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# Effectiveness of Kinesthetic Game-Based Training System in Children With Visual-Perceptual Dysfunction

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**ABSTRACT** Visual perceptual dysfunctions were common in children with developmental delays, and have severe adverse impacts on children's daily activities. Recent studies have shown that technologies such as virtual reality and imaging can provide a motivating and engaging tool for remediating visual perceptual dysfunctions. This study was aimed to present the work we were conducting in experimenting with augmented reality (AR) for visual perceptual rehabilitation in children with developmental delay. Sixty participants (mean age =  $7.96 \pm 1.4$ ) were equally divided into an experimental group trained with proposed KBTS (KBTS group) and a control group trained using traditional visual perceptual training (TVPT group). Each group completed an 8-week training program (two 30-minute sessions per week). Visual perceptual assessments (Test of Visual Perceptual Skill- 3rd Edition, Beery-Buktenica Developmental Test of Visual-Motor Integration- 6th Edition) and functional outcome measures (Vineland Adaptive Behavior Scale- Chinese Version, School Function Assessment- Chinese Version) were administered to investigate the effectiveness of the intervention. The KBTS group significantly outperformed the TVPT group in assessments of visual-motor integration, visual perceptual skills, and school functions. The effectiveness of the KBTS was supported by robust effect sizes for the pre- and post-intervention comparisons of visual perceptual and visual motor integrative functions between the KBTS group and the TVPT group. This study suggests that KBTS effectively improves visual-motor integration and overall visual perceptual functions in children with developmental delays. This study has discussed the ideas for incorporating several principles of game scenarios for visual perceptual rehabilitation, and the proposed KBTS still have raised a number of issues requiring further work. Enabling users to perform visual motor integrative tasks in an augmented reality world offers the potential for developing advanced visual perceptual skills which may be more easily transferable to activities of daily living than other techniques. Augmented reality has the potential to achieve entertaining and satisfying outcomes for visual perceptual rehabilitation, and making use of the potential applications of AR technologies should be considered more beneficial for the home-based rehabilitation during the current pandemic situations. Other clinical applications are discussed as well.

**INDEX TERMS** Visual perception, visual motor integration, game-based, developmental delay.

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## I. INTRODUCTION

Visual perception refers to neurological processes in which various visual information is received and interpreted [1].

Visual perceptual functions include visual-receptive and visual-cognitive components. In the visual-receptive component, sensory functions obtain and integrate visual stimuli in the surroundings, and visual-cognitive components perform specific mental functions needed to recognize, classify, and explain the visual stimuli. Visual-cognitive components generally include, in order of development, visual attention, visual memory, visual discrimination, and visual imagery [2]. Rehabilitation and education of children with visual-cognitive and visual-motor integration dysfunctions have been discussed extensively in the literature [3].

Visual attention is defined as the capability to concentrate on visual stimuli; through practice and learning, children develop capability to develop and retrieve long-term memories automatically without active visual attention [4]. Visual memory, both long-term and short-term, involves the processing and synthesis of visual information with previous knowledge and experience [5]. Visual discrimination is further classified as object perception and spatial perception, and each type of perception is governed by a different neural pathway [6]. Object perception is helpful for forming the long-term establishment of perceptual symbols needed for visual learning. Spatial vision provides the location details needed to guide movement and action. Visual imagery is an essential visual cognitive component that enables children to form mental pictures of an object even if the object is not physically present. Visual imagery is essential for reading comprehension, problem solving, motor planning, and organizational skills [7]–[8]. The cognitive processes involved in visual imagery and visual memory are similar but not identical. Visual motor integration is defined as the cooperation between visual perception and fine motor control, and it has major roles in most of the daily life and school activities of children.

Deficient visual perceptual functions can affect the performance of children in areas of occupation [9]. For example, information processing is considered one of the best predictors of readiness for elementary school. Visual perceptual and visual-motor integration are also essential for good academic performance, e.g., performance in writing and mathematics [10], [11]. In addition to educational performance, visual perceptual dysfunctions have implications in many other daily life activities, including play and social participation. Studies also suggest that good visual perception is important for normal social interaction and for further development of psychological function [12]. Therefore, a practical training system is needed to remediate delay in or impairment of visual perceptual functions.

