Collaborative puzzle game – an interface for studying collaboration and social interaction for children who are typically developed or who have Autistic Spectrum Disorder

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ABSTRACT

In this paper we present the design and some initial observations of the Collaborative Puzzle Game, an interactive play system designed with two main purposes: 1) to study social interactions and collaboration in boys with Autistic Spectrum Disorders and with typical development, and 2) to test the feasibility of the system as an instrument for the rehabilitation of social abilities of boys with ASD. Designed to run on the DiamondTouch, an interactive table supporting multi-user interaction, the CPG allows to implement "enforced collaboration", an interaction paradigm where actions on digital objects that can be performed only through the simultaneous touch of two or more users.

1. INTRODUCTION

1.1 *Autistic Spectrum Disorder*

Autism spectrum disorder (ASD) is a pervasive developmental disorder that is characterized by three main features including 1) a major impairment in social interaction, with difficulties in forming and maintaining social relationships, 2) a qualitative impairment in verbal and nonverbal communication and 3) a restricted repertoire of activities and interests, together with the presence of repetitive behaviours (DSM-IV-TR: APA, 2000). The cognitive and learning abilities of people with ASD can vary from gifted to severely challenged. ASD begins before the age of 3 years and lasts throughout a person's life. It occurs in all racial, ethnic, and socioeconomic groups and is four times more likely to occur in boys than girls. It currently affects approximately of one child in every 150 (ASA, 2008).

The social deficits of individuals with ASD detract from their full participation in school, work, and leisure activities in the community. These deficits are not only a matter of verbal and non-verbal communication difficulties but also include a core impairment, "social cognition". People with ASD are challenged in perceiving the thought processes of other people, which is crucial for understanding the feelings, intentions, and thoughts of others. Social cognition is compromised even in gifted individuals with ASD limiting their occupational opportunities. Rehabilitation efforts focus on finding ways to promote interpersonal skills in people with ASD, who find social interaction with others confusing and uncomfortable (Sigman and Ruskin, 1999). Social skills can be practiced through modelling, coaching, and direct practice of their application.

People with ASD also show certain strengths including visual-spatial abilities which are “an islet of ability” as first observed by Shah and Frith (1983), and confirmed by several experimental studies of visual-spatial tasks such as the block design subset of the Wechsler scale (Shah and Frith, 1993) and other visual search tasks (e.g., Shah and Frith, 1983; Mottron et al., 2003). The visual modality is often used to facilitate learning and independent performance of persons with ASD since such aids and cues can help to organize behaviour, understand task demands, and to sequence actions (Quill, 1997). This is important for individuals whose visual processing is strong relative to auditory processing.

1.2 Computer Intervention for ASD

During the last decade a number of experimental studies were carried out to assess the utility of innovative technologies for people with ASD. These studies were mostly conducted by interdisciplinary teams and considered a variety of different devices and interaction environments, such as virtual reality (Sik Lányi and Tilinger, 2004; Revel et al., 2002; Takahashi et al., 2004), robotics (Dautenhahn, 2003), multimodal interfaces (Bernard-Opitz et al., 2001), handheld devices (e.g. Sano et al., 2002), and collaborative technologies (Piper et al., 2006; Gal et al., 2008). The studies supported their usefulness and effectiveness as a means for supporting and acquiring social and interactional abilities in children with ASD. Children with ASD seem to be highly motivated by computer-based activities (Chen and Bernard-Opitz, 1993; Hart, 2005), and have made significant gains in learning vocabulary (Heimann et al., 1995; Moore and Calvert, 2000), emotional expressions (Silver and Oakes, 2001) and social problem solving (Bernard-Opitz et al., 2001). Moore (1998) suggested that computer interventions appear to be particularly appropriate for people with ASD since focusing on a computer screen, where only necessary information is provided, can help people with ASD to reduce distractions from unnecessary sensory stimuli. Moreover, computers are free from social demands and can provide consistent and predictable responses; this can be particularly useful for people with ASD who often find the surrounding environment confusing and unpredictable.

1.3 Objectives and Structure of the Paper

The objective of this paper is to present the design and some initial observations of the Collaborative Puzzle Game (CPG), an interactive game designed with the purpose of creating a technology-supported collaborative activity for studying collaboration and social skills in children with ASD and with typical development. The target population of the system is boys in an age range that spans from 8 to 11 years for the typically developed, while inclusion of boys with ASD extends to early adolescence, provided that their mental age corresponds to that of younger typically developing children.

