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# Multitouch Tabletop Technology for People with Autism Spectrum Disorder: A review of the Literature

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**Abstract**

Autism Spectrum Disorder (ASD) is a set of developmental disorders involving impairments in languages, cognitive, and social functions. Computer technologies such as affective computing, virtual reality, robotics and multitouch interfaces have been developed to support people with ASD. These innovative technologies, alone or in conjunction, can be used beneficially in a number of critical areas affecting individuals with autism, their families and professional who support them. This paper considers and reflects on existing researches on multitouch tabletop technology for ASD and identifies opportunities and challenges with designing and applying multitouch tabletop applications for people with ASD.



*Keywords:* Autism Spectrum Disorder; tabletop interfaces; multitouch; social skills; collaboration; communication; learning.

## 1. Introduction

Autism Spectrum Disorder (ASD) is a set of neurodevelopmental disorder characterised by impairment in social interaction, communication skills and in behaviour, which is restricted and repetitive [1]. ASD include three categories: Autistic disorder (also called “classic” autism), Asperger syndrome, and Pervasive Developmental Disorder – Not Otherwise Specified (PDD-NOS or atypical autism). Because the behaviour spectrum is continuous, boundaries between categories are somewhat arbitrary. Sometimes it is divided into low-, medium-, and high- functioning autism based on IQ thresholds, or on how much support the individual requires in daily life.

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Innovative technologies such as Eye Toy, Dance Dance Revolution, Wii, Diamond Table and Kinect have potential in training different skills (e.g. balancing, communication, motor skills) for individuals with ASD. Computer is popular and preferable among people with ASD because it is predictable, consistent, free from social demands and specific in focus of attention [2]. Therefore computer-based applications are considered to be useful tools for therapeutic and educational purposes. For example, applications have been developed to train social skills [3]. They can work on their own pace and level of understanding. Lessons can be repeated many times. They can maintain interest and motivation because the applications can provide personalized feedback [4].

In recent years multitouch tabletop interfaces have become available. They are large touch displays placed horizontally which allows multiple users' input simultaneously. This technology affords multiuser "cooperative gestures" as a new modality of interaction. The system interprets gestures of more than one co-located users as contributing to a single, combined command [5].

In this paper we review existing research on the use of multitouch tabletop technology for people with ASD. We argue that the potential of multitouch technology has been under-explored in our research community. Based on the review, we discussed possible research opportunities for future projects.

## 2. Affordance of Multitouch tabletop technology

Multitouch tabletop interface is a relatively new paradigm in human computer interaction. It is one of the post-WIMP (Window, Icon, Menu and Pointer) technologies that provide a shared interface to support interaction among co-located users. Post-WIMP interfaces are considered to be more natural and intuitive than traditional WIMP interfaces. Such technologies provide more opportunities for flexible collaboration compared with traditional WIMP interfaces through allowing face-to-face interaction and multiple simultaneous inputs from several users. Fingertip actions are highly visible and hence observable by others, increasing opportunities for building situational and peripheral awareness. Studies have shown that users find it more comfortable working together, hence more communication and participation, around a multitouch tabletop compared with sitting in front of a PC or standing in a line in front of a vertical display [6]. Applications designed to run on some tabletop surfaces have the ability to require user-specific actions and cooperative actions [7].

The characteristics of multitouch tabletop have advantages over traditional computers with mouse and keyboard. These characteristics provide special affordance for interactions.

- Touch screen allows for direct manipulation of digital objects on the surface. It also provides possibility of non-verbal and gestural communication.
- Large physical space allows for face-to-face interaction among multiple users. It is also more inviting and allows users to interact with larger shapes and more objects compared with smaller screens (e.g. iPad).
- Multitouch allows for simultaneous manipulation of objects. It is suitable to support tasks and situations where social skills are important.
- Tabletop supports intuitive and natural interactions and allows for rough motor skills and imprecise manipulation. It is advantageous compared with mouse pointer.

People with ASD vary in sensory tolerance and motor ability levels. For those who have motor coordination difficulties, traditional mouse and keyboard setup has an additional barrier between the users and on-screen objects. The direct touch input of tabletop technology has advantages because it allows individualised and unmediated control over the interface.

## 3. Multitouch tabletop hardware

Today there are several major tabletop hardware platforms such as SmartBoard, DiamondTouch, Microsoft Surface, and tabletops based on FTIR (Frustrated Total internal Reflection). In this section we describe those

that have been used to develop applications for people with special needs. We aim to provide readers with a brief overview of these hardware platforms that are relevant to this paper.

