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Development of tablet personal computer-based cognitive training programs for children with developmental disabilities whose cognitive age is less than 4 years

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Abstract

This study was to develop tablet personal computer-based cognitive training programs for children with developmental disabilities whose cognitive age is less than 4 years. Twelve cognitive training programs (named Injini) were designed comprising cognitive domains that included attention, visual and auditory perception, memory, executive function, language, and reasoning. In addition, programs related to learning experiences, such as self-regulation, role play, learning of number, and letter/shape concepts, comparison, classification, and pattern matching, were included. Six of 12 programs comprised approximately 10 levels for each program, with different difficulty levels. Other programs consisted of universal tasks that did not have a difficulty level. To ensure that the difficulty level was appropriate, we pre-tested the pilot version of Injini among 80 children with typical development aged 18 to 41 months. After modifying the pilot version, we developed the final version and tested it among 80 children with cognitive impairment whose cognitive age was 18 to 41 months. All children were assessed using the Bayley Scales of Infant and Toddler Development to determine their development and cognitive age. The difficulty level analyses in children with typical development revealed several inappropriate results wherein the success rate did not decrease with increase in level in some programs. After adjusting the difficulty level, the analyses in children with cognitive impairment demonstrated that the success rate gradually decreased with increasing level in all programs. Cognitive training programs for children with developmental disabilities were successfully developed.

Abbreviations: ADHD = attention-deficit/hyperactivity disorder, PC = personal computer.

Keywords: cognitive impairment, cognitive therapy, computerized cognitive training program, developmental disability, early intervention

1. Introduction

Cognitive impairment caused by developmental disabilities such as cerebral palsy, autism spectrum disorder, Down syndrome, and other genetic syndromes is commonly encountered in the pediatric rehabilitation setting. Cognitive impairment affects adaptive behavior, communication, and social skills, particularly participation in learning activities. This impairment consequently aggravates cognitive function development in a vicious circle.[1] Therefore, improving the cognitive function of children with cognitive impairment is an important issue in long-term medical care.

Although cognitive constructs were previously thought to be stable, recent reports have suggested that the cognitive function of children with developmental disabilities could be improved through cognitive interventions.[2–6] These cognitive intervention programs are based on Feuerstein theory of structural cognitive modifiability and mediated learning experience, and are directed at changes of a structural nature that alter the course and direction of cognitive development.[7,8] That is, appropriate cognitive intervention may not only improve specific training skills and behaviors, but also cognitive domains that have not been trained subsequently. Hence, various forms of cognitive interventions such as cognitive behavior therapy or computer-aided training programs have recently been applied to children

with developmental disabilities.[5] Furthermore, an important issue in cognitive training for children with developmental disabilities is early intervention. Recent studies indicate that cognitive training at a younger age can lead to more extensive training effects. It is not surprising that due to increased functional connectivity and specialization of cortical circuits of the developing brain, younger children are more likely to exhibit neural and behavioral plasticity and consequently, early intervention may be most effective.[9,10]

Over the last 2 decades, various computerized cognitive training programs have been developed to improve cognitive function in patients with stroke, traumatic brain injury, depression, attention-deficit/hyperactivity disorder (ADHD), and dementia/Alzheimer disease.[11–13] Computerized cognitive training has several advantages over conventional cognitive therapy. It allows adjustment of the difficulty level according to the patient's individual cognitive level, immediate feedback, and automatic storage of the training session; in addition, it involves standardized and cost-effective training programs.[14] Consequently, computerized cognitive training is a growing field, and empirical reports on this topic are increasing. In addition, computerized cognitive training programs for children have been recently developed, and the advancement of touch screen technology and the portable tablet computer have enabled very young children to do cognitive training.[5,15] However, most of them have been designed for school-aged children; 1 was designed for children aged 4 to 6 years (The Cogmed JM; http://www.cogmed.com/jm). To the best of our knowledge, there is no known appropriate computerized cognitive training program for

preschoolers aged <4 years. As mentioned, early intervention using computerized cognitive training may be more effective; therefore, we aimed to develop tablet personal computer (PC)-based cognitive training programs for children with developmental disabilities whose cognitive age is <4 years.

