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A case study of gesture-based games in enhancing the fine motor skills and recognition of children with autism

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ABSTRACT

Children with Autism Spectrum Disorder (ASD) perform poorly in complex fine motor skills and recognition, and they have difficulties in learning complex and multistep motor skills. Gestures-based games, which enable users to get timely feedback, to learn from failure, to engage in games at every moment, and to interact with computers intuitively have become promising tools. However, relevant empirical research on using gesture-based games to assist the learning of children with ASD is limited. With a case study method, we aim to examine the effects of using gesture-based games on the learning of children with ASD. Two gesture-based matching games were developed to improve the performance of children with ASD with respect to fine motor skills and recognition, and three young children with ASD participated in a three-week experiment. By comparing the participants' performance before and after the treatment, we found that the participants' performance in playing the gesture-based games improved greatly during the intervention, and intervention helped improve their performance regarding fine motor skills and recognition. Also, they were able to transfer the rules and skills they had learnt from the first game to completing the tasks in the second game. The findings above suggest the usefulness of using gesture-based games in assisting the learning of children with ASD. Some suggestions and implications for the development of the gesture-based games and future work are also discussed.

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Autism; leap motion; fine motor skills; recognition; gesture-based game

Literature review

Autism spectrum disorder (ASD) is a kind of neurodevelopmental disorder in which a child shows "persistent deficits in social communication and social interaction across multiple contexts" (APA, 2013, p. 50). Although not included in the diagnostic criteria, there can be problems in other aspects, such as special interests, unusual profiles of cognitive abilities and an increased sensitivity to specific sensory experiences (Attwood, 2008). Each of the dimension displays a range of expression, which can be considered as a spectrum. For instance, from the end of difficulties to the upper end of social continuum, different characteristics may be displayed, such as avoiding social interactions, interacting with others passively when encouraged, interacting actively but

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oddly due to a lack of social understanding and abilities, and wanting friends but having a significant delay in social maturity (Attwood, 2008).

According to the children's different expression of the social, communication, cognitive, interest, and sensory continuums, five subgroups were identified under the umbrella of ASD, including autistic disorder, Rett's disorder, childhood disintegrative disorder, pervasive developmental disorder-not otherwise specified (PDD-NOS), and Asperger's disorder (APA, 2000). Elaboration on the nuances of these types is beyond the scope of this study. We would only explain autistic disorder and childhood disintegrative disorder since the symptoms of our participants matched the descriptions of these two types best. Children with autism disorder have a distinct impairment in social interaction and communication and display stereotypes patterns of behaviours, interests, and activities (APA, 2000). Children with childhood disintegrative disorder develop typically before three–five years old, then their language, social interest and ability, play, and self-care abilities deteriorate dramatically and rapidly (APA, 2000).

Apart from the aforementioned five dimensions, motor skills deficits have been found common among children with ASD (e.g. Green et al., 2002; Jasmin et al., 2009; Liu & Breslin, 2013). For instance, Liu and Breslin (2013) found that the children with ASD performed significantly lower than typical developing age-matched peers in Movement Battery for Children-2, a widely-used motor skills assessment. Jasmin et al. (2009) indicated that pre-school children with ASD revealed a poor performance in gross motor composites (reflexes, stationary, locomotion, and object manipulation) and fine motor composites (grasping and visual-motor integration). A related area of fine motor functioning is the performance of gestures, which is used to connote the ability to perform skilled motor acts or sequences of purposeful motor movements and the ability to use tools (Hill, 1998). Some studies showed that children with ASD displayed impairments on gesture production related tasks compared with typically developing children. For example, Fuentes, Mostofsky, and Bastian (2009) indicated that children with ASD performed worse handwriting than that of age- and IQ-matched children who were developing typically. Anjana, Rebecca, and James (2011) indicated that children with ASD had weak fine motor coordination, such as poor performance on manual dexterity tasks.

