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Tablet computer-based cognitive training for visuomotor integration in children with developmental delay: a pilot study

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Abstract

Background Impaired visuomotor integration (VMI) is commonly observed in children with developmental delay (DD). This pilot study aimed to evaluate the effects of tablet computer-based cognitive training on the VMI in children with DD.

Methods This study included children aged 4 to under 18 years diagnosed with DD. The children participated in a 12-week tablet computer-based visual-spatial and visuomotor training program. They were administered the Mind Rx Kids Program (Brain Academy, Seoul, South Korea). The participants underwent daily 30-min tablet computer-based training for 12 weeks. The primary visuomotor function was measured using the Beery-Buktenica Developmental Test of Visual-Motor Integration, 6th Edition (VMI-6). For secondary outcomes, measurements were taken before and after 12-week treatment using the Quality of Upper Extremity Skills Test (QUEST), Functional Independence Measure for Children (WeeFIM), Childhood Autism Rating Scale (CARS), Attention deficit hyperactivity disorder Rating Scale (ARS), and Child Smartphone Addiction Observer Scale. The Wilcoxon signed-rank test was used to compare the pre- and post-treatment outcomes.

Results Ten children with DD participated in this study. The results of the 12-week tablet computer-based cognitive training showed significant improvements in the raw score, standard score, percentile score, and equivalent age of the Beery VMI-6. Additionally, there were significant improvements in QUEST and WeeFIM scores. Although there were improvements in the CARS, ARS, and smartphone addiction observer scale, these were not statistically significant.

Conclusion This pilot study confirmed that applying tablet computer-based cognitive training to children with DD not only improves VMI, but also enhances fine motor skills and activities of daily living. Furthermore, the results of this study indicate that tablet computer-based cognitive training does not increase digital media addiction. Therefore, children with DD can engage in tablet computer-based cognitive training at home without concerns about digital media addiction.

Keywords Developmental delay, Cognitive training, Visuomotor integration

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Background

Visual-Motor Integration (VMI) is the ability to coordinate visual perception and motor function. VMI is the interaction of visual, visual perceptual, and motor skills [1]. VMI skills are critical for participation in daily living and social activities [1, 2]. VMI skills are crucial for children's education activities and later success in kindergarten and primary school, as activities like handwriting, keyboarding, and ball-related skills rely on them [2].

Developmental delay (DD) is a term used to describe a delay in psychomotor development, which is categorized into four domains: gross and fine motor skills, speech and language, social and activities of daily living (ADL), and cognition [3]. The prevalence of DD has been increasing worldwide [4]. The prevalence of DDs in Korea steadily increased from 0.6 to 2.5% from 2003 to 2017 [4]. DDs are chronic conditions that impose physical, psychological, and economic burdens on families, while also contributing to a national increase in medical expenses and a decline in labor productivity [5, 6]. It is known that the risk of VMI deficits increases in DDs such as intellectual disability (ID), autism spectrum disorder (ASD), and cerebral palsy (CP) [2, 7].

Previous studies have suggested that a 14-week gross motor intervention and an intervention using the KaziKidz toolkit could improve VMI in pre-school children [8, 9]. These interventions are teacher- or therapist-led, which means they require the assistance of a teacher or therapist, presenting a limitation in terms of accessibility and implementation. Additionally, research in pediatric populations has indicated that stimulant medication may be helpful in improving VMI [10]; however, such pharmacological interventions have potential side effects. For children with DD, there is a need for a new treatment method that does not require specialized tools and has minimal side effects to improve VMI. Recent studies have highlighted the growing attention towards telerehabilitation for children with DD, due to its benefits in improving accessibility, saving time, and reducing infection risks [11]. In previous studies, computer game-based interventions have been utilized to improve eye tracking, motor skills, emotion regulation, language, and social skills [12–15]. However, there are few studies on the use of computer-based cognitive training to improve VMI in children with DD. Previous research has shown that a computerized VMI system can enhance VMI in adult stroke patients [16]. Therefore, it is necessary to investigate whether similar computerized training could also be beneficial for improving VMI in children with DD.

This pilot study aimed to examine the effectiveness of tablet computer-based cognitive training in improving VMI skills in children with DD. We hypothesized that 12 weeks of tablet computer-based cognitive training would enhance VMI function in children with DD without inducing digital media addiction.

