ICT and autism care: state of the art

Charline Grossard\textsuperscript{a,b}, Giuseppe Palestra\textsuperscript{b}, Jean Xavier\textsuperscript{a,b}, Mohamed Chetouani\textsuperscript{b}, Ouriel Grynszpan\textsuperscript{b}, and David Cohen\textsuperscript{a,b}

Purpose of review
Over the past 10 years, the use of information and communication technologies (ICTs) has increased in regard to the treatment of individuals with autism spectrum disorders (ASDs). ICT support mechanisms (e.g. computers, laptops, robots) are particularly attractive and are adapted to children with ASD. In addition, ICT algorithms can offer new perspectives for clinicians, outside direct apps or gaming proposals. Here, we will focus on the use of serious games and robots because of their attractiveness and their value in working on social skills.

Recent findings
The latest knowledge regarding the use of ICT in the forms of serious games and robotics applied to individuals with ASD shows that the field of serious games has already achieved interesting and promising results, although the clinical validations are not always complete. In the field of robotics, there are still many limitations on the use of ICT (e.g. most interaction are similar to the wizard of Oz), and questions remain concerning their eventual effectiveness.

Summary
To describe the implications of the findings for clinical practice or research, we describe two large projects, namely, JEMImE and Michelangelo, as examples of current studies that are aimed at enhancing social skills in children with ASD by including novel algorithms with clinical insights in robots or serious games.

Keywords
autism spectrum disorder, information and communication technologies, serious games, social robots, social skills

INTRODUCTION
Autism spectrum disorders (ASDs) are developmental disorders characterized by deficits in social interaction, communication and repetitive behavior. Among these deficits, all social skills, which include social initiation, social interaction rules, emotion production and recognition, can be affected. As a consequence, integration into society is a major ASD burden \cite{1}. ASD patients may also present with different difficulties that can affect attention and executive learning \cite{2}, general cognition or oral language \cite{3}. Academic skills are often impaired, thus impacting academic achievement \cite{4}.

Information and communication technologies (ICTs) have opened new ways to help people with ASD. These technologies allow creation of real-life situations in a controlled area and offer clinicians different supports to work with \cite{5}. Moreover, the presentation of information seems to be particularly adapted to individuals with ASD, and some studies have found that persons with ASD are particularly interested by ICT \cite{6}.

Information and communication technology-based interventions can be classified into three main categories \cite{7}. First, iPod and iPad apps aim to facilitate specific aspects of social life. Despite some promising apps (e.g. Rubycube or the Social Detective app), most available apps have received limited empirical clinical validation \cite{7}. Second, serious games can be described as ‘digital games and equipment with an agenda of educational design and beyond entertainment’ \cite{8}. Finally, ICT interventions include the use of robots with children with ASD \cite{7,9–11}. In this subdomain, clinical validation is also limited, as many studies have focused on the development of novel social skills for robots, thus
KEY POINTS

- ICTs are particularly attractive to children with ASD and are adapted to their needs.
- Serious games and robots are two support mechanisms that are particularly used for the treatment of social skills in children with ASD.
- Previous studies showed benefits in using ICT for the treatment of social skills.
- The field needs more robust studies to conclude that ICT is effective and that the skills learned during treatment can be generalized to real life.

narrowing down the expectation of social training [10].

The present study aims to briefly review the recent literature about the use of ICT in the form of serious games and robotics applied to individuals with ASD. ICT can be used to not only train abilities but also to compensate difficulties. We do not describe assistive technologies (see [12] and [13] for a review), but rather focus on serious games and robotics studies with a treatment agenda. Then, to illustrate how ICT research can integrate clinician insights into multidisciplinary research, we describe two large projects, namely, JEMmE and Michelangelo, as examples of current studies that seek to enhance social skills of children with ASD by including novel machine learning algorithms based on clinical expectations.

SERIOUS GAMES

Generality

Serious games can be described as a combination of education and entertainment. At present, many applications exist on portable devices that aim to be playful and to teach a targeted skill. However, most of these applications have not been the object of specific research in a clinical population and cannot be evaluated (see [14] for a list). Here, we focus on serious games created and evaluated on other platforms such as computers, multitouch tablets, and screens. Generally, the object of their training can be separated into two distinct areas. On the contrary, we found serious games teaching a specific cognitive domain (e.g. executive function) and academic skills (e.g. reading). On the contrary, there are several serious games that teach the core difficulties of ASD, such as social skills and emotion recognition.

