“Can you help me move this over there?”: training children with ASD to joint action through tangible interaction and virtual agent

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ABSTRACT

New technologies for autism focus on the training of either social skills or motor skills, but not both. Such a dichotomy omits a wide range of joint action tasks that require the coordination of two persons (e.g. moving a heavy furniture). The training of these physical tasks performed in dyad has great potential to foster inclusiveness while having an impact on both social and motor skills. In this paper, we present the design of a tangible and virtual interactive system for the training of children with Autism Spectrum Disorder (ASD) in performing joint actions. The proposed system is composed of a virtual character projected onto a surface on which a tangible object is magnetized: both the user and the virtual character hold the object, thus simulating a joint action. We report and discuss preliminary results of a field training study, which shows the potential of the interactive system.

CCS CONCEPTS

• **Human-centered computing** → Human computer interaction (HCI); Interaction paradigms; Mixed / augmented reality; Interaction design; Interaction design process and methods; User interface design.

KEYWORDS

Joint action, autism, tangible interaction, virtual agent

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1 INTRODUCTION

Many situations in interacting with physical objects require the collaboration with someone else: an object too heavy to be carried alone, an object too big to be held with both hands, an object too slippery to be held with both arms... As such situations require other individuals, the question arises as to what children with Autism Spectrum Disorder (ASD) are capable of, as such children have difficulties in social interaction. When co-acting individuals coordinate themselves to perform a joint action, social and motor capacities are at stake in such a way that they are inseparable. In this form of *embodied cooperation* [1], the movement of the other offers new possibilities for our own actions, as well as a tool offers more possibilities than our bare hands [2]. The idea that body effectors self-organize according to the dynamics of movement is all the more interesting: helping the other physically does not require talking to each other, and therefore a social situation of motor collaboration may be more accessible to non-verbal people

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with ASD. As synchronous imitation has been shown to be the earliest and the simplest way to share a common motor goal [3], joint action might be the next step to develop collaboration skills for children with ASD.

As interactive systems are perceived by children with ASD as stimulating and trustworthy environments [4, 5], many researchers have designed technology-based interventions. On the specific aspect of social interaction, computer simulations offer the possibility to propose a reduced and controlled social complexity. This complexity can be gradually increased throughout training to enable a smooth transition to real world tasks. Among this literature, social skills are trained either on distal communication tasks via robots or virtual agent [6] or on fine collaborative tasks via tangibles or tabletops [7], however, with no project on the embedded training of social skills into pragmatic motor actions. The MIMETIC project that we introduce in this article aims at developing joint actions among children with ASD, including non-verbal children with a severe autism condition. The underlying approach for such children is that the simplest and most direct way to improve social engagement is through motor activity. One of the goals is to encourage children to participate in family life at home. To train motor collaboration in children with ASD, we have designed a playful though experimentally controlled procedure. The procedure is nested in a virtual platform composed of mixed objects, half-virtual and half-tangible, which the child with autism must move with the help of a virtual agent. One of the agents collaborates with the child while the other agent behaves autonomously. In this article, we present in detail the iterative design approach we have followed as well as preliminary feedback from a field training study involving young children with ASD.

2 RELATED WORKS

2.1 Social play through tangible interaction

Tangible interaction provides physical interfaces particularly adapted to social and collaborative contexts, enabling both bodily engagement and shared controls [8]. For children, tangible interfaces are playful and facilitate collective interactions by providing multiple entry points into the interactive situation [9]. TUIs have been designed for children with ASD to develop individual skills such as fine motor skills [10] or pretend play [11], with the recurrent remark that physical toys can act as social facilitators. In the domain of social therapies for children with ASD, a collaborative training based on LEGOs has been designed and observed to improve communication, collaboration and role-taking mechanisms [12]. This type of activity is well accepted by children as it is grounded in everyday gaming practice. A key element of this therapy is that it simplifies social interaction by explicitly defining the role of each child (an *"engineer"*, a *"builder"* and a *"resources provider"*). Following this building therapy principle, Farr and colleagues studied the benefits of using augmented tangibles (i.e., Topobo©) where feedback mechanisms (visual, kinesthetic and audio) make objects more engaging and support the understanding of cause and effect. The programmed dynamics of objects was shown to foster peers' attention and to offer opportunities for cooperative play. In [13], a physical castle game with medieval figures was augmented with audio feedback. In a pilot study, the system configurability was shown to decrease solitary play. Lastly, a social ability training for children with ASD has been developed based on Reactable [14], an interactive table for live music performance. The study showed improvements in turn-taking skills [15]. Overall, tangible interaction for children with ASD has been used as a ludic way to trigger social initiations and collaborative play.

2.2 Structuring collective activities using computer mediated interaction

Interactive tabletop applications for children with ASD have been developed as they combine the flexibility of a digital interface with the collective dimension of a tabletop [16]. The SIDES project used the DiamondTouch table [17] to develop a four-player turn-based cooperative game where children with ASD had to build together a nenuphar path for a fog [16]. As each player decides when to end his/her turn via a button, the activity implied negotiation and turn-taking skills. One interesting result of the evaluation is that children found the activity easier and more relaxing in the computer-enforced rules condition. In the StoryTable project [18], dyads of children with ASD were involved in a collaborative story narration. Some action could be done by only one child, while others had to be done jointly (e.g., touching together a button to select a background). This enforced-collaboration paradigm was shown to foster more social initiations and shared play after the intervention. This training paradigm based on enforced cooperative gestures has also been successfully used in the development of two other tabletop applications. First a collaborative puzzle [19] designed to be solved by a children dyad through a series of cooperative gestures: touching together, displacing together and releasing together. The evaluation showed that the enforced collaboration condition induced more co-ordination moves for children with ASD. And second a series of three mini-games [20] aimed at training three social abilities: joint action (via a game of moving together a basket to catch apples), resources sharing (via a game of bridge building by sharing complementary pieces) and mutual planning (via a game of collecting stars, one child detaching the stars while the other catch them with a basket). Of particular interest is their consideration of the teacher as a secondary user which can modulate the interaction through a specific interface. Using the collaborative Ipad game Zody, Boyd and colleagues proposed a similar taxonomy of collaborative gestures, relating them to specific social skills [21]. While asymmetric sequential gestures encouraged turn-taking, parallel and symmetric gestures trained coordination, and parallel and asymmetric gestures fostered joint attention and communication.

Some projects have proposed to reduce the complexity of social interaction for children with ASD by using a collaborative virtual environment. Within this distal interaction paradigm, non-verbal communication cannot distract the child from the collaborative task. DOSE (Dyad-Operated Social Encouragement) is a collaborative pong game for children with TSA [22]. The game has four modes: playing alone for practicing, dyad playing against an artificial intelligence with a virtually shared controller, a "rally" mode where each child controls a bar with a common goal to get a maximum score, and a competition mode. The difficulty level can be adjusted by the practitioner through the ball size, speed and the bar size. Preliminary results suggest that the system was engaging, increased communication and activity coordination. In the CoMove application [23], children dyads had to realize a tangram. Three modes were implemented in the collaborative puzzle game: turn-taking, information sharing (i.e., only one child has access to the color information) and joint action (i.e., moving pieces together). A preliminary evaluation showed significant increases in success frequency and collaborative movements for children with ASD. Overall, these computer mediated interaction projects highlight the importance to structure collective activities to encourage children with ASD to undertake collaborative gestures. One limit of this literature is the difficulty to control for the complexity of non-verbal exchanges.

