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Design and Development of Interactive Therapy System for Children with Autism*

발달장애아동을 위한 상호작용 치료시스템의 디자인 개발

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Abstract

Early diagnosis of autism and intervention of medical treatment are very significant to develop specific social communication skill for children with autistic spectrum disorders (ASDs). But they have difficulties in medical treatment because of lack of a public welfare institution and special medical system. In particular, few children can access such treatment and the existing single-therapist clinics are inefficient with regard to cost and time. Therefore, new methods should be studied for developing various products, services, and systems for autistic children. This study discusses the potential use of an interactive design as assistive technology for such children. We utilize the experience gained in the collaborative design of the interactive therapy system (ITS). The key methods include a collaborative design with rapid interactive prototyping, heuristic evaluation, user-centered process, VR technology, tangible interface, and scenario-based contents. We applied these methods to the ITS and proved the efficiency of interactive design as an assistive technology through clinical experimentation.

Keywords : Autism, Interactive Design, Assistive Technology, Therapy, Collaborative, Usability, Emotion

요 약

발달장애아동은 사회적 의사소통의 기술을 개발하기 위하여 이른 시기의 진단과 의학적 치료가 매우 중요하다. 하지만 발달장애아동들은 공공 복지기관과 전문 의료시스템의 부족으로 인하여 의학적 치료에 큰 어려움을 가지고 있다. 특히 적은 수의 아동만을 대상으로 해야 되는 일대일 면접 치료방법의 특이성으로 인하여 발달장애 아동은 장소, 시간, 비용의 문제에 직면하고 있다. 이러한 문제점을 해결하기 위하여 다양한 상호작용의 기술과 보조기술, 서비스가 개발되고 있으며, 본 논문은 이러한 상호작용 디자인의 가능성을 탐색하고

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더 나아가 치료시스템의 구체적 디자인개발을 목표로 한다. 본 연구는 학제간 협업, 빠른 프로토타입 개발, 전문가와 사용자 평가중심의 프로세스, 가상현실 기술, 시나리오 중심의 디자인을 주요 개발 방법론으로 적용하여, 상호작용치료시스템(ITS)의 구체적 사례를 개발하였다. 또한 상호작용치료시스템(ITS)을 치료기관과 협력하여 실제 임상실험에 적용함으로서 이러한 상호작용 디자인의 효용성과 타당성, 활용방안 등을 검증하였다.
주제어 : 발달장애, 상호작용 디자인, 보조기술, 치료, 협력, 사용성, 감성

1. Introduction

Autistic spectrum disorders (ASDs, autism) encompass a wide continuum of associated cognitive and neurobehavioral disorders, including the core-defining features of impaired socialization, impaired verbal and nonverbal communication, and restricted and repetitive patterns of behavior (Flipek, 1999). Between 60,000 and 115,000 children under 15 years of age in the United States meet the diagnostic criteria for autism based on recent prevalence estimates of 10 to 20 cases per 10,000 people. Identifying children with autism and initiating intensive, early intervention during the preschool year results in improved outcomes for most young children with autism. Geenspan and Wieder(1997) report that of 200 children with an early diagnosis of ASD who receive intensive medical attention for two years, 58% can form relationships with other people, express their feelings, and verbally communicate effectively. Nevertheless, the parents of these children with ASDs have difficulties in seeking medical treatment because of lack of a public welfare institution, facilities, and system and government support. In particular, treatment is restricted to a few patients and existing single-therapist clinics and one-on-one therapy methods are inefficient methods with respect to the aspect of cost and time.

Therefore, research is necessary to create new methods for the development of various products, services, and systems for children with ASDs. This study discusses the potential use of interactive design for children with autism. Our discussions draw upon experience gained in the collaborative design of the therapy system for children with ASDs. The aim of this study is to explore the current interactive design methods, to apply the most effective process, method, and technology of an interactive design.

2. Interactive Design and Autism

2.1. Therapy Theories for children with ASDs

There have been many attempts to help children with ASDs develop specific social and communication skills. Because of the social difficulties, the emphasis has been placed on social and communicative competence regarding educational intervention (Kim and Volkmar, 2000). The majority of these interventions have utilized behavioral and cognitive methodologies.