Regarding the efficacy of serious games in both domains, Grynspan et al. [15] recently reviewed the literature and performed a meta-analysis to measure clinical impact through a nonspecific variable (standardized effect size) in individuals with ASD. The results showed that the use of ICT has a significant impact on the targeted skills. However, no study has evaluated the maintenance of treatment effects and the generalization to real life. Equally, the researchers could not contend that the use of ICT is more adapted to a subgroup of children with ASD. Finally, the authors reported that the use of ICT seems more efficient when a professional is involved during the session than when the child has to play alone at home.

Since this review, an interesting study described the use of the game SEMA-TIC [16], which aims to teach literacy skills. SEMA-TIC was developed by the Cobtek laboratory and is novel in the literature because it aims to teach literacy to children with poor functional language skills and ASD. The design of the game is thought to specifically increase the motivation of these individuals. The game includes feedback and reinforcements that align with the interests of the children, such as bright, moving objects and illustrations from mechanics. The player can follow his/her progression with a colored gauge, which gives him/her visual information. In addition, each game is thought to train specific literacy skills, such as word recognition, alphabet knowledge, syntactic rule, and so on. A 23-week study enrolled 25 children and showed good game usability and adaptability in the targeted population. The children exposed to SEMA-TIC (experimental group) improved their literacy skills on the targeted exercise significantly better than children in the control group. Moreover, three of the trained children were able to decode words after training.

Serious games to teach social skills

A large part of the recent research on serious games in ASD has dealt with games that try to teach social skills to patients. This interest is supported by two facts: the development of social skills represents a challenge for the integration of individuals with ASD [1]; and ICTs provide very good support in creating social situations in an immersive way [5], contrary to the classic therapy in an office.

In a recent review, Grossard et al. [17] listed 31 serious games that aim to teach social interaction. We separated those games into two groups: the first group was composed of 15 games that teach social skills, such as joint attention, collaboration or adaptation to social context; and the other group included 16 games that teach emotion recognition.
and production. Regarding the games to teach social skills, half of them try to teach collaboration due to ICTs that force collaboration. The other half uses virtual reality to work on how a player must adapt to a given context (e.g. how to sit in a restaurant) [18]. In the second group, a large part of the serious games focus only on emotion recognition. Although emotion recognition is multimodal in nature [19], most of these games only propose static visual stimuli. Four games try to teach emotion production, but only one of them aims to train this skill in a social situation [20]. Of the 31 games reviewed, we found that only a minority included a study trying to assess the clinical interest of the game with evidence-based methodology [17]. In Table 1, we summarize, for both domains (social skills training and emotion recognition), the games that also reported a clinical study. We also added Emotiplay, which is a serious game developed within a European project that was reported recently [21].

Most of the games present limitations regarding the evidence of their clinical benefits. Studies are often conducted with individuals with ASD and high IQs, omitting a large population of individuals with ASD. The studies do not include large samples of patients nor do they have control groups. However, in addition, most of the games are not attractive in terms of design and do not use the large possibilities offered by ICT regarding playability. Most of the games only use static images, do not include virtual environments and do not involve the player as a regular game does. This is particularly the case for the games that target emotion recognition and production, whereas games targeting social skills are often more attractive. However, the games targeting social skills were evaluated with weaker methodologies, contrary to the games targeting emotion recognition and expression. Despite these limitations, we believe that the use of serious games to train people with ASD is promising. Accessibility has not been a major focus but may also impact the way ICT can be used. The GOLIAH team (Table 1) is currently computing a novel version of the game e-GOLIAH that will be able, via a web platform, to provide easy use for families at home in combination with automatic gaming information that will be sent to therapists to follow a child’s progress [32].

The JEMImE project
As said previously regarding serious games that teach emotion, these games usually lack education of emotion production and social context. In this context, we are developing a novel serious game called JEMImE [33], which aims to train facial expression production in social contexts in children with ASD. The game is the next step of JeStimule (Table 1). It is designed to be not only fun and engaging but also to provide the player with several visual indications to understand and progress in the game, such as in the training part, different gauges of emotion that fill with pieces and when they are full, the game stops; and a wallet in the game part; when it’s full, the game stops. The specificity of the game in terms of ICT research is the computation and implementation of an algorithm (Fig. 1a) that provides feedback in real time regarding the quality of the child’s production. This feedback allows the children to correct their productions instantly in response to the colored gauges that represent a specific emotion (Fig. 1b). The performance of the algorithm has been evaluated recently and reached excellent performance, with an average accuracy of 82% [34]. A study evaluating the usability of JEMImE by children with ASD is currently underway. Initially, the results seem to indicate that children have fun playing JEMImE and that they quickly learn how to adapt their productions to meet the expectations of the algorithm. However, we must now develop more social scenarios to significantly increase training duration and settle a clinical study.

