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# A pilot study on evaluating children with autism spectrum disorder using computer games

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ABSTRACT

Evaluation of children with Autism Spectrum Disorders (ASD) is crucial to clinical diagnosis and educational intervention. The traditional evaluation methods based on questionnaires and scales rely on the experience and expertise of the evaluator, are time-consuming and clinically demanding. Computer games can provide an objective, motiving and safe way for evaluating and reflecting children's development. Therefore, the study aimed to investigate a technology-based method using computer games to evaluate children with ASD. The performance of 40 children with ASD and 51 aged-matched typically developing (TD) children was compared. We found: 1) The completion ratio for children with ASD was lower than TD children for the tasks in most of the games. 2) Significant differences between the ASD and TD groups, but no significant differences within group. 3) The performance of the TD group was better than ASD and the efficiency of TD group was proportional to age. While more research is needed to confirm its reliability and validity, the findings indicate that computer games have great potential in the field of special education as an evaluation tool to clarify difficulties associated with autism.

## 1. Introduction

Autism Spectrum Disorder (ASD) is a lifelong neurodevelopmental disorder involving core deficits in interpersonal communication and social interactions, as well as restricted, repetitive mannerisms and interests (American Psychiatric Association, 2013). Children with ASD struggle with significant relationships and behavioral challenges that in most cases have serious implications for social inclusion in adulthood. They display a great variety of characteristics, ranging from speech disabilities, to severe limitations in social skills which impair their ability to develop peer relationships appropriate to age(Diagnostic and Statistical Manual of Mental Disorders, 2000). They also show some inability in terms of imagination, manifested in the difficulty to generalize between environments, a limited range of imaginative activities, and difficulty in predicting future events and abstract ideas (Bartoli, Garzotto, Gelsomini, Oliveto, & Valoriani, 2014). The percentage of children identified as having ASD has increased significantly in recent years, and became a public health concern. In terms of global prevalence, 1 in 160 children are estimated to have ASD (Elsabbagh, 2012). However, CDC's Autism and Developmental Disabilities Monitoring (ADDM) Network estimates 1 in 68 American children have ASD (Christensen et al., 2016). The cause or etiology is complex, involving both genetic and environmental factors (Hall Mayer, 2011; Sandin et al., 2014). It is generally recognized that the most effective clinical route to treatment is early identification and intervention (Bradshaw, Steiner, Gengoux, & Koegel, 2015; Howlin, Magiati, & Charman, 2009), with accurate evaluation or diagnosis as the precondition. Early detection and intervention is crucial for children with ASD to maximize gains in communication and social skills (Fakhoury, 2015). The endeavor affords the family and caregivers the opportunity to adjust, in some cases, trigger the resources required for professional care and treatment. Moreover, early detection and intervention can also produce significant health and economic benefits and provide the best chance for lifelong improvement and relative independence (Peters-Scheffer, Didden, Korzilius, & Matson, 2012; Chasson, Harris, & Neely, 2007). In terms of financial cost, ASD can be a heavy burden for the families of affected children (Lee, David, Rusyniak, Landa, & Newschaffer, 2007). The earlier children with ASD can be identified, the sooner they can get the services needed to reach full potential.

Children with ASD often have comorbid medical conditions,

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including intellectual disabilities, anxiety, and depression that implicate the evaluation and diagnosis (Tuchman & Rapin, 2002). ASD can be diagnosed as early as at age two, but most children are not diagnosed with ASD until after they are four. As of now, it remains difficult to obtain a diagnosis of ASD. However, there are some well-developed and tested methods for diagnosing autism (e.g., ADOS) and other screening tests that provide quantitative indicators, such as the Social Communication Questionnaire (SCQ). In the SCQ, the cut-off (usually 15 or above) identifies individuals who are likely to suffer from ASD and for whom more extensive evaluations should be undertaken (Rutter, Le Couteur, & Lord, 2003). The use of these tools is followed by more extensive diagnostic evaluation using validated assessment tools (e.g., the Autism Diagnostic Interview-Revised or ADI-R; SCQ; ADOS). Currently, evaluation relies heavily on the experience and expertise of specialists, and the traditional questionnaire/scale-based methods of evaluation depend on interpretive coding of child observations, parent interviews, and manual testing, which can be time-consuming and clinically demanding. Whilst it might be useful to have simple, accessible tests that provide behavioral correlates as indicators of the presence of autistic traits (e.g., for preliminary screening), significant amounts of research would be required to develop screening tools that are both valid and reliable.

A growing number of investigators are on the verge of discovering and developing new markers or techniques to improve the diagnosis or intervention of ASD. ASD can be measured directly using sensitive and reliable quantitative approaches (Gabriele, Sacco, & Persico, 2014; Ruggeri, Sarkans, Schumann, & Persico, 2014). Several studies have shown that the majority of people with ASD exhibit a natural affinity for technology and a positive attitude towards computer-based intervention and training (Ding and Marchionini, 1997; Goldsmith and LeBlanc, 2004; Bernardini, Porayska-Pomsta, & Smith, 2014; Dehkordi & Rias, 2014). A research group at MIT implemented emotion-recognition algorithms on a mobile device to help people with ASD who have difficulty recognizing emotions in face-to-face situations (Madsen, Kaliouby, Goodwin, & Picard, 2008). Zachary Warren's team developed a novel VR-based dynamic eye-tracking system for children with autism, which is capable of delivering individualized feedback based on a child's dynamic gaze patterns during VR-based interaction(Lahiri, Warren, Sarkar, 2011). Serious games are of special interest in the field of autism study, since their rule-based environments presents a safe, appealing vehicle for interventions to improve a person's level of socialization (Grossard et al., 2017). For intervention e.g. training on social skills, computer games (mainly refers to serious games) are very promising, they can support interactions in diverse contexts and situations, some of which are real life simulation games. However, the currently available computer games present some limitations in terms of the evidence of their clinical benefits.

