Does virtual reality training using the Xbox Kinect have a positive effect on physical functioning in children with spastic cerebral palsy? A case series

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Abstract.

PURPOSE: The present study investigated the effects of virtual reality (VR) training using the Xbox Kinect on motor function, balance, gait, and functional mobility in children with cerebral palsy (CP).

METHOD: This was a case series. Four children with spastic diplegic cerebral palsy were provided VR training using the Xbox Kinect for 12 sessions (three sessions per week for 4 weeks). At baseline and follow-up, physical function was measured using the following: Selective Motor Control (SMC) for motor function, Pediatric Balance Scale (PBS) for balance, Timed Up and Go (TUG) test and Functional Mobility Scale (FMS) for functional mobility, and 6-meter walk test (6MWT) for gait.

RESULTS: As compared with the baseline scores, SMC, PBS, TUG, FMS, and 6MWT scores after training showed improvements. In participant 1, PBS and TUG scores improved after VR training. In participant 2, SMC (left ankle dorsiflexor, left knee extensor), PBS, TUG, and FMS scores improved after training. In participant 3, SMC (left hip flexor), TUG, FMS, and 6MWT scores improved after training. In participant 4, SMC (right ankle dorsiflexor), PBS, TUG, FMS, and 6MWT scores improved after training.

CONCLUSION: The results show that VR training using the Xbox Kinect may improve physical functioning in children with spastic diplegic cerebral palsy. However, its utility in the rehabilitation of children with CP requires further investigation.

Keywords: Cerebral palsy, spastic diplegia, virtual reality, Xbox Kinect, motor function

1. Introduction

Cerebral palsy is a disease in which irreversible damage to brain cells results in a permanent disorder [1]. It may involve immature brain development while a fetus is growing in the uterus or it can appear at birth or within a couple of years after birth [2]. Children with cerebral palsy may experience spasticity in their muscles or difficulty in controlling the move-
ments of each joint [3]. Additionally, they may have a reduced ability to control posture, which can result in problems, such as muscle weakness, limited range of motion, and spinal alignments [3]. These complications have a considerable negative effect on the performance of activities of daily living [4].

In rehabilitation programs for children with cerebral palsy, postural balance training is intended to increase the integration of the muscles engaged in postural control and improve the trunk’s range of motion to modify postural balance [5]. In addition, therapeutic approaches for treating children with cerebral palsy emphasize the repeated practice of diverse functions in the activities of daily life along with sufficient feedback [6]. Recently, therapeutic active movement using virtual reality (VR) has received an increasing amount of attention as an intervention to enhance postural control in children with cerebral palsy [7]. VR is a computer technology for generating environments where individuals can engage in interactions between the virtual situation and the user [7]. VR provides accurate and systematic environments of active movement through visual and auditory feedback. Such execution of space representation and 3-dimension visual feedback is very important to the motor learning of children with cerebral palsy [8]. Therefore, through practicing skills in a virtual environment, it may be possible to provide alternative intervention programs that have a positive effect on children’s cerebral motor development and their ability to perform limited activities of daily living.

In particular, VR training using games such as Nintendo Wii and the Xbox Kinect is suggested as an intervention. The Nintendo Wii, a home game system involving VR, uses technology to sense movements through a remote control, thereby providing children with information and feedback about movements. The Nintendo Wii can provide biofeedback for children with cerebral palsy with reduced balance, or provide a reasonable alternative for VR systems to enhance motor function [9]. Sharan et al. attempted to enhance motor function in children with cerebral palsy after they had undergone surgery (eight in the intervention group, eight in the control group) using the Nintendo Wii sport three times a week for 3 weeks. Although Virtual Reality interventions using Nintendo Wii sports significantly affected balance in the intervention group, no significant difference was observed in the control group. In addition, as reported in previous studies, the use of Wii-Fit has been shown to reduce swing in children with cerebral palsy while balancing and walking [10]. In addition, the effect of introducing VR using the Xbox Kinect has also been reported in [11]. The Xbox Kinect is a VR game system that controls actions with movement in a 3-D space. It is designed so that users may control space representation with body actions alone, without controllers or aids. It allows users to experience VR along with the actions of avatars through a home TV and provides the benefit of allowing the user to experience diverse activities of daily life while receiving visual and auditory feedback. The Xbox Kinect360 protocol has shown improvements in the balance and activities of daily life of school-age children with cerebral palsy in a school environment [11].

However, there has been little study on the effect of VR intervention using the Xbox Kinect. For this reason, the present study aimed to investigate the effects of VR training using the Xbox Kinect on motor function, balance, and gait in spastic diplegic children with cerebral palsy.