Evidence-based interventions for improving visual perceptual functions in children mainly apply perceptual-motor, neurophysiologic, sensory integration (SI), and compensatory strategies. Perceptual-motor approaches to using learning theories to remediate visual perceptual dysfunctions have a long history of use and are still the interventions preferred by many therapists and clinicians [13]. Perceptual-motor approaches assume a causal relationship

between motor performance and underlying visual perceptual functioning. Perceptual-motor approaches typically require the child to perform a series of sensorimotor activities under the guidance of an occupational therapist. The sensory and motor experience acquired in these activities is expected to improve perceptual function and academic performance [14]. The neurophysiologic approach focuses on identifying deficiencies in postural control and motor functions that could interfere with visual perception and then implements specific interventions to address these deficiencies [15]. An important principal of this approach is adaptation of the environment to reduce sensory over-responsiveness and distractibility [1]. The SI intervention assumes that sensory intake is crucial for optimal cortical function in children and that, since neural plasticity is highest in early childhood, early intervention can enhance underlying abilities and prevent potential dysfunctions later in life [16]. Sensory integration therapy has been validated for use in improving sensory processing problems in children with visual perceptual deficits, which strongly suggests that sensory processing problems are related to visual perceptual problems [17].

Children can be taught cognitive strategies, i.e., mental processes that support successful performance of visual perceptual skills. For example, a therapist might teach a child problem-solving strategies that enable the child to discover additional strategies for acquiring visual perceptual skills. One example of a cognitive strategy is the Cognitive Orientation to Daily Occupation Performance Approach (CO-OP) [18]. The compensatory approach modifies the teaching materials or methods applied in the learning environment to accommodate the limitations of the learner. For example, a therapist might decide to use compensatory strategies when a child has school-related problems such as reading and handwriting. Remedial strategies use repeated drills and exercises aimed at improving specific cognitive processes underlying visual perceptual functions in a teaching-learning environment. A drawback of traditional therapeutic interventions for visual perceptual dysfunctions is that, because of the repetitive nature of the interventions, maintaining the motivation of learners is difficult for therapists [19]. Disabilities (i.e., poor motor control, cognitive deficiencies, or short attention span) in children with developmental delay can hinder their participation in repeated therapeutic visual perceptual activities [20].

Hence, a variety of training systems had researched and developed for improving deficient visual perceptual functions. Such developments include the virtual reality (VR) based approach and augmented reality (AR) based approach [20], [21]. These approaches have been investigated since they could be able to provide with better encouragement and motivation via employing game-based exercise as a training platform. Research studies had confirmed that the embedded of VR in rehabilitation system provides positive results [22], and the independent VR based rehabilitation system integrated with biofeedback system also can be found effective [23], [24]. Although VR based developments have

proven with positive results, additional attachment of tracking device to the user, their heavy weight and total immersive in virtual world are inconvenient and dangerous for users especially in children with disabilities. Therefore, the AR based rehabilitation exercises have been developed for better and safer interactive environment. Augmented reality is the combination of real world and virtual world that enhance the user perception of reality. The user can view the computer generated virtual environment that is overlaid on top of real environment. Although these advantages have increased use of AR training for neurological and pediatric rehabilitation [25], particularly for rehabilitation of motor function [26], VR has not been widely used to improve visual perceptual function in young populations.

The high neuroplasticity of the human brain enables organizational and connectivity changes throughout the lifespan but is highest at young ages. In pediatric rehabilitation, the concept of exploiting high neuroplasticity in young learners is supported by research indicating that (1) active engagement with an enriched environment can enhance dendritic branching [27], (2) active involvement with an environment that provides multiple somatosensory feedback channels is linked to improved motor performance [28], and (3) neuronal plasticity can be boosted through active participation in multisensory activities at a young age [29], [30]. The mirror neuron system has been proved to be associated with neuroplasticity [31], [32]. When a child performs a specific action or observes another individual performing the same action, mirror neurons are activated in various areas of the brain [33]. Therefore, in addition to their benefit to development of functional skills, age-appropriate game-based VR have important therapeutic benefits.

Medical applications of gaming technology include the use of commercially available videogames to enhance the effectiveness of therapy [34]. The gaming industry has rapidly developed various AR systems that are easy to access and use in everyday environments (e.g., home, classroom, and playground). The AR-based training systems in the form of a game were proved effective since it was easily handled by individuals and trigger interest. The AR gaming systems could allow the children simultaneously performing actions and observing an avatar on the screen, and these perceptual-motor stimulations could be periodically adjusted to activate mirror-neuron systems [35]. The comparisons between the real and virtual feedback produced by AR gaming system could activate targeted neural pathways essential for visual perceptual development [25]. In the past decade, therapeutic applications of AR-based systems in children with disabilities, particularly in autistic spectrum disorder (ASD), have had promising results [20], [35]. Nevertheless, research in the effectiveness of an AR gaming system in children with visual perceptual deficits is scant. This study aimed to develop a kinesthetic game-based training system (KBTS) for enhancing visual motor integration and visual perceptual function in children with developmental delay. The research hypothesis was that a AR system using gaming technology

(Microsoft Kinect system) is as effective as standard rehabilitative protocols for improving visual perceptual function and visual motor integration in children with visual perceptual dysfunctions or impaired visual-motor integration.

