Magic Room: A Smart Space for Children with Neurodevelopmental Disorder

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The Magic Room is a smart space for use by children with neurodevelopmental disorder (NDD) and their caregivers designed in cooperation with NDD specialists and currently deployed at two therapeutic centers in Italy. It supports multimodal embodied interaction by providing controllable stimuli to the vestibular, proprioceptive, and tactile sensory systems through ambient sound and visual projections, soap bubbles, aromas, lights, toys and other physical objects. Results of an exploratory study involving 8 caregivers and 19 children with severe NDD impairments who used the Magic Room for four months are encouraging and might pave the way for new research and inspire novel interventions in this area.

Cyber-physical systems (CPSs) are “smart” systems made up of interacting networks of physical and computational components. As the power and popularity of these technologies increase, researchers face the challenge of making them accessible to and useful for people with disabilities. We address this issue in the domain of neurodevelopmental disorder (NDD). NDD is an umbrella term comprising a group of disorders—including intellectual disability, attention deficit hyperactivity disorder, and autism spectrum disorder (ASD)—that arise during childhood development and are associated with cognitive, social, and motor deficits, leading to severe impairments in adaptive behavior and basic life skills.

We leverage CPS technology to transform a regular therapy room into a multisensory, multimodal interactive environment called the Magic Room. The Magic Room aims to provide a pleasurable experiential space for children with NDD to learn through play, helping them to exercise the perceptual system and practice social, emotional, cognitive, and motor skills. Our
smart space supports multimodal embodied interaction (based on touch, manipulation, gestures, movements, and voice) with ambient projections, physical objects, and lights, and offers stimuli to the vestibular, proprioceptive, and tactile sensory systems. Stimuli and interactions can be digitally controlled on the fly by caregivers and customized to the needs of a single child or a group of children.

We have deployed the Magic Room at two therapeutic centers, in Milan and Rome. An exploratory study of 8 caregivers and 19 children with severe impairments in the NDD spectrum who used the smart space across 4 months has yielded encouraging results and will inform the design of future installations.

A video presenting the Magic Room project is available at i3lab.me/magicroom.

RELATED WORK

For the past seven years, we have been collaborating with special schools, care centers, and therapeutic institutions in Italy and abroad to design, develop, and evaluate interactive technologies for children with NDD. From a methodological and technological perspective, the Magic Room integrates and extends our previous experiences. It is also inspired by other researchers’ projects as well as existing multisensory practices for subjects with NDD.

The Magic Room’s rationale is grounded on the theories of embodied cognition and sensory integration. The former emphasizes the formative role of embodiment—the way an organism’s sensorimotor capacities enable it to successfully interact with the physical environment—in the development of cognitive skills. Embodied experiences promote cognitive processes linked to mastering sensorimotor contingencies and stimulate higher-level cognitive skills such as mental imagery, working and implicit memory, reasoning, and problem solving. Sensory integration theory posits that learning is dependent upon the ability to input, integrate, and process multiple types of sensory information in order to plan and organize behavior. When this process has deficits, as is thought to occur in subjects with NDD, an abnormal mental representation of the external world is created, which in turn affects appropriate behaviors in all aspects of life. Specific interventions for persons with NDD aim at stimulating basic perceptual mechanisms and promoting perceptual learning. They often take place in a dedicated multisensory environment, sometimes referred to as a Snoezelen room, that is equipped with physical items and devices that provide gentle multisensory stimulations through sounds, lights, projections, and tactile materials such as soft fabrics.

Prior human–computer interaction research indicates that combining the physical and digital worlds and offering multisensory stimuli through embodied interaction provides support for persons with NDD. Some works explored how tangible interaction with smart objects, smart toys, or soft robots can empower children with sensory processing disorders, particularly autism, to engage in self-reflection, self-directed activity, and language use. Several approaches have exploited large displays and movement-based interaction. In a controlled study, the use of Kinect games in ASD therapy led to improvements in selective and sustained attention, visual perception, and visual-motor integration. SensoryPaint allows persons with NDD to paint on a large display using physical objects, movements, and midair gestures, and to receive visual-aural stimuli. A field study showed that use of the system enables children to balance attention between their own body and sensory stimuli, and promotes socialization. MEDIATE generates sound and visual stimuli in response to gestures and footsteps on the floor in front of a large display, and can stimulate creativity, a sense of agency, and self-expression among low-functioning nonverbal children with autism.
THE MAGIC ROOM