Early behavioral methodologies for teaching social skills to preschool children with autism focused on the application of operant conditioning principles. In highly structured, single-handed settings, children with autism receive repetitive drilling in particular behaviors in discrete blocks of trials (e.g., imitating hand waving or completing a puzzle). This approach aims to equip children with fundamental social building blocks from which they could learn, develop, and generalize for a broad range of social situations (Frankel and Leary, 1987). These interventions were often very effective in teaching children new behaviors or skills, but suffered from a lack of therapists, as well as the cost and time for a one-patient-to-one-therapist setting. Sensory integration therapy (SIT) is based on a theory developed by Ayres, which emphasizes the relationship between (A) sensory experiences and (B) motor and behavioral performance (Ayres, 1972). SIT is intended to focus directly on the neurological processing of sensory information as a foundation for the learning of higher-level (motor or academic) skills (Baranek, 2002). There are some advantages of SIT－it is possible that unstructured therapy using role-play situations can provide social skills training by practicing intimacy with friends.

One of the most influential cognitive approaches to explain the social difficulties seen in autism is based on the "theory of mind" hypothesis. The term "theory of mind"(ToM) comes from the work of Premack and Woodruff, who used it to describe the ability to impute mental states to self and others (Premack and Woodruff, 1987). The ToM hypothesis states that the social difficulties in people with ASDs arise through an inability to recognize or think about the mental states of the self and others (McGregor and Whiten, 1998).

2.2. Related Studies for Children with ASDs

The potential usefulness of interactive design for the autistic population has already being recognized and various researchers have noted the possible benefits of interactive environments for people with ASDs (Habash, 2005). Trepagnier(1999) proposed that VR technology may be an ideal tool for allowing participants to practice behaviors in role-play situations. Wann(1996) performed a realistic cost and benefit analysis for the development of a VR interactive system, which can make a unique and useful contribution. Kaufmann et al.(2000) researched the potential and challenges of using collaborative augmented reality (AR) in education within the greater context of immersive virtual learning environments. Lewis(1998) suggested that the gaming aspect of this method can easily be incorporated into interactive design for children with ASDs. The gaming approach contributes to motivation for maintaining time on task, and has been customized to suit individual children's needs. Hirose and Tanigucchi(1994) developed a system that included computers and video conference. These children were able to communicate with their families in remote locations and play games interactively with other children in similar situations. Gips and Betke(2000) have used a new technology called the Camera Mouse to provide computer access for disabled persons. The Camera Mouse is non-invasive and uses a standard video camera and room lighting to track slight movements of the head, thumb, or toe, whatever part of the body a disabled person can control.

2.3. Useful Methods of Interactive Design for Children with ASDs

Various methods of interactive design are used for solving the difficulties and problems that disabled persons and children with ASDs present. A number of methods have been proposed that may influence presence; collaborative research with rapid prototype, VR and information technology, tangible interaction, and scenario-based design.

First, an interdisciplinary, collaborative set-up and heuristic guidance provide clear explanations of the target social skills and the most suitable methods for system design for disabled people. Rapid interactive prototyping can make it possible for collaborative researchers to develop the practical system needed to help children with ASDs practice and train with interactive technology (Rose and Attree, 2000). Second, VR technology is frequently used as specific implement method. There is certainly some encouraging evidence that interaction with another person with the use of VR-based tasks significantly improves learning outcomes. Third, applications involving a tangible interface and tangible interactive objects are very effective methods for children with ASDs. In particular, the inclusion of tangible representations of mental states (e.g., thought bubbles) helps children with ASDs pass false belief tasks (Parsons and Mitchell, 1999). Using tangible interactive objects is a suitable interaction method for children who exhibit an interest in reaction through constructing curiosity, because it requires more physical actions and psychological stimulus than a graphical user interface. Fourth, scenario-based task evaluation and presentation can improve the chances of generalizing skills across contexts. In addition, the inherent properties of VR as a specific interactive technology may facilitate the solving of problems in various contextual tasks from the virtual to the real world because of the shared features between virtual and real environments, in the form of realistic images and scenarios.

