborative way. The paper concludes with a reflection on the knowledge gained from testing in the field. Reflection-in-action happened while prototyping solutions and it allowed us to reshape our design. Reflection-on-action occurred after the final prototype was completed. This level of reflection was achieved by reflecting back on the overall experience with therapists and parents, questioning our beliefs, decisions and obtained results.**

Playfulness, Autism, Tangible Interaction, Interactive Game, Stimuli, Requirements.

I. INTRODUCTION

Play is an essential activity to develop cognitive, social and emotional competences in childhood. Through play, children learn to create and explore a world that they are able to handle. Growing up, they will be able to transfer the knowledge gained during play to the real world, and this will help them to understand and make sense of it. In play children learn and practice new behaviours and develop social skills [1]. In fact, cognitive processes involved in play activities are very similar to those involved in learning: motivation, meaning, repetition, self-regulation and abstract thinking [2]. Also the ability to read, to speak, to count depends on the child's ability to manipulate symbols, and this ability is typically developed in play [3]. For example, during play, a piece of wood may become a doll and a stick may become a horse: these are forms of symbolic play were imaginary objects are manipulated and embedded into a meaningful context. These forms of symbolic play contribute to the acquisition of cognitive as well as social skills.

However, children who are prevented from playing, either due to cognitive, developmental or physical impairments, which affect their playing skills, experience a serious limitation in their learning potential. For this reason it is very important to develop tailored tools to encourage play in order to break down barriers for development, fostering individual development up the person's potential.

The paper addresses challenges related to play development in autistic children. Autism is a disorder spectrum characterized by a high variability of social skills and intellectual ability. Changes in symptom severity and adaptive functioning can differ significantly among children with autism spectrum disorder and this reduces the chances of designing of a unique solution that can satisfy very different needs and requirements. A further challenge is the difficulty of eliciting requirements for a so varied population with a paucity of skills necessary to engage in a meaningful way with the design team [4]. The impairments of the children may limit the degree to which they can collaborate or express themselves appropriately, and most of the communications have to be mediated by therapists or educators and therefore depend on their experience and interpretation of the problem. Successful methods for human-centred design in such a complex setting are relatively under-developed.

For this reason we applied in the study a research-through-design approach, defined by [5] as a "systematic enquiry conducted through the medium of practical action, calculated to generate or test new, or newly imported, information, ideas, forms or procedures and to generate communicable knowledge". This kind of research is knowledge-directed. It generates new knowledge through testing and must be pursued through action in the real context of application, in all its complexity.

Thus we extended the concept of user-centered design to encompass not just the designer-user direct relation, but taking in the *ecology of the environment* where we were working, in all its complexity and richness.

II. RELATED WORK

Cognitive and social development in autistic children have been investigated in different studies and a large number of technological tools have been developed to support learning and play. These technologies include computer applications, robotics, mobile applications and interactive toys [6]-[9]. Recently, digital games on tablets and smartphones have been developed to facilitate social interaction amongst children with autism. For instance, Samsung designed the app “Look at me” [10], with the aim to facilitate eye contact, which is a difficult task for autistic subjects. Beside digital applications, an alternative paradigm is emerging that focuses on tangibility and embodiment in autism therapy. Touch can successfully mediate communication, and compensate the lack of eye contact or verbal language. Reference [11] observes that the lack of verbal skills and eye contact creates the need to explore tactile interaction as a means to communicate and minimize the detrimental effect of other modalities of communication. Through tactile interaction and exploration children can discover the world in social and physical terms.

However, any intervention based on tactile interaction with autistic children has to be carefully designed. In fact, when people with Autistic Spectrum Disorders are affected in the tactile system, they may withdraw when touched and may overreact to the texture of objects, clothing or food. This may be the result of tactile misperception, which can lead to behavioural problems, irritability, withdrawal and isolation. Some sources of stimulation cause avoidance, other types of stimulation may have a calming effect. Some individuals demonstrate a preoccupation with certain tactile experiences and seek out such feedback on a frequent basis, e.g., insisting on touching smooth surfaces. Reference [12] recognized that tactile interaction, if tolerated by children with autism, might be a key vehicle of communication and interaction. They experimented with touch-based interaction with autistic children using KASPAR, a robot equipped with tactile sensors to engage the autistic child in bodily interactions. Reference [13] compared the therapeutic efficacy of a programmable toy called Topobo© in comparison with a LEGO© kit.. Playing with Topobo©, children with Autistic Spectrum Disorder increased their collaborative skills and associative play, reducing solitary play. Reference [14] evaluated Reactable, a music-based tangible system, to help autistic children in the acquisition of social interaction abilities. The results of the study show that when playing with Reactable, children improved turn-taking skills.