Methods

Setting and participants

This is a prospective study. Children with DD were recruited from a rehabilitation outpatient clinic between May 2023 and December 2023. The inclusion criteria were: (1) children aged 4 to 18 years, (2) diagnosed with DD, and (3) capable of following simple instructions, enabling participation in tablet computer-based cognitive training. The exclusion criteria were: (1) children unable to follow simple instructions, rendering them ineligible for tablet computer-based cognitive training, and those for whom assessments such as the Beery-VMI were not feasible; (2) children with visual impairments or visual field issues, and (3) children who refused to participate in the clinical trial. This study was approved by our Institutional Review Board (2022-11-019). In this study, informed consent to participate was obtained from the parents or legal guardians of participants under the age of 16.

Tablet computer-based cognitive training

The participants underwent a 12-week tablet computer-based visual-spatial and visuomotor training program. The children were administered the Mind Rx Kids Program (Brain Academy, Seoul, South Korea). The adult version of the Mind Rx Kids Program (Brain Academy, Seoul, South Korea), known as Mind Rx, has been shown in a 2023 pilot study to not only enhance cognitive function but also improve depression in patients with mild cognitive impairment [17]. The Mind Rx Kids Program consists of 8 domains with a total of 96 cognitive training games. Among these, programs designed to enhance visuospatial and visuomotor functions were applied to the children. Each child underwent 30 min of tablet computer-based training daily for 12 weeks. The tablet computer-based visual-spatial and visuomotor training program comprised activities such as remembering a displayed map to navigate or solving puzzles by matching previously shown images (Fig. 1).

Measurement

The primary visuomotor function was measured using the Beery-Buktenica Developmental Test of Visual-Motor Integration-6 (VMI-6). It was used to assess children's VMI ability [18]. The Beery VMI-6 comprises 30 items. The first 3 items involve children scribbling on a piece of paper, while the remaining 27 items entail children copying shapes. Each item is assessed on a dichotomous scale (0 = incorrect,

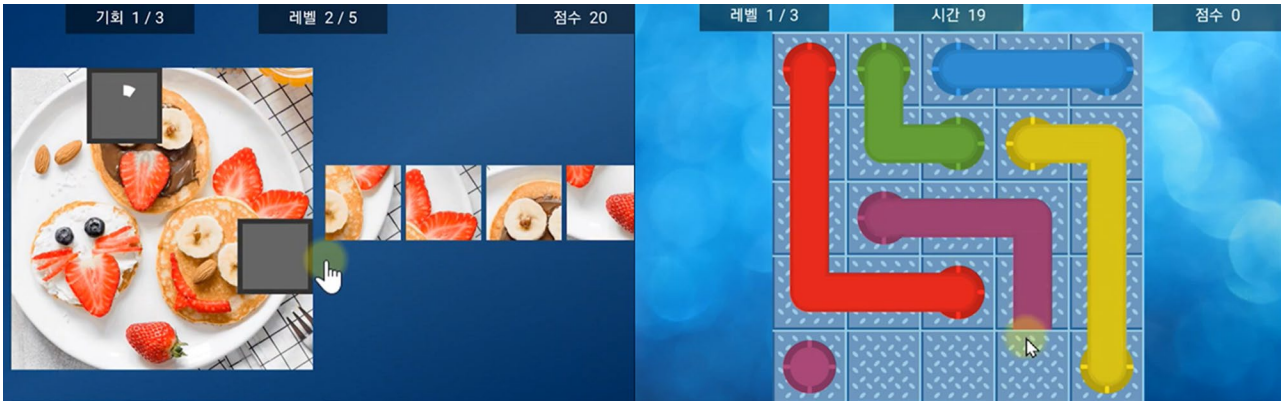


Fig. 1 An example of the Mind Rx Kids Program includes visuoperceptual activities, such as completing missing puzzles or connecting dots of the same color to create a path

1 = correct), and the cumulative score ranges from 0 to 30. A higher total score indicated greater ability.