3. Observation on Children with Autism

We visited Seoul Metropolitan Children's Hospital, interviewed four therapists and five children who participated in clinic program, and observed the treatment process. The therapy of children with ASDs was divided into individual one-to-one therapy and group clinics (3 - 4 people). The total number of observed children was 14. The sessions consisted of play-therapy, verbal-therapy, and music-therapy, focusing on programs to regulate the patient's inner and external vigilance and the cultivation of social interplay skills. Each therapy session was carried out for 30 - 40 minutes in turn.

We identified the features of therapy from the observations. First, all therapy programs have a common purpose, which is to learn about communication with other people and to expand this relationship. Second, all therapy programs need naturalness, a sense of stability, and enjoyment. These factors encourage children to participate positively through inducement and conversation, and then the therapy has a greater effect. Third, normal people feel reality through familiar interactions that come from previous experiences. Conversely, children with ASDs should learn about real interactions in a virtual interactive environment.

The above-mentioned observations and analysis discussion implies that an interactive therapy system (ITS) should perform the substance of established therapy programs and apply the interaction technology aggressively. System design requirements should include the following: a supportive therapy, an economical system structure, ease of maintenance and management, generation of various interactions, and effectiveness for repetitive therapy sessions. Interactive design can create therapy sessions that can save cost and time, work well for limited spaces, and enable the development of a high-quality interaction system that assures effective therapy. A system developer performed examinations with motion tracking, sensing technology, and display interaction for cost efficiency and simplicity of manufacture and management. A suitable tangible interface for children with ASDs also needs to be designed to develop interactions which are natural and enjoyable. In summary, by drawing on theoretical analysis along with observations regarding teaching social skills, it is possible to outline the key elements which should be included in a new interactive design. Ideally, the specific education and therapy system should incorporate the following factors:

- Repetition of the target skills or tasks (Parsons and Mitchell, 2002)
- Construction of tasks by stage
- Visual and pictorial expression of the social skills
- Consideration of how one's own behavior impacts others (i.e., understanding other's minds)
- Practice of skills in realistic settings
- The ability to practice target skills across contexts
- Contents according to scenarios and role play
- Accessibility and ease of use for assistants
- Affordability for home and hospital environments

Figure 1. Observation of Therapy of Children with ASDs

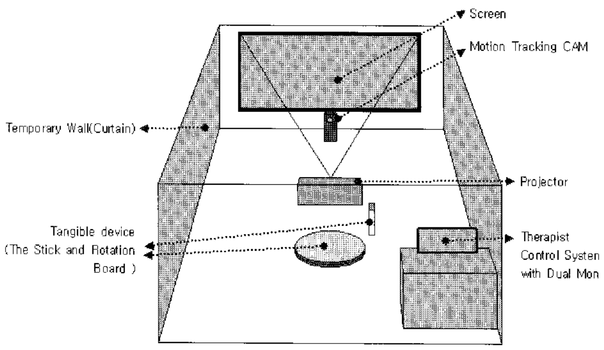

Figure 2. An Example of the ITS Construction

4. Design and Development of ITS

4.1. System Architecture Design

Figure 2 illustrates the platform design of the ITS in this study. The ITS has three components: a coordination ability measurement, social skill training, and SIT. Our ITS consisted of a PC, a projector, a screen (200 cm × 150 cm), an infrared reflector, a digital camera, and tangible devices (e.g., stick, rotation board, trampoline). Participants can see the result of their actions on the screen as they perform the tasks. The platform is designed for children to interact with tangible devices in front of the screen. Both sides of the screen are blocked with a partition board so that children feel more comfortable and concentrate on the screen. The therapist can control the therapy process in real time with an operating monitor which is separated from the screen that the children are looking at.

This study has developed an ITS for practical use in a clinic-treatment setting, with a concern for equipment cost and efficiency to enhance popularization of the system. For these reasons, a PC and general office hardware have been used as the basic platform. All software for treatment was designed using Adobe Director and Microsoft Visual Basic. Video tracking was used for all scenarios, which record children with a 30 cm stick. The stick has a green LED on the top, which makes it easy for tracing. TrackThemColors Extra (Smoothware Design) was used to develop software for video tracking. The rotation board, controlling speed and range for the Twister and Pinwheel was made from game controller hardware and connected software using Joystick Extra. Figure 3 illustrates the stick and rotation board.