2. Methods

This study was conducted with the approval of our International Review Board, and written informed consent was obtained from the parents of all participants after briefing them regarding the study. The development of tablet PC-based cognitive training programs proceeded in 3 steps:

(1) generation of domains and content,
(2) validation tests for children with typical development, and
(3) validation tests for children with cognitive impairment (Fig. 1).

2.1. Generation of domains and content

From 2009 to 2013, a multidisciplinary team comprising pediatric physiatrists, pediatric occupational therapists, a pediatric neurologist, a pediatric psychiatrist, researchers in developmental psychology, and a computer graphics team was formed to develop domains and content related to cognitive training. The programs comprised cognitive domains that included attention (focused, sustained, selective, visual, auditory, and divided attention), visual and auditory perception, memory
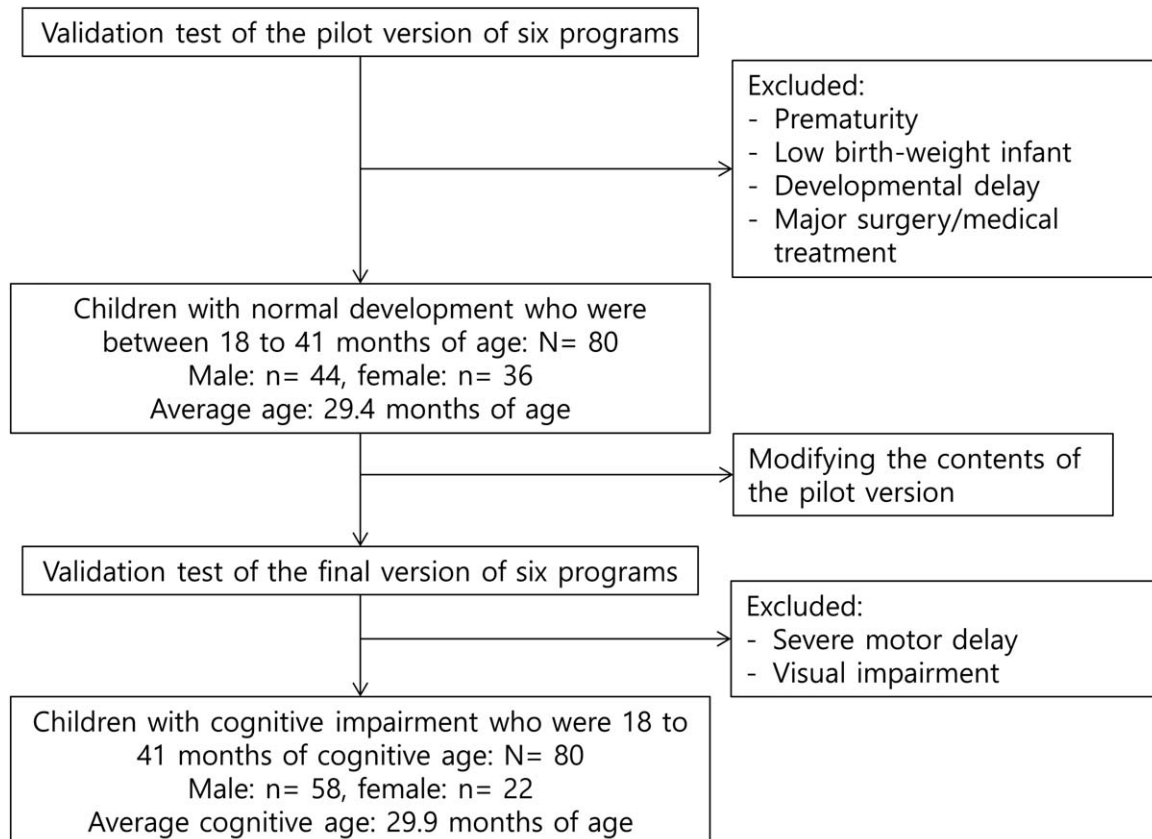

Figure 1. Flowchart detailing the subjects and methods in the present study.