The observations we report in the next sections of the paper have thee purposes: 1) to test the general feasibility of the system as an instrument for the study of collaboration both in children with ASD and with typical development and possibly for the enhancement of social abilities; 2) to verify whether the design choices we adopted for the interface (e.g., shape and dimensions of the digital elements of the game, use of audio and visual feedbacks in response of actions performed by players) were appropriate in terms of usability, intuitiveness and enjoyability, and 3) to test if and how a particular interaction paradigm called “enforced collaboration” (described in Section 2.3) has an effect on the way children interact and collaborate on the CPG.

During the design of the system we followed an iterative procedure consisting of the development, testing, and refinement of the interface on the basis of observations made with users. At each stage different groups of boys were involved and observed while playing with the CPG, both individually and in pairs. In Section 2.4 we report the results of a first group of participants who were involved in the selection of the stimulus set. In Section 3 we report on the usability of the system. In Section 4, we summarize two case studies, one with children with typical development and one with children with ASD, conducted after the development of the current version of the CPG interface. Finally, we conclude with a summary of the results to date.

2. COLLABORATIVE PUZZLE GAME

2.1 Hardware

The DiamondTouch Table (DT) is a multi-user, touch-and-gesture-activated screen for supporting small group collaboration produced commercially by Mitsubishi Electrics Research Laboratories (Dietz and Leigh, 2001). Images can be top-projected to its wide horizontal surface through any kind of commercial projector. The DT can determine, through a capacitive coupling system, which part of the surface is being touched and can identify up to four users simultaneously. The system does not require any additional devices, such as pens or stylus, and users can interact directly through finger touch or gestures. Several behavioural and interaction studies have already been conducted using this device involving adults (Everitt et al., 2004; Kobourov et al., 2005; Wang et al., 2005), children (Zancanaro et al., 2007), and children with high functioning autistic disorders (Gal et al, 2008; Piper et al., 2006). These works show the advantages coming from the use of the DT table in interaction studies:

- The big touch screen allows direct manipulation of digital objects on the surface. It also gives the possibility of using larger shapes and objects, or a greater number of objects, as compared to normal screens.
- Its multi-user property allows the simultaneous use of the interface by more than one person. The DT seems to be particularly suited to support tasks and situations in which social abilities and interaction play a major role.
- Being a table-top device, it allows for styles of work and interaction that are very common in scenarios such as the school and clinical environments.

Furthermore, the DT table features a very precise log system that makes it possible to track all the actions performed on the surface, making analysis of interaction much easier. The logs are XML files containing the list of the actions performed, along with information about the experimental condition. A time stamp is associated to each action, making it easy to run temporal analyses on interactions.

2.2 Software

The CPG is an interactive application developed at FBK-irst with the purpose of studying collaboration and social abilities in dyads consisting of children with ASD. The game resembles a traditional jigsaw puzzle (an activity that primarily involves visuo-spatial skills) the only difference being that pieces have a rectangular shape instead of the traditional interlocking curved shape, as shown in Fig. 1. At the beginning of the game, the following objects appear on the table surface: 1) A variable number of puzzle pieces; 2) a target picture shown in the upper part of the DT, which represents how the puzzle looks like once correctly completed; 3) a solution area, positioned in the region of the surface proximal to participants and horizontally centered, which is where pieces have to be dragged to complete the puzzle. The solution area is divided in a number of invisible cells corresponding to the positions where puzzle pieces can be released. The number of the cells corresponds to the total number of pieces.

The experimenter can set the game (e.g., different play conditions, number of pieces, dimensions of the solution area, and the picture to be shown) by means of a settings panel. The actions that players can perform are relatively simple. A puzzle piece can be dragged to a new position (either to the solution area, or away from it). Whenever a piece is released within the solution area, it anchors to the cell of the solution area closest to the releasing position. To remove a piece from the solution area, it is sufficient to drag it away and release it at any other position on the surface. Attempts at releasing a piece over a previously released one end in failure, with the former piece starting again to float around.