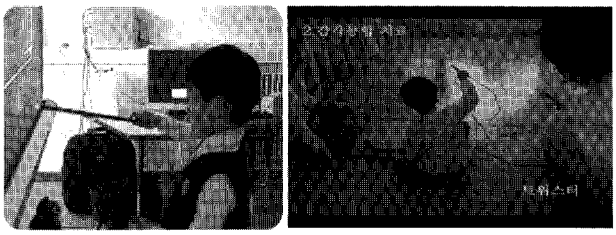

Figure 3. The Stick and Rotation Board for System Control-Used Tangible Interaction

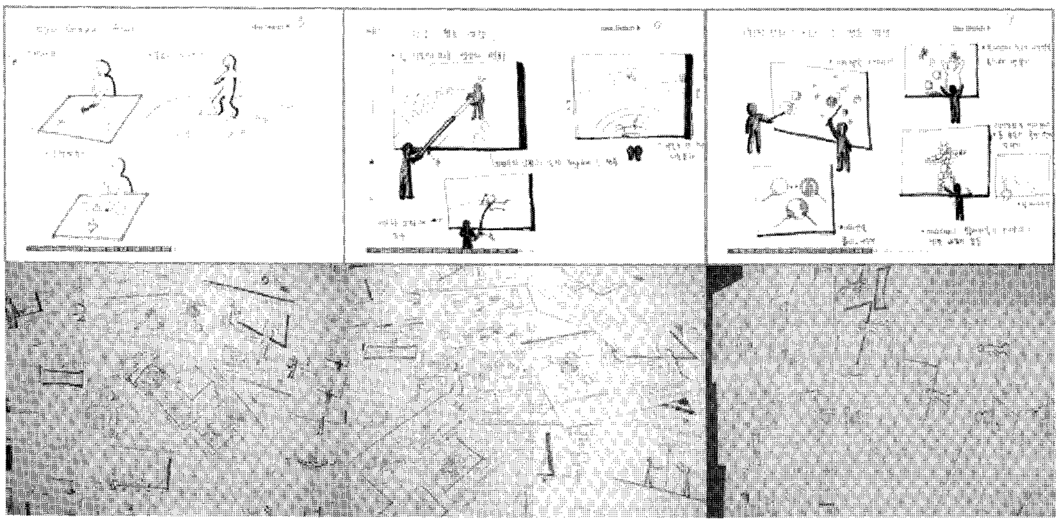

Figure 4. Examples of Scenario Ideation

4.2. Interaction and Scenario Design

A scenario was developed by two main interaction designers in conjunction with two therapists, two psychologists, and an engineer. The interaction scenario was designed according to behavioral and cognitive therapy methodologies, including the ToM theory and SIT therapy. The application of the interaction scenario attempts to measure each child's ability. The ITS consist of eight types of SIT scenarios, five types of social skills training scenarios (based on the ToM theory), and one type of visuomotor coordination ability assessment scenario (based on a behavioral approach).

4.2.1. Visuomotor Coordination Ability Assessment

The Visuomotor Coordination Ability Assessment is a program for measuring visuomotor coordination ability. The program involves breaking virtual balloons with a real stick; reinforcements are provided for success. The number of balloons increase and the type of reinforcement received differs at each increasingly difficult level.

The types of reinforcement were selected based on the therapist's experiences and outcomes of parent surveys. These were then classified into auditory and visual substances (Dawson and Watling, 2000): participants received one reinforcement (from eight visual and ten auditory reinforcements) as a reward for breaking each balloon. Each participant completed 10 sessions for this activity.

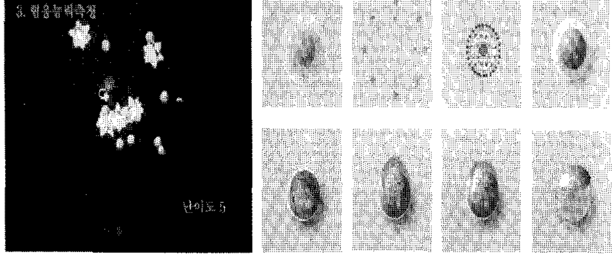

Figure 5. Examples of Visuomotor Coordination Ability Assessment and Visual Reinforcement