Computers are popular and preferable among people with ASD because they are predictable, consistent, free from social demands, and specific in terms of focus of attention (Murray, 1997). Therefore, computer-based applications are considered useful tools for therapeutic and educational purposes (Kagohara, van der Meer, & Ramdoss, 2013; Chen, 2012; Chen, Chen, Li, & Zhang, 2014). They are also good educational tools, as children with ASD often experience discomfort with unpredictable social environments and prefer a controlled learning environment (Wilkinson et al., 2008; Wainer & Ingersoll, 2011). Individuals with ASD enjoy learning and improving their skills with computer-based intervention. In recent years, multi-touch tabletop interfaces have become available. These consist of large touch displays placed horizontally, which allows multiple users' input simultaneously. The system interprets the gestures of more than one collocated user as contributing to a single, combined command. Anna et al. (2016) employed smart tablet computers with touch-sensitive screens and embedded inertial movement sensors to record the movement kinematics and gesture forces while children played serious games; 37 children with ASD aged 3–6 and 45 age- and gender-matched TD children were included in the study. The experimental results support the notion that disruption to fine motor skill is a core feature of ASD and demonstrate that children with ASD can be computationally assessed using a smart device while having fun. Furthermore, several studies also indicate that computers have the potential to be used as evaluation tools for children with ASD (Bartolomé, Zorrilla, & Zapirain, 2013; Costa, Soares, Pereira, & Moreira, 2012; Li & Elmaghraby, 2014).

In China, there are more than 10 million individuals with ASD (Lin, 2014) and because of high demand, professional and prompt evaluation and intervention are often difficult to obtain. Therefore, it is necessary to develop computer-based evaluation or intervention tools for ASD. The designed computer games might provide a motiving and safe alternative for evaluation, and objectively reflect children's developmental trajectories.

## 2. Methods

### *2.1. Participants*

The present study was approved by our institutional review board. Participants consisted of 91 children aged 2–6 years, 40 (M = 4 yrs. 5 months, SD = 11 months) with a clinical diagnosis of ASD (ICD-10, 2010 Edition; World Health Organization, 2011; DSM-5, 2013), referred to as the ASD group, and 51 with typical development (M = 4 yrs.7 months, SD = 11 months), referred to as the TD group (see Table 1). All the participants have normal or corrected visual acuity and no other sensory or motor deficits, and the children with simple mental retarded were excluded. Also those children who could not follow simple instructions were excluded. In particular, children with ASD were recruited from a special school, and required to have a clinical diagnosis of ASD from psychologists or clinicians according to DSM-5, which based on parent interviews, observation children's behavior, and professional scale, and be free of medication, history of traumatic brain injury or other neurological illnesses. According to the diagnosis of pediatrician and performance in the class of their teacher‘s comment, the participants in our study have the ability to complete general understanding task. The children in the TD group were recruited from regular kindergartens, and met the following criteria: 1) the gender and age match with children with ASD; 2) detailed physical and mental examination by clinician ruled out body disease, mental retardation, and other developmental obstacles or learning disabilities; 3) the normal visual development. The children's parents gave written informed consent for participation.

### *2.2. Theoretical foundation and overall approach*

There are many theories in the field of child development, each of which helps in understanding the cognitive and social development of TD children and the deficits associated with ASD children in particular. However, it is now commonly recognized that whilst each theory may relate especially well to some phenomena, individually they are unlikely to completely explain the challenges associated with ASD. Therefore, we used three key cognitive theories of child development in this study. ToM is the ability to reason about the mental states of others (Rajendran & Mitchell, 2007). ToM develops early in children without

**Table 1**
The description of Participants in the ASD and TD groups.

| Group | ASD(n = 40) | | | TD(n = 51) | | |
|---|---|---|---|---|---|---|
| Age range | (3yrs, 4yrs] | (4yrs, 5yrs] | (5yrs, 6yrs] | (3yrs, 4yrs] | (4yrs, 5yrs] | (5yrs, 6yrs] |
| *n* | 20 | 11 | 9 | 21 | 15 | 15 |
| *M* | 3.42 | 4.24 | 5.30 | 3.75 | 4.26 | 5.53 |
| *SD* | 0.38 | 0.32 | 0.27 | 0.27 | 0.22 | 0.36 |