Motor skills may influence how children with ASD engage in physical play (Bremer & Lloyd, 2016) and initiate social interactions. MacDonald, Lord, and Ulrich (2013) studied the relationship between the functional motor skills and social communicative skills of 35 children with high-functioning ASD at school ages. They found that children with weaker motor skills displayed greater deficits in social communicative skills. The motors skills of children with ASD were relatively underexplored in interventions, and the focus was on the deficits in social communication skills, which is part of the diagnostic criteria for ASD (MacDonald et al., 2013). However, a few studies on the intervention of motor skills of children with ASD have shown promising results. For example, Bremer and Lloyd (2016) explored the impact of two six-week blocks of fundamental-motor skill (FMS) intervention on the motors skills of five children with autism-like characteristics between three to seven years old. They found that the children showed improved individual FMS and social skill after the intervention and the special education teacher indicated increased readiness to teach FMS. Bremer, Balogh, and Lloyd (2015) investigated the effectiveness of a fundamental motor skill intervention on the motor skills, adaptive behaviour, and social skills of five four-year-old children with ASD. They found compared to the control group, the children who received motor skill intervention significantly improved their object manipulation and overall motor skills after the intervention, but not adaptive behaviour or social skills. The intervention was on locomotor (e.g. running, leaping) and object control (e.g. throwing, kicking).

In addition, children with ASD have difficulties with recognition, such as poor recognition of faces and colours as well as difficulties in matching voices and faces of people (e.g. Franklin, Sowden, Burley, Notman, & Alder, 2008; Williams, Goldstein, & Minshew, 2005). Among these recognition issues, poor recognition of colours is especially important since recognition of colours is usually considered as a prerequisite for other learning. For example, sorting things by colours is one of the basic ways of sorting objects even for kindergarten students. Anecdotal evidence suggests that compared with normally developing children, children with ASD perceive colours differently and are less accurate in detecting the difference between colours (Franklin et al., 2008).

Children are expected to transfer knowledge, statements, and skills from one environment, situation, or stimulus to another (Lloyd, Fuller, & Arvidson, 1997). However, it is a difficult task for children with ASD to generalize a learned behaviour from a trained situation to another (Glennen & DeCoste, 1997). Word learning studies suggest that generalization in ASD is specifically related to language level (Hartley & Allen, 2014). For example, de Marchena, Eigsti, and Yerys (2015) suggested that the tendency to generalize correlated with receptive vocabulary but not with age and those who had larger receptive vocabularies for their age showed a greater tendency.

Gesture-based games

In recent years, games have been increasingly used in many educational contexts (Gee, 2003). Gaming in educational contexts makes learning more engaging. Specifically, it is interactive and challenging to play games at every moment (Mayer, 2005). When playing games, learners can learn from mistakes and try repeatedly as they receive immediate feedback from failure. Also, feedback for completing tasks can motivate students to undertake more advanced tasks so as to improve constantly.

Impleness and safety need to be considered seriously when designing games and devices for children with ASD to meet their special needs. Children with ASD prefer to interacting with simplistic devices, as they can easily get overwhelmed by sensory stimuli when interacting with humans socially (Salter, Davey, & Michaud, 2014). Empirical data have shown that children with autism prefer to interact with less complex tools in a predictable way (Ferrara & Hill, 1980). Therefore, Dautenhahn and Billard (2002) built their robotic doll that behaved much simpler than human being rather than built an "artificial" human. Salter et al. (2014) provided a spherical robot, which was extremely simple in design. Well-designed games can provide a safer environment for children to practice. For example, children with autism can practice their social skills in virtual environments which reduce the impact of possible failure (Kandroudi & Bratitsis, 2013). Dautenhahn and Billard (2002) emphasized that any aspect which may make children upset or scared needs to be avoided by all means in order to make sure students can explore in an enjoyable and relaxed atmosphere.