2.3 Embodied agents to target specific non-verbal skills

By embodied agents we mean autonomous agents with a body, anthropomorphic or not, enabling corporeal engagement and non-verbal exchanges. The controlled expressivity and interactivity of embodied agents, whether being virtual agents or robots, enable researchers to develop adapted applications to the training of specific social skills. Due to their physical presence, robots are strong attractors and can take advantage of this attention to engage the child in interactive activities. Imitation skills, with its social and motor dimension, have been trained via social robots [24]. Robota and Nao are two popular robots used in these imitation therapies, where simple arm movements and postures have to be followed or initiated [25], [26], inducing more spontaneous imitation among children with ASD [27]. Similar results were found with Tito, puppet-like robot [28]. More complex interactive models combining imitation and joint attention mechanisms have been developed [29]. Results showed an improvement in multi-communication skills of the participating children.

Virtual agents were mostly developed to train affective communication [30], [31] and joint attention [32], [33], embedded within serious games. JeMime is a game to train emotion production skills [31]. The idea of the project is to guide the production of relevant facial expressions (thanks to gauges) depending on the social situation. A preliminary study with children with ASD showed a significant progression in the production of emotional facial expressions. The project ASC-Inclusion proposes a game which includes both emotion recognition and expressions tasks for the face, the body and the voice [34]. While progress in emotion expression has not been assessed, improvements in emotion recognition and socialisation have been reported. In the ECHOES project, the agent could act on the virtual environment, point at objects and orient his gaze to initiate joint attention [35]. The embodied agent is designed as an autonomous virtual character with the FATIMA agent architecture which controls internal goals, action strategies and affects regulation. This agent autonomy was meant to avoid task-based repetitive training. A training evaluation showed an increase in children's social initiations. To date, embodied agents have been developed to train distal social skills with some successes, but no project has been developed for the training of joint action in its social and motor dimensions.

3 DESIGN RESEARCH

3.1 Project background

3.1.1 Imitation therapies as a starting point. The present research has been conducted by an interdisciplinary team involving researchers in HCI and psychology, and researchers and practitioners in developmental psychopathology working in a care facility center. The developmental psychopathology team has a long research experience in developing imitation skills of children with ASD [36]. The literature on collaborative motor actions distinguishes two types of collaborative motor actions: 1) actions involving a different and complementary role of the two partners [2], and 2) actions involving the same role for both partners [1]. In the latter case, a motor dialogue is necessary because actions can only be carried out through an exact simultaneous movement by the two partners: movements are constrained not only by actions to be carried out but also by movements of the other. This may seem like a drawback. Yet the similarity of anatomy that responds in a similar way to the natural laws of the environment facilitates imitation and generates synchrony, based on perception-action coupling. As a result, simultaneous and similar motor actions may be the simplest to achieve [1], and imitation therapies are developed as a first inclusive step for children with ASD into the social realm. The team also experiments the therapeutic use of the Kinect-based game PictogramRoom [37, 38]. This practice provides the team with strong knowledge about how to design and run body-based interactive therapies for children with ASD.

3.1.2 From motor to social skills, a progressive joint action training. In synchronous imitation therapies, each partner negotiates the tempo with the other in order to realize a similar co-action, alternating roles of initiator and imitator [36]. In this case, the partners develop their own gestures without interfering physically with the other's gestures. To be aligned with the specificity of autistic sociality [39], imitation therapy tasks are realized limiting face-to-face interaction through the use of twin objects (i.e., the practitioner and the child hold a similar object). These twin objects mediate the interaction, the action to be imitated being an action with the object. Another entry point into the social realm in line with this autistic specificity is the collaborative realization of physical actions (i.e. joint actions). Grounding the training of social skills into concrete physical actions can provide a more direct way to reach collaboration with others. The goal of the project is therefore to train motor skills on physical actions which could progressively (in three phases) become joint actions requiring the motor collaboration with a partner:

- Phase 1: training motor autonomy to enable participants to realize alone the necessary task movements.
- Phase 2: training joint actions with a cooperative virtual agent which synchronizes with the child.
- Phase 3: training joint actions with an autonomous virtual agent which requires the child to adapt.

3.2 Design approach

3.2.1 Iterative user-centered design. The HCI mantra *"know your user"* implies various User-Centered Design methods (UCD) where designers consult users about their needs and aspirations, empathize with them and establish requirements. Participatory Design (PD) is a particular form of UCD in which users have a deeper impact on the design by being involved as partners [40]: users not only inform the design process but are engaged in design choices. The involvement of children with special educational needs and disabilities can be more complex due to their inherent position as children: when direct participation is difficult (as it is the case with non-verbal young children with ASD), the involvement of caretakers and practitioners become essential [41]. Framed as a design project of therapeutic training, the present project has been built together with a team of researchers and practitioners in developmental psychopathology in direct contact with children with ASD. These researchers – practitioners are involved in all stages of the project as partners, following an iterative approach with active integration of feedback from the field. Although the therapeutic framing of the project privileged the practitioner perspective, children were not out of the loop. As a matter of fact, not any child with ASD of our population participated in the elaboration of the design because they are all nonverbal or only able to respond to simple requests. However, this does not mean that they did not participate actively to the elaboration of the design, though in an indirect way. Indeed, their reactions to preliminary versions of the design, the careful observations of their play, their interests, their fears, their refusals of certain type of tasks, all this was considered to build a virtual environment as pleasant, attractive and secure as possible. Additionally, parents and representatives of parents' associations were consulted and expert advice was sought, from which the final device was designed. Thus, the children ʿs needs were our first priority. Our approach is participatory in the practitioner perspective, and user-centered in the children perspective.

3.2.2 Child – practitioner dyads as users. The proposed system is not meant to be a standalone platform: the goal is to propose a tool for practitioners to support them in the training of joint action skills. In this regard, we consider the child – practitioner dyad as the user group of the interactive device to be developed: the child-practitioner relationship is acknowledged to be at the core of the training. Care should be taken not to impair it and to allow practitioners to stay closely attentive to children's behaviors.

3.2.3 Design process. The project began with a design research phase aiming at specifying more precisely both the content of the training and the interactive system design. This phase included field participant observations within a daycare center and ideation meetings with practitioners. It ended up with a working prototype described in the system design section. The field experiments phase is composed of a laboratory study with neurotypical children to gather preliminary feedback on the usability of the device, and a field training study with young children with ASD to test the device within real conditions.

3.3 Field participant observations

3.3.1 Protocol. One researcher of the HCI team spent one day per week during three months in the daycare center as a participant observer. The children's schedule is structured in half an hour activities distributed within specific rooms (e.g., a social skills room, a sensory skills room, a motor skills room, an imitation therapy room, a Kinect room, etc.). The observant HCI researcher could access most of the activities but spent significantly more time in activities within the room for motor skills practice as it involves the manipulation of big foam objects and the training of coordination and gross motor skills.

On the participant – observer spectrum, our approach has been to adopt an observer-as-participant stance [42]. With little knowledge of the daycare center practices, our participation was limited but not excluded: being present within a small room with one practitioner and three children necessarily create engagement between the observer and the observed group. No observational notes could be taken within each activity: taking notes in front of children would have distracted them. Instead, each observation session of 30 minutes was followed by a 30 minutes time off reserved to write down observations. Notes were organized as followed [43] observational notes (i.e., about what happens, in chronological order), theoretical notes (i.e., reflections on these observations) and methodological notes (i.e., reminders, instructions to follow next time, etc.). A written synthesis was discussed with practitioners to get their feedback and identify possible misinterpretations.