### *3.1. DiamondTouch table*

DiamondTouch was developed in Mitsubishi Electric Research laboratories in 2001 [8]. It is a multi-user touch technology for tabletop front-projected displays which allows multiple and simultaneous touches. The environment consists of a ceiling-mounted video projector displaying onto a white table around which up to 4 users sit.

DiamondTouch table has been used in several studies concerning interaction and collaboration [9]. This device has also been used in researches involving children with high-functional autistic disorder [10,11]. Shen, et al. [12] developed DiamondSpin tabletop user interface toolkit for DiamondTouch table, which has been used to develop some applications on DiamondTouch table.

The main advantages of DiamondTouch table are: 1. It enables up to 4 users' touch input simultaneously; 2. It distinguishes between users and provides feedback on an individual basis [7]; 3. Objects left on the surface do not interfere with normal operations. Disadvantage with DiamondTouch table includes: 1. It requires users to remain seated and does not allow the involvement of facilitator, therapist or parent unless she or he is one of the four users; 2. The size of the table (107 cm diagonally) is not suitable for children because their arms are not long enough to access to the opposite side of the table while remain seated. 3. Users must be careful not to bump the table in order to maintain the alignment between the ceiling-mounted projector (static) and the table [11].

DiamondTouch table was found a promising medium for social competence training for children with ASD. However, there are some technical challenges that need to be addressed before it can have impact on larger special needs populations.

### *3.2. FTIR tables*

FTIR (Frustrated Total Internal Reflection) is a technology well known in the biometrics community for fingerprint image acquisition. It has been used to enable robust multitouch sensing at a minimum of engineering effort and expense [13]. Using infrared light (IR) and IR-sensitive camera combined with the FTIR technology, it is possible to detect the finger touches on a glass or acrylic surface.

The relatively low cost of the solution and the freely available libraries has made FTIR a popular choice for multitouch tabletop researchers. Because the tables are usually self-made and customized to the target users, their sizes are more suitable for the users. In addition, the projectors in the FTIR tables are under the table surfaces. Compared with the DiamondTouch tables which have the projector mounted on the ceiling, it is easier for FTIR tables to maintain the alignment between the projector and the table surface, thus makes the table more robust and mobile. One disadvantage of FTIR table is that it does not automatically identify different users.

## 4. Multitouch tabletop technology and ASD

The affordance of tabletop technology has inspired researchers to explore their potentials for educational purposes. Educational games on tabletops such as MatchingTable, PoetryTable [12] and ClassificationTable [7] have been developed to support collaborative language learning.

Researchers have also explored how multitouch tabletop technology can support people with special needs, especially those with impairment in social interaction and communication skills. Applications using tabletop technology have been developed to support social skill training and collaborative interaction among children

and adolescents with ASD. In this section we review five main research efforts aiming at using multitouch tabletop technology to help people with ASD.

### *4.1. SIDES*

SIDES (Shared Interfaces to Develop Effective Social Skills) is one of the pioneer projects exploring the use of tabletop technology to teach social skills [11]. A four-player cooperative tabletop game was developed to help children with Asperger syndrome practice effective group work skills such as negotiation, turn-taking, active listening and perspective-taking. The game was developed on a DiamondTouch table.

The project took a participatory design approach and involved students and adults with Asperger syndrome, social skills therapists and parents of children with Asperger syndrome. Observations and field studies were used to identify problems and evaluate prototypes. The project conducted two evaluations with resign and further development in between. Data were collected using observation, note taking, logging and video recording and in the second evaluation conversation analysis was conducted to evaluate group performance. The participants for the evaluations are students from a middle school social group therapy class. Because the DiamondTouch table was difficult to transport to a testing site, the evaluations were conducted in the university lab.

The first evaluation aimed to assess the appropriateness of tabletop technology for the target users. Five male students participated in the first evaluation (average age 12.6 years), among which three are adolescent boys clinically diagnosed with Asperger syndrome, one with Apraxia and one with Klinefelter's syndrome. The second evaluation focused on how the target users responded to computer versus human-enforced rules and how the elements of the design impact performance. Two groups of students participated in this evaluation. Group 1 consisted 4 male students from the first evaluation (average age 12.5 years), among whom two were adolescent boys with Asperger syndrome, one with Apraxia and one with Klinefelter's syndrome. Group 2 consisted of four students (average age 12.8 years), among which three male and one female. Two were clinically diagnosed with Asperger syndrome, one with Asperger and ADHD and one with high-functioning Autism. Each group played 4 rounds with different conditions: no rules (2 rounds), human-enforced rules, computer-enforced rules. These conditions are played in different orders. The results indicated that multitouch tabletop games could provide engaging experience and help adolescents with Asperger syndrome to build confidence in the social interaction.