Gesture-based games, a special form of gaming, is designed for players to interact with computer devices more simply and intuitively using natural user interfaces (Boutsika, 2014; Martin-SanJose, Juan, Mollá, & Vivó, 2017). In recent years, gesture-based games have been increasingly used in the filed of special education, and positive effects have been reported. For example, Wuang, Chiang, Su, and Wang (2011) indicated that Wii console virtual environment can improve the motor proficiency of the participants with Down's syndrome. Chang, Chen, and Chuang (2011) developed a Kinect-based system to assist participants with cognition disorder in their' pre-employment training. The results demonstrated that the system facilitated the disabled individuals' mastery of working skills. Vernadakis, Papastergiou, Zetou, and Antoniou (2015) indicated that it was feasible, valuable, and enjoyable to use the Kinect game console to intervene elementary school children's object control skills. The advantages of gesture-based games may satisfy the needs of children with ASD. These children have difficulties in learning complex and multistep motor skills (Mostofsky, Goldberg, Landa, & Denckla, 2000) as well as in understanding movement goals (Fabbri-Destro, Cattaneo, Boria, & Rizzolatti, 2009), which make explicit visual, oral and physical guidance and feedback helpful (Anjana, Rebecca, & James, 2011). In addition, high teacher-to-student ratio is usually required in interventions of children with ASD (e.g. Bremer et al., 2015; Bremer & Lloyd, 2016), which may be a challenge. Especially, many teachers often do not think they have the competence or skills to conduct physical intervention effectively due to lack of formal physical education training (Petrie, 2010).

Gesture-based games seem to have potential in dealing with the challenges since they require users to move their hands and fingers, can capture their gestures, provide timely feedback and make motor practice engaging and challenging. Although gesture-based games are promising in the intervention of children with ASD, relevant research is limited. To our best knowledge, only Tang, Falzarano, and Morreale (2016) investigated the potential of Leap Motion Controller (LMC)-based games for Children with ASD. However, only high self-reported acceptability and usability of gesture-based games by children and their family members were reported. The effects of using gesture-based games in assisting learning were not available in the study. Therefore, as one of the initial attempts, this study aims to explore if it is effective to use gesture-based games to enhance the fine motor skills and recognition of children with ASD.

Research questions

In this study, we developed two gesture-based games using LMC and explored if they were effective in improving the gaming performance, fine motor skills, and recognition of colours and fruits of children with ASD. Also, their ability of transferring was explored. More specifically, we aimed to investigate the following research questions:

(1) How does the participants' performance in playing games change during the intervention?
(2) To what extent do the fine motor skills of a child with ASD change with the intervention of gesture-based games?
(3) Does the gesture-based game intervention benefit the participants' recognition of colours and fruits?
(4) Are the children with ASD able to transfer the fine motor skills and recognition they have learnt to a different context?

Methods

Research design

Due to sample constraint, we used a single subject research design. This design could be used to investigate the functional relationship between independent and dependent variables (Galassi & Gersh, 1993) and had been widely used in the field of special education (Cakiroglu, 2012). Single subject research has several critical features: (1) individual data analysis rather than group performance of participants is used to represent the effectiveness of an intervention, which to some extent helps solve the issues of low proportion of students in special education; (2) operational definitions of study characteristics (e.g. participants, settings) are required to allow other researchers to replicate an experiment and evaluate the reliability of a study; (3) target behaviours are measured repeatedly both in the baseline and intervention phases to ensure the data recorded is a true representation of the participant's performance (Tankersley, Harjusola-Webb, & Landrum, 2008); (4) repeated measurements in baseline phase until stable representation of target behaviour is acquired helps researchers to attribute improvement on target behaviours to intervention rather than to other possible factors; and (5) visual analysis is usually used to demonstrate the effectiveness of an intervention, and the trend of the data over time, changes in data points, and the time between an intervention is implemented and the actual change of the participant's performance together help researchers decide whether an intervention is effective (Cakiroglu, 2012; Kennedy, 2005). However, single subject research is not without limitations. For example, the results of a single subject research may not be generalizable, and different researchers may interpret similar data differently.

The advantages of single subject research outweigh its limitations in our scenario. Therefore, it was adopted in this study which aimed to explore the effectiveness of using gesture-based games to enhance the fine motor skills and recognition of children with ASD rather than producing generalizable results. Especially, we adopted AB design to shorten the experimental time since it was near the winter holiday. A denotes the baseline condition (before intervention) while B represents the intervention phase.