Table 1. Types of Reinforcement

Visual Reinforcements	Auditory Reinforcements
	Laughing
Falling, like powder	Crying
Falling, like a water drop	Angry or irritating sound
Disappearing like a shining star	Horror sound
Exploding, like fireworks	Buzzing
Light rotation	Chatting
Changes into father's face	Firing of a laser beam
Changes into mother's face	Aircraft flying
Changes into baby's face	Firecracker explosion
	Water dropping

4.2.2. Social Skills Training

Social skills training components were designed to minimize sound effects and background noise to allow for conversation between participants and the therapist to occur, and to allow the participants to concentrate on the graphic factors. It was designed to look like a game, and each of the five phases could be progressed through gradually. Participants completed 10 sessions.

"Spot-eyes-face looking training" refers to training autistic children to gaze at people's eyes.

"Real face and graphic expression matching training" refers to training for understanding the emotions of people by looking at his or her face.

"Extensive training for facial expression" is also for improving the ability understanding facial expressions; the therapist lets children seek out a specific face among several different types of faces with a wand.

"Following the spot with eye movement" refers to the practice of looking at the eyes of others. A cartoon character with big eyes appears on the screen and starts to follow the small dot turning around it with its eyes.

"Matching game with eye movement" refers to the training that teaches understanding of what other people are looking at. In the center of the screen, a cartoon character is looking at one of four objects. When the children indicate the correct object, the reinforcement becomes animated. For instance, the screen will present an animation of a hamburger being eaten when children correctly indicate that the hamburger was the object the character was looking at.

4.2.3. Sensory Integration Therapy

Sensory integration therapy has attempted to stimulate the sense organs, making children stable at an awakening level for an effective treatment. To measure the functions of sensory integration treatment effectively, images were developed from various rides in an amusement park. It was expected that exposing the patient to such a range of vivid stimuli (which would be impractical or unsafe in the real world) would be beneficial. Conditions such as swaying from side to side and backward and forward, stairs, screen rotation, user rotary motion (such as turning four sides or turning the screen), running, and trampoline were used. The interactive images and movie clips were recorded in an amusement park and playground for providing a pleasant experience to children.

Table 2. Scenarios of Sensory Integration Therapy

Movement	Content	Remark
Right and left	Looking at carousel in the amusement park	
Front and rear wave	Viking in the amusement park	
Stairs	An elevator in the amusement park (still image)	
Twister	Riding carousel in the amusement park	Practicable for children
Pinwheel	Animation of huge pinwheel	Practicable for children
Running	Running on the road outdoor	
Trembling	An elevator in the amusement park (moving image)	

These interactive scenarios are screened in the platform to give children a virtual interactive experience. Playback of these interactive scenarios (such as play speed, range of action, and volume) can be adjusted in real time. For the “Right and left wave” case, the waving speed, range of right and left movement, and the background sound of the clip can be adjusted; the therapist controls these properties with a separate monitor. Particularly, in the case of the games Twister and Pinwheel, children can control the properties with a tumbler by themselves.

5. Test and Evaluation

5.1. Preliminary Test

The first ITS prototype evaluation was carried out to assess the testing usability and system performance in a practical treatment environment; the first preliminary test was performed at Seoul Metropolitan Children’s Hospital. The therapist performed a trial test with five children under the condition that the system producer and designer would be observing. Each child was given 5 - 8 minutes to participate in each program, and the therapist collected information about the feedback on the actions.

Analyzing the prototype in operation, the constraints of treatment environment, variables of feedback system and GUI guidance were collected and the proper task level of each scenario was identified. The main factors within the first ITS modification are summarized in Table 3.

Table 3. Modification Checklist after Preliminary Test

	Modification factors
System	System space modification Constancy of UI Dual screen for children and assistant Keyboard for exclusive use Manual and guidance for novice user Hotkey and shortcut Repeat menu structure Tangibility; shorten length of stick Color adjustment for tracking Data structure per child Creation of evaluation data
Visuomotor Coordination Ability Assessment	Motion tracking evaluation module Modification of setting UI Option of sound Reinforcement setting
Social Skill Training	Re-setting the step Size modification Removal of programming error
Sensory Integration Therapy	Swing－to control the speed-step Stair－to clear the noise and blurring Running－to rebuild the contents Rotation－to remove the traffic error

5.2. Procedure and Analysis Method of Clinical Test

We then tested the sensory integration training, social skill training, and visuomotor coordination ability in 10 sessions with the ITS. A total of 12 autistic children and 20 healthy children (controls), all aged between five and six years, participated in this study. All children in the autism group met the DSM-IV criteria for autism and were recruited from the outpatient unit at Seoul Metropolitan Children's Hospital. Unrelated healthy children were recruited from the kindergarten class from Chungang University in Seoul, Korea.