### *4.2. Collaborative Puzzle Game (CPG)*

The Collaborative Puzzle Game [14] is developed on a DiamondTouch table. It aims to study collaboration and social abilities in dyads consisting of children with Autism Spectrum Disorder as well as to test the feasibility of the system as an instrument for the rehabilitation of social abilities of boys with ASD. The CPG allows for enforced collaboration, an interaction paradigm which takes advantage of the DiamondTouch table's ability to support multiple users' simultaneous actions. In enforced collaboration, actions on digital objects can only be performed through the simultaneous touch of two or more users.

The puzzle game resembles a traditional jigsaw puzzle with the only difference being that pieces have a rectangular shape instead of the traditional interlocking curved shape. Users can play the game in two conditions: Joint Play condition where enforced collaboration is active and puzzle pieces can be moved to the solution area only by means of a joint drag-and-drop action; Free Play condition where users can move puzzle pieces individually.

A series of user testing and case studies focusing on the usability and the effect of enforced collaboration have been conducted with both typically developing children and children with ASD since 2007 [10,15,16]. Two most recent studies were reported in [14]. Study 1 involved typically developing boys aged 8-11 years

working in pairs to complete one 16-piece puzzle in either enforced collaboration or free play condition. Study 2 involved 16 boys aged 8-18 years who were diagnosed with ASD. 10 out of the 16 boys were described as low-functioning and 6 high-functioning. The children were paired based on their cognitive skills. All pairs played in both enforced collaboration and free play conditions. Both studies are conducted in familiar environments for children, either in schools or in centres for after-school activities. Based on the log file provided by the system, a number of quantitative measures have been used to provide indicators for task complexity, level of engagement of participants in the activity, and proportions between users' behaviours that effectively contribute to the task and others that are more related to the interaction and negotiation between participants. Results suggest that EC has a generally positive effect on collaboration and is associated with more complex interactions. For children with ASD, the EC interaction rule was effective in triggering behaviours associated with co-ordination of the task and negotiation. The results from Study 2 confirmed the finding from earlier study [11] that children with ASD may benefit from the presences of rules that shape interaction in order to solve the task.

### *4.3. Raketeer*

Raketeer [17] is a game developed on a multitouch table to teach collaboration skills to children with PDD-NOS. The game consists of six levels with different mathematical problems. Through the six levels, children in pairs have to collect parts for the rocket, collect inventory, mix fuel and defend their rocket to ensure its launch by solving equations. The levels represent different basic collaboration skills with which PDD-NOS children have difficulties. These skills include waiting for turn, handing mistakes of others, receiving criticism, sharing goals, tasks and objects, discussing tasks with others, and realizing one's actions having consequences for others.

Players are rewarded with math points and buddy bonus. Math points are rewarded when players solve an equation correctly. Buddy bonus is awarded for collaborative behaviours such as waiting for turn or sharing. Before the game, teachers can choose the appropriate difficulty of the equations for players based on their mathematical abilities. The game logs all the scores, equations and answers. After each level, depending on the total score, a player can receive a promotion to the next level. However, both players have to be promoted in order to move to the next level.

Raketeer was tested at an elementary school for special education. 13 boys and one girl aged 8-12 years played a session of 20 minutes every day during 4 weeks. Average playtime was 2 hours and 35 minutes. The teacher rated the mathematical abilities and collaboration skills before and after the test. During teacher interview, children's behaviours during play and in classroom were evaluated by the teachers. There was mixed results when comparing the pre- and post-experiment mathematical abilities. Average scores in all collaborative skills are higher after the experiment, which indicated the improvement of social behaviour. However, interviewing with teachers showed little behavioural transfer to classrooms – only one participant showed significant improvement of social skills in the classroom.

### *4.4. Join-In Suite*

Join-In-Suite [18] is a 3-user application implemented on DiamondTouch table to support therapists in their use of Cognitive-Behavioural Therapy (CBT) to improve the social competence of children with high-functioning ASD. CBT views social competence as a multidimensional concept and assumes reciprocity between the ways an individual thinks, feels and behaves in social situations. The design of Join-In-Suite explored different types of collaborative interaction patterns (e.g. choosing together, constraints on objects, different role, ownership) and reflects these patterns in the three games: the Apple Orchard game, the Save the Alien game and the Bridge game. Each of the game implemented a different intervention task. The Apple

Orchard game focused on joint performance, the Save the Alien game focused on mutual planning and the Bridge game focused on sharing. Each game consisted of two parts: a learning part which realizes a structured version of the CBT's social problem solving technique and an experience part based on the CBT's behavioural reinforcement technique.