2. Materials and methods

2.1. Participants

The present study was conducted on four children with spastic diplegic cerebral palsy. The inclusion criteria were: 1) attending regular school, 2) being with Gross Motor Function Classification System (GMFCS) or and Manual Ability Classification System (MACS) level 1 or 2 3) being able to understand and follow simple instructions. The exclusion criteria were: 1) severe visual and hearing impairment, 2) uncontrolled seizures, 3) genetic and syndromic conditions, 4) botulinum toxin injection in the lower extremities within the previous 6 months. Of the subjects who participated in the present study, three had cerebral palsy with GMFCS and the MACS level 1 and one subject was in GMFCS and MACS level 2. Table 1 shows their characteristics.

2.2. Ethical consideration

All participants provided signed informed consent after receiving an explanation of the study’s purpose and procedures. The study was approved by the Kyungnam University Institutional Review Board.

2.3. Design and setting

The present study was a case series conducted on
Table 1  
Characteristics of subjects

<table>
<thead>
<tr>
<th>Subject</th>
<th>Age</th>
<th>Gestation age</th>
<th>Gender</th>
<th>Birth weight</th>
<th>GMFCS</th>
<th>MACS</th>
<th>Assistive devices</th>
<th>Visual/auditory status</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subject 1</td>
<td>10 Y</td>
<td>31 Wks 7 days</td>
<td>F</td>
<td>1400 g</td>
<td>I</td>
<td>I</td>
<td>None</td>
<td>Weak eyesight</td>
</tr>
<tr>
<td>Subject 2</td>
<td>9 Y 5 mo</td>
<td>32 Wks</td>
<td>M</td>
<td>1900 g</td>
<td>I</td>
<td>I</td>
<td>None</td>
<td>Weak eyesight, Lt. strabismus</td>
</tr>
<tr>
<td>Subject 3</td>
<td>10 Y 5 mo</td>
<td>27 Wks 6 days</td>
<td>F</td>
<td>1380 g</td>
<td>II</td>
<td>II</td>
<td>AFO</td>
<td>Weak eyesight, Rt. strabismus</td>
</tr>
<tr>
<td>Subject 4</td>
<td>8 Y 1 mo</td>
<td>37 Wks</td>
<td>M</td>
<td>2000 g</td>
<td>I</td>
<td>I</td>
<td>None</td>
<td>Weak eyesight</td>
</tr>
</tbody>
</table>

Abbreviations; GMFCS, Gross Motor Function Classification System; MACS, Manual Ability Classification System; AFO, Ankle Foot orthosis.

Table 2  
Virtual reality training using Xbox Kinect

<table>
<thead>
<tr>
<th>Games using Xbox Kinect</th>
<th>Performed main movements</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soccer</td>
<td>– Active movement of hip flexion, hip abduction, hip external rotation, hip internal rotation, knee flexion, knee extension, ankle dorsiflexion, and ankle plantarflexion</td>
</tr>
<tr>
<td></td>
<td>– Weight-shifting and weight-bearing training</td>
</tr>
<tr>
<td></td>
<td>– Balance training</td>
</tr>
<tr>
<td>Beach volley ball</td>
<td>– Active movement of hip flexion, hip abduction, hip external rotation, hip internal rotation, knee flexion, knee extension, ankle dorsiflexion, and ankle plantarflexion</td>
</tr>
<tr>
<td></td>
<td>– Weight-shifting and weight-bearing training</td>
</tr>
<tr>
<td></td>
<td>– Balance training</td>
</tr>
<tr>
<td>Bowling</td>
<td>– Active movement of hip flexion, hip abduction, hip external rotation, hip internal rotation, knee flexion, knee extension, ankle dorsiflexion, and ankle plantarflexion</td>
</tr>
<tr>
<td></td>
<td>– Weight-shifting and weight-bearing training</td>
</tr>
<tr>
<td></td>
<td>– Balance training</td>
</tr>
</tbody>
</table>

children with cerebral palsy who were outpatients at the Children Development Center in the Changwon of South Korea. The characteristics of the participating subjects were collected through brief interviews. Following interviews, motor function, balance, and gait abilities were tested or measured by research assistants. After tests or measurements, the participants attended VR training using the Xbox Kinect. All training was conducted for 12 sessions (three sessions per week for 4 weeks). VR training was provided for 40 minutes (30-minute training and 10-minute preparation). VR training using the Xbox Kinect was provided by composing individual programs in accordance with the abilities of each subject.