3.3.2 Insights. *Activities adapted to each child.* Practitioners made it clear that it was essential to consider that "each child is different". In practice, this tenet implies that practitioners take great care to adapt each activity to children specificities. In the movement room, one activity is to build and go through a series of obstacles made of big soft objects. Many different constructions were observed (e.g., using high obstacles for a child who likes to climb or building narrow bridges to train a child with issues of balance). These adaptations were functions of children's abilities, but also interests, moods and sensory preferences. All proposed activities had the possibility to be performed in many different ways.

Doing with the child. Almost all activities were tasks to be jointly performed by children and practitioners. Taking again the example of the obstacle path, practitioners took many different roles: doing the path themselves to invite children to imitate them, going through the path with children side by side, or following children to encourage them. Those three different roles (initiator, partner and follower) were recurrent across activities. This constant support was the occasion for practitioners to adapt to each child rhythm (some children are very impulsive while others are very slow) and learning progress (by decomposing and repeating the task as required).

Being attentive to children's attention. Children with ASD are very attentive to many details related to their sensorial sensibilities. Practitioners took care of keeping children engaged in the task and avoiding over-stimulation and restrained behaviors. Practitioners were very attentive to children behaviors and could identify very subtle signs of distractions. This required practitioners to be fully present to avoid unwanted behaviors (e.g., while one practitioner crawled through a tube to show the path, a child went to open all the cupboard doors in the room).

Toys as soft, robust and varied tangible objects. Many different tangible objects were used: large colorful foam objects with various geometrical shapes (without sharp edges) to build obstacles, balls and skittles to play various games or a large red sheet to be manipulated by several children. Each object could be used in many different ways, as for a large foam cylinder used either as a tower obstacle, a piece to be rolled, an object to train balance or a hiding place. Objects had to be robust and harmless as they were recurrently launched or bitten by children. The objects variety enabled practitioners to often switch between them and discard objects for which children developed restrained interests.

Collaborative activities through tangible objects. These tangible objects are often used to develop collaborative activities. For the obstacle path activity, building the path at the beginning and storing all the elements at the end was performed together with children. Children's participation in these two phases was very diverse: some children grasped easily and spontaneously the large objects to put them at their right place, while some others were not interested or had difficulties in manipulating the objects. One joint action we identified was the manipulation of large and thick carpets to be moved across the room. For this task, practitioners had to explicitly ask children to help them and few children successfully performed the task. Another less constraining joint action was the joint manipulation of a large sheet by the practitioner and 2 or 3 children. The goal of the activity was to move the sheet in rhythm with others on music. Here again children reacted in very different manners: some can move in rhythm with others, some move enthusiastically but independently, and for some others holding the sheet together was already a success. As pointed by practitioners, some collaborative activities required motor schemes not always acquired by children thus limiting their participation (e.g., one child was not able to launch a ball although he could run and grasp it).

3.4 Ideation sessions

3.4.1 Protocol. The first 9 months of the project were dedicated to the exploration of design alternatives for the interactive training. In total, 9 ideation sessions involving both the HCI and developmental psychopathology team enabled us to converge toward the design described in the next section. To guide our exchanges during this ideation phase, we stablished a shared document summarizing the identified needs and a list of specifications associated with design alternatives. Between each meeting, this document was updated considering the practitioners' feedback.

3.4.2 Insights. *Device innocuity.* The first element that conditioned the design process was the need to develop a system that is harmless for children. This innocuity has to be considered given the specific condition of children with ASD: they can self-hit, throw or bite any object at their disposition. As an interactive installation example, practitioners explained to us how they adapted the Kinect room to run therapeutic activities: the Kinect is hidden within a console, the video-projector is placed high enough to be inaccessible to children, and everything is placed in order to have no visible cable.

The project aims to design an interactive device where a child with ASD physically interacts with an agent, whether it is virtual or robotic. Those discussions around innocuity issues led us to discard the humanoid robotic option. The design challenge was then to find a solution to enable the child with ASD to physically interact with a virtual human in a perfectly safe environment. The proposed concept was to display the virtual agent on a thin wall on which tangible objects can be manipulated. These objects could be magnetized to another part behind the wall thanks to magnets. With this system, the tracking apparatus could be placed at the back of the wall, leaving the front object free of any technology. To evaluate the feasibility of this proposal, we prototyped a wall covered by different low friction materials and tested the sliding sensation varying magnets strength (Figure 1.a). Together with practitioners, we identified a solution with a good trade-off between slipperiness (to allow easy movements) and magnetic strength (to keep the objects attached to the wall).

This innocuity requirement also influenced the making process of the tangible object to be manipulated. To be robust and harmless, objects in the daycare center are mostly made of either plastic or foam. The additional constraint to easily produce varied shapes oriented us toward the choice of foam objects. Foam objects found in the daycare center are made of EVA high density foam (Ethylene-Vinyl Acetate) making it resistant to bites while being harmless. Another advantage of this foam is that it can be easily milled to make various 3D shapes. A first prototype with inserted magnets enabled us to validate the concept together with practitioners (Figure 1.b).

Task realism. Another topic discussed during these ideation meetings was the realism of the task. When the HCI team proposed various game concepts that the child could play with the virtual agent (e.g., moving a tangible plane to avoid moving clouds), the developmental psychopathology team expressed three concerns regarding such metaphorical games: these concepts might be too abstract for children with severe ASD; children with ASD have a rigid relation to objects limiting their ability to perform pretend play; and the goal of the project is to provide a training transferable to real life.

From these discussions emerged the concept of a real-virtual window where the 3D word is the continuity of the real world [44]. This interaction paradigm had two consequences on the proposed design:

- The design of a wooden frame and console to materialize the window
- The back-side element magnetized to the front object should be a twin object with the same shape. This ensure that when detaching the front object, the virtual part still has behaviors that match its visual shape.

The shape of the virtual human was influenced by this concept of the real-virtual window. The starting point for the virtual agent was to propose a design similar to the skeleton agent in the PictogramRoom application. This design presented the advantage to be familiar to children at the center and to focus the training and the attention on bodily motor interaction (i.e., no addition of facial expressions). To be consistent with the 3D interaction paradigm, we proposed two 3D designs, one similar to a stick-like skeleton and one closer to a real child morphological appearance (Figure 1.c). The second design was preferred by the developmental psychopathology team as it was more in line with the goal to foster peer interactions.

Lastly, the design of foam objects was also informed by the requirement to be transferable to real-life. Rather than making abstract but playful shapes such as Bobles©products, the choice was made to propose a series of objects which could be named as real-life objects since one of the goals is to encourage children to participate in family life at home. We decided to produce three different objects: a *"table"*, a *"stool"* and a *"box"* (Figure 1.d).

Scenarios and motor dialog. For the definition of the task, the developmental psychopathology team put as a key training element the possibility to decompose movement scenarios in simple motor

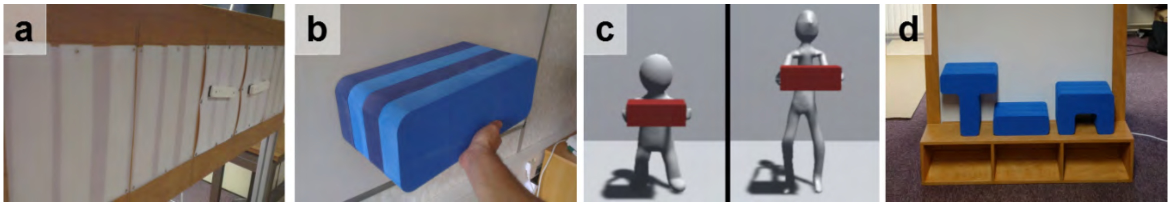

Figure 1: a. Wall prototype covered by different low friction materials. b. Foam tangible object prototype. c. Two virtual agent prototypes. d. Series of three tangible objects.