(working and short-term), executive function, language, and reasoning. In addition, the subprograms targeted abilities such as learning body parts, numbers, letters, shape concepts, and the function of different objects as well as comparison, classification, pattern matching, role play, and self-regulation. The content of the programs included familial objects, animals, and plants related to the daily life of children. Moreover, auditory stimuli such as instrument and animal sounds were used. We referred to developmental assessment tools such as the Korean-Bayley Scales of Infant and Toddler Development (second edition), the Korean-Ages and Stages Questionnaires, and the Korean-Denver Developmental Screening Test II used in children under 4 years of age to develop appropriate contents according to age-specific cognitive development. For example, in the puzzles, the level of difficulty was increased in order of circles, triangles, squares, inverted triangles, symmetrical shapes, and asymmetric shapes, and the degree of difficulty was controlled using the complexity, number, and size of shapes. The language of the program was Korean, and all content was designed as per the Korean cultural environment.

Twelve cognitive training programs were designed (Fig. 2) (a demonstration: https://youtu.be/U_4FzNGiLp8), of which 6 consisted of 9 or 10 levels of difficulty. Each level consisted of 10 tasks, and every task was randomly provided. The 6 programs that contained different difficulty levels were puzzles (target cognitive domains: selective attention and visual perception) (https://youtu.be/Yra2csxC9xs), hidden object games (selective/sustained attention and working memory) (https://youtu.be/a3byhePQ-zY), animal matching (visual perception) (https://youtu.be/h-L5uY4L5hc), pattern matching (reasoning, divided attention, short-term/working memory, and executive function) (https://youtu.be/AcaBaW–IK0), identical image identification (visual perception, sustained, and selective attention) (https://youtu.be/tQrGtG61HMw), and memory games (short-term and working memory) (https://youtu.be/anV9eSjQQSQ). All data such as the performance of the individual children, success rate, and the level at which they stopped were stored at the separate data server. The other 6 programs were designed as universal tasks that did not have difficulty levels. These 6 programs were game-based and consisted of tracing (eye-hand coordination and shape/number/letters concepts), object matching (selective attention, receptive language, and color/face concepts), sound matching (auditory perception, selective/sustained attention, and short-term memory), balloon games (color/shape concepts and selective attention), farm games (selective attention and sustained attention), and daily activity games (simulation activities of daily living and receptive language). The program could be set for use at a predetermined time and to prevent individual children from using it for more than 40 minutes. Additionally, the preface to the program noted that use by a child without the guidance of a therapist or parent was prohibited. The program was named Injini, and it is not yet commercialized.

Figure 2. Front page of the 12 cognitive training programs; the titles of the programs are translated into English (the actual programs are run only in Korean).

Table 1

Characteristics of the children with cognitive impairment (N=80).

	Subjects
Age, mo	46.9±15.5 mo (25–103)
Cognitive age	29.9±7.4 mo
Male:female	58:22
Diagnosis	
Down syndrome	6
Williams syndrome	2
Prader–Willi syndrome	1
18q deletion syndrome	1
Cerebral palsy	17
Encephalitis	4
Traumatic brain injury	1
Neurofibromatosis	1
Intellectual disability, unknown etiology	47

Values are presented as mean±SD or number (range).
The Bayley Scales of Infant and Toddler Development (second edition) was used to determine patients' cognitive age.
SD = standard deviation.

2.2. Validation tests for children with typical development

We pre-tested the pilot version of the 6 programs with different difficulty levels among 80 children with typical development ages 18 to 41 months to ensure that the difficulty level was adequate. Children and their families were recruited from several local kindergartens through advertisements. All children's birth and medical records were reviewed. In addition, they were assessed using Korean-Bayley scales of Infant and Toddler Development (second edition) to ensure their typical development which was defined as an 85 or higher composite score on both mental development and psychomotor developmental indexes. Although the program was developed for preschoolers aged <4 years, we recruited children aged 18 to 41 months because the Bayley Scales of Infant and Toddler Development covers children aged <42 months. Children were excluded if they were premature, had low birth-weight, or were diagnosed with a developmental delay or had major surgery/medical treatment within 6 months before enrollment. Eighty children were divided into 8 groups according to 3-month age intervals, and each group included 10 children. All tests were performed at the child's home by a well-experienced psychologist who did not know the children's ages or the cognitive test results. It was conducted facing each other in an independent space. The subjects were asked to perform all 6 programs and not to exceed 60 minutes in a single experiment, with a sufficient break in the middle. The remaining experiments were carried out on different dates and all children completed the tests 3 times. Success at a given level was defined as the ability of the child to correctly perform ≥7 (of 10) tasks in each level.