## II. METHODS

### A. PARTICIPANTS

The inclusion criteria in this study were (a) age 6 to 10 years old; (b) impaired or delayed development of visual perception; (c) ability to comprehend and follow simple instructions; and (d) written parental consent. The exclusion criteria were associated developmental disabilities, major sensory impairments, and known neurological conditions (e.g., epilepsy). The 60 children who met the inclusion criteria were randomly assigned to either the experimental or the control group ( $n = 30$  per group). The experimental group used the KBTS, and the control group used the traditional visual perceptual training (TVPT) program. All participants in each group completed tests of visual perceptual and functional outcomes (school functions and adaptive behaviors) before and after the intervention.

### B. KBTS

The senior pediatric occupational therapists guided the game design, goal setting, and training processes monitoring. An AR-based gaming framework was developed by integrating kinesthetic and game-based learning methods to enhance children's motivation, and the maker-free whole body motion capture technology was as well used to investigate visual perceptual functions and integrated motor behaviors. The overall developmental concepts and process of the proposed training system was shown in Fig. 1. Each of the training game was best suited to specific kinds of visual perceptual dysfunctions, based on current rehabilitation approaches, training context, and subject considerations. In addition, the concepts of flow theory [37], play theory [38] and sensory integration theory (SI) were embedded into the system design. The Test of Visual-Perceptual Skills (non-motor) - Third Edition (TVPS-3) [36] was used to guide the development of difficulty grading system. The optimal flow state was created when children tackled the challenges they perceived to be at just the right level for their skill sets. An appropriate difficulty grading system could enable the children to enter the optimal flow state in which the child is fully immersed in a feeling of full involvement and enjoyment in the game process. These just right challenges (game parameters) could be adjusted dynamically according to the child's reactions and feedbacks. The proposed system was able to create an attractive and productive AR environment through blending intuitively interpretable content, well-scaled training and detailed motion analysis. And this system could be used to evaluate the training effects and user's response simultaneously.

The system was developed by Microsoft Visual Studio 2015,.NET framework 4.5 environment and Kinect for Windows SDK v1.8. The Microsoft ACCESS 2010 database was used to store user profiles, test content, game parameters

and training-related records for individual users. The flowchart of the training programs in the proposed system was illustrated in Fig. 2. At the beginning of each training session, the therapist selected the test type and game parameters at the suitable difficulty level for each child. The game parameters included object (target) dimensions and occurrence frequency, orientation of object movement, initial position and moving speed of object, tolerance range of hit, skeletal presentation (standing or sitting), and default completion time of each training session. The child was required to use either hand to eliminate (hit) the target object appearing from different directions, and the related feedback would be immediately shown on the projector screen. The child had to predict and adjust their posture and movements constantly as the game scene changed. The display interface integrated real-time image of the child and his skeletal motion information received by Microsoft Kinect. This system could simultaneously facilitate close interactions between the user and the targets, and provide the therapists to evaluate the functional status of the child.

For example (shown in Fig.3), the child adopted a proper posture and used one hand to hit the green ball appearing on the right-lower corner of projector screen. The game parameters of the above task were displayed on the left side of the KBTS interface, and it appeared that it took 30 seconds to hit the target with 70 seconds remaining in this 100-second exemplary test. Live motion skeletal images were also displayed for evaluating user’s movements in performing various visual- motor coordination tasks (e.g., ball hitting) (Fig. 4). As a consequence, the occupational therapists could modify the training contents and goals promptly according to this information. All quantitative information during different KBTS sessions was recorded for further analysis.

**C. MEASURES**

1) TVPS-3 [36]

The TVPS-3 utilizes 112 black and white designs to assess the comprehensive visual perceptual abilities of an individual. Motor function is not required. The seven TVPS-3 subtests are arranged in order of difficulty from low to high. The easiest subtest is visual discrimination. The other subtests are visual discrimination, visual memory, spatial relationship, form constancy, sequential memory, visual figure- ground, and visual closure. The test is appropriate for school-age children up to age 18 and is administered on an individual basis. The 7 subtest raw scores can be converted to scale scores (mean = 10, SD = 3) and percentile ranks. The overall scores are derived from the sum of scale scores and converted to standard scores (mean = 100, SD = 15). The TVPS-3 has sound test-retest reliability (0.97) and concurrent validities [36], [39], [40].