AUTISM SPECTRUM DISORDER AND SOCIAL ROBOTS

Generality
The use of robots for people with ASD began 20 years ago, and has specifically increased over the past 10 years [35]. Different robots exist, and their characteristics depend on the research interaction. The robots can take humanoid, nonhumanoid, animal, or biomechanical forms. The possibility of controlling them, their capacities to move, to offer feedback and rewards, and to socially interact do not allow the same type scenario when one wants to settle an experiment or a therapy session with a child–robot interaction [10]. However, what is the purpose of researching the use of a robot with a child with ASD? This is not an easy problem to grasp. However, the literature can be classified as follows: research aiming to induce a targeted behavior, such as joint attention, imitation, emotional expression, or spontaneous interaction; research used to teach special tasks to the children; and less research attempting to study the quality and quantity of interactions between a child and a robot [10], which could help clinicians in their diagnosis [11].

Social robots and autism spectrum disorder
As for serious games, children with autism seem to have greater interest in robots than typical children
Table 1. Description of the main serious games targeting social interaction

<table>
<thead>
<tr>
<th>Games targeting emotion recognition and production</th>
<th>Name</th>
<th>Population</th>
<th>Targeted skills</th>
<th>Design</th>
<th>Playability</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Junior detective program</td>
<td>Children with AS</td>
<td>Emotion recognition and social skills in context</td>
<td>RCT (49 patients)</td>
<td>Game in 3D allowing a good immersive experience</td>
<td>Improvement in social skills after training and at 5 month follow-up</td>
<td></td>
</tr>
<tr>
<td>FaceSay2 [23]</td>
<td>Children with ASD</td>
<td>Facial expression recognition and joint attention</td>
<td>RCT (49 patients)</td>
<td>Static photos not allowing a real game experience</td>
<td>Significant improvement in emotion recognition for the individuals with HF-ASD after training</td>
<td></td>
</tr>
<tr>
<td>JeStimule [24]</td>
<td>Children with ASD</td>
<td>Emotion recognition in context</td>
<td>Open trial (33 patients)</td>
<td>Game in 3D allowing a good immersive experience</td>
<td>Significant effect of session x task x emotion interaction for avatars and near significance for pictures of real-life characters</td>
<td></td>
</tr>
<tr>
<td>Let’s Face it [25]</td>
<td>Children with ASD and AS</td>
<td>Emotion recognition</td>
<td>RCT (42 patients)</td>
<td>Static photographs, not allowing a real game experience</td>
<td>Significant improvement in attention to eyes and mouth in the treatment group</td>
<td></td>
</tr>
<tr>
<td>LifeGame [20]</td>
<td>Individuals with ASD</td>
<td>Emotion recognition and production in context</td>
<td>Qualitative study</td>
<td>Use of an avatar in 3D</td>
<td>Participants enjoyed playing the game. No assessment</td>
<td></td>
</tr>
<tr>
<td>MindReading [26]</td>
<td>Individuals with HF ASD</td>
<td>Emotion recognition in context</td>
<td>2 non-RCTs (experiment 1: 19 children with ASD and 2 control groups with 22 children with ASD and 24 typical children; experiment 2: 13 children in each group – ASD, ASD control and typical control)</td>
<td>Films and written examples, not allowing a real game experience</td>
<td>Improvement in emotion recognition only in close but not distant generalization tasks</td>
<td></td>
</tr>
<tr>
<td>The transporters [27]</td>
<td>Children with ASD</td>
<td>Emotion comprehension in context</td>
<td>non-RCT (56 children)</td>
<td>Series of videos with QCM at the end</td>
<td>Improvement in emotion recognition</td>
<td></td>
</tr>
<tr>
<td>Emotiplay [21*]</td>
<td>Children with HF ASD</td>
<td>Emotion recognition</td>
<td>non-RCT (89 children)</td>
<td>3D environment and short games with photos</td>
<td>Improvement in all emotion recognition measures and parents reported reductions in autistic symptoms</td>
<td></td>
</tr>
</tbody>
</table>