After the 10 test sessions, we discussed the usefulness of our ITS system with the therapist and assistants. We measured the reaction time of children in the tasks of stopping the balloon, moving the balloon, and reading the mind, in order to find the changes in reaction time and adaptation of the children to each task. We also measured the accuracy, the distance the stick moved, and mean reaction time of coordination ability, to find the adaptation and improvement in the adaptation ability exercise in each session. The data were analyzed by a repeated-measure analysis of variance (ANOVA).

5.3. Result of Visuomotor Coordination Ability Assessment

We tested the Visuomotor Coordination Ability measurements of reaction accuracy, movement of the stick, and average reaction time by repeated measure ANOVA analysis. As the number of repetitions increased, the accuracy of the reaction increased, and the movement of the stick decreased. However, the mean reaction time changed greatly (a = 0.031, $R2$= 0.011). Measuring a variable of the mean reaction time had no effect ($F(1,3) = 0.038$, p = n.s.) and the slope of the movement of the stick was high (a = - 1.792, $R2$ = 0.5961); however, there was no meaningful result because of the higher deviation for each session and child. This is a meaningful relation to the therapist's reported result that the children's interest decreased with increased repetition.

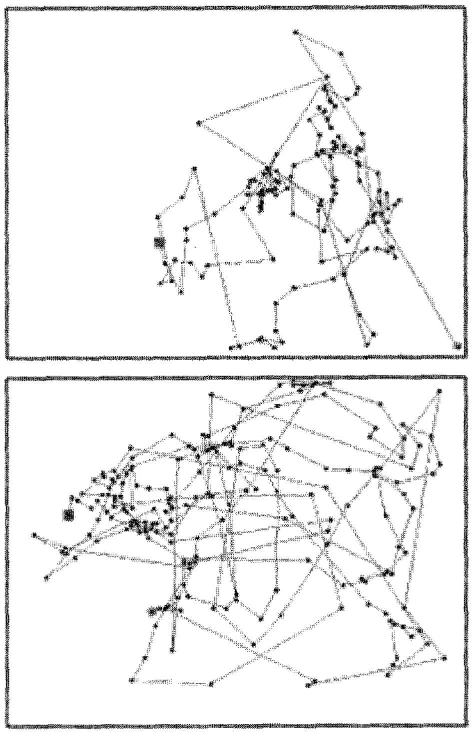

Figure 6. Stick Movement From Early Sessions (Left) and Later Sessions (Right)

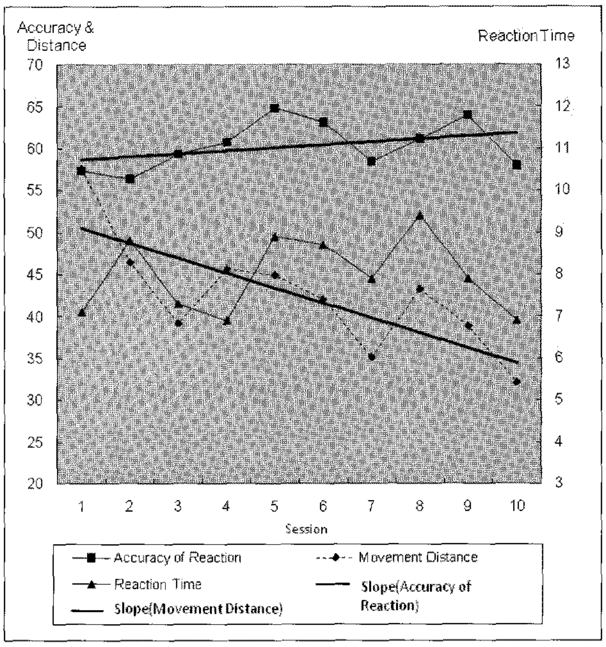

Figure 7. Variation of Reaction Accuracy, Stick Movement and Reaction Time for Coordination Ability Measurement

Movement of the stick was more efficient in later sessions. Although the movement was not great, the accuracy improved and more space was used as the sessions progressed. Reaction accuracy was the highest when reinforcement was a firecracker explosion sound with water dropping at the same time (60.2%), followed by the mother's smiling sound (59.7%). As we expected, the lowest accuracy was when reinforcement was the smiling sound with the laser sound of the star, of which children with social disabilities abhor (53.3%, 51.9%).