2) THE BEERY-BUKTENICA DEVELOPMENTAL TEST OF VISUAL-MOTOR INTEGRATION -6TH EDITION (BEERY™VMI) [41]

The Beery™VMI examines the visual and motor integrative abilities (eye-hand coordination) displayed by a subject

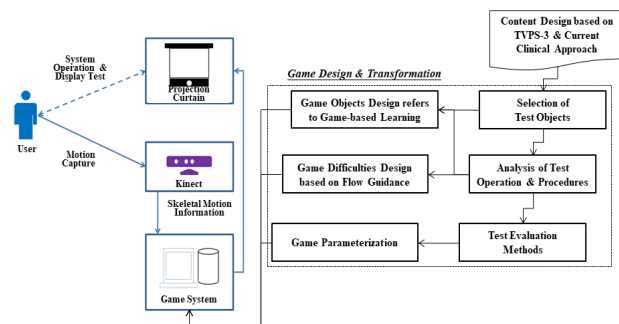


FIGURE 1. Development of the AR-based gaming training system.

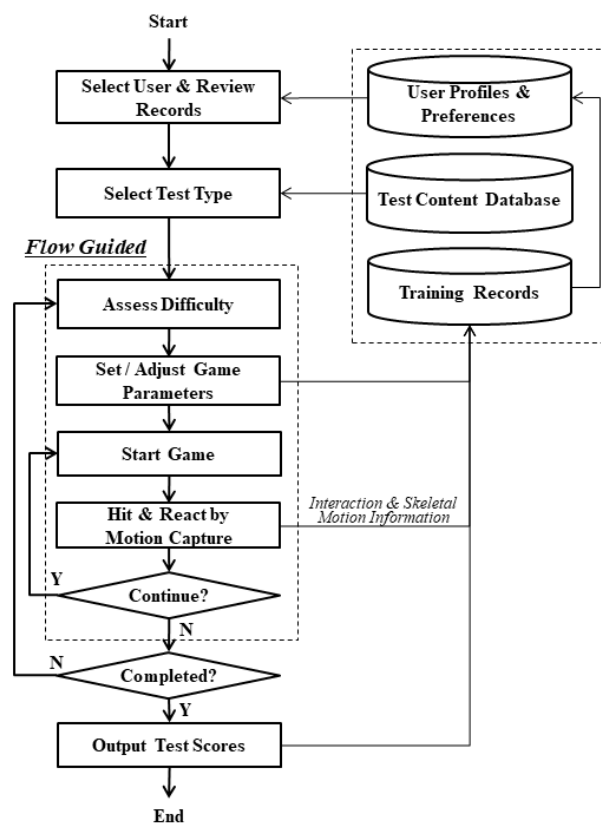
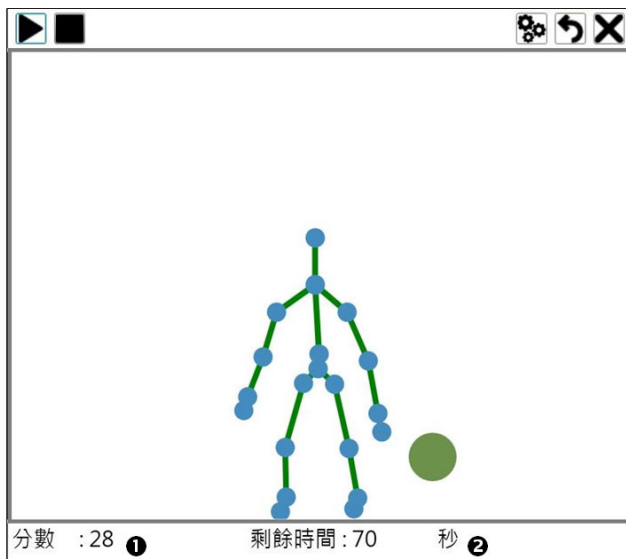


FIGURE 2. Flowchart of the proposed Kinesthetic Game-Based Training System.

using paper and pencil to imitate or copy a developmental sequence of geometric forms. The 30-item Beery™VMI for ages 2 through 100 can be administered in 15 minutes in an individual or in a group. In the present study, raw scores for the VMI were converted to standard scores (mean = 100, SD = 15). The VMI has good psychometric properties in children with typical development. The internal consistency, test-retest coefficient, and interrater reliability were 0.88, 0.87, and 0.98, respectively. Rasch-Wright analysis strongly supports the content validity of the Beery™VMI. The Beery™VMI has also demonstrated moderate or higher correlations with standardized tests used to measure similar constructs [41]. The following basic Beery™VMI constructs



**FIGURE 3.** Game parameters set of the proposed training system include: ❶ Object Dimension, ❷ Object Occurrence Frequency, ❸ Moving Orientation, ❹ Initial Position, ❺ Tolerance range of Hit, ❻ Skeleton Presentation: Standing or Sitting, ❼ Moving Speed, and ❽ Default Completion Time; moreover, test performance with ❹ Score, and ❺ Remaining Time.