Our research focuses on play and development in autistic children. In the following, we briefly describe the features of the Autistic Spectrum Disorder and later we illustrate the research-through-design process leading to the development of GoS. The process includes testing intermediate prototypes in the field with six autistic adolescents and their therapists and educators.

III. Autism Spectrum Disorder

Autism Spectrum Disorder (ASD) is a lifelong disorder arising before the age of three, affecting mainly a male population. It is categorised as a pervasive developmental disorder (PDD) [15], although the scientific community agrees on defining autism as a “spectrum” [16]. The term implies a variety of skills and behaviours that might change along a continuum, from child to child and over time [15]. In fact, there is no unequivocal definition of autism related to the symptoms’ analysis: every subject fluctuates on the interval in between high-functioning (or Asperger) and low-functioning, according to the level of social skills and intellectual ability. Children who fall into the low-functioning category do not possess verbal communication and they show cognitive underdevelopment together with difficulties in reading facial expressions. Children who belong to the high-functioning category do not manifest significant delays in verbal communication and cognitive development. This variance leads to the fact that criteria for diagnosis still represent a debated topic. Reference [17] first defines autism as “Triad of Impairment”, stating that children with autism have problems in three different development areas: communication, cognitive and social interaction. Autistic subjects are not capable of filtering out the irrelevant interfering stimuli within the environment and therefore they process a significant amount of unnecessary information. This results in experiencing difficulties in sharing attention, adopting viewpoint of peers, taking turns in social interaction and decoding environmental stimuli.

In relation to play, children with autism spectrum disorder in most cases prefer solitary play, and rarely engage in cooperative games. Of course, the level of play that they can reach is mostly related to the level of impairment and the complexity of the game itself. Low-functioning autistic children mostly prefer practice play and their interest is directed to the physical properties of the toy. High-functioning autistic children are usually able to perform and engage in rule-based games where they can master cause and effect relations.

Objective of this study is to design a game that can sustain play activities along different types, from practice to rule-based play, that appear at different stages of the child’s life. Each stage involves re-elaboration and adjustments of the competencies of the previous one. A major challenge of the study is to envision through GoS how to support different stages of play development in autistic children.

IV. Game Of Stimuli: a research-through-design process

The design process started with an extensive literature review on autism combined to an analysis of autistic children play abilities. We adopted the guidelines on play activities and disabilities as defined in the European project COST Action LUDI [18]. Four different categories of play where defined [19]:

- *practice play* (the toy can be manipulated to discover basic properties of objects and reality and how these are related to the child’s own movements and the environment);
- *constructive play* (the toy can be modified in appearance and interaction capabilities by adding modules to create new games that can exploit different interaction possibilities);

- *symbolic play* (the toy can have a character, showing emotions and moods, and can participate to invented stories);
- *rule-based play* (the toy behaves in pre-defined ways activated by some specific action and stimuli initiated by the child, so that a game can be played with other children and play strategies can be developed by any player);

This play developmental model should not be regarded as a unidirectional, waterfall model. It is rather a spiral showing the progression of the play types, their coexistence and their possible contaminations and reactivation.

Following this model, we aimed at developing a game to determine the current level of development of autistic children, and to stimulate them exploring different stages of play, from practice play to rule-based play, both in solitary and collaborative mode. It must be noted that collaborative play is usually very challenging for autistic children.

In parallel with the literature review, observation in the field and the study of clinical cases and therapeutic practices, different prototypes were developed and used to brainstorm with therapists and a neuropsychiatrist. Our research-through-design approach generated a diversity of concepts that were continuously assessed by therapists and physicians. The design went through three layers of iterative cycles and layers of exploration, each one contributing to test hypotheses and to generate new research questions. The study was performed the Centre for Autism “Piccolo Principe”, and the Neuropsychiatry Department of the ASL7 in Siena, Italy.