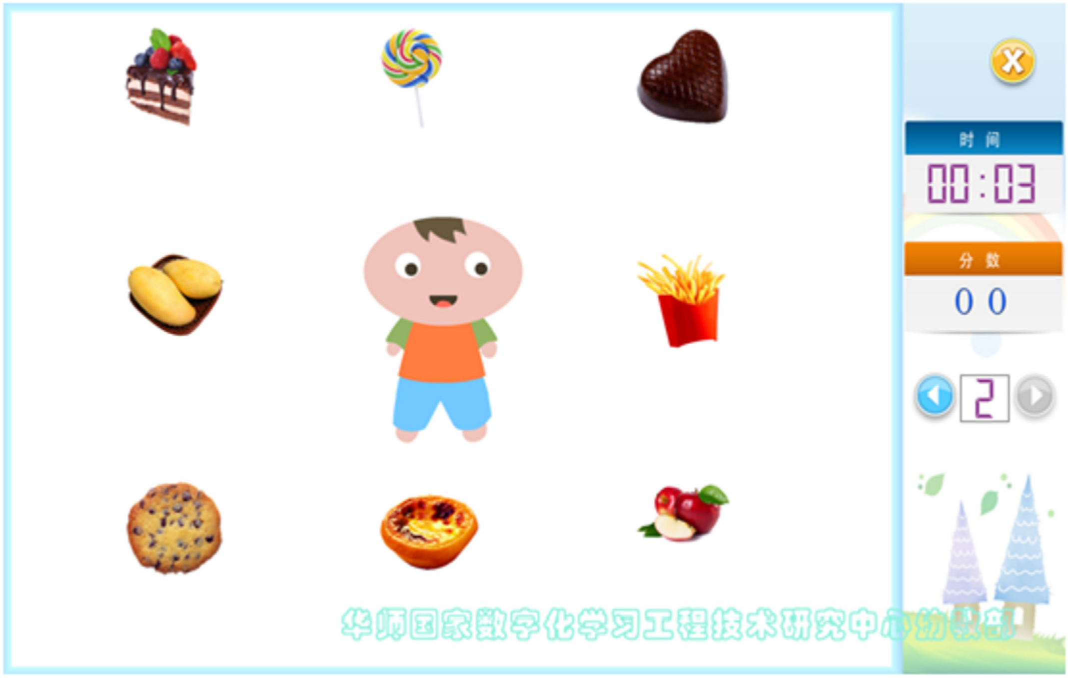


**Fig. 1.** The designed game of Find food.

disabilities, but it is significantly delayed in children with ASD (Moran et al., 2011; Peterson, 2014). Executive functioning is an umbrella term for functions that include initiating, sustaining, shifting, and inhibition/stopping (Charman & Baron-Cohen, 1995), and Central Coherence Theory relates to the inability of children with ASD to integrate pieces of information into a coherent whole (Ozonoff, Pennington, & Roger, 1991).

We designed game tasks and visual content based on the above-mentioned theories to investigate the performance of children. Our guideline takes into account the characteristics of children with ASD, particularly in relation to low to medium functioning children. The tasks comprise six modules to evaluate joint attention, psychological inference, visual search, fine motor, concept classification, and cognitive understanding skills. Each of the game tasks tests more than one ability. To accomplish a specific game task, a child requires multiple abilities in order to collaborate, and all these abilities strongly relate to the social interaction and adaption of children with ASD. Joint attention allows for two or more individuals to exchange information regarding goals in non-verbal cooperative activities without relying on verbal communication (Brinck & Gärdenfors, 2003). The term encompasses complex behavioral forms, including gaze and point following, showing, and pointing (Brooks & Meltzoff, 2005; Tomasello & Carpenter, 2007). The consistent presence of joint attention impairments among children with ASD means that this is a key aspect in early screening and diagnostic instruments (Lord, Rutter, DiLavore, & Risi, 2001; Wetherby & Prizant, 2002). Psychological inference (i.e., ToM) is the ability to attribute mental states (e.g., beliefs, intents, desires, etc.) to oneself and others and to understand that others have beliefs, desires, intentions, and perspectives that are different from one's own (Premack & Woodruff, 1978). Children with ASD often lack this capability. Visual search is a type of perceptual task requiring attention that typically involves an active scan of the visual environment for a particular object or feature (the target) among other objects or features (the distractors) (Treisman & Gelade, 1980). Fine motor skills refer to the coordination of small muscle movements that occur, for example in the fingers, usually in coordination with the eyes (Craig, Kermis, & Digdon, 2001). Concept classification is the capacity to classify something according to type, property, rank, or nature. People with ASD cannot always associate concepts with specific physical objects. Cognitive understanding is the mental action or process of acquiring knowledge and understanding based on thought, experience, and the senses; it refers to an information processing view of an individual's psychological functions (Blomberg, 2011). Each of these abilities is an appropriate target for a technology-based intervention for preschoolers with or without ASD.

### 2.3. *Description of the computer games*

Using the theories described above, six different computer games were designed and developed, as follows. All games are strongly customizable according to the characteristics and learning needs of specific children who play with systems. The games have very simple user interfaces with little or no words to better appeal to a population that can often better process information visually rather than verbally. The relevant parameters that can be modified, such as difficulty level (e.g., for the Recognize the shape of object game, more shapes and objects appear on the screen as the difficultly of the game increases). The games automatically collect the scores of the players and the information relative to the played configuration and generate a session report that can be used to evaluate or fine-tune the treatment. When a child succeeds in the game mission, he or she will be given a verbal reward (e.g. you're great.). Next, we provide a brief description of the games we designed.

#### 2.3.1. *Find food*

The goal of this game is to evaluate the joint attention, gaze following, and selective attention abilities of the child. At the same time, the game can also test the abilities of conceptual understanding (e.g., recognize fruits, food, etc.) and social interaction (e.g., following instructions).