Autistic children became more accurate with practice. However, there was no significant difference between the autistic and healthy control children because the variance of the autistic children was so dramatic ($t = 1.803$, $p =$ n.s.). The healthy children showed more movement of the stick ($t = 4.962$, $p < .01$) and faster reaction times ($t = 3.931$, $p < .01$), indicating that they performed more efficiently than the autistic children. The following formula was used for the principal component analysis of coordination abilities:

$$\text{CA index} = 0.797 \times (\text{reaction accuracy}) - 0.799 \times (\text{movement of stick}) - 0.687 \times (\text{mean reaction time}).$$

This formula was adapted to healthy control and autistic children. There was a significant difference between the autistic and healthy control children ($p < .01$), which implies that the autistic children had performed the tasks inefficiently.

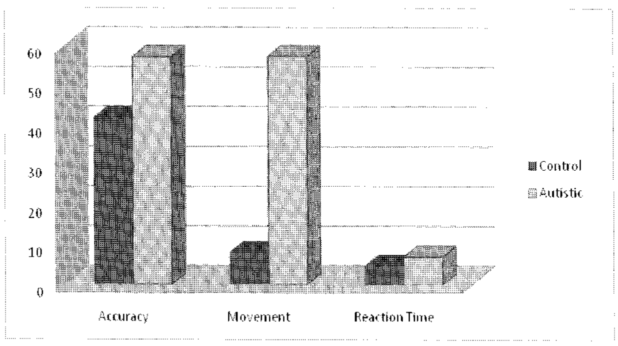

Figure 8. Comparison Between Groups for Coordination Ability

5.4. Result of Social Skills Training

We tested the reaction time of each child for social skills training (such as stopping the balloon, moving the balloon, and reading the mind). A repeated measure ANOVA for the 10 sessions was used. As the number of sessions increased, the mean reaction time gradually decreased, but the variance was very high. Skills related to reading the mind ($F(1,2) = 0.663$, $p =$ n.s.) and moving the balloon ($F(2,3) = 10.401$, $p = 0.08$) did not show any significant results; however, for the stopping the balloon skill, the reaction time ($F(1,2) = 21.339$, $p < .05$) and slope ($a = -0.403$, $R2 = 0.335$) decreased as the sessions progressed.

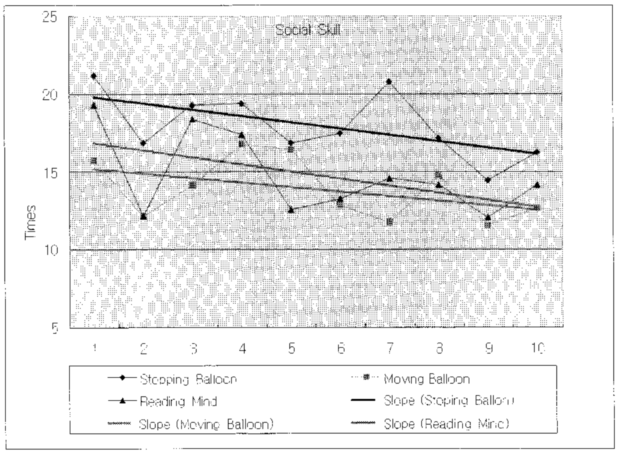

Figure 9. Variation of Reaction Time for Social Skills Training

We also compared autistic children with normal kindergarten children. It was difficult to compare directly, because the autistic children had more practice in adapting to the system; however, it can still be useful to compare the differences. As Figure 16 shows, there was no significant difference between autistic children and healthy control children undoubtedly because of the autistic children's extra practice time, but the autistic children did show longer response times and higher standard deviations in each task.