A. *First Prototype: a Chaos-generative Musical Interface*

The first step in the design process consisted in prototyping a musical instrument and exploiting the contrast between assonance and dissonance as positive or negative reinforcement feedback during the exercise. The interface (Figure 1) consisted of a 3X3 matrix where nine tokens were located. Three of them were red, three were white and three were black. At the beginning they were grouped in rows according their colour. The purpose of the game was to break the order of the tokens by moving them around the plate. When three tokens of the same colour happened to be in either the same row or same column, a disharmonic sound was generated, which we interpreted as a negative feedback. The more the order was broken, the more pleasant sounds were generated.

This first prototype was submitted to the assessment of design professionals and a clinical expert in a participatory design workshop. From a design viewpoint, the shape and material of the glasses did not afford a compelling tactile experience; from a clinical viewpoint, the system proved to be weak because the negative feedback was not properly articulated to the user. In fact, different sensorial skills might lead to different interpretations of the sound feedback, and this could impair the overall functioning of the game.

Figure 1. Chaos-generative Musical Interface.

B. *Second Prototype: a Haptic Stimuli Generator*

The focus of the second iteration was played with self-generating stimuli, in opposition to the stimuli generated by the computer of the first prototype. We also further investigated tangible interaction modalities afforded by the system, exploring the opportunity of continuous interaction as opposed to the discrete interaction enabled by the plastic glasses of the first prototype.

With the second prototype, we designed a tangible interface that mapped the pressure exerted on a simple keyboard to the visual output on a computer screen. This resulted in the building of three pressure sensors, which detected continuous input from the user. Any variation in the pressure resulted in a change in shape of the icons displayed on the screen display (Figure 2). Each sensor controlled one parameter associated to the icons (e.g. form, size, colour). The more force was applied to a sensor, the more the parameter varied the appearance of the icons creating chaotic patterns. For instance, in Figure 2, the first key (first pressure sensor) controlled the darkness of the pink circle while the second one controlled the dimension of the pink circle, and in the third one, the flickering of the entire image. When the configuration became overloading, the user could stop the animation by releasing the pressure. The user could create his own visual performance by exploring the concept of force associated to the tactile experience.

A second participatory design workshop was organized to assess the new prototype. During the workshop, which again joined design and clinical expertise, it emerged that, despite the exploratory nature of the game, the playful dimension of the activity became lost. Ultimately, the objective of the game was unclear and after few minutes the player tended to lose interest in the activity itself. On the positive side, we realised that the continuous interaction created by mapping the pressure exerted on the keyboard along with its corresponding visual animation, became a promising future option.

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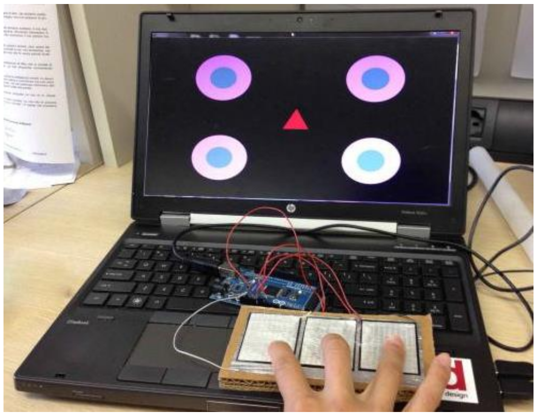

Figure 2. The Haptic Stimuli Generator.

C. Third Prototype: a Game of Stimuli

During the third cycle of prototyping, we built up on the outcomes of the participatory design activity of the first two iterations. On the one hand, the chaotic musical instrument informed us on the potential of the tangible interaction but on the other hand, the continuity of interaction realised in the second prototype turned out to be an opportunity for future design. The final prototype is called Game of Stimuli – GoS. It is an interactive tangible game resulting from an incremental design process where we build up on the evaluation of previous iterations. Early prototypes included a chaotic musical instrument and a haptic stimuli generator. However, none of these prototypes raised the interest of therapists and educators who collaborated to the project. Even if tangibility was considered to be a winning feature of both prototypes, none of them could cover the high variability of play skills in the autism spectrum, from low to high functioning.