In the game, the child needs to focus his or her attention on the virtual character and follow the character's gaze to select the correct food in a different azimuth (up, down, left, right, etc.), as shown in Fig. 1. The highest possible score for this game is eight points. If the child makes a correct choice, he or she acquires one point. If the child selects all the correct food items according to the virtual character's gaze, then he or she acquires eight points, at which time the game is over.


**Fig. 2.** The designed game of Help the girl to find what she needs.

### *2.3.2. Help the girl to find what she needs*

The main goal of this game (see Fig. 2) is to evaluate a child's psychological inference ability. The game can also be used to test a child's cognitive ability, their ability to understand requirements, and their facial expression recognition ability.

In this game, the virtual character puts forward some requirements (e.g., "I'm hungry; can you help me?" "I want to brush my teeth; can you help me?"). The child needs to make a judgement based on the virtual character's requirements. If the child selects the correct thing that the virtual character needs, then the child gets one point; if not, the child loses one point. During the game, the child can make a judgement about whether his/her choice is right or wrong according to the character's facial expression. If the child makes the correct choice, the virtual character will smile; otherwise, the character will cry.

### *2.3.3. Find the baby animal*

The main goal of this game is to evaluate a child's visual search and concept classification skills (i.e., demonstrate some knowledge about animals). As seen in Fig. 3, there are three kinds of animals—a cat, a dog, and a rabbit—that are very common in our daily lives and that children love.

Following the voice prompt (e.g., Can you help the mother cat find the baby cat?), the child should match the baby animal to the mother animal that appears on the upper right side. If the child selects the correct baby animal, then he or she acquires one point.

### *2.3.4. Catch the falling fruit*

The main goal of this game is to evaluate fine motor skills and hand-eye coordination. In addition, the child can memorize different kinds of fruit during the game. As shown in Fig. 4, during this game the child needs to catch the falling fruit by moving the basket horizontally. The game is divided into four grades corresponding to four levels of difficulty; with the increase in difficulty, the fruit falls faster. When the child catches one falling fruit, he or she acquires one point. The playtime was set to 1 min. Completing this game task successfully requires children's hand-eye flexible coordination.

### *2.3.5. Recognize the shape of the object*

The main goal of this game (see Fig. 5) is to evaluate a child's ability to recognize shapes, their abstract thinking skills, and their visual discernment skills. The game also tests the child's ability to match shapes to common objects in daily life. There are five shapes-a rectangle, a square, a triangle, a circle, and an oval—that can appear in the "thought cloud" above the virtual character. The child needs to select the object that correctly matches the shape in the thought cloud. The number of objects increases with the difficulty level.

### *2.3.6. Help me find the toilet*

The main goal of this game is to evaluate gender conceptual distinction, fine motor, and hand–eye coordination skills. Fig. 6 shows the interface of this game. The screen shows two types of people and toilet signs. The child must differentiate between males and females and then drag the person's picture to the sign with the corresponding gender. The distinction between gender concepts is especially important for children's social behavior.

## *2.4. Procedures*

The study was performed at a therapeutic center and a kindergarten to investigate the differences between children with ASD and TD children in terms of social, motor, and cognitive skills using these evaluation games. Both ASD and TD were assessed in the same setting at a quiet room about 16 m square, and the child can play the games with tablet PC or PAD without disturbing. The game evaluation test is divided into three phases: (1) Initialization stage to establish a trust between the researchers and the participants and to explain how to use the application. In this phase, the children are allowed to familiarize themselves with the games without being required or prompted to do anything; (2)Test phase in which the participants are informed to complete the evaluation games one by one (see Fig. 7) and are given the necessary instructions and guidance and in which detailed records of the evaluation process and the performance of every child is noted; each session is usually 15–20 min long; and (3) Analysis stage in which text recording materials and test data are collated and analyzed using SPSS and Excel.

## **3. Results**

### *3.1. Descriptive statistics*

The completion rate used to evaluate the TD and ASD groups are shown in Table 2. Completion rate means the ratio of the number of


**Fig. 3.** The designed game of Find the baby animal.

people who complete the game to the total number. e.g., r = C/N. Participants who only partly completed the games are not included in C. Based on the descriptive statistics, we found that the completion rate for the TD group is higher than that for the children with ASD. For the TD group, the completion rate for children aged under 4 years old was 91.31% and that for children aged 4–6 was 93.54%. For the ASD group, the completion rate for children aged less than 4 years old was 89.16% and that for children aged 4–6 was 79.17% (with some necessary assistance). The completion rate showed that the computer games used in the study are feasible to some extent. It is worth noting that the completion rate for the Find food game is rather low compared with the other games for the children with ASD, which reflects the core symptom (e.g., joint attention deficit) of children with ASD.