As the left side of Figure 1 shows, the Magic Room is equipped with two projectors, one video camera, one ambient sound system, one Kinect, various smart objects (3D soft geometric shapes and stuffed toys), smart appliances (a bubble maker and an aroma emitter), mobile graspable smart lights, ambient lights, and a Philips Luminous Carpet (made of carpet tiles embedding LED grids to enable the display of words and graphic patterns). The boards inside smart objects integrate pressure sensors, multi-axis accelerometers, a gyroscope, a magnetometer, and various actuators for light, sound, and vibration. The Kinect detects midair gestures, body position, movements, and voice. A joystick enables caregivers to suspend/restart the current stimuli or activate new ones.

A multilayered software and hardware platform controls sensors, actuators, and output devices; manages their communication; and orchestrates their behaviors. It integrates an interactive tool called MAT to define the smart space behavior by associating stimuli to interactions or time events, and aggregating them. MAT’s intuitive visual interface, shown on the right side of Figure 1, is easy to use by caregivers and others without technical expertise.

The Magic Room combines and extends the features of existing multisensory digital systems in a unique way. In the SensoryPaint and MEDIATE environments, stimuli and embodied interaction occur in front or in the immediate surroundings of the large display. In the Magic Room, these are pervasive. Children can use the whole space to regulate the reactive behavior of interactive items and learn spatial awareness—that is, the ability to be aware of oneself in space, create a contextualized body schema representation, and understand the spatial relationship between physical objects and oneself in the physical environment. Ambient sound and visual projections on the walls and floor create a sense of immersion that is thought to be a powerful educational tool for subjects with NDD.

The Magic Room also offers Snoezelen-inspired stimuli such as lights, soap bubbles, and aromas. Differently from Snoezelen rooms, these effects are generated by smart devices connected to all room components, which makes it possible to control stimulations and orchestrate them in countless ways. Smart lighting enables a vast gamut of luminous effects with different colors, intensity, and dynamics. Lights provide pleasurable stimuli for relaxation or reward purposes like in Snoezelen environments, but are not merely embedded in physical objects like in other multisensory (smart) spaces. Ambient lights increase the immersive effect of the projections
and the sense of magic. Mobile lights circumscribe the space, orient children’s movements, and can be manipulated to offer focused luminous effects without introducing any other sensory stimuli.

Finally, the Magic Room considers that any technology for those with a disability needs customization to address the unique characteristics of each person or group. Whereas in existing smart multisensory systems all features are “hard-coded” and any user experience modification requires operations at the programming level, the MAT tool integrated into the Magic Room is very easy to use by caregivers to create new activity or customize existing ones.

DESIGNING THE CHILDREN’S EXPERIENCE

We designed the children’s experience in the Magic Room during three weekend-long workshops at the care center in Milan where the first Magic Room was deployed. We involved all 10 therapists and special educators at the center and 4 groups of children with NDD who played in the smart space after workshop 1.

Workshop 1

After the caregivers had experienced the Magic Room’s stimulatory and interaction capability, we discussed how therapeutic programs, learning goals, and practices at the center could inform design of the children’s experience. We focused on free-play scenarios, initially using sketches and sticky notes and then MAT to progressively prototype the coordinated behaviors of smart devices.

Supporting relaxation at the beginning of any experience in the Magic Room emerged as the first requirement. Subjects with NDD tend to manifest anxiety in any change in routine. Helping children to reach a state of relaxation is fundamental to engage them in any experience. The caregivers proposed projecting videos employed for relaxation purposes in regular activities, and integrating these projections with soft ambient lights of coordinated color.

We then defined scenarios for spontaneous interaction with smart toys such as a stuffed dolphin. When a sea world is projected and a child grasps the dolphin (and, in the case of verbal subjects, also says “blue”), the mobile lights turn on in blue; when the child releases the object, they turn off. These simple interactions help children familiarize themselves with the smart environment and develop a sense of agency.