A field study was conducted in a mainstream primary school, which has three special classes for children with ASD. Eight boys with high-functioning ASD, aged 9-12 years participated in the study. The goal was to obtain deeper insight into the effectiveness of Join-In-Suite in providing support for a CBT session. Each session lasted about one hour and involved two children who played the three games and one therapist who facilitated the collaboration. All sessions are video-taped with two cameras, one facing the children to record the peer interaction and the other facing the table to record the operations on the interface. After each session there was a debriefing with the children and interview with the therapist. In addition, two usability questionnaires were used: the Intrinsic Motivation Inventory was answered by the children and the System Usability Scale was answered by the therapists.

A quantitative analysis was conducted based on the answers to the questionnaires. The results showed that children enjoyed the different parts of the scenarios (learning and experience), responded appropriately to the different collaboration strategies and showed clear preferences for two of the three games [19]. A qualitative analysis was conducted based on the field note, video recording and interviews. Adaptability, efficacy and efficiency were evaluated from the facilitator's point of view. Playability, level of engagement and collaborative strategies were investigated from the children's point of view. Among other findings, this study also confirmed the results from earlier studies that children with high-functioning ASD benefit from constraints embedded in the system [11]. The study results in a number of lessons learned when designing games for therapeutic intervention.

### *4.5. Trollskogen (The Troll Forest)*

Trollskogen [20] is the most recent research published exploring tabletop technology for children with autism. A range of small software applications, also called "micro applications" is developed on a purpose-built multitouch tabletop. The main interface depicts a forest setting where mushroom icons represent different micro applications. Each micro application is aimed to improve, strengthen, or exercise one or more particular aspects of communication skills.

Four micro applications were used in user testing. The Forest Cabin Program uses social stories to reinforce and strengthen behaviours in social situations. Children are to explore the social situations and exercise social skills. The Dancing Troll Program and Talking Symbols are to help children with speaking and written language. The former allows children to use microphone input to trigger, control and manipulate different animation sequences of an animated troll figure. This is to help children improve intonation and enunciation by promoting muscular growth in the mouth. The latter uses virtual pictograms – a pictographic language that uses symbols based on pictures of objects instead of letters. Children can place these symbols on the table and move them to form sentences. The program can speak out each word in the sentence while highlighting each of them during the process. The Finger Paint Program allows children to use fingers to creatively paint stories on the table using forest characters provided by the program. The stories made in the Finger Paint program can be printed out for parents and caregivers.

The research also adopted a participatory design approach. Throughout the project, six children (5-8 years) diagnosed with ASD or Down's syndrome have been involved as well as teachers, parents and caregivers. These children were also participated in the preliminary user testing. The testing was conducted in a classroom setting with two steps. In the first step all children explore the system together. In the second, each individual child together with the teacher interacted with the four micro applications. After each session, the researchers discussed the process with both the teacher and the child. Based on the observation and discussion with

children and teachers, it is concluded that the system was well received by both children and teachers. Some of the programs, especially the Finger Paint program was found most engaging. In addition, the testing provided clues for further improvement of the system.

## 5. Challenges and Opportunities

Table 1 and 2 summarize existing research on using multitouch tabletop technology for people with ASD. Most of the applications are developed for children and early adolescents and target on high-functioning autism without difficulties in motor coordination, verbal communication or visual motor integration. These applications mainly focus on social skills training. Out of the five applications, three of them were developed based on DiamondTouch table.

The design and development of the applications takes mainly participatory design approach, involving target users, teachers, parents, therapist or caregivers. Most of the applications have gone through several iterations incorporating feedback from stakeholders between iterations. Several of the applications provided possibilities for teachers or facilitators to customize the system configuration based on the children's abilities.

As for user testing and evaluation of these applications, most of them aimed to test the usability and user satisfaction. Some evaluated the effects of interventions on social skills. However, since most of the evaluations were conducted in one session (except for Raketteer which ran for 4 weeks), the findings on improvement of social skills are not conclusive.