**FIGURE 4.** Display of live motion skeletal images (❹ Score and ❺ Remaining Time).

have been validated: (1) the test results are age-dependent, (2) the test results have moderate correlations with non-verbal intelligence and academic achievement, (3) the test is sensitive to certain disabling conditions [41].

### 3) VINELAND ADAPTIVE BEHAVIOR SCALE-CHINESE VERSION (VABS-C) [42]

The Vineland Adaptive Behavior Scale (VABS) [43] is a norm-referenced instrument used to assess adaptive and maladaptive behaviors in individuals aged 0 to 18 years 11 months. The four domains of the VABS are daily living skills (personal, domestic, and community), communication, socialization, and motor skills. The present study used the VABS-C and the classroom/teacher form for children aged

3 years to 12 years, 11 months. The sound reliability and validity of the VABS-C have been validated [42].

### 4) SCHOOL FUNCTION ASSESSMENT-CHINESE VERSION (SFA-C) [44]

The SFA-C is the Chinese version of the School Function Assessment [45]. This assessment was designed to investigate participation, support needs, and school-related activity performance in school-aged children. The SFA-C consists of three parts: Participation in major school settings, Task Support, and Activity Performance in physical and cognitive/behavioral tasks. In the current study, three components were used to assess overall school function: (a) participation in major school settings was evaluated in six settings, (b) Activity Performance-Physical was evaluated in twelve physical tasks (e.g., travel, using materials, and hygiene), and (c) Activity Performance-Cognitive/Behavioral was evaluated in nine cognitive and behavioral tasks (e.g., positive interaction and safety). The teachers rated these items for each participant in this study. Both the reliability and validity of the SFA-C are well supported [46].

### D. PROCEDURE

Before enrolling each student in the study, the researchers obtained written consent from the parent or guardian using consent forms approved by the Institutional Review Board of Kaohsiung Medical University Hospital (KMUH, form ID no. KMUHIRB-SV (I)-20150039). The 60 children (aged 4-10 years) with developmental delays who participated in this study were further divided into two equal-sized groups (n = 30 per group): an experimental group that received the KBTS and a control group that received the TVPT. In each participant, the KBTS and the TVPT programs were administered by two senior pediatric occupational therapists in two 30-minute sessions per week over an 8-week period. All participants completed the TVPS-3, VMI, VABS-C, and SFA-C before and after the 8-week program. The pre- and post-test assessments were performed by a pediatric occupational therapist that had no knowledge of the study.

### E. DATA ANALYSIS

The SPSS 20 software was used for data analyses. To facilitate data analysis, the following scores were calculated for each subject: SFA-C raw score, scale or standard scores of TVPS-3, VMI, and the VABS-C.

#### 1) INTER-GROUP ANALYSIS

Analysis of variance (ANOVA) was used to examine differences in visual-motor integration, visual perception, adaptive behaviors and school functions between the experimental and control groups.

#### 2) INTRA-GROUP ANALYSIS

To investigate the effectiveness of the KBTS intervention, paired t-test was used to compare VMI and TVPS-3 before

**TABLE 1. Post-intervention difference between KBTS and TVPT groups.**

Measurement	Group mean test score		<i>p</i>
	KBTS	TVPT	
TVPS-3			
Visual discrimination	13.90	10.22	0.01*
Visual memory	12.17	12.77	0.07*
Visual spatial relations	15.15	11.97	0.01*
Visual form constancy	11.63	10.20	0.06
Visual closure	12.44	10.37	0.05*
Visual figure round	12.05	10.07	0.04*
Visual sequential memory	12.12	11.97	0.08
Total scores	85.88	77.04	0.03*
VMI	111.03	103.82	0.03*
VABS-C			
Communication	88.13	81.10	0.02*
Daily living skills	84.80	74.97	0.02*
Socialization skills	85.59	80.37	0.06
Motor skills	88.11	85.27	0.04*
Total scores	92.03	76.07	0.03*
SFA-C			
Participation	60.50	62.13	0.06
Activity Performance-Physical Tasks	777.53	742.29	0.04*
Activity Performance- Cognitive/Behavioral Tasks	544.10	513.56	0.04*

Abbreviations:

TVPS-3, Test of Visual-Perceptual Skills (non-motor)- Third Edition

VMI, The Beery-Buktenica Developmental Test of Visual-Motor Integration -6th Edition

VABS-C, Vineland Adaptive Behavior Scale- Chinese Version (VABS-C)

SFA-C, School Function Assessment- Chinese Version

*p*, a measure of the probability that an observed difference occurred just by random chance

and after the intervention in the KBTS group. The VABS-C and SFA-C scores in the group before and after the intervention were also calculated. In each group, improvements obtained by the interventions were also summarized. Effect sizes (ES) were calculated to quantify the size of pre- and post-intervention differences in each measure. For t-test, the ES (d) was defined as the difference between pretest and posttest means divided by the SD in pretest scores. According to [47], the magnitude of change is small if ES is .20 or less, moderate if ES is .50, and large if ES is .80.