Observing Children in the Magic Room

After workshop 1, we carried out the free-play scenarios with the children attending the center. The exploratory nature of this experimentation required the inclusion of heterogeneous subjects to understand how people with different capabilities might respond to an experience in the Magic Room. Therefore, we involved all children attending the center every afternoon in group activities that stimulate motor, social, and cognitive skills; lead to pleasure and well-being; and improve autonomous behavior. Each group was guided by two therapists and composed of four to six children with similar educational needs and functional competences, regardless of diagnosis.

Table 1 summarizes the children’s profiles. “Severity” is a global measure of a child’s impairments and is based on assessments performed twice a year that consider quantitative data from clinical tests (including IQ) and subjective qualitative observations by therapists and parents. “Severe” is normally associated with IQ = [30:35], “moderate” with IQ = [35:50], and “mild” with IQ = [50:70].
Each group used the Magic Room together with their two therapists for two or three sessions lasting on average 35 minutes. All sessions started with the projection of a relaxing environment integrated with soft lights, as Figure 2a shows. Therapists introduced smart objects progressively, asking children to play with any item. All sessions were video-recorded. An intern therapist and a member of our team served as observers.

<table>
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<tr>
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Table 1. Profiles of the children participating in our research.

Figure 2. Experiences in the Magic Room: (a) inducing a state of relaxation with sea-world projections, (b) Catch the ..., (c) Magic Ball, (d) Pass the Light, (e) Shapes, (f) Storytelling.
Workshop 2

In workshop 2, we examined the videos and applied deductive analysis to the observers’ notes based on the themes that emerged in workshop 1. There were several indications that all of the children found the experience positive. No child was afraid to enter the Magic Room or experienced prolonged distress. The time to reach a state of relaxation was different for each child but, according to caregivers, shorter than normal when a change of routine occurs in the classroom. Subjects with mild or moderate impairment manifested curiosity for the smart objects and manipulated them from the first session. Children with severe disability sat quietly near the caregiver and did not interact with the smart space, yet their eyes gaze was often directed toward active peers and the objects they were playing with. This is a positive result especially for children with autism. Two subjects who always moved frantically in the regular classroom progressively learned to control their excitement, wait for their turn, and sit still when requested by caregivers in the Magic Room. Lights on the carpet, mobile lights, and bubbles attracted the immediate attention of all subjects, suggesting that these stimuli might be particularly engaging for children with NDD.

Before the sessions, caregivers worried that “children would get trapped in the projection like they do with TV.” Afterward, they happily observed that “indeed this did not happen—children perceived the projection as part of a bigger environment that enhances not only their creativity but also the process of switching from imaginary worlds to the real one, and vice versa.”

Caregivers regarded the free-play opportunities and the ability to smoothly repeat stimuli and interactions as useful to reassure the children and help them to consolidate cause–effect understanding. Still, caregivers also raised the risk of boredom as well as the need for more challenging tasks and activities focused on specific skills. Based on this feedback, we started designing new combinations of stimuli and interactions, which were expanded in workshop 3.

Workshop 3

This workshop was devoted to designing structured activities, exemplified in Figures 2b–f, that provide flows of stimuli-interaction-stimuli situations (tasks) and require children to perform specific actions properly in order to proceed. We discussed with the caregivers the main therapeutic goals addressed by regular interventions and incorporated the ones that could be impacted by our smart environment.

Catch the …

This activity focuses on gross motor skills and was invented by caregivers without any reference to regular activities. A video is projected on the front wall (for example, showing a galaxy with stars and planets) and luminous patterns alluding to the video (for example, blinking white LEDs for the stars) randomly appear on the carpet. The children must jump on the patterns to make them disappear.

Magic Ball

Caregivers proposed drawing eyes and a smile on the white fabric of the soft smart ball, projecting an image that indicates a spatial relationship (for example, a cat on the table), and asking the child to press the corresponding area on the ball (for example, “up”). In the case of correct interaction, this area is highlighted, nice ambient music is played, soap bubbles are emitted, and a happy face is projected. This activity promotes visual-motor coordination (particularly hand-eye coordination) and understanding of spatial relationships.
Pass the Light

This activity aims to enhance social skills and is inspired by the classic Circle Game. The children pass a mobile light to one another after naming the light color, something with the same color, and the name of the child receiving the lamp. The lamp changes its color when shaken and changes color randomly. When it turns red, a cheerful ambient music is played, bubbles appear, and the game restarts.