2.3. Validation tests for children with cognitive impairment

After modifying the pilot version according to results of the validation tests performed in children with typical development, we developed a final version and tested it among 80 children with cognitive impairment whose cognitive age was 18 to 41 months; these tests were performed in a similar manner as were the validation tests in the children with typical development. All children were enrolled from a single general hospital and assessed using the Bayley Scales of Infant and Toddler Development (second edition) to determine their cognitive age. Children were excluded if they had severe motor delay or visual impairment that made them incapable of using a tablet PC. Eighty children were divided into 8 groups according to 3-month age intervals, and each group included 10 children. All tests were performed in the occupational therapy room of the same hospital by 2 highly-experienced occupational therapists who did not know the children's ages or the cognitive test results.
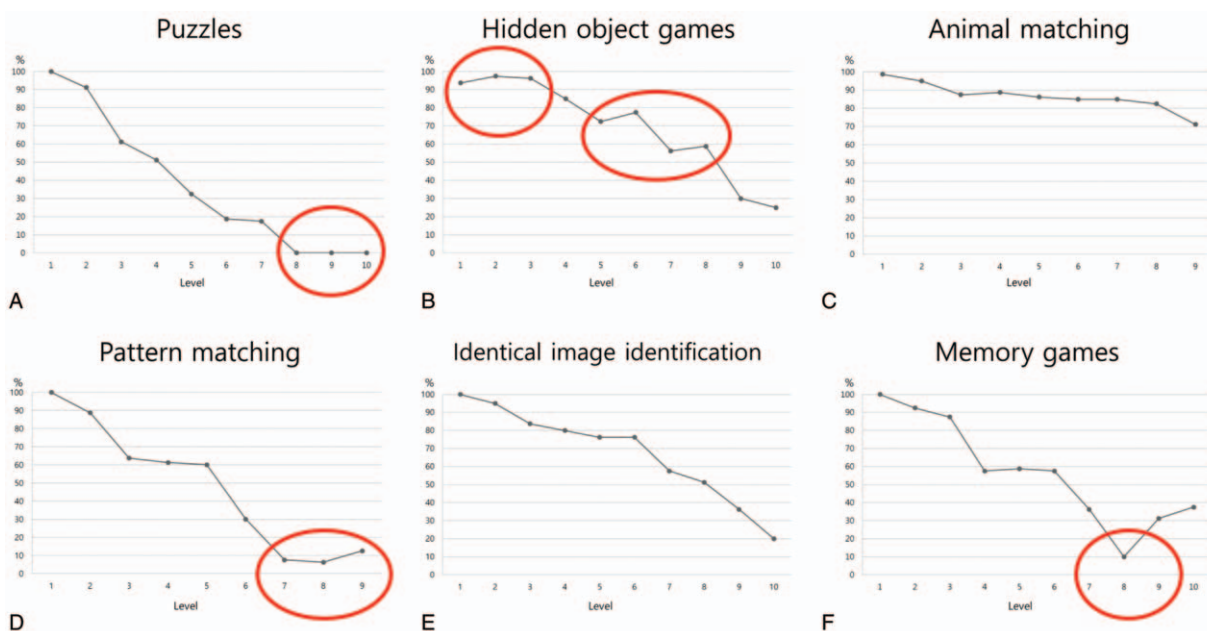
3. Results

A total of 160 children were recruited for the present study, including 80 children in each of typical development and cognitive impairment groups. The mean age of the typical development group was 29.4±6.9 months, with 44 males and 36 females, and the mean age of the cognitive impairment was 46.9±15.5 months (range 25–103 months), with 58 males and 22 females. Diagnoses of children were intellectual disability with unknown etiology was the most common (47/80) followed by cerebral palsy (17/80) and Down syndrome (6/80) (Table 1).