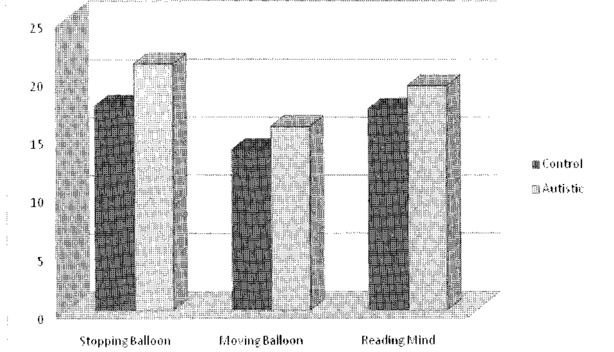

Figure 10. Comparison between Groups for Social Skill Training

5.5. Result of Sensory Integration Therapy

Fewer sessions (from three to eight) and a limited number of stimuli are tested for sensory integration training (primarily focused on vestibular organs). This made measuring the effects of ITS quite difficult. Moreover, there are no quantitative variables that can be measured in research differ from the social skills training and coordination ability measurement. According to the therapist's feedback, boredom had a large effect, as in other forms of therapy. The children had time to adapt to the system but became bored easily. For example, interest in the interactive stepping floor was decreased because of the repeated contents. On the other hand, a preference for un-repeated stimuli (such as running) increased as the sessions progressed. Thus, we can assume that the preference for tangible interaction had an effect. Statistically, SIT had no influence on the social skills program and coordination ability that operated after the therapy.

5.6. Experiment Discussion

As a result of the clinical experiment, we found that it is possible to apply ITS for children with ASDs. ITS based on an interactive design overcame three main limitations of traditional therapy for autistic children: the limited number of places or situations that can be experienced in the therapy, poor repetition results from use of the same tools repeatedly, and the inefficiency of single-handed therapy methods. Children who participated in this research performed tasks using tangible devices without any particular difficulties. Moreover, children showed the greatest interest in the program with interactive contents while they were performing the tasks. Tangible interactions, such as the stick, trampoline, and interactive stepping floor, have to be used in many fields. Social skills training and coordination ability measurement showed a better efficacy than sensory integration or trampoline by providing a sense of reality. This was due to individual differences in the case of SIT. In addition, the contents of the problem solving tasks and recognition of social training and coordination ability tasks were more interesting to the children than any other tasks. This level of interest and effectiveness are due to scenario-based contents and tangible interaction. The social skills training program produced more interactive scenarios through conversations with the therapist. The sociable module could be made more interesting by including the transcripts or voices of these conversations.

Some limitations of our study need to be considered. There are differences in the preferences and adaptation levels of participants, even though they have the same symptoms therefore, the therapy should be individualized, but our program was not. Thus, in future trials, the therapy should be individualized to be more effective. The variety of content should also be individualized. During the 10 sessions of the test, many children became bored even though we had attempted to vary the contents. We used a wide and dark room to allow for a larger screen projection. This led to the room being too dark for face-to-face interactions, an indication that it is very important to consider the mental aspects of autistic children. It would be helpful to expand the interactive design area to the environment and space, and carefully consider the lighting and sound for face-to-face interactions. Some limitations in this study are apparently due to the use of ITS for assessment of autistic children for the first time. However, ITS might be a useful tool for assessing and treating the children with autistic in the clinical field.

6. Conclusions and Future Works

This study illustrates the possibilities of interactive design for children with ASDs. We discussed the meaning and value of interaction design as an assistive technology, and extracted useful methods for design development. We also applied the specific interactive design methods to content and system design for children with ASDs, and suggested ITS for more effective education and therapy. ITS was inspected within a clinical experiment environment, and proved the efficiency of therapy and education. Through the collaborative research and heuristic evaluation of designers, engineers, psychologists, and therapists and parents, we created effective development and evaluation guidance in spite of the expert features of ITS for children with ASDs. We view this research as a successful example of a collaborative design project for particular users. We suggested economical and public methods through camera tracking, real-time video control, movement sensors, and PC-based platforms. The scenario-based method was very effective for contents design and visual expression. In particular, playful stories, role-play experiences, and reflections of real tasks and environments will be the core component of this method.

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