Several visual and auditory feedback signals have been implemented to make the interaction more understandable, motivating and fun. When a piece is released in an incorrect position on the solution area, an unpleasant buzz is played and a red halo surrounds the piece until it is removed. A pleasant sounding beep and a green halo (which disappears after a few seconds) are associated with the correct positioning of a piece within the solution area.

2.3 The Enforced Collaboration Paradigm

One of the goals of this study was to investigate in a preliminary way the effect of an interaction paradigm called “Enforced Collaboration” on the way people work together on collaborative tasks. In particular our interest is to focus on its effect on social interaction. Enforced collaboration requires that actions on digital objects (e.g., touch, drag) to be effective must be carried out by two or more users simultaneously. Preliminary investigation with dyads of children with high functioning autism has shown that forcing the simultaneous execution of selected tasks may foster the recognition of the presence of the other, stimulate social behaviour (increased eye contact, emotion sharing, and enhanced interest toward the partner) and improve social skills (Bauminger et al., 2006; Zancanaro et al., 2005; Gal et al., in press).

The enforced collaboration paradigm is realized by taking advantage of the DT table’s capability of supporting multiple-user actions; that is, drag-and-drop, click and double-click that are executed simultaneously by more than one person. Enforced collaboration is active in the Joint Play Condition, in which puzzle pieces can be moved to the solution area only be means of a joint drag-and-drop action. In the Free Play Condition, players can move puzzle pieces individually.

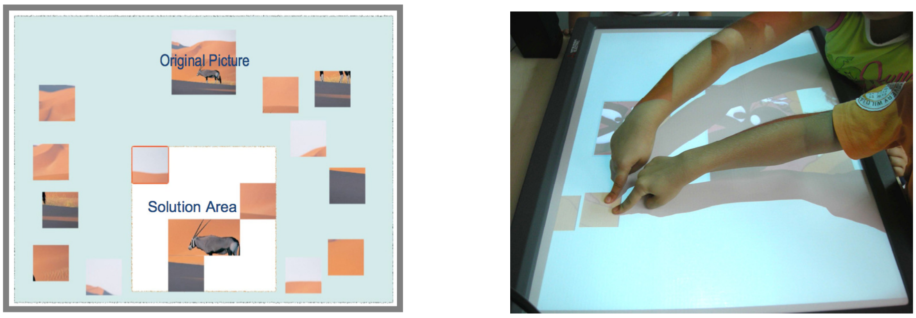

Figure 1. *The Collaborative Puzzle Game interface (left), and an example of a joint action in the "enforced collaboration" condition (right).*

2.4 Selection of Puzzle Pictures

In order to have enough pictures to select from of comparable difficulty, a preliminary study was carried. Six high resolution screen shots were extracted from an animated movie (Shrek 2, chosen during an initial survey of popular children's movies). Pictures taken from animated movies are less complex and have clearer discontinuities and contrast among the represented objects in comparison to real photographs. The pictures were edited to get the optimal size, brightness and contrast for the digital puzzle.

Fourteen typically developed Israeli boys (mean age = 9.9 years, SD = 0.77), were asked to individually complete six puzzles corresponding to the six pictures, using the CPG interface in the free play condition. The picture order was random. Complexity was defined in terms of puzzle completion time, number of errors made before correct completion, and by means of the subjective perception of difficulty rated on a ten-point Likert scale. The design was within-subject with a six-level factor (picture) and three dependent variables; age was treated as a covariate. Since no significant effects were detected by the multivariate test (MANOVA with repeated measures), the complete set of six pictures was retained.

3. USER TESTING

3.1 Objective

We conducted user studies to probe the usability of the CPG.

3.2 Participants

Twenty-two boys with typical development, aged 8 to 11 years, and three boys with ASD, aged 13 to 15 years participated in the development stage of the CPG interface. Children with ASD were diagnosed using the Autism Observation Diagnostic Scale (ADOS), had a good level of verbal communication and an IQ at the lower end of the normal range.