For this reason we decided to develop a modular game of increasing complexity in the number of physical modules, the generated stimuli and in play scenarios ranging from practice play to rule-based play (Figure 3). The hardware consists of one core element where most of the electronic components are located. Next to it, the structure expands into a variable amount of modules, which can be attached to the main element. The materials used to build the modules varied along the prototyping process, from cardboard to plywood. The same happened for the buttons: their softness was changed many times to reach the ideal balance between malleability and robustness when pushed.

Each module consists of a block with a push button on top of it. On the one hand, the button can detect the pressure exerted, while on the other one it can emit a light by means of a RGB LED.

One additional block including a piezo speaker completes the set-up. It generates a rewarding sound as a positive reinforcement to correct actions.

The system is currently composed of five modules, but there is no limit to the amount of modules that can be added. Each module contains a pressure sensor with two foils of conductive material separated by a semi-conductor. The values detected by the sensors are continuous and managed by an Arduino. On top of each sensor, a LilyPad Tri-Colour LED is located, which is operated by the same Arduino. Eventually, a silicon-like material covers the LED with a twofold purpose: first, it can amplify the amount of light emitted, and secondly, it makes the tactile interaction more compelling. In this sense, we were interested in testing on field the relevance of viscous material in empowering the continuous tactile interaction, as opposed to rigid buttons.

Figure 3. GoS system.

V. Play Scenarios

The play scenarios were categorised in three main groups: cause and effect, turn-taking and collaborative. Each scenario demanded a different level of engagement and interaction, from practice play, where children could explore the physical properties of the modules and their behaviour (e.g. properties of soft buttons, visual stimuli), to rule-based play, where the game was based on rules shared with the children at the beginning of the play session. The scenarios were designed in an increasing order of complexity.

A. Scenario 1. Tactile Exploration

The child is invited to play with four modules. At the initial stage, all the lights are turned off. The child is invited to press the buttons and see what might happen. The goal is to find where the blue light is located. The tactile interaction is used to stimulate the interest of the child to the game: the force applied to the button is mapped to the intensity of the light emitted. When the correct button is fully pressed, a rewarding sound is played. This scenario is mainly related to practice play.

B. Scenario 2. Stimuli Recognition

The child is invited to press only the fixed blue light, which randomly moves in between the five modules. A successful action will trigger a positive sound. The exercise is designed so to have six increasing levels of difficulty. If in the first level of difficulty there is only one light popping up at a time, the next levels introduce more disturbances. These include additional blinking red and green lights. Children are asked to maintain the focus and attention on the task, despite the irrelevant stimuli which are simultaneously presented. This scenario requires the mastering of practice play as well as rule-based play.

C. *Scenario 3. Cooperative Game*

The subject is invited to adopt a collaborative attitude with the playmate in hopes of accomplishing the game. The exercise is designed to have two levels of difficulty. In the first level, one blue light is presented simultaneously with two green lights. The subject is then asked to press a green button, and the partner is called to mimic with his own green button. When both manage to synchronise their actions, the blue light turns off and a rewarding sound is played. The lights then move randomly in between five modules. In the second level of difficulty, four green lights have to be pushed in order to turn the blue light off. This scenario is far more complex than the other two. It implies the understanding of rules and implies a social competence related to turn-taking and imitation with the playmate.

VI. TESTING IN THE FIELD

GoS was tested with six autistic children with the aim to test their stage of play development, and to engage them in play scenarios at different levels of complexity. Complexity could vary from different respects: number and type of stimuli, number of modules, play scenarios (practice or rule-based), play modality (solitary or collaborative).

As stated above, the study was conducted in the Centre for Autism "Piccolo Principe" in Siena, Italy, which accommodates children and adolescents for after-school activities. Six male children, ranging in age from ten to sixteen joined the study, together with their therapists and a neuro-psychiatrist. They were diagnosed with different levels of autism. Four children showed the typical traits of low-functioning autism, such as communication difficulties, cognitive deficits and motor skill impairments. In fact, they needed the constant presence of at least one therapist, to prevent stressful or dangerous situation. The other two subjects were twins and showed medium-functioning ASD. None of them had motor impairments. One of them had severe difficulties in social, communicative and cognitive areas. The verbalization was not always appropriate to the context, and the comprehension was only limited to simple statements. Attention level was generally low during the play activities and had to be stimulated by the therapist. Stereotyped behaviours were common. The other child had poor verbalization, but the comprehension was sufficiently developed. Furthermore, his logical and abstract thinking was underdeveloped. He showed stereotyped behaviours and socialization skills not adequate to the age.