### 3.2. Performance results

Table 3 shows the performance results for the computer games. One can see that there are significant differences between the ASD group and the TD group. The present study focusses on two aspects of the differences: (1) the efficiency, which is the ratio of average score and average time and (2) the standard deviation of the score or the spent time; the larger the value, the greater the differences between individuals. As shown in Table 3, we can see that the efficiency of children in the TD group is higher than that of the children in the ASD group and that this is proportional to the age of the participants. In addition, children did well in 'Catch the falling fruit' and its corresponding efficiency is higher than in other games. Taking the

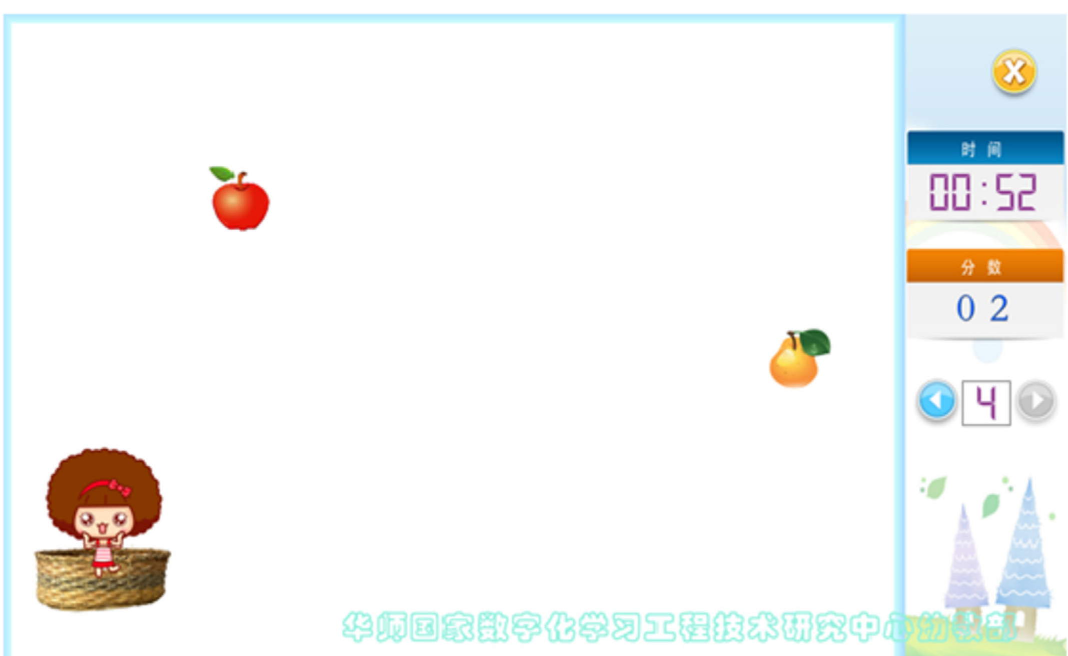


**Fig. 4.** The designed game of Catch the falling fruit.


**Fig. 5.** The designed game of Recognize the shape of the objects.

evaluation item "joint attention" as an example, for the results of Find food game, the children in the ASD group (i.e., efficacy: less than or equal to 4 years = 0.089; over the age of 4 years = 0.105) were not able to follow the character's gaze easily and could not make the correct choice, leading to a longer reaction time than in the TD group (i.e., efficacy: less than or equal to 4 years = 0.105; over the age of 4 years = 0.136). The children's performance is proportional to their age, and the TD children showed normal gaze direction. Based on the characters in the game, they could find the corresponding direction where the food was located as quickly as possible.

### 3.3. Analysis of differences using t-tests

The differences between the performance of ASD and TD children are described in this section. We ran a *t*-test to check if there are any differences between the efficiency of ASD vs. TD children. It provides the p-value and effect size to clearly show the significant differences. Also, we ran a *t*-test to check if there are any differences between the efficiency within ASD and TD groups. The results show no significant differences within the ASD and TD groups.

We compared efficiency for the ASD and TD groups using *t*-test and found statistically significant differences for most of the evaluation games. Table 4 shows the differences of efficiency for age ≤ 4yrs.of the


**Fig. 6.** The designed game of Help me find the toilet.

**Fig. 7.** One of the participants playing one of the games.

ASD and TD group.

We can see that there are significant differences in efficiency of some games. For the Find the baby animal game ($t = 3.617$, $p = 0.001 < 0.01$, $r = 0.501$), the Catch the falling fruit game ($t = 3.782$, $p = 0.001 < 0.01$, $r = 0.526$), There were no significant differences in the results for the Find food game ($t = 1.976$, $p = 0.058 > 0.01$, $r = 0.339$), the Help the girl to find what she needs game ($t = 1.155$, $p = 0.256 > 0.05$, $r = 0.187$), the Recognize the shape of the object game ($t = 1.808$, $p = 0.081 > 0.05$, $r = 0.288$), and the Help me find the toilet game ($t = 1.751$, $p = 0.089 > 0.05$, $r = 0.818$), but the TD group performed better than the ASD group from Table 3. This could be because the number of participants who completed this game was small or because the game is a little difficult for young children. Table 5 shows the results of the *t*-test for the efficiency between the ASD and TD group of the age > 4yrs. We can clear to see that the efficiency of ASD and TD has some differences of age above 4years. There are significant differences for the Recognize the shape of the object game ($t = 2.568$, $p = 0.015 < 0.05$, $r = 0.407$), the Help me find the toilet game ($t = 5.601$, $p = 0.000 < 0.001$, $r = 0.707$). As for the other games, there is no significant differences between ASD and TD