Table 1. Overview of projects

| Projects | Targeted disorder | Targeted skills | Table |
|---|---|---|---|
| SIDES | Asperger syndrome | Social skills | DiamondTouch |
| Collaborative Puzzle Game | Moderate severity Autism | Collaboration and social skills | DiamondTouch |
| Raketeer | PDD-NOS | Collaborative skills | Not specified |
| Just-in Suite | High-functional autism | Social competence | DiamondTouch |
| Trollskogen | Autism Spectrum Disorder | Social communication skills, and language skills | Purpose-built table |

Table 2. Overview of evaluation in projects

| Projects | Study Focus | Participants | Length | Setting | Data Collection Method |
|---|---|---|---|---|---|
| SIDES | Usability and skills development | 7 boys and 1 girl, 12 years old | 4 rounds of game | 4 in a group | Observation, video, conversation analysis |
| Collaborative Puzzle Game | Usability and effect of enforced collaboration | 16 boys 8-18 years old | 2 16-piece puzzle | Pair | Observation, log, |
| Raketeer | Mathematic and collaborative skills | 13 boys and 1 girl, 8-12 years old | 2 hours and 35 minutes over 4 weeks | Pair | Pre- and post- rating, observation, interview |
| Join-In Suite | Usability and user (children and therapist) experience | 8 boys, 9-12 years old | 1 hour | Pair with one facilitator | Observation, video, interview, questionnaire |
| Trollskogen | Usability | 6 children 5-8 years old | Non specified | Individual with teacher | Observation, discussion |

The manifestations of autism covers a wide spectrum, ranging from individuals with severe impairments

who may be silent, aloof, of low IQ, and locked into rocking and hand clapping – to high functioning individuals with pedantic and verbose communication, an active but odd social approaches, rarefied special interests [21]. The variation of autism calls for interventions supported by different technologies and applications. Based on the summary of existing research which is limited in target user group, application types and intervention methods, we argue that the potentials of multitouch tabletop technology are not yet fully explored. In the remaining of this section, we will discuss some opportunities and challenges of such technology for people with ASD.

### *5.1. Applications for wider user groups*

Existing research focused mainly on high-functioning children and adolescent with social impairment. Adults who have grown up with an autism diagnosis also face many challenges. For example, difficulties with social cognition (the ability to understand social cues) can often prevent adults with autism from participating in communities and functioning in jobs, which are suitable to their skills and knowledge. Better interventions are required to help them develop skills to understand social interactions. We believe that tabletop technology can play an important role in helping adults with autism. For example, multitouch tabletop games can also be developed to help adults with ASD develop social skills. For adults with motor coordination difficulties, tabletop technology can be a good alternative for desktop computers in their daily living. It is also a challenging task to develop multitouch applications for people with severe impairment in cognitive and motor skills.

### *5.2. Longitudinal study and transfer of skills*

People with ASD will benefit from well-researched evidence-based practice in school, at home and workplace. So far there is not enough empirical evidence for multitouch tabletop technology. Almost all the research we have reviewed stated that longitudinal studies are necessary. Some of the projects were planning such study.

Feedback from teachers or therapists who participated in the evaluation of the multitouch tabletop applications indicated that there was very little transfer of the social skills to classroom or real life situations. This could be explained by the short time period that the children used the applications. However, more research into the applications and their association with real life social functioning is required.

### *5.3. Combining multitouch tabletop technology with other applications*

Multitouch tabletop applications can be used in conjunction with other technologies. For example, it is well established that emotion recognition and mental state recognition are core difficulties in people with ASD. These underlie their social difficulties. *Mind Reading* is an interactive systematic guide to emotions in teaching individuals with Asperger syndrome [22]. Experiments show that Mind Reading is effective in teaching adults with Asperger syndrome or high-functioning autism to recognise complex emotions. However, the skills they learn through Mind Reading are hard to generalize to real social situations. Multitouch tabletop applications could be considered a real social situation. A well-design tabletop application for communication and collaboration following the Mind Reading sessions will likely be able to help them generalise the emotion recognition skills they have learned. In addition, combing multitouch tabletop applications with tangible objects could provide interaction with both physical and virtual objects, improve motion perception and create better associations with real life situations.

## 6. Conclusion

Innovative technologies carry great promise for enhancing and accelerating the pace of autism research and treatment [23]. Despite of the limited research, evidence does suggest that multitouch tabletop technology is an applicable technology with great potentials for people with ASD. However, we still need to understand how to take advantage of the affordance of this technology to provide the best possible support for individuals with autism, their families and professional who support them. Future projects could pursue enquiry in many directions in order to fully explore the potential of multitouch tabletop technology.

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