3.1. Validation tests for children with typical development

The overall success rate of the 6 programs was 60.5% in the children with typical development. The highest success rate was noted for the animal matching (86.7%), the hidden object games (69.3%) followed, and the lowest for the puzzles (36.6%) (range was 36.6%–86.7%). The validation tests generally showed that the success rate decreased with increasing level of the content (Table 2 and Fig. 3). However, several inappropriate results in

Table 2

Validation tests for children with typical development (N=80).

	Puzzles		Hidden object games		Animal matching		Pattern matching		Identical image identification		Memory games	
	Success	Failure	Success	Failure	Success	Failure	Success	Failure	Success	Failure	Success	Failure
Level 1	79	1	75	5	79	1	80	0	80	0	80	0
Level 2	72	8	78	2	76	4	71	9	76	4	74	6
Level 3	48	32	77	3	70	10	51	29	67	13	70	10
Level 4	40	40	68	12	71	9	49	31	64	16	46	34
Level 5	25	55	58	22	69	11	48	32	61	19	47	33
Level 6	15	65	62	18	68	12	24	56	61	19	46	34
Level 7	14	66	45	35	68	12	6	74	46	34	29	51
Level 8	0	80	47	33	66	14	5	75	41	39	8	72
Level 9	0	80	24	56	57	23	10	70	29	51	25	55
Level 10	0	80	20	60	Not designed	Not designed	16	64	30	50		
Success rate	36.6%		69.3%		86.7%		47.8%		67.6%		56.9%	

Figure 3. Success rates of children with typical development for the pilot version. The success rate generally decreased with increasing level of the content, however several inappropriate results in some programs were identified (red circles).

some programs were identified. For example, levels 8, 9, and 10 of the puzzles had similar difficulty levels and too difficult for them (success rate was 0), and level 8 of the memory games was more difficult than levels 9 and 10. We modified the content according to the test results and prepared a final version of the cognitive training program. Some of the difficulty levels of the puzzles, hidden object games, and pattern matching were modified. In detail, for levels 8, 9, and 10 of the puzzles, the color combinations were made simpler to distinguish them, and more familiar objects (fish, crocodile, boat, etc) were used. In addition, the level of difficulty was controlled by gradually widening the position of the puzzles. For example, the puzzles were mainly centered in the level 8, widened to the left and right in the level 9, and widened up, down, left, and right in the level 10. In the case of the hidden object games, the level of difficulty was controlled by adjusting the exposure time of the targets, the number of disturbance stimuli and the number of movements. For the pattern matching, the difficulty was adjusted mainly by

providing cues and adjusting the complexity of the picture. For the memory games, the level 8 was changed into the level 10, and difficulty was further adjusted by the number of objects, numbers, and faces to remember. In the identical image identification and animal matching, there were minor changes such as adjusting the exposure time and the number of distractors.

3.2. Validation tests for children with cognitive impairment

After modifying the pilot version, we tested the final version among 80 children with cognitive impairment. The overall success rate of the 6 programs was 44.8% in the children with cognitive impairment (Table 3 and Fig. 4). The highest success rate was noted for the animal matching (56.0%) and the lowest for the puzzles (38.3%), which was similar to the results obtained in children with typical development. Contrast to the pilot version; however, similar success rates were showed in the 6

Table 3

Validation tests for children with cognitive impairment (N = 80).