The activity took place in a period of one month, twice per week, for a total of 8 sessions. However, not all the children managed to participate in all sessions. The four low-functioning ASD children participated in 1-2 sessions (2 children followed 2 sessions, the remaining 2 children followed only 1 session). The 2 medium-functioning ASD subjects, instead, participated in all sessions. In 4 sessions they were invited to play together.

The play sessions took place with one child at a time, because the presence of more people could be perceived as intrusive or represent an obstacle for social interaction. The same designer/experimenter conducted all sessions. If any problem occurred during the session, the therapist, who attended as non-participant observer, was allowed to intervene. Fortunately, this was not the case for any session. At the end of each session, the therapist was asked to take notes and fill in a questionnaire related to the behaviour of the child. The sessions were video-recorded. During the play sessions with children with low-functioning autism, the presence of a second therapist was necessary to support them in performing the games and in some cases contain their excitement (Figure 4).

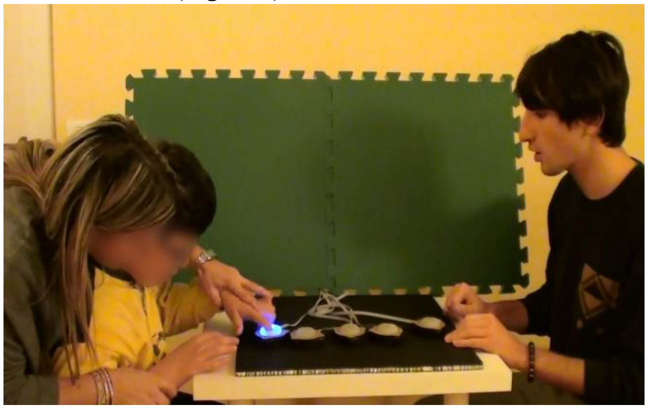

Figure 4. A child with low-functioning autism performs the game with the support of the educational therapist.

The setting was kept simple to avoid distractions. Each play session was structured in three parts:

Welcome. The experimenter welcomed the subject, inviting him to sit. The therapist sat in a corner of the room, in a position that allowed her to observe the scene while not being visible by the child.

Playing together. The experimenter introduced the three different play scenarios described above, which were played in sequence.

Time to say Good Bye and See you next time. At the end of the session, the experimenter turned the system off and said goodbye. The therapist completed the questionnaire.

The sessions were designed to last approximately thirty minutes, but they were subject to changes, according to the attention span of the children and response behaviour.

VII. REFLECTION-IN-ACTION

The reflective practice is fundamental in research-through-design. Testing in context does not necessarily lead to a deep knowledge of the problem without a conscious look at emotions, serendipitous experiences, actions, and responses. For [20], professional knowledge in gained *within action*, at two levels. Reflection-in-action occurs during the activity as a manifestation of "theory in use". It is a mix of knowing and doing that allows the professional to act and intervene on the scene. Reflection-on-action occurs after the activity has taken place and is used to learn from a repertoire of experiences, and to generate new knowledge and visions about future activities.

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In our study, reflection-in-action was conducted during the evaluation sessions, by confronting the observation of the designer, the comments of the neuropsychiatrist, and the notes of the therapists who evaluated the following items:

• *Attention*: the ability of the child to focus on the game, to swap from one stimulus to the next one and to call for attention with sharing the gaze or with gestures;

• *Mood:* child's behaviour in terms of agitation, nervousness, aggressiveness, inappropriate verbalization and sadness;

• *Autonomy*: the ability of the child to execute the activities without any prompt received by the experimenter as well as the level of proactivity during the play session;

• *Relationship with the experimenter:* the ability of the child to establish a relationship with experimenter and the level of appreciation for the given task.

Children with low-functioning autism maintained a level of attention on the game varying from 2 to 8 minutes. This testifies their difficulty with playing even the simplest scenarios. Three of them had to be physically contained by the therapist to limit their excitement. However, they were all able to engage in practice play. They enjoyed exploring the material qualities of the game, by experimenting with the soft buttons and showing interest in the visual stimuli of the changing lights. We noticed how fond they were of manipulating the objects. They were attracted by the soft material of the buttons, trying to stretch, bite and smell it. Less interest was shown towards the visual stimuli and the interactivity of the system. Even if none of them was autonomous in playing, one of them was able to fulfil the rule-based scenario through the use of verbal and physical prompt provided by the experimenter. This was a surprising achievement. The therapist knew that the child could do practice play, but she did not believe he could engage in a rule-based game. This result generated an extensive discussion about how to combine physical prompt in GoS.