### III. RESULTS

#### A. DEMOGRAPHIC DATA

Of the 60 children who participated, 33 (55%) were female (16 in the experimental group and 17 in the control group). The average age was  $7.96 \pm 1.4$  years. All participants were right-handed.

#### B. EFFECTIVENESS OF THE KBTS

##### 1) GROUP COMPARABILITY

The two groups did not significantly differ in age ( $F=3.98$ ,  $p=0.55$ ) or gender ( $\chi^2=0.66$ ,  $df=3$ ,  $p=0.65$ ). The pre-intervention scores for the TVPS-3, VMI, VABS-C and SFA-C did not differ significantly between the KBTS

and TVPT groups since the overall ANOVAs for the pre-intervention tests were non-significant (all  $p > 0.39$ ).

##### 2) POST-INTERVENTION DIFFERENCES BETWEEN KBTS AND TVPT GROUPS

Table 1 shows that the two groups significantly differed in scores for the VMI and most TVPS-3 tests. The two groups did not significantly differ in form constancy and sequential memory in the TVPS-3. The KBTS group outperformed the TVPT group on most VABS-C and SFA-C items except for school participation and socialization domains.

##### 3) WITHIN-GROUP DIFFERENCES BEFORE AND AFTER THE INTERVENTION

The paired t-test results for the KBTS group revealed that all VABS-C and SFA-C scores except socialization skills significantly differed after the intervention (Table 2). Scores for the TVPS-3 test significantly improved in all domains except visual closure and visual sequential memory. Table 3 summarize the estimated ES values obtained in the KBTS and TVPT groups. The ES ranged from medium to large in the KBTS group and from small to medium in the TVPT group. The Cohen d values for the pre-post comparisons of visual motor integration and visual perceptual functions in the KBTS group exceeded .8, which indicated substantial improvements.

**TABLE 2.** Pre-intervention and post-intervention difference within KBTS group.

Test	Mean test score		<i>t</i>	<i>p</i>
	Pre-test	Post-test		
TVPS-3				
Visual discrimination	10.57	13.90	10.33	0.01*
Visual memory	10.03	12.17	14.26	0.01*
Visual spatial relations	11.70	15.15	10.98	0.01*
Visual form constancy	11.17	11.63	33.87	0.06
Visual closure	9.78	12.44	11.28	0.03*
Visual figure round	9.20	12.05	14.46	0.02*
Visual sequential memory	11.77	12.12	20.89	0.17
Total scores	74.50	85.88	6.53	0.04*
VMI	88.52	111.03	20.36	0.03*
VABS-C				
Communication	81.17	88.13	0.27	0.04*
Daily living skills	70.08	84.80	0.23	0.01*
Socialization skills	84.44	85.59	0.96	0.06
Motor skills	82.03	88.11	0.28	0.04*
Total scores	86.63	92.03	0.30	0.04*
SFA-C				
Participation	50.87	60.50	8.88	0.02*
Activity Performance-Physical Tasks	723.19	777.53	8.17	0.03*
Activity Performance-Cognitive/Behavioral Tasks	465.30	544.10	8.35	0.02*

Abbreviations:

TVPS-3, Test of Visual-Perceptual Skills (non-motor)- Third Edition

VMI, The Beery-Buktenica Developmental Test of Visual-Motor Integration -6th Edition

VABS-C, Vineland Adaptive Behavior Scale- Chinese Version (VABS-C)

SFA-C, School Function Assessment- Chinese Version

*t*, the size of the difference relative to the variation in sample data.

*p*, a measure of the probability that an observed difference occurred just by random chance

#### IV. DISCUSSION

The TVPS-3 and VMI scores after the 8-week training programs indicated that visual-motor integrative and visual perceptual functions had improved in both the KBTS and TVPT groups. However, the KBTS group had higher scores after the intervention for all TVPS-3 subtests and VMI compared to the TVPT group. The effectiveness of the proposed KBTS in enhancing functional outcomes was supported by the larger improvements in school functions (SFA-C) and adaptive behaviors (VABS-C) in the KBTS group compared to the TVPT group. Like most game-based virtual training programs, the KBTS was characterized by interactive learning and dynamic scenarios. The incorporation of flow theory and play elements in the KBTS may have contributed to the larger improvements in overall psychosocial functions in the KBTS as well [48], [49].