	Puzzles		Hidden object games		Animal matching		Pattern matching		Identical image identification		Memory games	
	Success	Failure	Success	Failure	Success	Failure	Success	Failure	Success	Failure	Success	Failure
Level 1	75	5	73	7	72	8	80	0	75	5	78	2
Level 2	63	17	57	23	62	18	59	21	65	15	57	23
Level 3	43	37	47	33	51	29	45	35	53	27	52	28
Level 4	39	41	43	37	49	31	38	42	48	32	40	40
Level 5	28	52	33	47	44	36	27	53	40	40	35	45
Level 6	21	59	30	50	39	41	17	63	36	44	26	54
Level 7	19	61	23	57	32	48	10	70	22	58	21	59
Level 8	8	72	19	61	30	50	8	72	21	59	16	64
Level 9	6	74	16	64	24	56	7	73	11	69	14	66
Level 10	4	76	10	70	Not designed	Not designed	6	74	13	67		
Success rate	38.3%		43.9%		56.0%		40.4%		47.1%		44.0%	
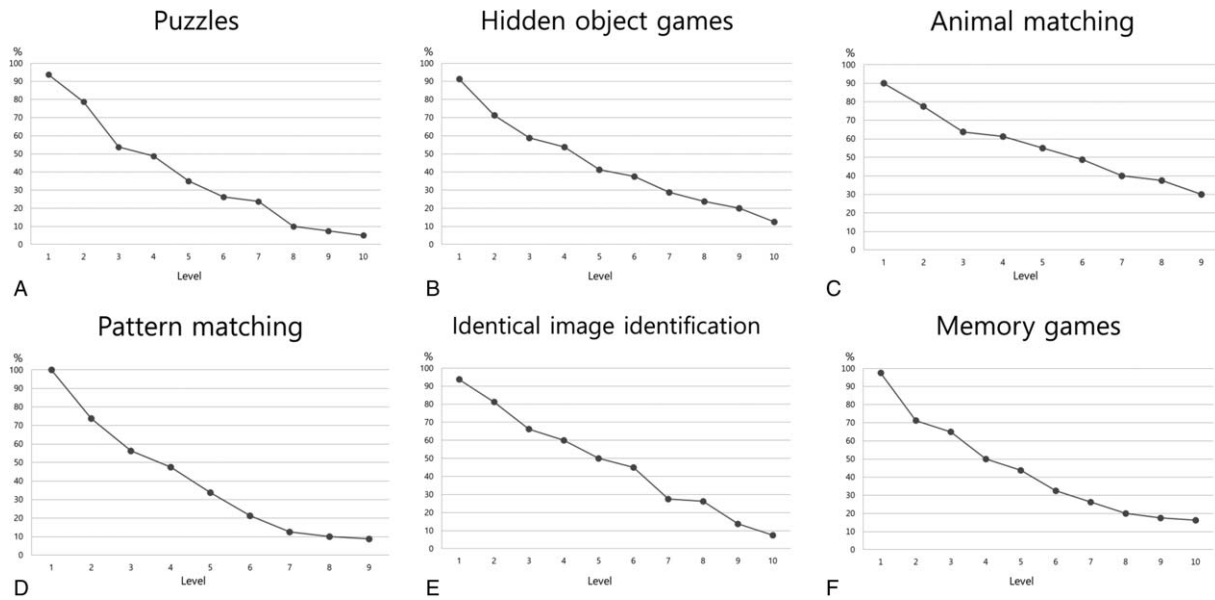
Figure 4. Success rates of children with cognitive impairment for the final version. A decrease in the success rate with an increase in the level of all programs was identified.

programs (range was 38.3%–56.0%). In addition, the final version had an appropriate difficulty level, with a decrease in the success rate with an increase in the level of all programs.

4. Discussion

Cognitive training for children focuses on basic cognitive functions, such as attention, memory, visuospatial perception, and executive function, and is conducted in the form of cognitive-behavioral therapy or computerized cognitive training.[5] Conventional programs require a lot of items and tools for training, and establishing the difficulty level is challenging. These programs are time-consuming and necessitate the effort of therapists. Conversely, computerized cognitive training has advantages such as less requirement of space and adjustability of difficulty according to individual cognitive levels.[14]

To our knowledge, our tablet PC-based cognitive training program is the first computerized program for preschoolers aged <4 years. Most computerized cognitive training programs are for school-aged children or preschoolers aged >4 years. We developed 6 programs with different difficulty levels, and each program was designed to include the basic components of the cognitive domain such as attention, visual and auditory perception, memory, and executive function. The overall success rate of the 6 programs was 60.5% in children with typical development and 44.8% in those with cognitive impairment. Children with cognitive impairment would exhibit a lower success rate because they had fine motor difficulties and visuomotor coordination problems even if their overall cognitive age was the same as that of children with typical development. We also developed 6 programs designed as universal tasks. These 6 programs were game-based and were similar to several other previously developed computer-based functional games. These game-type universal tasks were mainly aimed at improving attention span and eye–hand coordination; in addition, these tasks were familiar, interesting, and motivational.