Participants

Three children with ASD from a special needs school at Beijing participated in this study. They were selected according to these criteria: they were children with ASD; they were able to understand teachers' instructions; they had some fine motor skill problems; they could not match colours or fruits; and they did not resist playing the games. The same two games used in the intervention phase were used to assess if children meet the criteria. The following is the detailed information of the three participants:

Tony was a nine-year-old boy who developed severe autism after a fever at age four (according to his mother). Before that, he developed typically in speaking, playing, social interaction and communication. The symptoms well match the descriptions of childhood disintegrative disorder (APA, 2000). The teachers mentioned that Tony had better motor skills but weaker cognitive ability compared with his classmates.

Ann was an eleven-year-old girl. She was diagnosed with severe autism when she was three. She had better cognitive skills than Tony but she was inactive and unwilling to move.

Ben was a ten-year-old boy born in Australia. According to the teachers, he was diagnosed with severe autism as an infant, and his elder brother had Asperger's.

The three participants were from the same class and the two teachers of the class helped fill out the Social Responsiveness Scale (Constantino & Gruber, 2012), which is a valid assessment of autism severity (Hilton et al., 2007). The three participants scored 101, 96, 95 in the scale respectively, indicating severe autism, which matched the teachers' descriptions.

It was mentioned by the teachers that all the three participants came from families with middle socioeconomic status. Their parents were willing to participate in their education.

Measures

Fine motor skills scale for children with ASD

The development assessment scale for children with ASD developed by the China Federation of Disabled Persons (2009) is widely used in practice in China. It is our conjecture the assessment scale fit the local context better. Fourteen items were chosen from this scale and formed the fine motor skills scale. The items were mainly on visual-motor integration, reaching, picking up and placing items. During the baseline and after the intervention phase, this scale was used to evaluate the three participants' fine motor skills.

Recognition scale for children with ASD

Similarly, the recognition scale used in this study consisted of seven items selected from the instrument developed by the China Federation of Disabled Persons (2009). The scope of the seven items involved recognizing and naming colours and fruits. The scale was used before and after the intervention to assess the participants' recognition levels.

Procedures

There are two major phases in an AB design of single subject study: baseline phase and intervention phase (Galassi & Gersh, 1993). Before these two phases, we designed two games. Therefore, three major sequential phases are introduced.

Game design phase

In the game design phase, two gesture-based games with different difficulty levels were developed. In the first game, balls of different colours (red, green, and blue) need to be placed into matching coloured boxes. For instance, a green ball has to be put into the green box. Once a ball is put into the matching box, another ball will appear on the screen for another attempt. In the second game, fruits need to be put on matching sticks. In the first game, for any ball, the matching area is a rectangle with a width of 120 pixels. In the second game, the width of matching rectangles is 80 pixels, which indicates the second game required more precise motor skills. The interfaces of the games are shown in Figure 1.

The LMC captures the positions of the participants' fingers for multiple frames every second and analyses the vector (the general direction in which a finger is pointing) of each finger. In the games, in order to pick a ball/fruit up and move it on the screen, a user's thumb and index finger need to be close but also leave some space in between. After pilot experiments, we set the angle of 30 degrees between the vectors of thumb and index as the threshold for picking and holding items. The games provide immediate feedback. For example, if a ball is placed into the matching box, a smiling face will appear on the screen, and then another ball will appear.

Baseline phase

In the baseline phase, we selected the participants and evaluated their individual baseline performances. Using the two games developed by our team, we selected three participants from ten children on the spectrum of autism according to the aforementioned criteria. Later, we spent ten days to separately assess each participant's fine motor skills and recognition of colours and fruits for three times using the instruments mentioned above.