Poor visual skills can adversely affect motor proficiencies of posture, mobility, and coordination. Children with visual perceptual deficiencies may have difficulty using tools, managing space, and maneuvering material. For example, children may have problems using scissors, playing constructive games, dressing, routine daily activities, and social-emotional adjustment [50]. Acquisition of skills, experience and knowledge related to information management, time management, and spatial and object arrangement,

and accurate adaptations can all be influenced by visual perceptual function, which then affects visual motor integration. Understanding of spatial relationships and visual memory is apparently associated with visual motor integration; other important contributing factors include nonverbal reasoning and visual-spatial attention. [51], [52]. Among the functional tasks that require visual motor integration abilities, poor handwriting is one of the most commonly reported reasons for referral to an occupational therapist [53]. School-aged children usually spend up to 50-60% of their school time completing tasks that require use of paper and pencil [54]. Several correlational studies agree that visual motor integrative ability is the best predictor of handwriting legibility [55]. Interventions aimed at improving visual motor integration may help to prevent development of handwriting problems in children [56].

Approximately 80% (n = 48) of the study participants were born preterm. Survival rates of children born prematurely have increased largely due to medical advances that have increased the prevalence of high-risk infants and children in the population. Preterm children always suffer from white matter abnormalities that negatively affect their neural connectivity. The resulting impairments interfere with visual information processing [57]–[59] and further jeopardize the development of visual perceptual and visual

**TABLE 3.** Summary of intervention gains and effect sizes for KBTS and TVPT groups.

Measures	KBTS		TVPT	
	Change	Cohen's <i>d</i>	Change	Cohen's <i>d</i>
TVPS-3				
Visual discrimination	3.33	0.84 <sup>a</sup>	2.47	0.69 <sup>b</sup>
Visual memory	2.14	0.12	2.65	0.21 <sup>c</sup>
Visual spatial relations	3.45	0.85 <sup>a</sup>	2.36	0.60 <sup>b</sup>
Visual form constancy	0.46	0.10	1.84	0.68 <sup>b</sup>
Visual closure	2.66	0.84 <sup>a</sup>	2.87	0.59 <sup>b</sup>
Visual figure round	2.85	0.80 <sup>a</sup>	1.93	0.32 <sup>c</sup>
Visual sequential memory	0.35	0.13	0.42	0.21 <sup>c</sup>
Total scores	11.38	0.81 <sup>a</sup>	8.47	0.54 <sup>b</sup>
VMI	22.51	0.89 <sup>a</sup>	17.88	0.59 <sup>b</sup>
VABS-C				
Communication	6.96	0.37 <sup>b</sup>	2.96	0.12
Daily living skills	14.72	0.65 <sup>b</sup>	6.11	0.22 <sup>c</sup>
Socialization skills	1.15	0.57 <sup>b</sup>	1.97	0.58 <sup>b</sup>
Motor skills	6.08	0.51 <sup>b</sup>	5.81	0.58 <sup>b</sup>
Total scores	5.4	0.22 <sup>c</sup>	1.30	0.17
SFA-C				
Participation	9.63	0.47 <sup>c</sup>	5.19	0.51 <sup>b</sup>
Activity Performance- Physical Tasks	54.34	0.58 <sup>b</sup>	42.99	0.55 <sup>b</sup>
Activity Performance- Cognitive/Behavioral Tasks )	78.8	0.59 <sup>b</sup>	68.55	0.45 <sup>c</sup>

<sup>a</sup> A Cohen's *d* value > 0.8 indicates a large effect size.

<sup>b</sup> A Cohen's *d* value  $\geq 0.5 < 0.8$  indicates a medium effect size.

<sup>c</sup> A Cohen's *d* value  $\geq 0.2 < 0.5$  indicates a small effect size.

Abbreviations:

TVPS-3, Test of Visual-Perceptual Skills (non-motor)- Third Edition

VMI, The Beery-Buktenica Developmental Test of Visual-Motor Integration -6th Edition

VABS-C, Vineland Adaptive Behavior Scale- Chinese Version (VABS-C)

SFA-C, School Function Assessment- Chinese Version

motor integrative functions. Dysfunctions associated with premature birth include impairments in visual acuity [60], visuospatial working memory [61], depth perception [62], and visual attention [59]. Impairments in visual perception and motor skills have also been documented, such as reduced sensitivity to local motion, global motion, and two-dimensional motion [63].

Most of the traditional rehabilitative protocols for improving visual perceptual functions and visual motor integration are table-top activities. These activities may include repetitive drills and exercises such as visual memory exercises as well as puzzles and games such as pegboard games and card games. Another example is the use of ball games and activities to improve visual motor integration ability. Occupational therapists using these remedial strategies believe that visual motor integration and visual perception are composed of subcomponents, which can be remediated by a building block approach that emphasizes improvements in the hierarchical subcomponents to allow the structure of visual perception to be reconstructed. The therapist would design strategies to remediate basic problems to improve higher level visual perceptual functioning [64]. In children with developmental disability, who tend to exhibit a short attention span and limited environmental exploration, the main challenge of

traditional rehabilitative strategies is sustaining visual attention and motivation [65].