2.4. VR training using the Xbox Kinect

The present study used the Xbox Kinect 360, which is a VR system. The Xbox Kinect 360 is a game device and second version of software that was developed by the Microsoft corporation. The game device has an infrared camera sensor (Kinect sensor) that perceives the user’s movement without needing a special controller. The user’s movement in the VR environment can be seen through the monitor in real time. This movement perception does not require special buttons to be pressed, which allows users with impaired fine motor skills and impaired dexterity to participate effectively in the game. When the task is not properly performed in the VR environment, visual and auditory sensory feedback are provided. For training, monitors were set up in a quiet environment that was not influenced by external factors. The infrared camera sensor was positioned, and the participants were made to stand approximately 1.5–2 m from the screen [11].

Game programs which were comprised of soccer, beach volleyball and bowling were selected in the Xbox Kinect 360 considering the participants’ motor function. The soccer, beach volleyball, and bowling games were conducted in a way that, to win the game, a subject had to earn points through mutual communication with the other participant avatars. Games were conducted in a way that the participants were able to experience postural control only with physical movements, not using the system controller or tools. Usually, the game programs including soccer, beach volleyball, and bowling required active movements of the lower extremities in the standing position. The participants usually performed active movements of hip flexion, hip abduction, hip external rotation, hip internal rotation, knee flexion, knee extension, ankle dorsiflexion, and ankle plantarflexion in the standing position.
Table 2 shows the detailed VR training using the Xbox according to each game program.

2.5. Outcome measurements

Clinical assessment of selective motor control (SMC) in children was used to assess motor function [12]. SMC determines control of voluntary movement in each joint or co-contraction, extension and flexion of muscles, and the individual joint’s capacity for executing active movement. Targeting 51 children with spastic diplegic cerebral palsy and spastic quadriplegic cerebral palsy, this tool reported the increased reliability of the correlation coefficient from 0.88 to 0.91, and the validity of Spearman correlation coefficient \( r = -0.83, p < 0.001 \) [12].

The pediatric balance scale (PBS) was used to assess balance [13]. This assessment tool comprised 14 items: sitting to standing, standing to sitting, transfers, standing unsupported, sitting unsupported, standing with eyes closed, standing with feet together, standing with one foot in front, standing on one foot, turning 360 degrees, turning to look behind, retrieving object from floor, placing alternate foot on stool, reaching forward with outstretched arm [13]. Points from 0 to 4 are recorded for each item depending on the degree of active movement. Targeting 20 children with impaired balance aged 5 to 15 years, this tool reported a reliability and validity of Intraclass Correlation (ICC) = 0.997 and Spearman correlation coefficient of \( r = 0.89 \) [13].

To assess mobility, the Timed Up and Go (TUG) test and Functional Mobility Scale (FMS) were used. In TUG, markers are placed on the floor at a distance of 3 m from a chair. The time taken to stand from an armchair, walk along the shown markers following the assessor’s instruction, and return to sitting in the chair, is measured. This tool was reported to have a test-retest reliability of ICC = 0.99.

FMS is a tool used to assess locomotion in three places, home (5 m), school (50 m), and community (500 m). These three places are assessed with grades 1–6 according to their ability of movement to each place. Grade 1 means a need for a wheelchair in locomotion, Grade 2 a need for frame or walker, Grade 3 a need for crutches, Grade 4 a need for one or two canes, Grade 5 independent locomotion possible on a level floor, and Grade 6 independent locomotion possible on floor with uneven surfaces [14]. Targeting 118 cerebral palsy patients, this tool was reported to show a reliability of kappa coefficient of 0.86–0.92 regarding the mobility grade [14].

Gait ability was tested using a 6-meter walk test (6WT). This tool measures the time to walk 6 m (19.7 feet) without assistance. The subjects are allowed help for 2 m before and 2 m after the 6 m test distance to allow for acceleration and deceleration over the total 10 m (32.8 feet) distance [15]. Targeting patients with Down syndrome aged 11 to 26 years, this tool was reported to show the test-retest reliability [15].

2.6. Data analysis

For Statistical analysis, SPSS 18.0 was used. General and medical characteristics of the subjects were expressed as mean (standard deviation) or frequency. Comparisons between measures taken before and after intervention were analyzed using descriptive statistics.

3. Results

Tables 3 and 4 show the results of this study.