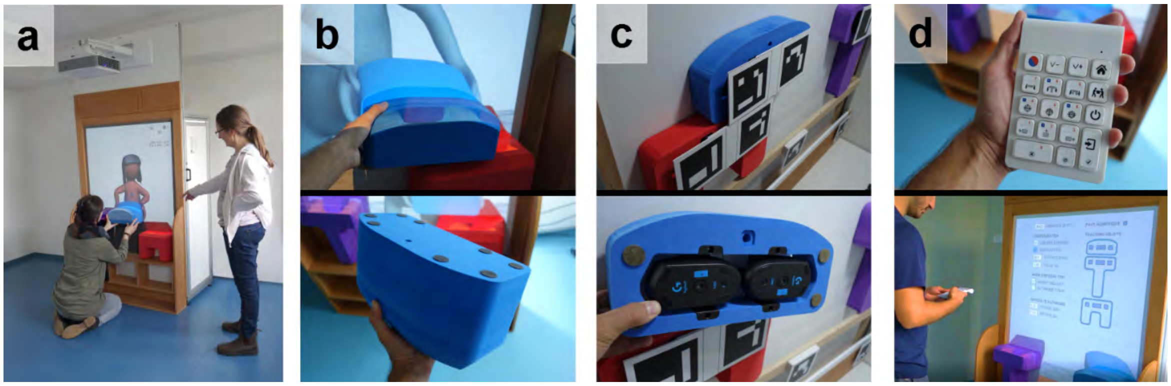

Figure 2: a. Whole interactive setup. b. Tangible object on and detached from the wall. c. Tracking system embedded in the twin back side object. d. Remote control to configure the training.

schemes. As planning complex sequences of action can be difficult for children with ASD, qualifying scenarios in terms of motor schemes enables to control the motor complexity of the task. To keep the task accessible to children with severe ASD, a first list of simple motor schemes was defined: posing, lifting, pushing and pulling. This list in mind, we decided to design the training as a storing task where the child helps the agent put tangible elements in specific locations. Storing activities are everyday tasks already performed by children with ASD, sometimes collaboratively. Training joint action within this task context would facilitate the transferability to family life.

A second question related to training scenarios was how to enable the virtual agent to take two different roles during the joint activity (a cooperative follower and an independent leader). This implies to endow the agent with the ability to initiate and lead movements. A first solution was to realize this motor dialog through active haptic feedback. Among the various technological alternatives that we envisioned (e.g., cables, pantograph, XY table, robotic arm), no one was able to offer large movement amplitudes (more than 50 cm to involve gross motor skills) and control several objects on the same plane without heavy custom engineering and security challenges. Another major drawback of an active haptic solution is the induced difficulty for practitioners to guide and support the child as haptic feedback are invisible. The alternative solution was to rely on the visual alignment of the virtual and tangible part of the object: in a leading mode, the character initiates a movement with the virtual part of the object which visually detaches itself from the tangible part of the object. In this alternative solution, the motor dialog is mediated by the visual information of the gap between the real and virtual part of the object, making it available to both the child and the practitioner.

4 SYSTEM DESIGN

4.1 Interaction paradigm

The proposed system aims at simulating joint action between a child and a virtual character (Figure 2.a). It is composed of a virtual character projected on a vertical surface on which a tangible object is magnetized: both the child and the virtual character *"hold"* and move the object enabling the simulation of a joint action. The child can hold and move the tangible object. The virtual character can move what looks like the graphical part of the tangible object. This system is based on the interaction paradigm of real-virtual window [44]: the projected wall is a window on the virtual space of the virtual character assumed to be the continuity of the real space of the participant, participants can *"see through"* the wall.

4.2 Device structure

Figure 2.a shows the device structure with three interactive tangible objects. An aluminum structure embeds the interactive window (1.5m * 1m), a wooden structure designed as a console and a frame for the window, the video-projector, and a back side (0.6m depth) closed by a door with all the necessary hardware inside, making the device self-contained. The device is stable and withstands knocks and punches without any risk. As the device is imposing, the wooden facade brings some familiarity and the white color of

the top part of the device limits its salience in the perceptual field. An ultra-short throw video-projection was chosen to limit shadows during the interaction.

4.3 Interactive objects

4.3.1 Materials and sliding. Tangible objects are EVA custom-made, a high-density foam used for children's games and carpets. In this project, the choice was made to design three objects representing a table (in purple), a stool (in red) and a box (in blue). Each tangible object holds on the wall as it is magnetized to a twin object located behind the wall (Figure 2.b & 2.c). To enable the front and back parts of the objects to easily slide while being firmly attracted to each other, the wall is made of a thin composite material (i.e., 4mm Alu Dibond©) covered by a slippery coating on both sides (i.e., Velleda©). Magnets of different strengths were tested to find the best trade-off between strong attraction and good slipperiness. Chamfers were added to front objects to afford grasping the object closer to the wall which limits the risk of incidental removal.

4.3.2 Objects tracking. As the child slides the front object along the wall, the corresponding twin object hidden behind the wall follows. Thanks to this principle, the tracking can be embedded in the twin object and be hidden to the child. The design choice of the tracking system was guided by three factors (by order of importance):

- Reliability: the window interaction paradigm relies on the robust continuity between the virtual and the real part of the tangible object. One critical aspect was to design a tracking solution that offered a minimal lag to create the feeling that the virtual and the tangible part "stick together" and form the same object
- Compactness: the system should fit within the back side of the device
- Reproducibility: the device is designed to be reproducible and easily maintainable
- The real-time 2D tracking of the tangible object is realized through a combination of two systems (Figure 2.c):
- A relative and low lag tracking realized with two embedded mice. In addition to their high reactivity, mice are compact and highly reliable.
- A marker-based absolute tracking made with a webcam and two Aruco markers on each object. This system was added as a complement to the mouse tracking to correct the accumulated drift.

The fusion of these realtime data is realized according to movement speed: mouse tracking data are used above a speed threshold and marker tracking data are used below, correcting the accumulated drift.

4.4 Interactive virtual characters

4.4.1 Morphology and behaviors. The software part of the device was designed with the Unity game engine. The anthropomorphic virtual characters were designed without facial features and expressions to limit the social complexity of the virtual scene. As the training implies to interact in two modes (a follower and a leader mode), two different virtual characters were designed differentiated from the other by a different color and hat (Figure 3.a). Attributing a specific role to an identifiable character enables to simplify the social interaction as well as bring some appealing variability to the training. Names were given to each character to personify them and facilitate oral instructions for practitioners (i.e., "Michou" for the following character, "Lola" for the leading character).

The bodily interaction was kept as simple as possible. While doing nothing, the character is animated by an idle animation. On demand of the practitioner, the virtual character can grasp a virtual object. This grasping animation was done using humanoid inverse kinematics algorithms and two interaction mode were designed:

- Following mode: the character holds the virtual object which stays aligned to the tangible part. The child has to lead a movement toward a specific target instructed by the practitioner. In Figure 3.b, the instruction is to move with Michou the blue box from the purple table to the red stool.
- Leading mode: the character initiates a movement with the virtual part of the object which visually detaches itself from the tangible part of the object. The child has to follow the character's movement toward a specific target that is unknown to the child. If the child does not follow close enough the virtual object, the leading character releases the object and a smoke animation is displayed around the virtual part of the object. In Figure 3.c, the instruction is to move with Lola the blue box by following Lola (without specifying the destination).