The secondary outcomes were assessed using the Quality of Upper Extremity Skills Test (QUEST), the Functional Independence Measure for Children (WeeFIM), the Childhood Autism Rating Scale (CARS), the Attention Deficit Hyperactivity Disorder (ADHD) Rating Scale (ARS), and the Child Smartphone Addiction Observer Scale [19]. The QUEST evaluates the quality of upper extremity function across four domains: dissociated movement, grasp, protective extension, and weight bearing [20]. The WeeFIM is a valuable tool for evaluating functional independence in children aged between 6 months and 7 years. Additionally, it can be used for children with developmental disabilities aged 6 months to 21 years. Consisting of 18 items, the WeeFIM employs a 7-level ordinal scale to gauge a child's consistent execution of fundamental daily functional skills. This assessment covers three primary domains: self-care, mobility, and cognition, which are evaluated through either interviews or observations of a child's task performance based on established criteria [21]. CARS is a extensively utilized rating scale for identifying and diagnosing autism [22]. The CARS comprises 14 domains that evaluate behaviors associated with autism, with the 15th domain providing a rating of general impressions of autism. Each domain is scored on a scale ranging from one to four, with higher scores indicating higher levels of impairment. Total scores on the CARS can vary from a low of 15 to a high of 60; scores below 30 suggest that the individual falls within the non-autistic range; scores between 30 and 36.5 indicate mild to moderate autism; and scores between 37 and 60 suggest severe autism [23]. Recent studies have indicated that digital therapeutic interventions in patients with ASD lead to improvements in CARS scores as well as sensory, motor, and response inhibition functions. Therefore, in this study, CARS was assessed as one of the secondary outcomes [24]. The ARS is one of the most frequently employed scales for evaluating ADHD [25]. Developed in alignment with the diagnostic criteria for ADHD, it comprises 18 questionnaires gauging inattention and hyperactivity/impulsivity. The ARS generates scores for three domains: inattention, hyperactivity, and the overall sum score. Elevated ARS scores indicate reduced attention and impulse control abilities [26]. According to recent research findings, digital therapies have been shown to improve impulsive hyperactivity in children with ADHD, including those in this study. Therefore, the ARS was also administered in this study to measure these improvements [27]. The Korean Smartphone Addiction Proneness Scale (SAPS or S-Scale), developed by the Korea Information Society Development Institute, is based on existing scales that measure internet addiction [28]. It comprises 15 items. These items are categorized into daily life disruption, virtual world orientation, withdrawal, and tolerance. The respondents provide responses ranging from 1 to 4 for each item. Based on the total sum of survey responses or the values of the subfactors, individuals were classified into a high-risk user group, a potential risk user group, or a general user group. In the SAPS, individuals scoring 45 points or above are classified as high-risk users.

Statistical analysis

SPSS version 21.0 software (SPSS Inc, Chicago, IL, USA) was used for all statistical analyses. In this study, since the number of participants is small, the data cannot be assumed to follow a normal distribution. Therefore, the Wilcoxon signed-rank test was used for analysis. The Wilcoxon signed-rank test was used to compare scores on the Beery VMI-6, QUEST, WeeFIM, CARS, ARS, and Child Smartphone

Table 1 Demographic data of the children with DD

Total 10 children		Mean ± Standard Deviation
Age (month)	The youngest: 4 years The oldest: 17 years	7.90 ± 4.93
Sex	Male	7
	Female	3
Diagnosis	Autistic spectrum disorder	2
	Intellectual disability	5
	Borderline cognitive impairment	3

Table 2 Comparison of primary and secondary outcomes before and after 12 weeks of tablet computer based cognitive training

		Pre-treatment	Post-treatment	*p*-value
VMI	VMI raw score	10.60 ± 5.32	13.20 ± 5.65	**0.005***
	VMI standard score	58.70 ± 20.67	66.40 ± 25.18	**0.007***
	VMI percentile score (%)	2.87 ± 4.27	11.18 ± 21.44	**0.028***
	VMI-age	46.30 ± 17.77	55.80 ± 23.56	**0.005***
QUEST		81.68 ± 23.84	82.85 ± 24.01	**0.042***
WeeFIM		81.40 ± 23.80	84.60 ± 24.60	**0.007***
CARS		19.85 ± 3.46	19.50 ± 4.14	0.838
ARS		15.80 ± 9.97	11.90 ± 7.44	0.065
Smartphone Addiction Observer Scale		54.20 ± 14.60	50.50 ± 13.67	0.236