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<tr>
<th>Games targeting social skills</th>
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<th>Playability</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cooperative Puzzle Game</td>
<td>Children with HF ASD</td>
<td>Collaborative skills</td>
<td>2 open group studies (22 boys with ASD in experiment 1 and 16 boys with ASD in experiment 2)</td>
<td>Puzzle game with enforced collaboration on a multitouch tabletop</td>
<td>Higher number of ‘negotiation moves’</td>
<td></td>
</tr>
<tr>
<td>ECHOES [30]</td>
<td>Children with ASD</td>
<td>Joint attention and symbol use</td>
<td>Open group study (19 children)</td>
<td>Interaction with an avatar who can adapt his responses to the child’s behavior</td>
<td>The children responded significantly more often to the practitioner after the sessions</td>
<td></td>
</tr>
<tr>
<td>Teachtown [31]</td>
<td>Children with ASD</td>
<td>Social, adaptive and emotional skills, language</td>
<td>non-RCT study (40 children)</td>
<td>Software educational program with photos and video. Not an immersive game</td>
<td>The treatment group performed better than the control group on the Brigance Inventory of Early Development, but these differences were not significant</td>
<td></td>
</tr>
<tr>
<td>Goliah [32]</td>
<td>Children with ASD (IQ &gt; 60)</td>
<td>Imitation and joint attention</td>
<td>Study 1: Non-RCT (24 patients); Study 2: Open 6-month study with EEG correlates</td>
<td>Short tasks with enforced collaboration on 2 tabletops connected to each other</td>
<td>Improvement in both groups with no significant superiority of the training group</td>
<td></td>
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</tbody>
</table>

AS, Asperger syndrome; ASD, autism spectrum disorders; HF, high functioning.
Robots present some characteristics that make them less anxiety-inducing for people with ASD. They interact in a simple manner and make social situations less complex. This is why researchers focus their experiments on robots and children with ASD in order to work on social and communication skills. These researchers generally target joint attention, imitation, and social behavior, and less often language. Very few studies have focused on the reduction in stereotypes, but the results are actually promising. Given the number of experiments and robotics platforms, it is not within the scope of this brief review to summarize all the literature. At a glance, Table 2 presents the main
<table>
<thead>
<tr>
<th>Robots</th>
<th>Description</th>
<th>Targeted skills</th>
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<tbody>
<tr>
<td>Nao [39–53]</td>
<td>50 cm tall, 25 degrees of freedom, 2 cameras, Microphones, Speakers, Touch sensors, LEDS, Sonars, Wi-Fi and ethernet connection</td>
<td>Joint attention, Imitation, Turn taking, Eye contact, Pointing, Basic academic skills, Facial expressions, Verbal communication, Improve spontaneous social interaction, Improve robot responses to children’s affective state and engagement</td>
</tr>
<tr>
<td>Kaspar [54*,55,56,57]</td>
<td>Semiautonomous, Software allows creation of new scenarios, Child sized, Touch sensors, Head, arm and hand movements, Customizable, Speaker</td>
<td>Support interaction, Support simple facial and body expressions, gestures and speech, Learn about socially acceptable tactile interaction, Imitation, Turn taking, Collaboration skills, Hygiene or food learning</td>
</tr>
<tr>
<td>Charlie [58]</td>
<td>Low cost (200 USD), 2 degrees of freedom in arms, 2 degrees of freedom in the head, 1 webcam, 1 speaker, Can be connected to a PC via USB, Can detect hands and head</td>
<td>Joint attention, Imitation, Turn taking</td>
</tr>
<tr>
<td>TEO4 [59]</td>
<td>80 cm tall, 2.5 h autonomy, Possibility to stick different faces magnetically, Dedicated to children with ASD, Distance sensors, Touch sensors, 1 camera, Autonomous reactions but can also be driven by an operator, Can move and speak</td>
<td>Teo was used in the krog project [60] as a companion for the child during game sessions on a large screen. It reacts when it is touched.</td>
</tr>
<tr>
<td>Riby [59]</td>
<td>The new version of the TEO robot, Dedicated to adults with ASD, 130 cm tall, Sonar sensors</td>
<td>Engaging interaction</td>
</tr>
<tr>
<td>Robots</td>
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</tbody>
</table>
| R50-Alice « Mina » [41,61] | 69 cm tall  
32 degrees of freedom with 11 degrees of freedom in the head of which 8 are for facial expression and 3 are for neck movements  
Speaker | Facial expression production  
Facial expression recognition  
Imitation |
| QT Robot [62]   | Screen as his face  
14 degrees of freedom for upper-body gestures  
3d camera  
1 microphone  
Connection by Wi-Fi | Training emotional abilities  
Body language  
Increasing the efficiency of therapy by encouraging an active and engaged interaction |
| IRobiQ [63]     | 45 cm tall  
Speakers  
1 touch screen  
Touch sensors  
Sonars sensors  
IR sensors  
1 RGB camera in the head  
LEDS | IRobiQ showed the following four emotions with the different shapes of its mouth: happiness, sadness, surprise, and shyness. It is a commercial robot that had access to many children’s songs that were accompanied by adjustable arm movements |
| CARO [63]       | 93 cm tall  
1 touch screen  
Touch sensors  
Depth camera  
RGB camera  
LEDS | Caro is specially designed to engage in emotional interplay that is focused on emotions that are expressed through the eyes of children with ASD |
| KiliRo [64,65]  | Semiautonomous  
2 degrees of freedom in each leg  
Head can move down, up, right and left  
Tail can move right and left  
One speaker attached on the robot | Improves learning and social interaction abilities |
robots used in relation to autism in 2017 and 2018. Previous studies were reviewed in [9–11,38*].