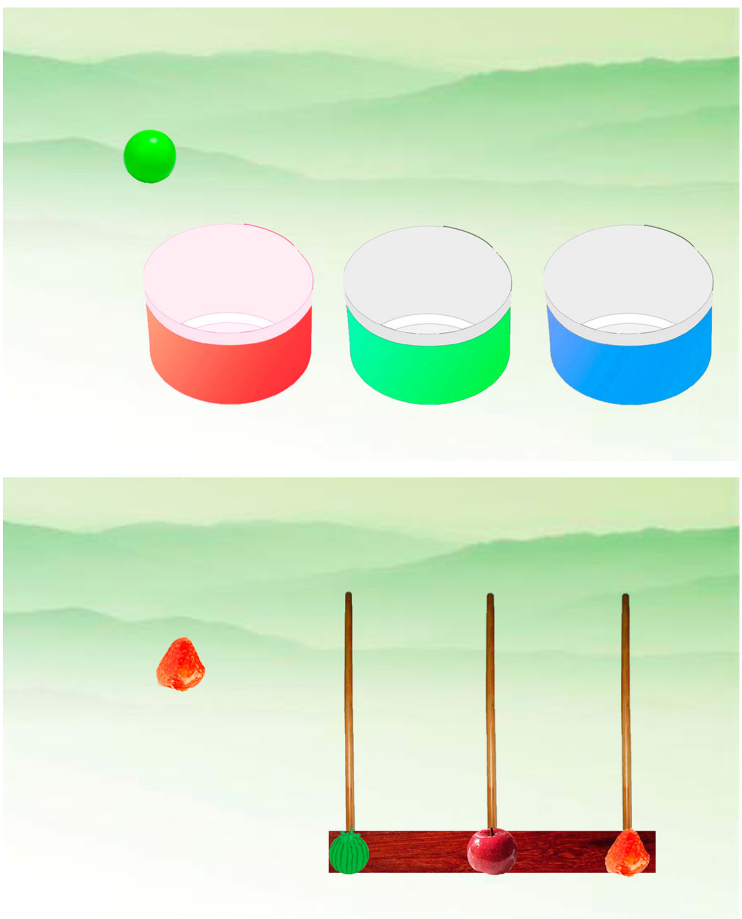

Figure 1. Interfaces of the two gesture-based games.

Intervention phase

The intervention was undertaken by the second author who had some experience in intervening the motor skills of children with ASD, and the intervention was instructed by the fifth author, an experienced researcher in studying children with ASD. The intervention lasted for 11 days. The two gesture-based games were used as the main material to intervene the participants' fine motor skills and recognition. In order to run the games, a laptop was installed with Java, and a LMC was connected with the laptop to capture the participants' gestures.

The participants were expected to receive intervention every morning during school days. However, if a participant had some emotional problems, or needed to take quizzes in class, the intervention for him/her would be suspended. Interventions were conducted in an office for each participant individually. The participants were asked to move his/her hands, pinch and place balls, as shown in Figure 2.

Since children with ASD often have a short attention span, the researcher reminded the participants to focus on the games if necessary. Also, the rules of playing the games and the skills of modifying their fingers were emphasized during the intervention when necessary. When a participant obtained an accuracy of 100% in the first game, he/she was guided to playing the second game.

Data collection and analysis

Both quantitative and qualitative data were collected in this study. In order to answer question 1 (How does the participants' performance of playing games change during the intervention), field notes based on observation were taken during the intervention. Also, at the end of each learning session, the accuracy of placing ten balls using the first game was considered as the participant's performance for that day. Regarding the calculation of accuracy, in the first game, only when a ball was placed into the correct box would a new ball appear, so the player had many opportunities to place a

Figure 2. Participants playing with the first game during the intervention phase.

ball, and could eventually place the ball into the matching container. Thus, only when the participant placed a ball into the matching box for the first attempt did the accuracy increase. For example, if a participant could place seven balls into the correct boxes without trial-and-error, the accuracy would be 70%. We analysed the change of the three participants' performance in matching balls.

In order to answer question 2 and 3 (To what extent do the fine motor skills and recognition of colours and fruits of a child with ASD change with the intervention of gesture-based games), we collected and analysed the participants' performance on fine motor skills and recognition before and after the intervention using the aforementioned measures. The participants were evaluated three times in the baseline phase to look for stable representations. For each participant, his/her mean score of the evaluation was regarded as his/her level in the baseline phase.

To answer question 4 (Are the children with ASD able to transfer the fine motor skills and recognition they have learnt to a different context), we asked the participants to play the second game immediately without any instructions once they achieved 100% accuracy in playing the first game. Their accuracy in playing the second game was recorded and compared with their performances in playing the first game.

Results and discussion

In this section, firstly, we report the participants' problems and progress in playing the first game by integrating the field notes and their performance of matching balls. We also discuss why the three participants showed different progress patterns. Then we describe the participants' performance of fine motor skills and recognition before and after the intervention phase. This is followed by a discussion on which particular fine motor skills (e.g. staring at hands, reaching for items) our games can help improve. In addition, the participants' transfer ability is reported and compared with that of existing research.