Children with medium level of autism maintained a level of attention in between 15 and 22 minutes, which the therapists defined as positive (Figure 5).

Figure 5. A child with medium-functioning autism performs the game with the expert

Furthermore, one child showed a significant improvement in the area of shared attention. He started to establish eye contact with the experimenter as a means to call for attention. Regarding their mood, the therapists reported that the play activities were pleasant for both of them. Only one of them established a collaborative relationship with the experimenter, showing interest in achieving something together. The child with verbal skills showed a significant progression with the cooperative games with the experimenter. The other child improved his performance in the cognitive tasks.

Since they both were able to engage from practice to rule-based play, the complexity of the games was increased along the sessions, and they were asked to play together (Figure 6).

Figure 6. Children with medium-functioning autism playing together

In the cooperative game session the children played together, whilst the experimenter observed the activity intervening from time to time. Especially during this session we noticed that the game became extremely competitive. The peer-to-peer activity stimulated each child to score higher than the playmate and the experimenter supported their engagement with verbal support. As a result, we positively noted that their attention spanned from 10 to 12 minutes of collaborative gaming. Their performance, in terms of errors and time to complete the game, slightly improved over the four sessions.

VIII. REFLECTION-ON-ACTION

Testing GoS in the field, trying out different patterns of stimuli and play scenarios was a process of continuous learning.

The system helped us to test the play skills of the children and challenge their potential to master the evolution from one stage of play to the following. Children diagnosed with low-functioning autism can generally engage in practice play, where free exploration and manipulation of the platform are at the core. If no external help is given, they rarely can progress toward the next types of play. Both physical prompt (e.g. showing the action to be performed through physical guidance) and verbal prompt (e.g. vocal guidance) are vital during the play session and should be integrated in the interaction design of the game.

A customizable system like GoS allows for adaptability to different types of autism profiles. Quality and quantity of stimuli can be tailored to the child's play skills.

Modularity allows for tweaking the difficulty of a game. It is important that this feature is represented at hardware level (i.e., the number of modules to be used is custom) as well as software level (i.e., the various amount of stimuli that can be programmed).

The material qualities of the game are fundamental in fostering exploration and interaction. In particular, qualities like being malleable, stretchable, soft and scented. The material properties of the buttons in GoS, their softness and flexibility afforded various types of manipulation additional to pressing. The buttons were caressed, squeezed, pinched. This explorative behaviour was solitary. It stopped when the game became collaborative. Children were able to move their attention from the material qualities, which at the beginning held almost all of their attention, to the interactive features of the system.

The simplicity of the proposed games associated with the modularity of the system is definitively a winning aspect. The design of GoS enabled the generation of a wide range of interactions and a significant amount of play scenarios. A modular hardware and an easy-to-hack software allowed for tailoring the system to the different children's skills.

Furthermore, the therapist expressed the need for more independency, as until this moment it was necessary for the experimenter to manually load new lines of code every time the activity would pass on to the next one. For the future iteration we envisioned a tablet application that would allow the therapists to control the system without assistance (Figure 7). The application allows the configuration of the game by selecting the type of stimuli (e.g. colour and light patterns), play rules (e.g. turn taking) and play styles (e.g. individual vs collaborative game). Furthermore it records the progress of each subject, monitoring the development of individual play skills.

Figure 7. The screen-based interface that would allow the therapist to load and configure new play scenarios, as well as to keep track on the progress of each subject.

Testing in the field also revealed that the role of an adult supervisor is pivotal in creating a friendly, encouraging and inclusive atmosphere, and the use of a shared physical interactive toy can greatly facilitate the social exchange among them.

A major contribution of the study is the design of play scenarios that are mapped to different stages of child development as well as to different properties and functionality of the system. Since improvements of play skills in autistic child are slow and demand constant monitoring, a game like GoS can support the therapists in evaluating any improvement in play skills. Furthermore, it allows the children to practice their skills and challenge them through small, recognisable, repetitive variations of increasing complexity of the games.

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