**Table 2**
The completion rate of the ASD and TD groups.

| Games/Group | ASD | | | | | | TD | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Age ≤4 years | | | Age > 4 years | | | Age ≤4 years | | | Age > 4 years | | |
| | ASD_NP | ASD_CNP | ASD_CR | ASD_NP | ASD_CNP | ASD_CR | TD_NP | TD_CNP | TD_CR | TD_NP | TD_CNP | TD_CR |
| Find food | 20 | 13 | 65% | 20 | 7 | 35% | 21 | 19 | 90% | 30 | 28 | 93% |
| Find what is needed | 20 | 18 | 90% | 20 | 16 | 80% | 21 | 21 | 100% | 30 | 28 | 93% |
| Find the baby animal | 20 | 20 | 100% | 20 | 20 | 100% | 21 | 20 | 95% | 30 | 29 | 97% |
| Catch the fruit | 20 | 20 | 100% | 20 | 20 | 100% | 21 | 15 | 71% | 30 | 21 | 70% |
| Shape recognition | 20 | 18 | 90% | 20 | 15 | 75% | 21 | 19 | 90% | 30 | 29 | 97% |
| Find the toilet | 20 | 18 | 90% | 20 | 15 | 75% | 21 | 20 | 95% | 30 | 27 | 90% |
| Completion rate | 89.16% | | | 79.17% | | | 91.31% | | | 93.54% | | |

Notes.
Game, the name of the designed games.
TD, typically developing children; ASD, children with autism spectrum disorder.
TD_NP, the number of typically developing children.
TD_CNP, the number of typically developing children who complete the assessment.
TP_CR, the completion rate of typically developing children.
ASD_NP, the number of children with ASD.
ASD_CNP, the number of children with ASD who complete the assessment.
ASD_CR, the completion rate of children with ASD.

**Table 3**
The efficiency and standard deviation of the results.

| Items | Game | Dimension | ASD | | TD | |
|---|---|---|---|---|---|---|
| | | | Age ≤4 years | Age > 4 years | Age ≤4 years | Age > 4 years |
| Joint attention | Find food | Efficiency | (0.089) 8/90 | (0.105) 8/75.9 | (0.115) 8/69.8 | (0.136) 8/59 |
| | | t_std | 33.529 | 35.33 | 27.3 | 33.19 |
| Psychological inference | Find what is needed | Efficiency | (0.064) 3.17/49.3 | (0.095) 4.19/44.1 | (0.091) 4.38/47.9 | (0.128) 4.39/34.2 |
| | | s_std | 1.79 | 1.167 | 0.86 | 1.1066 |
| Visual search skills | Find the baby animal | Efficiency | (0.073) 5.55/76.2 | (0.092) 6.75/73.2 | (0.171) 8.25/48.2 | (0.196) 8.31/42.4 |
| | | s_std | 3.2683 | 2.573 | 1.333 | 1.039 |
| Fine motor skills | Catch the fruit | Efficiency | (0.323) 19.4/60 | (0.330) 19.8/60 | (0.382) 22.9/60 | (0.328) 19.7/60 |
| | | s_std | 4.6371 | 5.136 | 2.89 | 5.071 |
| Cognitive understanding | Recognize shape | Efficiency | (0.064) 4.65/72.1 | (0.100) 6.93/69.3 | (0.085) 6.32/74.4 | (0.139) 7.1/50.9 |
| | | s_std | 3.27 | 1.718 | 2.93 | 2.738 |
| Concept Classification | Find the toilet | Efficiency | (0.075) 8.78/116.5 | (0.082) 9.24/111.8 | (0.152) 11.4/74.9 | (0.171) 11.11/65 |
| | | s_std | 3.282 | 3.073 | 0.9 | 1.618 |

Notes: Items, the ability under evaluation.
Game, the name of the designed games.
ASD, children with autism spectrum disorder; TD, typically developing children.
Efficiency, the ratio of average score and average time; the greater the value, the stronger the ability.
t_std, the standard deviation of the spent time; as the score of the game is fixed, the higher the value, the greater the individual differences.
s_std, the standard deviation of the score; as the time of the game is fixed, the higher the value, the greater the individual differences.

group.

Table 6 shows the results of the *t*-test for the efficiency of the ASD group between age = < 4 years and age > 4 years. There is no significant differences for most of the evaluation games between the groups age = < 4 years and age > 4 years of the children within the ASD group, e.g., the Find food game ($t = -0.826$, $p = 0.420$, $r = 0.191$), the Help the girl to find what she needs game ($t = -1.451$, $p = 0.157$, $r = 0.248$), the Find the baby animal game ($t = -0.925$, $p = 0.361$, $r = 0.148$), and the Catch the falling fruit game ($t = -0.291$, $p = 0.773$, $r = 0.047$), and the Recognize the shape of the object game ($t = -1.367$, $p = 0.181$, $r = 0.238$). As for the Help me find the toilet game ($t = 2.145$, $p = 0.041 < 0.05$, $r = 0.376$), the significant difference could be various living environment in which the children stay.

Table 7 shows the results of the *t*-test for the efficiency of the TD group between age = < 4 years and age > 4 years. We can see that there is no significant difference between individuals within the group of TD. For the Find food game ($t = -1.033$, $p = 0.309$, $r = 0.172$), the Help the girl to find what she needs game ($t = -1.522$, $p = 0.141$, $r = 0.291$), the Find the baby animal game ($t = 0.367$, $p = 0.716$, $r = 0.062$), the Catch the falling fruit game ($t = 0.888$, $p = 0.382$, $r = 0.157$), the Recognize the shape of the object game ($t = -1.382$, $p = 0.178$, $r = 0.255$), and the Help me find the toilet game ($t = 0.659$, $p = 0.514$, $r = 0.111$).