Performance of playing games

Before the intervention, Tony had difficulty in staring at his hands, moving his hands in line with his eyes, reaching for items, and matching items with boxes or sticks. He could not match or name colours or fruits. As a result, he only obtained seven points in fine motor skills, and zero points in recognition, as shown in Table 1. Moreover, he constantly knocked the desk and reached for unrelated items. During the intervention, Tony learned how to play gesture-based games with LMC. Based on observation during intervention and accuracy assessments after each learning session, we found that on the 11th day (the first day of intervention), Tony realized that he should modify his hands in the air, and he obtained 10% accuracy in matching balls. On the 12th day, he modified his hands in the air vertically rather than horizontally. He began to pay more attention to the game, but when a new ball appeared, he did not place it into a box voluntarily. His accuracy was 30%. On the 13th day, he could place a new ball voluntarily with an accuracy of 50%. On the 14th day, he could put a ball in the matching box. However, he stopped and played for a while after placing a ball. Within seven minutes, he could put ten balls with an accuracy of 100%. On the 15th day, he played the second game, placing fruits on matching sticks, with an accuracy of 100% without any instructions.

In another case, Ann, played on her iPad frequently at home, and she was accustomed to touching the screen with her fingers. She had poor complex fine motor skills, for example, she could not pinch

Table 1. Participants' fine motor and recognition score during the baseline.

Participants	Score of fine motor skill (full mark: 14)	Score of recognition (full mark: 7)
Tony	7	0
Ann	5	1
Ben	8	0

with her thumb and index finger or hold a pencil well. She was very inactive and did her best to avoid moving. She got five points in fine motor skills and one point in recognition during the baseline phase. During the intervention, from day 11 to 15, Ann always put her fingers on the screen, leading to an accuracy of zero in matching balls. Gradually, she understood the rules of modifying her fingers. On the 16th day, she no longer put her fingers on the screen, but she still could not pinch a ball, resulting in an accuracy of zero. On the 17th day, she could pinch a ball, but she always touched the screen first, and then moved her fingers in the air and modified them to pinch balls. Fortunately, her accuracy increased to 20%. On the 18th day, she could put a ball in the matching container, but when a new ball appeared, she did not pinch it again voluntarily. She achieved an accuracy of 40%. On the 19th day, she could put ten balls in the matching containers in 2 min with an accuracy of 100%. She could also play the second game immediately with an accuracy of 100%.

During the baseline, the third participant, Ben, attempted to match things but did not succeed. On average, he obtained eight points in fine motor skills and zero points in recognition in the assessments. According to our observation and the results derived from assessments, on day 11, Ben could not focus his attention, and performed some negative emotional behaviours (not because of the intervention, the teachers mentioned the student had periodical emotional problems), for example, crying and knocking computers. Thus, the intervention was interrupted until he felt better. His accuracy from day 11 to day 14 was zero. Then, on day 15, he participated in the intervention again since the teachers mentioned that he was in a good emotional state. He exhibited some behavioural issues and was not able to understand the rules of modifying his fingers. However, his gesture of pinching was accurate, and he achieved 20% accuracy. On day 16, he could pinch the ball, but could not place the ball in the matching box without instructions. Often, he placed the ball randomly with an accuracy of 30%. On the 17th and 18th days, he tried repeatedly until he placed the ball accurately. However, when a new ball appeared, he always placed the ball in the same box as for the previous one. For example, if he put a red ball in the red box, and got positive feedback, then when a green ball appeared, he would put it in the red container as well. He got 40% and 60% accuracy on 17th and 18th days. On the 19th day, when there were some balls in a box, for example, in the green box, he would place a new green ball in the green container. However, when the green box was empty, it was difficult for him to place the green ball accurately. He would try many times before he placed the green ball correctly. His accuracy was 70%. On the 20th day, he could place 10 balls and 10 fruits (the second game) at 100% accuracy.