### Table 3

| Comparison of TUG, PBS, FMS, and 6mWT |
|---------------------|---------------------|---------------------|---------------------|---------------------|
|                      | Subject 1 | Subject 2 | Subject 3 | Subject 4 |
| TUG                  | Pre-     | Post-     | Pre-     | Post-     |
| PBS                  | Pre-     | Post-     | Pre-     | Post-     |
| FMS                  | Pre-     | Post-     | Pre-     | Post-     |
| 6mWT                 | Pre-     | Post-     | Pre-     | Post-     |
|                      | 8.30     | 8.18      | 30.36    | 19.49     |
|                      | 43.00    | 47.00     | 41.00    | 42.00     |
|                      | 17.00    | 17.00     | 14.00    | 16.00     |
|                      | 4.45     | 4.54      | 7.64     | 9.83      |
| Abbreviations: TUG, Timed Up and Go test; PBS, Pediatric Balance Scale; FMS, Functional Mobility Scale; 6mWT, 6-meter Walk Test. |

### Table 4

3.1. Participant 1

Participant 1, a 10-year-old girl, was diagnosed with spastic diplegic cerebral palsy at birth from being born underweight and having preterm periventricular leukomalacia. After birth, the girl was kept in an incubator for 40 days. She was at GMFCS and MACS level 1. She had ophthalmic problems in both eyes and was receiving regular treatment for weak eyesight. She showed a high level of motivation for VR intervention and displayed shaking of the left and right upper limbs before intervention. After reality training, her PBS and TUG scores improved.

3.2. Participant 2

Participant 2, a 9-year-and-5-month-old boy, was diagnosed with spastic diplegic cerebral palsy at birth with superior tension in right-side muscle spastic-
Table 4
Comparison of SMC

<table>
<thead>
<tr>
<th></th>
<th>SMC</th>
<th>RAD</th>
<th>RKE</th>
<th>RHF</th>
<th>RHA</th>
<th>LAD</th>
<th>LKE</th>
<th>LHF</th>
<th>LHA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subject 1</td>
<td>Pre: 2</td>
<td>Post: 2</td>
<td>Pre: 2</td>
<td>Post: 2</td>
<td>Pre: 2</td>
<td>Post: 2</td>
<td>Pre: 2</td>
<td>Post: 2</td>
<td>Pre: 2</td>
</tr>
<tr>
<td>Subject 2</td>
<td>Pre: 1</td>
<td>Post: 1</td>
<td>Pre: 1</td>
<td>Post: 1</td>
<td>Pre: 1</td>
<td>Post: 1</td>
<td>Pre: 1</td>
<td>Post: 1</td>
<td>Pre: 2</td>
</tr>
<tr>
<td>Subject 3</td>
<td>Pre: 1</td>
<td>Post: 1</td>
<td>Pre: 1</td>
<td>Post: 1</td>
<td>Pre: 1</td>
<td>Post: 1</td>
<td>Pre: 1</td>
<td>Post: 1</td>
<td>Pre: 1</td>
</tr>
<tr>
<td>Subject 4</td>
<td>Pre: 2</td>
<td>Post: 1</td>
<td>Pre: 2</td>
<td>Post: 2</td>
<td>Pre: 2</td>
<td>Post: 2</td>
<td>Pre: 2</td>
<td>Post: 2</td>
<td>Pre: 2</td>
</tr>
</tbody>
</table>

Abbreviations: SMC, Selective Motor Control; RAD, right ankle dorsiflexor; RKE, right knee extensor; RHF, right hip flexor; RHA, right hip abductor; LAD, left ankle dorsiflexor; LKE, left knee extensor; LHF, left hip flexor; LHA, left hip abductor.

ity due to periventricular leukomalacia. He was at GMFCS and MACS level 1. He had weak eyesight and wore glasses to correct a squint, which was more serious in the left eye. He had a rather high motivation for intervention, showing, before intervention, a slanted trunk caused by tilting his head to the right due to his ophthalmic problem. After reality training, his SMC (left ankle dorsiflexor, left knee extensor), PBS, TUG, and FMS scores improved.

3.3. Participant 3

Participant 3, a 10-year-and-5-month-old girl, was diagnosed at birth with spastic diplegic cerebral palsy from periventricular leukomalacia caused by an underweight and premature birth. She was receiving hospital treatment for symptoms of rhinitis. She received incubator care for 50 days and was treated with prescription lung surfactant. She had weak eyesight in both eyes and had been wearing glasses to correct a squint in her right eye. She had a rather high motivation for intervention and, before intervention, had stiff muscle spasticity. She was at GMFCS and MACS level 2. To aid in locomotion, she wore an ankle foot orthosis when going out, but not at home. After reality training, her SMC (left hip flexor), TUG, FMS, and 6MWT scores improved.