3.3 Procedure

All boys first engaged in an individual training phase when they completed one 16-piece puzzle. During this practice phase, the experimenter provided clarification about the on-screen digital objects and demonstrated how to interact with the interface. During the subsequent study phase, the boys played in pairs, completing two 16-piece puzzles, one after the other. In the typically developing group, six pairs played using the "enforced collaboration" condition and five pairs played using the "free play" condition. The boys with ASD (A, B and C) were paired two of them at a time such that three pairs were formed (A+B, A+C, and B+C). Each pair played completed one puzzle using "enforced collaboration" and one using the "free play" modality. All sessions were video-taped. After the sessions, the experimenter interviewed the children about their experience, probing the level of involvement and enjoyment, the difficulty/ease of use, comparisons with non-technological cardboard puzzles, willingness to play again with the CPG in the future.

3.4 Results

Both typically developing children and those with ASD appeared to find the interface enjoyable, highly intuitive, and to understand quite quickly how to interact with the elements of the CPG, often prior to an explicit explanations. As expected, the "enforced collaboration" condition made the interaction more complex, as demonstrated by longer completion times. However, none of the children found that joint actions interfered with the task, and they showed a good level of engagement. In no case did they express the desire to quit the CPG because it was boring or difficult. The use of joint actions appeared to stimulate task-related conversation, both among children with ASD and those with typical development. During the interaction, children invited their peer to join them in dragging a piece they had selected (e.g., "Let's move this one that goes there") or, as we observed in an interaction of one pair of children with ASD, to prompt working together (e.g., "Come on… help me with this, we need to do it together").

One complication was due to the way the audio-visual feedback was used. Children with ASD seemed to use feedback as planned, that is, as an aid in detecting wrongly positioned pieces. Children with typical development, however, used the negative feedback to engage in a "trial and error" process to complete the puzzle, relying more on the feedback than on their own judgment to find the correct placement of pieces. This strategy was clearly not present when feedback was not provided and children had to base their choice on comparison with the target picture. This observation led to a modification of the setting panel of the CPG such that it is now possible to independently deactivate audio or visual feedback.

4. CASE STUDIES

4.1 Objectives

In order to obtain initial data about relevant behavioural patterns emerging during the joint interaction with the CPG, a study was conducted to focus on collaboration, verbal and non-verbal indicators of social behaviour, as well as on the identification of behaviours typical for individuals with ASD that might emerge during the collaborative game.

4.2 Participants

Two pairs of boys, one with typical development and the other with ASD, participated. The boys with ASD were recruited from an afterschool program designed for children with ASD. Inclusion criteria included intact visual acuity (with corrective glasses if needed), field and intact hearing, a score ranging from 29.5 to 36.5, corresponding to a moderate severity of ASD on the *Childhood Autism Rating Scale* (CARS, Schopler et al., 1980), corresponding to a moderate severity of ASD. The parents reported that the two boys, O. (10 years) and I. (12 years), used computer games on a regular basis, did not like being stopped during such an activity, but did not have an unusual special interest in puzzles. Based on the *Beery-Buktenica Developmental Test of Visual-Motor Integration (VMI 5th ed.)*, O. showed good visual perception skills but poor motor coordination and visual motor integration skills, while I. had strong visual motor integration skills.

4.3 Procedure

Both pairs of boys completed two 16-piece puzzles in the "enforced collaboration" condition. Before the session, each boy completed one puzzle individually and was instructed, when needed, about how to interact with the interface. In the session when boys with typical development were involved, audio and visual feedback were deactivated, in order to avoid the "trial and error" strategy previously observed; when children with ASD used the CPG, feedback was activated. All sessions were videotaped.

4.4 Typically Developed Pair

The two typically developing boys (R. and B., 10 and 10,5 years old respectively) completed the two puzzles in 4.55 minutes; the number of actions initiated by the two boys was similar and decreased from the first puzzle (R. = 18, B. = 17) to the second one (R. = 12, B. = 12), showing evidence of learning while playing with the CPG. Most of the actions were suggested by R., who pointed to a specific puzzle piece before touching it or letting B. be the first to touch it. The leading role of R. was particularly evident since most of the actions were accompanied by his verbal hints. However, as the game proceeded, a balance between the actions initiated by the two players could be observed together with a "spatial specialization": the boys tended to contribute to the completion of the puzzle by picking up pieces that were closer to them than to their peer, suggesting a form of collaboration based on division of territory.