Some studies reported that the maximum child engagement appears with nonhumanoid robots. However, humanoid robots elicit a better generalization of the skills learned by the child during the child–robot interaction [66]. A key limitation in the use of robotics is the fact that most of the interactions provided thus far are similar to the wizard of Oz, meaning that an operator is teleoperating the robot during the child–robot interaction [10]. In comparison with serious games, the clinical application of robotics in ASD is still limited, although progress has been great in recent years. An interesting achievement is the formulation of a deep learning algorithm for the automatic perception of the affective state and engagement of children during robot-assisted autism therapy that can offer a better tailored robot response to tackle the heterogeneity among individuals with ASD [53].

The Michelangelo project

The FP7 Michelangelo project is a European project involving partners in Malta, the UK, Ireland, Italy, and France. One task was dedicated to the design of GOLIAH – a serious game that aims to improve joint attention and imitation that was based on the Early Start Denver Model agenda [67]. Two experiments were also performed to investigate scenarios for controlled social interactions between children with ASD and the Nao robot. The first experiment was designed to induce the behavior of joint attention with the child. Nao proposed different behaviors to solicit a response from the child: the robot could look at a picture, look at it and point it, or point to it and ask the child to look at it. During the experiment, automatic measures were collected with three-dimensional (3D) cameras, and specific algorithms were used to assess the child's movements. The results showed that, contrary to some expectations, children with ASD more easily produced joint attention behavior with a human partner than with Nao. However, the experiment showed us that children with autism produce more micromovements and are more unstable in their posture than typical children [51]. The second experiment targeted motor imitation and imitation learning. Children had to imitate movements that the robot produced randomly. The robot was able to recognize when

![Figure 2](image-url)
he/she was imitating. After 2 min of interaction, the robot learned to imitate, and the two roles could be exchanged: the child proposed the movement and the robot imitated him (Fig. 2). When we compared how the robot was able to learn with adults, with typically developing children, and with children with ASD, we found that, despite adequate learning in the three groups of partners, the number of computational neurons recruited to allow learning increased significantly during interaction involving children with ASD [52]. In other words, it seems that the robot was able to identify a form of social signature in ASD children motricity.

To conclude, regarding robotics, the use of robots with ASD individuals seems to be relevant to research on social and communication skills. A recent review found that participants with ASD often show better performance when interacting with a robot than when interacting with a human [38]. Individuals with ASD demonstrate some social skills with robots that typical children only use with humans. However, even if some researchers are optimistic, the studies published so far indicate that autonomous interactions between robots and children remain limited [10]. Moreover, most studies included very few children and were not adequately powered to show a possible generalization of the targeted skills.

CONCLUSION

The use of ICT for individuals with ASD has increased over the past 10 years. ICTs present some characteristics, such as predictability, visual support, and a sequential presentation of information, which particularly align with the interest and needs of individuals with ASD. Moreover, children with ASD have a specific need for these supports. Equally, ICTs are particularly adapted to work on social and communication skills, such as imitation, joint attention, emotion production, and recognition, which are impaired in ASD. ICTs offer clinicians new ways to interact and work with people with ASD. Serious games and robots are two different support mechanisms that are particularly promising in terms of research, although the former domain has reached better clinical achievements than the latter one. However, the lack of robust studies with strong methodologies and the lack of proof for generalization do not allow evaluation of the benefits of ICT interventions in individuals with ASD.

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Conflicts of interest

There are no conflicts of interest.

REFERENCES AND RECOMMENDED READING

Papers of particular interest, published within the annual period of review, have been highlighted as:

• of special interest

• of outstanding interest


This review lists 31 serious games to teach social skills and proposes two different scales to evaluate serious game on methodology and on playability.
ICT and autism care Crossard et al.


This review resumed the different social robots use in ASD, their application, and the remaining questions.