As summarized in Figure 3, the three participants' performance of putting balls into the matching boxes increased notably in the intervention, although differently. Line A in Figure 3 shows Tony' accuracy. During the baseline, the accuracy was zero because Tony did not know that he should modify his fingers in the air. He did not know how to match the balls and boxes, or maybe he did not understand the rules. During the intervention phase, Tony learned how to play gesture-based games quickly. This result might be attributed to his good motor skills foundation. Line B in Figure 3 reveals the trajectory of Ann's performance of putting balls. The accuracy was zero during the baseline and the first six days of intervention since she always modified her fingers on the screen rather than in the air. Then the accuracy increased sharply and eventually reached 100%. The trajectory of Ben's accuracy is shown as Line C in Figure 3. After taking several days' break from the intervention because of emotional problems, Ben's accuracy of placing balls increased gradually.

One may be interested in why the three participants showed different progress patterns. Possibly, it is due to their prior experience in using different technology devices. For example, before the intervention, Ann had a lot of experiences in playing iPad. At the beginning of the intervention, she always touched the screen with her index fingertip instead of grasping simulated balls with fingers in the air. As a result, she made slow progress in the beginning. Poor emotional control ability might be another reason. For example, Ben's emotional problem caused the interruption of intervention for him for four days. In sum, the three participants showed improved performance in playing the gesture-based games developed in this study. Although they showed different patterns in progress, they achieved 100% accuracy in playing the games eventually.

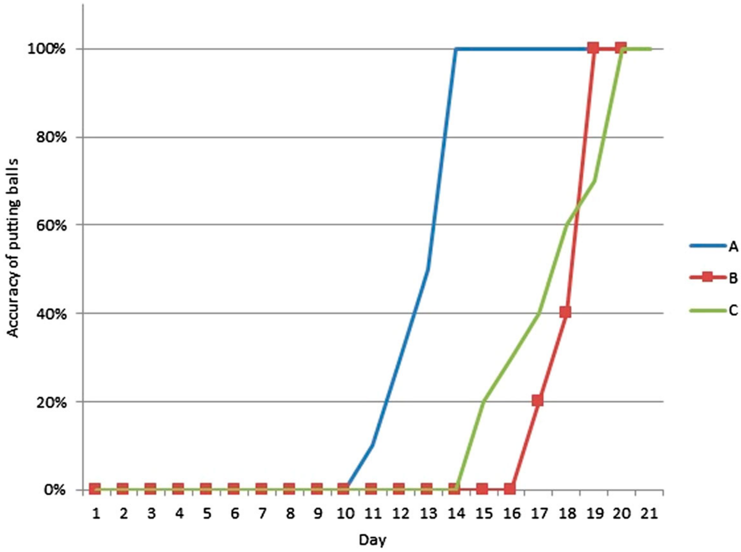

Figure 3. Three participants' accuracy of putting balls.

From our observation of the participants' performance in playing games, we can tell that they required some instructions at the beginning on how to modify their gestures since they were used to touching screens. But once the participants learned that they should modify their fingers in the air in order to interact with the gesture-based games, they needed fewer instructions. Jong, Hong, and Yen (2013) indicated that kindergarten children preferred touch-based interaction than gesture-based interaction. Possibly, it is because that they are used to touch-based interaction. Once children become familiar with gesture-based interaction, they might enjoy it. Then gesture-based games, which can capture childrens' hand and finger movements, may play a more important role in improving their fine motor skills.

Progress in fine motor skills and recognition

After the intervention, all of the three participants' fine motor skills improved dramatically (as shown in Tables 1 and 2), Tony got 13 points, while Ann and Ben got 12 points. Additionally, their performance in recognizing colours and fruits improved. Tony and Ben received four points, and Ann received five points.

By checking students' performances in each item of the fine motor skills assessments, we found that some skills, for example, staring at objects, looking at one's own hands, moving eyesight with objects, were enhanced by using our games. However, it is difficult to determine the exact factors that contributed to the participants' improvement in other items which aim at assessing more complex skills, for example, putting down an object and grasping another one. Just like the limitation of motor assessments proposed by Anjana et al. (2011), researchers are unable to discern whether poor motor performance is only reflective of primary motor impairments or comprised of language

Table 2. Participants' fine motor and recognition score after the intervention.