4.4.2 Controls and feedback. Within each training session, a scenario corresponds to the task of moving a specific object to a specific target along with the virtual character. The practitioner controls the types and the quantity of scenarios he/she wants to run with the child. A scenario is automatically considered a success (with stars displayed and rotating around the virtual part of the object) when the tangible object held by the child reaches the target. It is automatically considered a failure (with a soft smoke animation) if the child does not succeed to follow the leading character properly. In addition to these automatic decisions, the practitioner can manually tag a scenario as a success, a failure or an aborted scenario. This flexibility was important to allow them to experiment with the device and adapt the training evaluation to each child. Practitioners can also configure the session within a welcome screen (i.e., audio feedback, height, interactive mode, speed, fail threshold).

During a session, practitioners need to stay focused on the interaction with the child and avoid any distractions from the task. We thus designed a lightweight custom remote control to manipulate the device (Figure 2.d). Using a wireless keypad covered by custom icons, practitioners can configure the session in the welcome screen and control the scenarios within the interaction scene. The remote control can be operated while held in the hand or while positioned in its custom mount on the side of the device.

5 FIELD TRAINING STUDY

In this section, we report on a field training study with the aim to provide preliminary elements on the use of the developed interactive system for the training of joint action in children with ASD.

Figure 3: a. The two virtual agents. b. Movement sequence in following mode. c. Movement sequence in leading mode.

5.1 Participants

The consent was given by parents via a detailed letter of consent. None of the children was able to give their informed consent given their age (4 years to 8 years) and their verbal inability. None of the children who refused at first to enter the room and look at the platform were enrolled. Our motivation to choose nonverbal participants is as follows: most virtual devices in use require a minimum of verbal or language understanding abilities. Severe non-verbal autism is a forgotten part of new technologies. We wanted to face this challenge despite the difficulties it generates. Twelve children diagnosed with ASD participated to the study (2 females). They were diagnosed according to the DSM5 and ADOS criteria by confirmed child psychiatrists in specialized children hospitals. They were aged from 5 years to 9 years and 4 months (chronological age: mean 7 years and median 6 years and 6 months) with a follow-up of sessions based on the performance achieved. Of these 12 children, 7 had a little conversational language.

5.2 Protocol

The training has been run during 3 months in a daycare center where the twelve participants come on a daily basis. The general procedure is an individual procedure in three stages designed by the developmental psychopathology team: familiarization, training to move the object with Michou, the agent that follows the child, and then training with Lola, the agent that the child must follow.

Before the familiarization, each child is invited to enter the room that contains the tangible-virtual platform. The child must therefore get used to the different layout of the room. This may take several sessions. Once the place is accepted, we move on to familiarize the child with the use of the tangible object in relation to the virtual object.

In this familiarization, a first difficulty is to maintain the goal of moving the object together with Michou all along the route designed by the scenario. For Michou to follow, the child must control throughout the scenario that the adhesion between the real object and the virtual object is maintained. In addition to train gross motor skills required to slide the object along the wall, testing and training the ability to maintain a goal is thus part of the therapies that can be used with the device. A second difficulty of the collaborative task is that the child has to perform 4 scenarios on a record, representing 4 different routes: hoisting the box on the floor to the table; slide the stool next to the table; take the box on the table and place it on the stool; take the box on the stool and place it on the floor. The instruction is verbal for children with a small language, and modeled for non-verbal children. The training phase is effective if the four needs are respected: drag the tangible object along the wall instead of taking it in hands, make the tangible object to adhere the real object, maintain the grip throughout the route and not to give priority to its own motivation.

Once the collaboration with Michou is completed, the training to collaborate with Lola (the leading agent) can begin. The great difficulty for the child is to follow Lola who is self-reliant. Lola chooses the object she wants to move, chooses a scenario, chooses the target of the move (i.e. where to place the object), so the child must analyze her posture as indicating the trajectory of movement (up, bottom, right, left). Lola chooses the speed of her movement among 3 possible speeds: the speed of the child when he was driving the scenarios (i.e. the easiest speed to follow), the fast speed that forces the child to accelerate to follow Lola, and the slow speed, the most difficult to follow because it requires the child to control his motor skills not to exceed Lola, which would lead to failure. The three speeds are presented in the order of increasing difficulty. As a matter of fact, the real test of synchronization abilities on the movement of the other is to move the object with the Lola agent.

The following insights are based on observational data (postures, preparation for the objective, an understanding of the scenario - the path of an object to a target-, the ability to withstand failure and resume the exercise, the ability to attribute agency to the avatar) and interpretative analysis of logged data. The following data was logged by the software throughout the session: fail or success of a session, their number, scenario duration, and visualizations of recorded trajectories. At this stage of the process, insights are only preliminary and focused on the device usability. We are currently working on the integration of quantitative movement analysis and observational data for the training evaluation. Ethical approval was given by the ethical committee of Universite Paris-Saclay (reference CER-Paris-Saclay-2019-10).

5.3 Insights

Device acceptability. Although the device could be a bit intimidating at first, the device was accepted by all participants. For two children, several sessions were needed to get them used to this new room layout, but no children expressed fear in front of the device. Two children voluntarily stopped the training: one because he did not understand the task and one because she was disturbed by the fact that tangible object on the wall does not fall down when not held. Apart from these two cases, the interactive device was perceived as playful with children asking for training sessions.

Getting the sliding right. The constraints of the platform that are to drag the tangible object along the wall instead of taking it in hands, is somehow counter-intuitive and represents the major difficulty of the familiarization training with Michou. Tangible objects successfully afforded grasping as children took spontaneously the physical object into their hands. Then the first step is to make them understand that they have to drag the object along the wall. This first step is more or less long for the children. Three children did not understand this sliding technique: they detached the object and put it directly on a different location. Added to this difficulty is the need to struggle against the gravity associated with the magnetization of the object. Indeed, the tangible character is manifested by resistance to thrust. When it is necessary to move the object by raising it, the work against gravity is at its peak and explains failures and discouragements. Two children were not able to overcome this difficulty: one child understood the sliding principle but was not able to align the tangible object with the virtual part, and a second child understood the requirement to put the object on the wall and then slide it but was not able to do both at the same time. Overall, six children succeeded in interacting with the following agent.

Real-virtual continuity. Children seemed to perceive the real – virtual continuity. Although the interaction paradigm required participants to stand close to the wall, we did not notice any backward move caused by a difficulty to see the virtual environment or remarks about visible pixels. For the six children able to interact with the device, when accidentally detaching the physical object from the wall, children spontaneously did put back the physical part aligned with the virtual part on the wall. This alignment was not always a direct success due to a lack of clear texture differentiation between the front and side faces of the virtual part. Some children stroked the interactive wall to touch the virtual agent and some tried to find the virtual agent behind the wall: they turned around the device, tried to enter in and lied down flat on the floor to find where the agent where. Interestingly, the fact that magnetized tangible objects do not fall down as it would be expected with the real-virtual continuity caused a crisis for one child: this discrepancy in the interaction paradigm was not accepted.

Avoiding distractions. Some details of the device can disrupt children and cause them to lose their original purpose by deviating to interfering interests. Although the virtual environment was designed as minimalist, two of our partly verbal children identified and focused on the small score table indicating successes and failures for the practitioner. One child looked only at the counter, neglecting the goal of the task, the agent and the objects to carry. Another child tried various behaviors unsuited to the task in order to change in scores. Nothing could bring them back to the task and from one session to the next they confirmed themselves in their misguided objectives. This allows us to see that, despite the precautions taken and the clean nature of the device, the environment was still too rich in possible diversions of attention.