## 4. Discussion

This study describes whether it is possible to use computer games to distinguish children with and without ASD by analyzing their performance differences. The activities and learning measures in the evaluation game provide a quantitative description of children's capacities, which would be a more objective and feasible way of identifying ASD as compared to traditional qualitative methods. These games may also be used as a supportive tool in educational intervention for children with ASD.

Due to the individual differences in children's developmental trajectories, cognitive characteristics, and adaptability to the external environment, the completion rate for some games is not as high as we expected. For example, the completion rate for the Find food game is relatively lower for the children with ASD (ASD group: age ≤ 4 years = 65%; age > 4 years = 35%) than for the other children. When a child plays this game, they need to follow the character's eye gaze to find the corresponding food in the game context, which seems to be difficult for children with ASD. The poor performance of the ASD group with low scores reflects the core symptom (e.g., joint attention deficit) of children with ASD (Charman, 2003). Furthermore, children with ASD are more likely to give up and have low self-efficacy when facing difficulties, which may be an important factor (Burkhardt, 2008). In addition, each child manifests unique strengths and skill deficits, and things that are reinforcing or rewarding for one individual may be unpleasant for another. One of the novel finding is that the older ASD have more trouble completing some tasks (e.g. the game of 'find food 'and 'help me Find the toilet') than the young, but the TD have the opposite result. As we all know, the impairments in joint attention, imitation, and cognition are well documented in children with ASD, the developmental trajectories of these symptoms remain unknown. A

**Table 4**
T-test to check the differences in efficiency for the age ≤ 4yrs. of the ASD and TD.

| Game | Evaluation item | Efficiency | Levene's test for equality of variances | | T-test for equality of means | | | |
|---|---|---|---|---|---|---|---|---|
| | | | F | Sig. | Mean difference | t | Sig. (2-tailed) | Effect Size (r) |
| Find food | Joint attention | E1 | .069 | .795 | .03705 | 1.976 | .058 | 0.339 |
| Find what is needed | Psychological inference | E2 | .479 | .493 | .02751 | 1.155 | .256 | 0.187 |
| Find the baby animal | Visual search skills | E3 | .019 | .892 | .11818 | 3.617 | .001** | 0.501 |
| Catch the fruit | Fine motor skills | E4 | .668 | .419 | .08546 | 3.782 | .001** | 0.526 |
| Shape recognition | Cognitive understanding | E5 | 5.442 | .026 | .06014 | 1.808 | .081 | 0.288 |
| Find the toilet | Classification, fine motor skills | E6 | 1.959 | .171 | .10347 | 1.751 | .089 | 0.818 |

Note. ** Correlation is significant at the 0.05 level (2-tailed).
***Correlation is significant at the 0.001 level (2-tailed).
E (1–6) means the efficiency of the six evaluation games.

**Table 5**
T-test to check the differences in efficiency for age > 4yrs.of the ASD and TD.

| Game | Evaluation item | Efficiency | Levene's test for equality of variances | | T-test for equality of means | | | |
|---|---|---|---|---|---|---|---|---|
| | | | F | Sig. | Mean difference | t | Sig. (2-tailed) | Effect Size (r) |
| Find food | Joint attention | E1 | .031 | .862 | .03398 | 1.548 | .135 | 0.047 |
| Find what is needed | Psychological inference | E2 | .748 | .396 | .02635 | 1.003 | .326 | 0.219 |
| Find the baby animal | Visual search skills | E3 | 1.150 | .291 | .06351 | 1.344 | .187 | 0.216 |
| Catch the fruit | Fine motor skills | E4 | .180 | .674 | .05544 | 1.950 | .059 | 0.298 |
| Shape recognition | Cognitive understanding | E5 | .936 | .341 | .06660 | 2.568 | .015** | 0.407 |
| Find the toilet | Classification, fine motor skills | E6 | 3.558 | .069 | .13056 | 5.601 | .000*** | 0.707 |

Note. ** Correlation is significant at the 0.05 level (2-tailed).
***Correlation is significant at the 0.001 level (2-tailed).
E (1–6) means the efficiency of the six evaluation games.

study on exploring individual trajectories of social communicative development in toddlers at risk for ASD indicates that the quality of joint attention behaviors does not significantly improve among 2 and 4years age (Dereu.et al., 2012). Delayed versus deviant social communicative development and individual differences in children with ASD may be the reasons of this result.

We compare the performance of the children with and without ASD in terms of score, time spent, and efficiency after they completed all the games. As the results show, we can see that there are some significant differences between different groups and games. As each game has a different scoring method, we introduced the concept of 'efficiency (***e***)', which means the ratio of score and time spent. It is clear that the group of TD children performed better than the group of ASD children and that the value of ***e*** is proportional to age (see Table 3). The data also suggests that children with ASD usually have difficulty with joint attention, ToM, visual search skills, fine motor skills, cognitive understanding, and concept classification. For autistic individuals, some problems are serious and some symptoms are mild in these areas (Worley & Matson, 2012). It is important to note that the ASD group sometimes performed better than the TD group (in terms of raw scores) on several tasks. Individual differences may also make it hard to distinguish between the two populations. Therefore, further research is required to design reliable and valid indicators of the difficulties associated with autism for quantitative assessment.