3.4. Participant 4

Participant 4, an 8-year-and-1-month-old boy, was diagnosed with spastic diplegic cerebral palsy at the age of 2. At 4, he was diagnosed with orthopedic scoliosis of the trunk and also was diagnosed with weak eyesight. He had a rather high motivation for intervention. He was at GMFCS and MACS level 1. When going to and from school he wore a scoliosis brace. Before intervention, he moved his upper limbs in an asymmetric manner. After reality training, his SMC (right ankle dorsiflexor), PBS, TUG, FMS, and 6MWT scores improved.

4. Discussion

The present study investigated the effects of VR training using the Xbox Kinect on motor function, balance, and gait in children with diplegic cerebral palsy. Recently, there has been a remarkable increase in the use of VR for rehabilitation of patients with cerebral palsy. The use of VR training for children with cerebral palsy has been studied intently to demonstrate the effects on subjects with limited ability or other impairments of body structure and function who are unable to participate in other rehabilitation programs [16].

Continued research on VR for children with cerebral palsy has reported that it has effects on brain reorganization, plasticity, volume of motor function regions in the brain, visual perception ability, social participation, and other personal factors [16]. Most studies have reported that VR reduced dependence in children with cerebral palsy and increased self-help motor control [16]. Gorden et al. [17] included Wii games in treatment for 6 weeks, twice a week, for six children with cerebral palsy, between 6 and 12 years of age. Measurement of motor function using Gross Motor Function Measure (GMFM) showed mean changes in scores of 7%, with the biggest change observed in the sitting position assessment score (12%). The smallest change was observed in the rotation assessment score (2%). Balance assessment was used to explain the differences in postural control. Sharan et al. [10], after operations on children with cerebral palsy, included Nintendo Wii sport in treating 16 subjects (eight for intervention, eight for control) for 3 weeks, three times per week, in their investigation. Significant differences were observed after PBS, and although VR showed important effects on balance, there were no significant differences compared to the control group. Using Wii-Fit, researchers have shown that balance training causes a reduced swing in the walking motion of children with cerebral palsy and improves the development of their balance [10]. Furthermore, Brien and Sveistrup investigated functional balance and mobility...
of adolescents with cerebral palsy at GMFCS level I after a short-term intervention with VR. Adolescents with cerebral palsy between 13 and 18 years of age underwent intervention with IREX for 5 days, 90 minutes a day, and assessed TUG, 6MWT, Community Balance and Mobility scale (CB & M), and GMFM-E (24 items of the 88 GMFM items, including walking, running and jumping) [18]. By practicing with short-term intensive VR, a significant effect was seen in functional balance and mobility. Using VR games, Brien and Sveistrup investigated active movement of ankle dorsiflexion in 10 children with cerebral palsy and six healthy children and showed that VR provided more repeat counts of active movement than existed before VR training [18]. Active movement within the range of motion and active movement of the ankle joint with a stretched range of motion were shown to be useful after being active in VR. Ankle movement was recorded using an electromyographometer [19]. In addition to the studies above, many previous studies have reported that training with VR has a positive effect on children with cerebral palsy.

However, other studies have reported that it had no positive effect. Holden et al. reported the possibility of using VR for motor learning regarding activities of daily life. Although the methods they used were interesting, they reported that VR did not prove successful as a therapeutic option [20]. Another study reported that it was hard to explain the qualitative pattern of change because of the reduction in the volume of muscle activity in the contracting antagonist and assisting muscles that are needed for pattern, which is the chief cause of impaired postural control in children with cerebral palsy [21].

Additionally, in the present study, the application of VR training using the Xbox Kinect to children with spastic diplegic cerebral palsy showed positive responses in selective motor control, balance, and gait after training, compared to before training. That is to say, we confirmed small improvements in motor functions, balance, gait, and functional mobility. However, in the present study, there were a few limitations. Since the present study had a shorter training period for participants, compared to previous studies, and they continued to receive standard physical therapy, it is possible that significant improvements in motor function were unlikely. Additionally, since the present study had a small number of subjects and was a case series study without a control group for comparison, there could be many biases involved. Consequently, the results of this study alone are not sufficient to reach a definitive conclusion on the effect of VR training. In previous studies, the Xbox Kinect protocol has resulted in improvements in balance and activities of daily living in cerebral palsy participants in a school environment [11]. Seen from this viewpoint, VR training using the Xbox Kinect could be used for children with cerebral palsy as a potential intervention. That is why continued studies are needed. Since these studies are fun and provide motivation as well as a method of intervention for children with cerebral palsy, further investigations into the possibility for clinical intervention of VR training using the Xbox Kinect are needed. In particular, a high quality clinical trial, such as a randomized controlled trial, will be needed.

**Conflict of interest**

The authors have no conflict of interest to report.

**References**