Joint action perception. As participants were mostly non-verbal, it is difficult at this stage to know if the interaction was perceived as a joint action. One hint could be the tendency for participants to personify more the leading agent Lola as she chooses the object, the target, the direction and the speed. Children with minimal verbal abilities called the agents by their names and asked to play with the agents, for example one verbal child said "go on Lola!". One participant said he preferred the following agent because he did not know what the leading agent would decide. Among the four children that arrived at the stage of the leading agent, the most successful child clearly made pauses in his action to see where the leading agent would go.

Device control. Two persons from the developmental psychopathology team were present for each session: one staying with the child and one controlling the device with the remote control. With this setup, practitioners made sure the remote control did not distract the child from the task. Practitioners had no difficulty to use the remote control, adapting scenarios when required. During the training, one practitioner suggested that it would interesting for them to be able to control the leading agent speed during the interaction to create more complex scenarios.

6 DISCUSSION

In this article, we presented the design process we went through in developing an interactive device to train joint action for children with ASD. Informed by therapeutic requirements, field observations and iterative ideations, the process ended up with a virtual platform based on the interaction paradigm of real-virtual window composed of mixed objects, half-virtual and half-tangible, which the child must move with the help of a virtual agent. One of the agents collaborates with the child while the other agent behaves autonomously. To our knowledge, this interactive system is the first to propose such a joint action training adapted to children with ASD. Preliminary feedback from a field training study showed the system potential: the device was mostly accepted and perceived as attractive, the interactive paradigm of the real-virtual window worked and practitioners managed to run the training independently, which establishes the basis to successfully train social and motor skills. The training also highlighted some limits to be discussed.

Driven by the strong constraint to design a harmless and visually minimalist system, we developed a device with all the required technologies embedded inside. With the proposed system, moving an object together with the virtual agent implies to understand and to be able of two things: tangible objects should be moved by sliding them along the wall, and this sliding motion should be done while maintaining the tangible part magnetized to the back-side part (i.e., staying aligned with the virtual part). These interaction-constrains made the training difficult for five of the twelve training participants. For two of them, the main difficulty was to maintain the tangible object magnetized on the wall while sliding: as the magnets are not very strong to limit friction (which would make the sliding too hard for young children), the tangible object can detach itself easily from the back-side if the movement is too impulsive or not perfectly aligned with the back-side. One way to overcome this issue is to modify the sliding system. After the training we experimented alternative sliding systems: a solution with bearing balls enabled us to make the sliding easier while increasing the magnet strength twice. A consequence of this change is that objects sliding easily fall down even when magnetized. Thus, this new feature also avoids to cause the training rejection because of violation of gravity rules (as for one child in our training). For three children, the difficulty was more related to the nature of the task: why drag what can be carried from one point to another? During the training, practitioners realized this difficulty and adopted two strategies to limit it: they modeled how to handle tangible objects and they extensively used the world *"sliding"* instead of *"carrying"* in their instructions. Another possibility to be explored is to integrate some interactive feedback related to detaching events. In this first version, as all the technology is within the device, the system does not know when the child detaches an object from the wall. One solution would be to integrate reed switches on the back-side aligned with some additional magnets on the front-side of the tangible object. With such a system, we could visually signify that aligning the tangible object to the virtual one is the good way to interact. Lastly, a deeper reflection on this tendency of children to grab objects rather than sliding them would be to consider these *unintended interactions* [45, 46] as a design opportunity to be integrated in the therapy scenario. A first direction would be to integrate the attaching / dis-attaching event on the tangible side: the tangible object could be made of two parts, an object part always on the wall (aligned with the virtual one, the object stays always attached), and a "handle" part that the child takes and plugs on the object to be moved. This handle could be designed to afford the action of carrying vertically (the action of pulling the handle being explicitly associated with the action of dissociating the handle from the object). The task of putting in place the handle could be part of the cooperative game, both the agent and the child having to place in synchronization with the handle. Another direction would be to modify the interaction paradigm to afford more explicitly a 2D interaction. During the design process, we restrained ourselves to focus on the reproduction of a daily activity which could be transferred to a collaborative activity in the family context (i.e., storing objects). Along the iterative design process, various choices have been made resulting in a prototype which cannot be considered as realistic (i.e., similar to a real-life task). It opens up the opportunity to work on alternative task scenarios within the real-virtual window metaphor, more attractive and affording a 2D interaction, for example playing a "connect 4" or a "tetris" game with the agent, guiding a plane across moving clouds, etc.

Despite the precautions taken to avoid distractions, two children lose the training purpose by focusing on 2D score counters designed to provide training feedback to practitioners. Although they were designed small, with discrete colors (i.e. grey) and located on the upper right of the wall, these two children identified and focused on the counters of successes and fails. One identified solution for future versions is to replace the keypad remote control by a tablet or a smartphone on which both graphical controls and feedback could be displayed. Such an interface for practitioners would also allow to propose more controls to adapt the interaction to each child, as with the suggestion from one practitioner to continuously control the agent speed. In this perspective, we could also propose the possibility to trigger agent's behaviors to keep children engaged in the task.

Lastly, preliminary feedback from our training study provide insightful elements on the use of the developed interactive system within a real setting, but does not provide elements on the success of the training. Detailed analyses of recorded movement trajectories across the training will provide some elements on progresses regarding synchronization abilities. What the system currently misses is a way to record children behaviors while interacting with the device: it would enable to automatically analyze postural adaptations and indices of social engagement. For this first version, we tried to integrate various solutions (i.e., several Kinect versions and locations, and several webcam versions and locations together with software solutions like OpenPose [47] or OpenFace 2.0 [48]). But all of them are designed for front interaction whereas in our setup the child stand facing the wall at a distance of 30 cm. One solution came from a solution recently available in Europe: our preliminary tests with the Kinect Azure revealed that the tracking from above (i.e., on the top of the wall, facing down) was working and robust, opening the door for more detailed behavioral analyses.

7 CONCLUSION

Throughout this article, we have presented the design of a tangible and virtual interactive system for the training of children with Autism Spectrum Disorder (ASD) in performing joint actions. This is particularly challenging since we consider children with a severe autism spectrum condition: such a joint action training is more relevant for those who are not able to speak and who have low abstract capabilities. The proposed system is composed of a virtual character projected onto a surface on which a tangible object is magnetized: both the user and the virtual character hold the object, thus simulating a joint action. Preliminary feedback from a field training study showed encouraging results given the great diversity of the population. About one third of the population was able to go throughout the training, another third could make it with minimal revisions of the device, and unexpected interactions raised opportunities for alternative designs.