Participants	Score of fine motor skill (full mark: 14)	Score of recognition (full mark: 7)
Tony	13	4
Ann	12	5
Ben	12	4

and cognition issues which lead to poor understanding of what is asked. To put it in another way, it is quite complicated, if not impossible, to tell what factors particularly contributed to the participants' improvements in motor skills. In this study, since the participants had limited abilities in speaking and identifying their own cognitive processes, we did not obtain verbal feedback from them. Their improvements might be a mixed result of their increased understanding of the rules of the games, better skills of operating LMC, and improved fine motor skills and recognition of colours and fruits.

Learning transfer

Learners' application of learned knowledge in novel contexts (i.e. the transfer of learning) is an important issue for educators (Haskell, 2001). After the participants reached 100% accuracy in playing the first game, we immediately asked them to play the second gesture-based game, which was more complex (as described in the Procedure section). It turned out that Tony, Ann, and Ben were all able to transfer the skills they had learned in the first game to complete the tasks in the second game. Some studies indicate that people with ASD have difficulty in generalizing learning achievements across contexts (Dautenhahn & Billard, 2002). However, our study showed that the participants were able to transfer the rules and skills, suggesting the positive effects of using gesture-based games as an aid for children with ASD to transfer fine motor skills and recognition. Further research could be conducted to explore if children with ASD can transfer further, for instance, exploring if they can generalize the fine motor skills and recognition ability they have learned in playing gesture-based games to daily living skills (Jasmin et al., 2009).

Conclusion

This study is one of the initial attempts to explore the effect of using gesture-based games in the learning of children with ASD. Two gesture-based matching games were developed to improve the performance of children with ASD with respect to fine motor skills and recognition, and three young children with ASD participated in a three-week experiment (half an hour a day and five days a week). By comparing the participants' performance before and after the intervention, we found that the participants' performance of playing the games improved greatly during the intervention, and the gesture-based games did help improve their performance with respect to fine motor skills and recognition. Also, they were able to transfer the rules and skills they had learnt from the first game to complete the tasks in the second game. The findings above suggest the effectiveness of using gesture-based games in assisting the learning of children with ASD.

As we know, children with ASD have difficulties in learning. More research focusing on how educational technology could be used in enhancing the learning of children with ASD should be crucial. We are hopeful that researchers will build on our results with more samples, in various contexts, using different games and targeting diverse motor skills, to contribute to our collective understanding of how motor interventions affect motor functioning and what we can do to benefit the well-being of the children with ASD.

Limitations

The first limitation of this study is the small sample size and the single subject research AB design itself. Only three participants participated in the intervention phase at almost the same time. We were unable to include a control group due to limited sample size, nor were we able to adopt withdrawal design to remove the gesture-based game intervention during one or more phases of the study in order to better demonstrate the functional relationship between the intervention and target behaviours (Richards, Taylor, & Ramasamy, 2013). However, the findings still provide some important insights to this research field.

Another limitation is that the participants' improved performance in playing the gesture-based games may be the mixed results of several factors: improved ability to control emotion that affected concentration, increased understanding of the rules of the games, better skills of operating LMC, and improved fine motor skills and recognition of colours and fruits due to rote learning. In future studies, more in-depth studies should be conducted to study these factors and the interaction effects of these factors.

Besides, how gesture-based game intervention might influence the social interaction and communication skills of children with ASD in the long run needs further investigation. Evidence shows that the children with ASD prefer to interacting with objects (e.g. computers) rather than with people. Interacting with gesture-based games tends to improve the children's fine motor skills and helps deal with the unsatisfying ratio of teacher-to-student in special education. However, will this kind of interaction reduce the opportunities of children interact with people and worsen their social interaction and communication skills? Or is it possible to include the social and communicative elements in the games?

Finally, when selecting participants, we found it might be difficult for one child with ASD to use our games if he/she could only focus his/her attention for several seconds, and could not understand our instructions. Any educational technology has its limitation in assisting students' learning, especially for a group with developmental disorders. Educational technology, including educational games, may only benefit those who were able to interact with them. Therefore, efforts should also be made to the development of gesture-based games.

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