*: $p < 0.05$

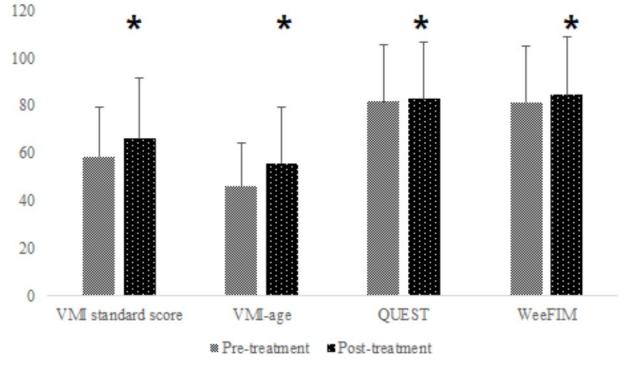


Fig. 2 Comparison of primary and secondary outcomes before and after 12 weeks of tablet computer based cognitive training

Addiction Observer Scale before and after 12 weeks of tablet computer-based cognitive training.

Results

The clinical characteristics of the study participants are shown in Table 1. Ten participants were included in this study. The average age of the participants was 7.90 ± 4.93 years. There were seven male participants, diagnosed with the following conditions: two with ASD, five with ID and three with borderline cognitive impairment (Table 1).

Table 3 Comparison of outcomes before and after 12 weeks of tablet computer-based cognitive training in children under 10 years and those 10 years and older

		Under 10 years	10 years and older	*p*-value
Diff_VMI	VMI raw score	4.00 ± 2.16	1.67 ± 0.82	**0.038***
	VMI standard score	12.25 ± 15.71	4.67 ± 4.68	0.476
	VMI percentile score (%)	16.78 ± 32.81	2.67 ± 3.93	0.762
	VMI-age	12.50 ± 9.98	7.50 ± 8.17	0.171
Diff_QUEST		0.35 ± 0.70	1.71 ± 2.31	0.257
Diff_WeeFIM		3.50 ± 0.58	3.00 ± 3.16	0.352
Diff_CARS		0.37 ± 4.60	-0.83 ± 4.27	0.762
Diff_ARS		-0.75 ± 2.36	-6.00 ± 9.59	1.71
Diff_ Smartphone Addiction Observer Scale		3.25 ± 17.46	-8.33 ± 11.04	0.352

*: $p < 0.05$

Diff_= Value of post-treatment – Value of pre-treatment

The results of the 12-week tablet computer-based cognitive training showed significant improvements in the raw score, standard score, percentile score, and equivalent age on the Beery VMI-6 (Table 2; Fig. 2). Additionally, there were significant improvements in the QUEST and WeeFIM scores (Table 2; Fig. 2). Although there were improvements in the CARS, ARS, and Smartphone Addiction Observer Scale scores, these did not reach statistical significance (Table 2; Fig. 2).

In addition, the age range in this study was broad, spanning from 4 to 17 years. Analysis by age group revealed that the group under 10 years showed a significant improvement in the VMI raw score compared to the group aged 10 years and older (Table 3).

Discussion

This study aimed to assess the changes in the VMI of children with DD after 12 weeks of tablet computer-based cognitive training. VMI depends on intact visual perception, sustained attention, fine motor coordination, and motor inhibition [29]. This skill is a good indicator of a child's overall level of ADL as this skill correlate significantly with academic achievement and intellectual functioning. In this study, the evaluation of the Beery VMI-6 was divided into three assessment types: VMI that emphasized motor function was evaluated using the QUEST, VMI that emphasized visual perception function was evaluated using the Beery VMI-6, and VMI that emphasized ADL was evaluated using the WeeFIM. Through this pilot study, it was observed that tablet computer-based cognitive training could improve fine motor and visual perception skills in children with developmental delays as

well as enhance their ADL. Furthermore, it was noted that 12 weeks of tablet computer-based cognitive training did not lead to addiction to digital media.