The major advantage of our computerized cognitive training is that it provides adequate difficulty levels for children ages

<4 years. For cognitive intervention programs to be effective, structured and intensive training for the child's performance should be appropriately provided. Therefore, the difficulty level of each cognitive training program should be adaptively adjusted according to the child's cognitive conduct in every training session.[16] In the present study, as the level increased, the success rate gradually decreased in all programs of the final version for children with cognitive ages 18 to 41 months. Therefore, our program can provide effective cognitive training according to the child's ability and performance. To our knowledge, our program is the first computerized cognitive training program to validate the appropriate difficulty level in children with typical development and those with cognitive impairment. In addition, each task of the program is randomly provided, so the child can perform intensive training with motivation and without getting bored.

Other advantages relate to the use of a tablet PC to develop the computerized cognitive training program. Tablet PCs have a touch screen system and are easy to handle. Many children with cognitive impairment also exhibit fine and gross motor delay; hence, they have difficulty in manipulating devices, such as a computer mouse or keyboard, or may not be able to reach a conventional computer because of the short length of their arm. However, a tablet PC is a tool to overcome these barriers, as children can use their fingers or hand to adequately control the programs as closely as needed. As demonstrated in the present study, school-aged children with severe cognitive impairment can smoothly use the program. In addition, a tablet PC is portable; it can be used in various environments such as home, hospitals, and special schools; it can be easily updated; and it can provide users with new guidelines and precautions because the program is based on a smart system. Furthermore, our program has the advantage of being well-structured to train various areas of the cognitive domain compared with other programs for children such as the Cogmed JM (mainly working memory, http://www.cogmed.com/jm), play attention (mainly attention, http://www.playattention.com/), and fast for word language (mainly language, http://www.scilearn.com/products/fast-forword).

The main reason we developed a computerized cognitive training program for children aged <4 years is that cognitive therapy should begin early. The Abecedarian project revealed that early enrichment interventions significantly enhance the cognitive development of children at a high risk of developmental disability.[17] In addition, in prospective studies of children with fragile X syndrome, cognitive abilities declined with age.[18] These findings indicate that early interventions for cognitive impairment can be more effective to improve cognitive function in children with developmental disabilities.

Although there is limited evidence for the effectiveness of computerized cognitive therapy in pediatric patients, recent studies have demonstrated improved cognitive function in various disorders, including children with very low birth-weight, ADHD, traumatic brain injury, and epilepsy.[13,19–21] We hope that the tablet PC-based cognitive training programs developed in the present study will be of practical use for children with cognitive impairment. Follow-up studies should be conducted to verify the effectiveness of our cognitive training programs. Unfortunately, we were unable to retest the final version among children with typical development because of time and cost constraints, which is a limitation of the present study.

In conclusion, tablet PC-based cognitive training programs designed for children with developmental disabilities whose cognitive age is <4 years were successfully developed. We suggest that this program will help patients improve their cognitive ability by enabling early intervention, which is crucial for children with cognitive impairment.

5. Ethics statement

This study was carried out in accordance with the recommendations of the institutional research review board of the Asan Medical Center with written informed consent from all subjects. All subjects gave written informed consent in accordance with the Declaration of Helsinki. The protocol was approved by the institutional research review board of the Asan Medical Center.

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Author contributions

Ki Jeong Yun M.D., Jin Sook Yuk O.T. and Eun Me Byun, O.T. contributed to data collection.
Jae Yong Jeon, M.D., Han-Wook Yoo M.D., Ph.D. Tae-Sung Ko M.D., Ph.D. and Hyo-Won Kim M.D., Ph.D. contributed to study design and reviewed articles.
In Young Sung, M.D. wrote the article and critically reviewed articles.
Dae-Hyun Jang, M.D. takes responsibility for the study as a whole.

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