In determining the differences between the ASD and TD groups, the independent *t*-test on the data revealed differences in efficiency for each group. The results suggest significant differences between the ASD and TD groups (see Tables 4 and 5). As for the ASD and TD groups separately, the efficiency reveal no obvious differences between the age = < 4 years and age > 4 years groups (see Tables 6 and 7). Children with autism frequently experience language difficulties and may be developmentally delayed. Age matching for developmental age is more appropriate but difficult to do.

The pilot study provides evidence that these computer games could be used as assessment tools for children with ASD. More appropriate support is required to improve their use as assistive evaluation and intervention tools.

## 5. Conclusion

This study presents a novel method of educational evaluation for children with ASD. A series of computer games were designed and implemented to explore the quantitative differences between children with ASD and TD children in the development fields of joint attention, ToM, visual search skills, fine motor skills, cognitive understanding, and concept classification. The results show that, in general, most of the children with ASD have lower development levels than the TD children, and there are significant differences between the ASD and TD groups. The performance of the group of TD children is better than that of the group of ASD children, and the value of efficiency is proportional to age. Computer games have great potential as support, evaluation, or intervention tools in the field of special education. Technology-based intervention has been proved successful in teaching new skills to children with ASD. And the use of this platform as an intervention tool needs substantial modification. Computer games used as evaluation tools can objectively reflect the development level of children. We believe that the social interactions in the computer games were easier and more comfortable for participants because they happened in the context of an enjoyable activity using a computer or pad. This made the children more confident and less anxious and actively engagement.

The present study has several limitations. Firstly, the two groups were matched in terms of chronological age but not in terms of developmental abilities, which may have accentuated group differences relating to the dependent variables of interest. Secondly, our small and uneven sample size may have reduced our statistical power and ability to detect differences. Thirdly, the complexity of some of the designed games may not be appropriate and therefore the results may be a little deviation. Children with ASD also vary their behavior significantly based on context, and conducting similar activities in different contexts could yield different results. In the future, research should be conducted in natural settings to enhance the ecological validity of the experiment. One more limitation was that the general cognitive functioning of

**Table 6**
T-test for the efficiency of the ASD group between age = < 4 years and age > 4 years.

| Game | Evaluation item | Efficiency | Levene's test for equality of variances | | T-test for equality of means | | | |
|---|---|---|---|---|---|---|---|---|
| | | | F | Sig. | Mean Difference | t | Sig. (2-tailed) | Effect size (r) |
| Find food | Joint attention | E1 | .002 | .961 | -.02009 | -.826 | .420 | 0.191 |
| Find what is needed | Psychological inference | E2 | .109 | .744 | -.03513 | −1.451 | .157 | 0.248 |
| Find the baby animal | Visual search skills | E3 | .926 | .342 | -.04309 | -.925 | .361 | 0.148 |
| Catch the fruit | Fine motor skills | E4 | .566 | .457 | -.00750 | -.291 | .773 | 0.047 |
| Shape recognition | Cognitive understanding | E5 | .094 | .761 | -.03785 | −1.367 | .181 | 0.238 |
| Find toilet | Classification, fine motor skills | E6 | 1.789 | .192 | .06183 | 2.145 | .041* | 0.376 |

Note:*Correlation is significant at the 0.05 level (2-tailed).
E (1–6) means the efficiency of the six evaluation games.

**Table 7**
T-test for the efficiency of the TD group between age = < 4 years and age > 4 years.

| Game | Evaluation item | Efficiency | Levene's test for equality of variances | | T-test for equality of means | | | |
|---|---|---|---|---|---|---|---|---|
| | | | F | Sig. | Mean Difference | t | Sig. (2-tailed) | Effect size (r) |
| Find food | Joint attention | E1 | .025 | .875 | -.01701 | − 1.033 | .309 | 0.172 |
| Find what is needed | Psychological inference | E2 | 4.771 | .038 | -.03397 | − 1.522 | .141 | 0.291 |
| Find the baby animal | Visual search skills | E3 | .005 | .946 | .01159 | .367 | .716 | 0.062 |
| Catch the fruit | Fine motor skills | E4 | 4.440 | .042 | .02252 | .888 | .382 | 0.157 |
| Shape recognition | Cognitive understanding | E5 | 8.820 | .005 | -.04432 | − 1.382 | .178 | 0.255 |
| Find toilet | Classification, fine motor skills | E6 | 2.802 | .103 | .03474 | .659 | .514 | 0.111 |

Note:*Correlation is significant at the 0.05 level (2-tailed).
E (1–6) means the efficiency of the six evaluation games.

participants was unavailable, and needs to be noted in future investigation.

In future, we will further investigate game design theory and explore methods for systematic evaluation. Using computer games to evaluate children with ASD is promising, but the robustness of the evaluation would be a concern in follow-up studies. A case could also be made for the use of carefully designed screening tools in the form of computer games; if a child scores above a certain threshold they would then be recommended for further assessment. More attention could be paid to combining the technology and the art, enriching game content, and extending the fields of application. More game resources will be developed for the dual purposes of assessment and intervention for children with ASD. Whilst it might be useful to have simple accessible tests that provide behavioral correlates as indicators of the presence of autistic traits (e.g., for preliminary screening), significant amounts of research would be required to develop screening tools that are both valid and reliable.

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The authors have no potential conflict of interest to declare.

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