While steady-state VMI primarily engages the cerebral cortex, brainstem, and spinal cord, the adaptability of VMI depends on two major subcortical networks, the cerebellum and basal ganglia [30]. Cerebellar dysfunction is apparent in various developmental disorders such as ASD, ADHD, and developmental dyslexia. Early damage to the cerebellum can have long-term effects on movement, cognitive function, and emotional regulation [31]. Previous studies showed that the cerebellum is the brain structure most consistently found to be abnormal in ASD, and there is a dependent association between cerebellar damage and an increased risk for ASD [32]. Moreover, abnormalities in the cerebellum are commonly observed in children with ID, which was the largest patient group in this study [33]. Previous research indicates that cognitive training can strengthen the subcortical-cerebellar network. In this study, the improvement in VMI observed after 12-weeks of tablet computer-based cognitive training was likely due to enhancement of the subcortical-cerebellar network [34].

Children with DD often struggle to concentrate on multiple stimuli simultaneously because of limited selective attention towards learning stimuli, short attention spans, and a narrow focus of attention. Computer games have been acknowledged as a valuable resource for external motivation, particularly for children with DD, as they require repeated exposure to learning environments [35]. According to previous studies, computer games have been shown to have a beneficial impact on sensorimotor abilities and cognitive functions through the processing of audiovisual stimuli [36, 37]. VMI can be improved through repetitive practice, and the use of computers to educate children with DD can facilitate their participation in enjoyable learning experiences, diverging from traditional one-way teacher-led training approaches [38]. Additionally, the advantages of the computerized cognitive rehabilitation program are subdivided by cognitive domain; economic benefits and immediate feedback are possible by controlling the flexibility of treatment and shortening the treatment time, and it has the advantage that the difficulty can be adjusted according to the level.

According to previous research on digital therapies targeting children, such as the one conducted in this study, computer game-based treatments face difficulties in resisting internal and environmental interference, as well as in determining the optimal duration of treatment [27]. Furthermore, there is a risk of internet addiction [27]. According to previous studies, early-life exposure to digital media (i.e., screens) is associated with atypical sensory processing related to ADHD, ASD, and developmental coordination disorder [39]. Such digital media exposure has been shown to be associated with early child development, behavior as well as media addiction [40]. Therefore, media exposure in children is discouraged. However, the results of this study showed an improving trend in VMI, fine motor function, and ADL, although not statistically significant, on the CARS, ARS, and Smartphone Addiction Observer Scale. In other words, the tablet computer-based cognitive training used in this study could be considered a safe method for improving VMI without causing side effects such as atypical sensory processing or media addiction, which are associated with media exposure.

Limitation

This study had several limitations. First, only a small number of participants were included; therefore, parametric statistics could not be performed. Second, this study included children with various diagnoses such as ASD, ID, and borderline cognitive impairment, which led to a lack of consistency. Future studies should focus on children with a single diagnosis. The third limitation is the large age interval of participants, ranging from 4 to 17 years. Future research should address this issue by segmenting the age groups into preschool, school-age, and adolescence categories. The fourth limitation of this study is the lack of a control group. In future research, it will be essential to include a control group, such as one receiving face-to-face care or conventional occupational therapy, and to conduct a randomized controlled trial.

Conclusion

Children with DD can engage in tablet computer-based cognitive training at home with a reduced concern for digital media addiction.

Abbreviations

VMI	Visuomotor integration
DD	Developmental delay
VMI-6	Beery-Buktenica Developmental Test of Visual-Motor Integration, 6th Edition
QUEST	Quality of Upper Extremity Skills Test
WeeFIM	Functional Independence Measure for Children
CARS	Childhood Autism Rating Scale
ARS	Attention deficit hyperactivity disorder Rating Scale
ID	Intellectual disability
ASD	Autism spectrum disorder
CP	Cerebral palsy

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Author contributions

JHS: Designed the study, collected and analyzed data, drafted and revised the manuscript. HSY and SHP: Collected data. SJH and SAC: Recruited patients.

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Data availability

To request the data from this study, please contact the corresponding author, Prof. Jee Hyun Suh, via email at jeehyun.suh1@gmail.com.

Declarations

Ethics approval and consent to participate
This study was approved by the Ewha womans university mokdong hospital Institutional Review Board (Approved number: 2022-11-019) In this study, informed consent to participate was obtained from the parents or legal guardians of participants under the age of 16.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

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