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REFERENCES

[1] Michael J. Richardson, Kerry L. Marsh, and Reuben M. Baron. Judging and actualizing intrapersonal and interpersonal affordances. J. Exp. Psychol. Hum. Percept. Perform., vol. 33, nº 4, p. 845-859, 2007. https://doi.org/10.1037/0096-1523.33.4.845

[2] Richard C. Schmidt and Michael J. Richardson. Dynamics of Interpersonal Coordination. In Coordination: Neural, Behavioral and Social Dynamics, A. Fuchs and V. K. Jirsa, Ed. Springer Berlin Heidelberg, 2008, p. 281-308. https://doi.org/10.1007/978-3-540-74479-5_14

[3] Jacqueline Nadel. Perception–action coupling and imitation in autism spectrum disorder. Dev. Med. Child Neurol., vol. 57, nº s2, p. 55-58, 2015. https://doi.org/10.1111/dmcn.12689

[4] Ouriel Grynszpan, Patrice L. (Tamar) Weiss, Fernando Perez-Diaz, and Eynat Gal. Innovative technology-based interventions for autism spectrum disorders: A meta-analysis. Autism, vol. 18, nº 4, p. 346-361, 2014. https://doi.org/10.1177/1362361313476767

[5] Bertram O. Ploog, Alexa Scharf, DeShawn Nelson, and Patricia J. Brooks. Use of Computer-Assisted Technologies (CAT) to enhance social, communicative, and language development in children with autism spectrum disorders. J. Autism Dev. Disord., vol. 43, nº 2, p. 301-322, 2013. https://doi.org/10.1007/s10803-012-1571-3

[6] Simon Provoost, Ho Ming Lau, Jeroen Ruwaard, and Heleen Riper. Embodied Conversational Agents in Clinical Psychology: A Scoping Review. J. Med. Internet Res., vol. 19, nº 5, p. e151, 2017. https://doi.org/10.2196/jmir.6553

[7] Gill A. Francis, William Farr, Silvana Mareva, and Jenny L. Gibson. Do Tangible User Interfaces promote social behaviour during free play? A comparison of autistic and typically-developing children playing with passive and digital construction toys. Res. Autism Spectr. Disord., vol. 58, p. 68-82, 2019. https://doi.org/10.1016/j.rasd.2018.08.005

[8] Eva Hornecker and Jacob Buur. Getting a grip on tangible interaction: a framework on physical space and social interaction. Proceedings of the SIGCHI Conference on Human Factors in Computing Systems, Montreal, Quebec, Canada, 2006, p. 437–446. https://doi.org/10.1145/1124772.1124838

[9] Ylva Fernaeus, Jakob Tholander, and Martin Jonsson. Towards a New Set of Ideals: Consequences of the Practice Turn in Tangible Interaction. Proceedings of the 2Nd International Conference on Tangible and Embedded Interaction, New York, NY, USA, 2008, p. 223–230. https://doi.org/10.1145/1347390.1347441

[10] Victoria Tam, Mirko Gelsomini, and Franca Garzotto. Polipo: a Tangible Toy for Children with Neurodevelopmental Disorders. Proceedings of the Eleventh International Conference on Tangible, Embedded, and Embodied Interaction, Yokohama, Japan, 2017, p. 11–20. https://doi.org/10.1145/3024969.3025006

[11] Amani I. Soysa and Abdullah Al Mahmud. Tangible Play and Children with ASD in Low-Resource Countries: A Case Study. Proceedings of the Fourteenth International Conference on Tangible, Embedded, and Embodied Interaction, Sydney NSW, Australia, 2020, p. 219–225. https://doi.org/10.1145/3374920.3374951

[12] Daniel B. Legoff and Michael Sherman. Long-term outcome of social skills intervention based on interactive LEGO©play. Autism, vol. 10, nº 4, p. 317-329, 2006. https://doi.org/10.1177/1362361306064403

[13] William Farr, Nicola Yuill, and Steve Hinske. An augmented toy and social interaction in children with autism. IJART, vol. 5, p. 104-125, 2012. https://doi.org/10.1504/ijart.2012.046270

[14] Sergi Jordà, Gunter Geiger, Marcos Alonso, and Martin Kaltenbrunner. The reacTable: Exploring the Synergy Between Live Music Performance and Tabletop Tangible Interfaces. Proceedings of the 1st International Conference on Tangible and Embedded Interaction, New York, NY, USA, 2007, p. 139–146. https://doi.org/10.1145/1226969.1226998

[15] Lilia Villafuerte, Milena Markova, and Sergi Jorda. Acquisition of Social Abilities Through Musical Tangible User Interface: Children with Autism Spectrum Condition and the Reactable. CHI ’12 Extended Abstracts on Human Factors in Computing Systems, New York, NY, USA, 2012, p. 745–760. https://doi.org/10.1145/2212776.2212847

[16] Anne M. Piper, Eileen O’Brien, Meredith R. Morris, and Terry Winograd. SIDES: A Cooperative Tabletop Computer Game for Social Skills Development. Proceedings of the 2006 20th Anniversary Conference on Computer Supported Cooperative Work, New York, NY, USA, 2006, p. 1–10. https://doi.org/10.1145/1180875.1180877

[17] Paul Dietz and Darren Leigh. DiamondTouch: A Multi-user Touch Technology. Proceedings of the 14th Annual ACM Symposium on User Interface Software and Technology, New York, NY, USA, 2001, p. 219–226. https://doi.org/10.1007/s00146-009-0199-0

[18] Eynat Gal, Nirit Bauminger, Dina Goren-Bar, Fabio Pianesi, Oliviero Stock, Massimo Zancanaro and Patrice L. (Tamar) Weiss. Enhancing social communication of children with high-functioning autism through a co-located interface. AI Soc., vol. 24, nº 1, p. 75,2009. https://doi.org/10.1007/s00146-009-e0199-0

[19] Alberto Battocchi, Ayelet Ben-Sasson, Gianluca Esposito, Eynat Gal, Fabio Pianesi, Daniel Tomasini, Paola Venuti, Patrice Weiss and Massimo Zancanaro. Collaborative puzzle game: a tabletop interface for fostering collaborative skills in children with autism spectrum disorders. J. Assist. Technol., vol. 4, nº 1, p. 4-13, 2010. https://doi.org/10.5042/jat.2010.0040

[20] Leonardo Giusti, Massimo Zancanaro, Eynat Gal, and Patrice L. (Tamar) Weiss. Dimensions of Collaboration on a Tabletop Interface for Children with Autism Spectrum Disorder. Proceedings of the SIGCHI Conference on Human Factors in Computing Systems, New York, NY, USA, 2011, p. 3295–3304. https://doi.org/10.1145/1978942.1979431

[21] Louanne E. Boyd, Kathryn E. Ringland, Oliver L. Haimson, Helen Fernandez, Maria Bistarkey, and Gillian R. Hayes. Evaluating a Collaborative iPad Game’s Impact on Social Relationships for Children with Autism Spectrum Disorder. ACM Trans Access Comput, vol. 7, nº 1, p. 3:1–3:18, 2015. https://doi.org/10.1145/2751564

[22] J. Wade, A. Sarkar, A. Swanson, A. Weitlauf, Z. Warren, and N. Sarkar. Process Measures of Dyadic Collaborative Interaction for Social Skills Intervention in Individuals with Autism Spectrum Disorders. ACM Trans. Access. Comput., vol. 10, p. 1-19, 2017. https://doi.org/10.1145/3107925

[23] Lian Zhang, Qiang Fu, Amy Swanson, Amy S. Weitlauf, Zachary Warren, and Nilanjan Sarkar. Design and Evaluation of a Collaborative Virtual Environment (CoMove) for Autism Spectrum Disorder Intervention. TACCESS, vol. 11, p. 11-11, 2018, https://doi.org/10.1145/3209687

[24] Melanie Jouaiti and Patrick Henaff. Robot-Based Motor Rehabilitation in Autism: A Systematic Review. Int. J. Soc. Robot., vol. 11, nº 5, p. 753-764, 2019. https://doi.org/10.1007/s12369-019-00598-9

[25] Kerstin Dautenhahn and Aude Billard. Games Children with Autism Can Play with Robota, a Humanoid Robotic Doll. Universal Access and Assistive Technology, London, 2002, p. 179-190. https://doi.org/10.1007/978-1-4471-3719-1_18

[26] Zhi Zheng, Eric M. Young, Amy R. Swanson, Amy S. Weitlauf, Zachary E. Warren, and Nilanjan Sarkar. Robot-Mediated Imitation Skill Training for Children With Autism. IEEE Trans. Neural Syst. Rehabil. Eng., vol. 24, nº 6, p. 682-691, 2016. https://doi.org/10.1109/TNSRE.2015.2475724