The KBTS proposed in this study differed from conventional remedial strategies in several ways. First, the KBTS provided discrete feedback in multiple sensory channels to maximize comprehension and attention in the user. The continuous feedback provided by the KBTS not only enabled the therapist to target specific deficits in visual perceptual and visual-motor integrative function, but also enhanced cooperation and rapport between the participating children and therapists and enriched the game-playing experience. Comparing actual and expected sensory feedback of movement could facilitate the cerebellar integrity [66]. Second, the KBTS can be implemented in a real-world physical environment, e.g., school teachers can implement the system in the classroom, and family members can implement the system in the home. Therefore, the user can receive consistent training with minimal time and location constraints and without the participation of a professional therapist. The high ecological validity of the KBTS could facilitate the transfer and generalization of skills from expandable scenarios simulated in a virtual environment to real-world scenarios [67].

Third, for therapists and teachers, limited resource is the main obstacle to designing and implementing novel



learning activities. Whereas children may quickly lose interest in highly repetitive games, the KBTS develops visual perceptual and visual-motor integrative abilities by providing numerous enjoyable games with varying difficulty levels. Additionally, the system enables therapists/teachers to modify activities according to the ability, performance, and motivation of individual students. The motion-sensing feature of the KBTS also enables the therapist/teacher to monitor the activity performance of the user and to modify task content in real time.

Fourth, visual-motor skills require multi-dimensional development of skills, including kinesthesia, motor function, and motor planning [64]. The KBTS includes various activities in a therapy session instead of training the user in a specific visual-motor task (e.g., drawing) or in the use of a specific tool (e.g., scissors or a pencil). These activities were full of multiple sensory feedbacks and thus could activate a complex network involving cortical and subcortical structures participating in motor planning and learning [68]. Unlike the traditional rehabilitation strategy, which emphasizes fine motor training, the KBTS incorporates whole-body activities to facilitate visual motor integration. The rationale for using gross motor activities in KBTS is the perception-action perspective [69], [70], i.e., early movement patterns are the foundation of subsequent visual-motor integration ability. The perception-action perspective supports the concept of simultaneously combining multiple intervention strategies, including gross movement patterns, to develop a foundation for tool use in most visual-motor integration tasks. Deficits in visual-spatial and visual-motor integration observed in this study may have been caused by impaired occipital-parietal-frontal neural circuitries, and early and continuous neural connectivity disruptions are an assumed cause of persisting visual-motor integrative and visual perceptual dysfunctions [71]. Motor training has also proven beneficial for boosting occipital-parietal-frontal neural circuitries and functions [59].

The fifth difference is that the KBTS can be used non-verbally and is motor-oriented. Most developmental changes in visual perception and visual-motor integrative functions occur at approximately 9 years of age [72], [73]. Our study indicated that, for children at this age or younger, KBTS is more effective than table-top activities in terms of effectiveness for systematic training to improve visual perceptual functions and visual motor integrative abilities.

The present study had several limitations. The sample size was small, and the follow-up did not investigate the long-term effectiveness of KBTS visual motor integration and visual perception in children with developmental delays. Further studies are suggested to broaden and refine the training activities used in the KBTS.

## V. CONCLUSION

Visual perceptual and visual-motor integrative dysfunctions are known to be severe impediments to academic performance and daily function. The proposed KBTS

provides therapists or teachers with an effective alternative strategy for training visual-motor integration abilities and visual perceptual functions in children with developmental delays. The KBTS had two additional advantages. First, the KBTS provides continuous kinesthetic feedback and reinforcement to the user. Children use kinesthetic information to develop the upper-extremity speed and the manual dexterity needed for most visual-motor integrative activities (e.g., ball skills and handwriting). The KBTS enables therapists to modify the type and intensity of sensory stimuli to maintain the attentiveness of the user while avoiding sensory hypo/hyper responsiveness. Second, the KBTS is practical and feasible because it is easily accessible with a widely used commercially available gaming console and an internet connection. The system is also applicable for use in a group therapy format in school settings or clinical settings that have limited availability of personnel. Unlike conventional visual perceptual interventions, the effective KBTS enables the use of highly interactive gross motor activities to enhance visual perceptual functions. As important as fine motor skills, gross motor function is an important component of visual perceptual and visual-motor tasks. Gross motor activities should be incorporated into the therapeutic activities while designing visual perceptual training programs. The KBTS adopted in this study mainly utilized AR approach, the AR-based therapy milieu could be incorporated as well in a suitable scenario for age-appropriate users.

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