The two boys communicated verbally in order to negotiate whether R. or B.'s choice would be acted upon. For instance R. said: "No, no, let's take this one". R. joined B.'s initiated actions primarily when his own were unsuccessful. When R. did not agree with B.'s selection he verbalized this (e.g., "Wait a second, let's try this piece"). B. was less verbal than R. and spoke in a lower tone. He tended to pause to wait for R. to collaborate rather than trying to convince him to accept his choice. When R. resisted, B. tried to persuade him verbally (e.g., “Believe me, this is right”). A considerable amount of non-verbal interaction, such as visually tracking of the other’s actions, waiting for the other to join the action, smiling, could be observed.

4.5 Pair with ASD

Throughout the experiment O. was non-verbal, made minimal eye contact, and usually showed neutral facial expression. He was task-oriented and did not express frustration. I. used single words and non-words during the experiment as well as high pitched sounds. He understood the task instructions once they were written. I. made minimal eye-contact and his affect was neutral to negative throughout. He was easily distracted by sounds and covered his ears after the auditory feedback he received from the table and adult upon completing the puzzle. “I” frequently bit his hand and covered his mouth particularly when he was frustrated by not succeeding to move a puzzle piece.

It took them 7.68 minutes to complete the two puzzles Overall the pair with ASD made almost twice as many actions (touch + release) in comparison to the typical pair. The number of action initiations was quite balanced between the two boys but only I. showed a decrease during the second puzzle, i.e., his selection of puzzle pieces became more effective. These data were confirmed by the higher ratio between correct and incorrect releases shown by I. (28/6) in comparison to O. (26/17).

Initially the two boys engaged in parallel attempts to move the puzzle pieces without attending to each other’s actions. Occasionally one of the boys would try to move the other boy’s hand away from the puzzle pieces in order to move the piece he wanted. In the same way observed for typically developing children, as the session proceeded, a gradual increase in spontaneous collaboration efforts was observed. This was apparent by a decrease in adult directed instructions (e.g. “work together”) and by an increase in responses to each other’s initiations. While I. rarely responded to O.’s initiations, after several verbal prompts to touch the puzzle pieces together by the adult, O. began to more consistently respond to I.’s actions and reduced his own initiations.

Individual characteristics that contributed to the pair’s performance included O.’s ability to stay on-task and to be flexible in problem solving (i.e., using several fingers, two hands) and in joining I. I.’s strong visual motor integration skills enabled him to persist in initiating correct actions but his high distractibility and sensory sensitivity compromised his level of participation in the task.

4.5 Comparison of interaction patterns

The differences in interaction patterns between the two pairs included the extent of verbal negotiations, and waiting for other’s response in the typical pair compared to the attempts of parallel play and hand removal strategies by the pair with ASD. For both pairs there was some visual tracking of the other user’s action however these were brief in the ASD pair. Similarities in the patterns of interaction of the two pairs were: (1) an increase in collaboration as the session progressed, (2) one boy tends to lead and dominate the interaction while the other tends to follow, and (3) the leading boy tries verbally or non-verbally to convince the other boy to select his choice. Although completion times differed dramatically for the two pairs, the total percent of correct releases did not.

5. SUMMARY AND CONCLUSIONS

We have presented the design process of the CPG, a system developed with the purpose of studying collaboration and social interaction among children with ASD and children with typical development. We also presented some initial observations conducted with users that helped to structure the iterative process of development of the system.

Our initial results suggest that both children with typical development and those with ASD enjoyed using the CPG, and were readily able to learn and execute the various functions of the game within one session with minimal explanations. Initial observation of the videotaped records indicates that there is a difference between children with typical development and those with ASD in the way they use the CPG and in their interaction patterns. An increase in collaboration as the sessions progressed for both typical children and those with ASD was observed. Our tentative conclusion is that the CPG encourages children to interact, whether they have ASD or not.

All children with ASD have, by definition, social deficits. These deficits have an impact on their ability to fully participate in school, work, and leisure activities in the community. The use of an intervention tool such as the CPG, can be considered to be an enjoyable leisure time activity that is age appropriate for these children. However, it is also an educational tool that can directly address one of their major core difficulties, social interaction. These preliminary results are encouraging in light of the difficulty to find interventions that will both be enjoyable for children with ASD and will encourage them to improve their social abilities.

Future work will focus on a deeper quantitative and qualitative analysis of interaction, using the data provided by the log files of the application and through behavioural observation scales focusing on the assessment of collaborative and social abilities.

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