[27] Aude Billard, Ben Robins, Jacqueline Nadel, and Kerstin Dautenhahn. Building Robota, a Mini-Humanoid Robot for the Rehabilitation of Children with Autism. Assist. Technol., vol. 19, nº 1, p. 37-49, 2007. https://doi.org/10.1080/10400435.2007.10131864

[28] Audrey Duquette, François Michaud, and Henri Mercier. Exploring the use of a mobile robot as an imitation agent with children with low-functioning autism. Auton. Robots, vol. 24, nº 2, p. 147-157, 2008. https://doi.org/10.1007/s10514-007-9056-5

[29] Sara Ali, Faisal Mehmood, Darren Dancey, Yasar Ayaz, Muhammad Jawad Khan, Noman Naseer, Rita De Cassia Amadeu, Haleema Sadia, and Raheel Nawaz. An Adaptive Multi-Robot Therapy for Improving Joint Attention and Imitation of ASD Children. IEEE Access, vol. 7, p. 81808-81825, 2019. https://doi.org/10.1109/ACCESS.2019.2923678

[30] Sylvie Serret, Stephanie Hun, Galina Iakimova, Jose Lozada, Margarita Anastassova, Andreia Santos, Stephanie Vesperini and Florence Askenazy. Facing the challenge of teaching emotions to individuals with low- and high-functioning autism using a new Serious game: a pilot study. Mol. Autism, vol. 5, nº 1, p. 37, 2014. https://doi.org/10.1186/2040-2392-5-37

[31] Charline Grossard, Stéphanie Hun, Arnaud Dapogny, Estelle Juille, Fanny Hamel2, Heidy Jean-Marie, Jérémy Bourgeois, Hugues Pellerin, Pierre Foulon, Sylvie Serret, Ouriel Grynszpan, Kevin Bailly and David Cohen. Teaching Facial Expression Production in Autism: The Serious Game JEMImE. Creat. Educ., vol. 10, nº 11, p. 2347, 2019. https://doi.org/10.4236/ce.2019.1011167

[32] Matthieu Courgeon, Gilles Rautureau, Jean-Claude Martin, and Ouriel Grynszpan. Joint Attention Simulation Using Eye-Tracking and Virtual Humans. IEEE Trans. Affect. Comput., vol. 5, nº 3, p. 238-250, 2014. https://doi.org/10.1109/TAFFC.2014.2335740

[33] Sara Bernardini, Kaska Porayska-Pomsta, and Tim J. Smith. ECHOES: An intelligent serious game for fostering social communication in children with autism. Inf. Sci., vol. 264, p. 41-60, 2014. https://doi.org/10.1016/j.ins.2013.10.027

[34] Erik Marchi, Bjorn Schuller, Alice Baird, Simon Baron-Cohen, Amandine Lassalle, Helen O’Rielly, Delia Pigat, Peter Robinson, Ian Davies, Tadas Baltrusaitis, Ofer Golan, Shimrit Fridenson-Hayo, Shahar Tal, Shai Newman, Noga Meir-Goren, Antonio Camurri, Stefano Piana, Sven Bolte, Metin Sezgin, Nese Alyuz, Agnieszka Rynkiewicz, Aurelie Baranger. The ASC-Inclusion Perceptual Serious Gaming Platform for Autistic Children. IEEE Trans. Games, vol. 11, nº 4, p. 328-339, 2019. https://doi.org/10.1109/TG.2018.2864640

[35] Charline Grossard, Ouriel Grynspan, Sylvie Serret, Anne-Lise Jouen, Kevin Bailly, and David Cohen. Serious games to teach social interactions and emotions to individuals with autism spectrum disorders (ASD). Comput. Educ., vol. 113, p. 195-211, 2017. https://doi.org/10.1016/j.compedu.2017.05.002

[36] Jacqueline Nadel, How Imitation Boosts Development: In Infancy and Autism Spectrum Disorder. Oxford University Press, 2014.

[37] Gerardo Herrera, Xavier Casas, Javier Sevilla, Luis Rosa, Carlos Pardo, Javier Plaza, Rita Jordan and Sylvain Le Groux. Pictogram Room: Natural Interaction Technologies to Aid in the Development of Children with Autism. Annu. Clin. Health Psychol., vol. 08, p. 39-44, 2012.

[38] Gerardo Herrera, Patricia Perez-Fuster, and Gael Poli, . Pictogram Room: son efficacite dans le trouble du spectre de l’autisme (TSA). Enfance, vol. N{°} 1, n^{o} 1, p. 31-50, 2018. https://doi.org/10.3917/enf2.181.0031

[39] Elinor Ochs and Olga Solomon. Autistic Sociality. Ethos, vol. 38, no 1, p. 69-92, 2010. https://doi.org/10.1111/j.1548-1352.2009.01082.x

[40] Michael J. Muller. Participatory design: the third space in HCI. The human-computer interaction handbook: fundamentals, evolving technologies and emerging applications, USA: L. Erlbaum Associates Inc., 2007, p. 1051–1068.

[41] Laura Benton and Hilary Johnson. Widening participation in technology design: A review of the involvement of children with special educational needs and disabilities. Int. J. Child-Comput. Interact., vol. 3-4, p. 23-40, 2015. https://doi.org/10.1016/j.ijcci.2015.07.001

[42] Lynn Westbrook. Qualitative research methods: A review of major stages, data analysis techniques, and quality controls. Library & Information Science Research, vol. 16, no 3, p. 241-254, 1994. https://doi.org/10.1016/0740-8188(94)90026-4

[43] Thomas Groenewald. A Phenomenological Research Design Illustrated. International Journal of Qualitative Methods, vol. 3, no 1, p. 1-26, 2004. https://doi.org/10.1177/160940690400300104

[44] Kangsoo Kim, Ryan Schubert, and Greg Welch. Exploring the Impact of Environmental Effects on Social Presence with a Virtual Human. Intelligent Virtual Agents, Cham, 2016, p. 470-474. https://doi.org/10.1007/978-3-319-47665-0_57

[45] Alyssa Alcorn, Helen Pain, Gnanathusharan Rajendran, Tim Smith, Oliver Lemon, Kaska Porayska-Pomsta, Mary Ellen Foster, Katerina Avramides, Christopher Frauenberger, and Sara Bernardini. Social Communication between Virtual Characters and Children with Autism. Artificial Intelligence in Education, Berlin, Heidelberg, 2011, p. 7-14. https://doi.org/10.1007/978-3-642-21869-9_4

[46] Alyssa M. Alcorn, Helen Pain, and Judith Good. Motivating children’s initiations with novelty and surprise: initial design recommendations for autism. Proceedings of the 2014 conference on Interaction design and children, New York, NY, USA, 2014, p. 225–228. https://doi.org/10.1145/2593968.2610458

[47] Zhe Cao, Gines Hidalgo, Tomas Simon, Shih-En Wei, and Yaser Sheikh. OpenPose: Realtime Multi-Person 2D Pose Estimation using Part Affinity Fields. IEEE Trans. Pattern Anal. Mach. Intell., 2019. https://doi.org/10.1109/tpami.2019.2929257

[48] Tadas Baltrusaitis, Amir Zadeh, Yao C. Lim, and Louis-Philippe Morency. OpenFace 2.0: Facial Behavior Analysis Toolkit. 13th IEEE International Conference on Automatic Face Gesture Recognition (FG 2018), 2018, p. 59-66. https://doi.org/10.1109/FG.2018.00019