Shapes

This activity has cognitive learning goals and is designed to help children understand simple concepts like shapes, sizes, and colors. It is inspired by games performed in the regular classroom using colored blocks and colored chalk to draw on the floor. A color (or shape) is projected on the wall and luminous shapes appear on the carpet. Children are required to move on the carpet area matching the on-screen image, or to place their smart object on the corresponding projected color or shape.

Storytelling

In the regular classroom, stories are used to convey information to children, exercise their selective and sustained attention, motivate them in a task, and stimulate their imitation skills by having them mimic characters. In the Magic Room, a multimedia animated story is projected on the wall, pausing after each scene. To proceed to the next scene, children in turn must imitate the character(s) using gestures or movements, or grasp colored smart objects that make sense for the current scene. Appropriate actions by the children might also trigger aromas and bubbles to enhance fun.

EXPLORATORY STUDY

To uncover the Magic Room’s potential to promote skills in specific areas, we conducted an exploratory study involving all 19 of the children who participated in the design process. Each of the four groups used the Magic Room with their two caregivers weekly for at least six sessions across three months. For each session, we defined an activity plan that was customized for each group. An intern therapist observed the participants and took notes. All of the sessions were video-recorded.

The eight group caregivers and observer met at the end of each session and completed the observation form shown on the left side of Figure 3 for each child. The form is based on the main themes used in regular interventions and the therapeutic goals addressed by the structured activities in the Magic Room. Goals are organized in five macro-areas—cognitive, communication, relational, emotional, and motor—and each goal is associated with an observable behavior and a numeric score indicating the level of complexity of that behavior (1 is the lowest; the highest varies by area). The specialists marked a line on the form if the subject manifested the corresponding behavior(s) during the session. For two months after the study, the caregivers kept a diary and annotated children’s behaviors that, during regular activities, could refer to the experience in the smart space.

The original activity plan was continuously adapted during the study to meet the children’s evolving needs. Some activities were repeated within and across sessions, particularly those the children explicitly requested. All members of group 1 (G1) and group 2 (G2) attended all sessions. For health and other reasons, several children from the other two groups participated in two or three sessions only. The session duration progressively increased, lasting on average 39 minutes (minimum 20 minutes–maximum 52 minutes).
We performed data analysis with all nine specialists at the center using a mixed-method approach. To analyze qualitative data (videos and textual notes in the form and diary), we used Grounded Theory techniques grouping quotes or events to uncover emerging themes related to children’s behaviors. For each session, we aggregated quantitative data from the forms by child, summing the scores for all behaviors that were marked by caregivers for that child, and by group of children.

For space reasons, here we discuss only the main results. The right side of Figure 3 plots by session and area the average score of all children in the same group for G1 and G2, who attended all sessions. Diagrams also show standard deviation (SD) per child and trends across sessions (cross-bar lines). As in most NDD studies, SD pinpoints a strong variability among subjects. Still, the comparison between the first and last sessions and the trends indicate improvements by both groups in all areas.

Cognitive Area

Caregivers observed the strongest improvements in the cognitive area. The scores in the last session are almost double the initial ones for G2 and triple those for G1. The caregivers detected several positive results in this area during Storytelling activities. The therapists noted that “children started to pay attention to the story more quickly than usual and sustained attention for a longer time … they were living those moments inside the story in first person.” The persistence
of some positive results related to memory surprised the therapists. During the study and in the following weeks, all of the children either mentioned or pointed to the Magic Room as they passed by it. Several children, including those with severe memory deficits and difficulties externalizing needs, asked to go to the smart space again and play their favorite games. Caregivers noticed signs of generalizing concepts related to stories. One child (C2) associated the Magic Room experience with events in the classroom, saying “like in Piera the Frog story?”

Communication and Relational Areas

Comparing the first and last sessions, G1 improved 28 percent in the relational area and 64 percent in communication. The latter was mainly associated with verbal skills and intentional communication. One girl (C5) did not communicate spontaneously with peers and caregivers. The second time she played with the smart dolphin, she started speaking with the fish in the projection and eventually also with therapists and classmates (“Look, Mario, at that big fish … moving away!”). In the last session, a child who has problems formulating words (C3) could spell colors correctly (saying “rosso,” Italian for “red,” instead of “rozz”). Storytelling activities seemed to be particularly effective at triggering socialization. A usually shy and passive girl (C13) started engaging in previously unmanifested proactive behaviors toward her classmates, inviting them to play together (“Let’s use the magic stick together like Piera the frog!”). Another child (C12), who seldom externalizes curiosity, asked a caregiver “What’s happening next?” during a story pause.

Emotional Area

A comparison of scores in the first and the last sessions showed an increase of 25 percent for G1 and 80 percent for G2. One child (C8) who rarely externalizes emotions smiled and applauded himself after completing the Shape activity in the last session. The lighting effects seemed to be particularly effective at inducing the feeling that the Magic Room was truly magical. Speaking to his parents, one child (C5) said, “Today I went to a place where, if I were to say ‘blue,’ everything would become blue like the sea [because the ambient blue light turned on] … and there is a dolphin you can touch and then it shows a rainbow of light on its back! We were doing enchantments!”

Motor Area

Observed improvements between the first and last sessions were weaker in the motor area than in the other areas for G1 (20 percent) and G2 (33 percent). Still, according to the caregivers, most children engaged in more movement in the Magic Room than during regular activities. Caregivers observed that “some children … engaged in motor activities that are complex for them without even noticing they were pushing harder, overcoming their own limits, and doing movements we’ve never ever seen them doing.” For example, a child with biparesis (C3) completed a task that required her to stand upright and then move and walk, and she did so without asking for help.

Problematic Behaviors

We also observed some negative behaviors that needed to be regulated by caregivers. For example, one child (C8) became overexcited when bubbles were emitted as a reward after he completed a task during the first session; he pushed away the other children to pop as many bubbles as possible and ran frantically about the room until the caregivers grasped him and helped him to reassess and stabilize himself. While waiting for his turn during a Storytelling activity, another child (C7) started kicking the Magic Ball and became aggressive toward peers. Therapists noted
that “the pleasure resulting from the experience may have created excitement and an intensive
willingness to play; this can be frustrating and make self-regulation and control more difficult. In
addition, while waiting for their turn children feel in ‘competition’ with peers for the appropri-
tation of the play stage and of the therapist’s attention.”

CONCLUSION

To our knowledge, the Magic Room uniquely supports a range of stimuli, interaction modes, and
play experiences that are not available together in existing smart spaces for children with NDD.
It could be integrated in regular therapeutic practices at a relatively affordable installation cost of
less than one-quarter that of a commercial Snoezelen room, which is about €30.000. A Magic
Room can serve as a living lab to explore how children with NDD behave when exposed to dif-
f erent controlled stimuli and interaction modes, and to experiment with various innovative inter-
vention scenarios.

Our exploratory study exemplifies how children with NDD and their caregivers might use the
Magic Room to develop various skills. The empirical results of the study are encouraging. In the
caregivers’ subjective judgment, the observed learning improvements were achieved much faster
in the Magic Room than in the classroom with traditional interventions. Still, our findings are
very preliminary and should be taken with great caution. Our study has many limitations, mainly
due to the lack of control of several variables as well as variability among the subjects. Without a
control group, we cannot claim that the children’s improvements can be ascribed to the Magic
Room as opposed to general growth in each individual’s development or to experiences outside
the smart space.

Since the end of the study, we have interviewed the caregivers at the center in Milan approxi-
mately every two months about their experiences with the Magic Room; interesting insights and
new uses of the smart space are continuously emerging. The next step in our research agenda is
to conduct a more rigorous, year-long empirical study at the second Magic Room in Rome. It
will involve 60 subjects (split into a control group and an experimental group) and complement
descriptive results with clinical tests performed before, during, and after the study to compare the
Magic Room’s effects to those of regular interventions.

REFERENCES


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