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Treadmill Training with Virtual Reality Improves Gait, Balance, and Muscle Strength in Children with Cerebral Palsy

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Independent walking is an important goal of clinical and community-based rehabilitation for children with cerebral palsy (CP). Virtual reality-based rehabilitation therapy is effective in motivating children with CP. This study investigated the effects of treadmill training with virtual reality on gait, balance, muscular strength, and gross motor function in children with CP. Eighteen children with spastic CP were randomly divided into the virtual reality treadmill training (VRTT) group (9 subjects, mean age, 10.2 years) and treadmill training (TT) group (9 subjects, mean age, 9.4 years). The groups performed their respective programs as well as conventional physical therapy 3 times/week for 8 weeks. Muscle strength was assessed using a digitalized manual muscle tester. Gross motor function was assessed using the Gross Motor Functional Measure (GMFM). Balance was assessed using the Pediatric Balance Scale (PBS). Gait speed was assessed using the 10-meter walk test (10MWT), and gait endurance was assessed using the 2-minute walk test (2MWT). After training, gait and balance was improved in the VRTT compared to the TT group ($P < 0.05$). Muscular strength was significantly greater in the VRTT group than the TT group, except for right hamstring strength. The improvements in GMFM (standing) and PBS scores were greater in the VRTT group than the TT group ($P < 0.05$). Furthermore, the VRTT group showed the higher values of 10MWT and 2MWT compared to the TT group ($P < 0.05$). In conclusion, VRTT programs are effective for improving gait, balance, muscular strength, and gross motor function in children with CP.

Keywords: balance; cerebral palsy; gait; muscular strength; treadmill training
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Introduction

Children with cerebral palsy should be able to walk independently before being integrated into school and society. Independent walking plays an important role in activities of daily living, improves bone density and cardiopulmonary endurance, reduces obesity, etc (Dodd and Foley 2007; Mattern-Baxter et al. 2009). Therefore, independent walking is the most important goal of clinical and community-based rehabilitation for many children with cerebral palsy. Therapeutic methods for improving the walking ability of children with cerebral palsy include strength exercise, cardiopulmonary endurance exercise, functional electrical stimulation approaches, task-oriented gait training, neurodevelopmental treatment approaches, and proprioceptive neuromuscular facilitation (Rosenbaum et al. 2007). Gait training using a treadmill is a common therapeutic method applied to children with cerebral palsy. Treadmill gait training helps such children repeat task-centered activities while walking; accordingly, they control velocity and develop a proper walking pattern by processing repeated sensory inputs obtained during walking (Cernak et al. 2008; Mattern-Baxter et al. 2009).

Mattern-Baxter et al. (2009) applied short-term high-intensity treadmill gait training to children younger than 4 years with cerebral palsy in order to improve their ambulatory function. However, there is a limit when trying to continually arouse children's interest in such therapeutic programs provided they are appealing. Virtual reality training is another therapy that can continue to hold children's interest and can be applied to children with cerebral palsy. Accordingly, Bilde et al. (2011) applied virtual reality training to children with cerebral palsy and reported increases in muscular strength and visuoperceptual ability. Brien and Sveistrup (2011) reported improved balance ability and walking endurance in such children. When used for rehabilitation treatment, virtual reality training is sometimes combined with a commercial game using a virtual reality system (Deutsch et al. 2008).

Virtual reality-based rehabilitation treatment is more effective in motivating children with cerebral palsy (Harris and Reid 2005). It provides children with cerebral palsy

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the opportunity to safely play, learn, and acquire skills. Therefore, virtual reality is considered a promising method for motivating participation in rehabilitation programs (Harris and Reid 2005). However, few studies have investigated the application of virtual reality in treadmill training for children with cerebral palsy (Harris and Reid 2005; Deutsch et al. 2008).

Therefore, this study examined the effects of virtual reality treadmill training on the ambulatory ability of children with cerebral palsy. This study was designed to compare the effects of existing treadmill gait training reinforced with virtual reality on muscular strength, gross motor function, dynamic balance, and ambulatory ability used by videogame. The purpose of this study was to suggest better therapeutic methods for gait training in children with cerebral palsy.

Subjects and Methods

Participants

Eighteen children with spastic cerebral palsy who are currently receiving exercise treatment as outpatients of the Seoul welfare center were enrolled. Only those who provided written consent to participate were included. The inclusion criteria were as follows: (1) diagnosis of spastic cerebral palsy and below grade 2 on the Modified Ashworth Scale in the lower limbs; (2) age 4-16 years; (3) cognitive abilities enabling communication using only simple language; (4) Gross Motor Function Classification System level I-III; (5) ability to walk farther than 10 m for more than 2 minutes using a walker with ankle foot orthosis (AFO); (6) no neurological disease other than cerebral palsy; (7) have not received an injection of anti-spastic medicine to reduce rigidity within the last 3 months; and (8) no history of epileptic seizure. This study was approved by the Institutional Review Board of Sahmyook University, and all participants and their parents signed informed consent forms after receiving a detailed explanation of the study. The general characteristics of the participants are shown in Table 1.

Protocol

In this study, a pretest and posttest with a control group design was conducted during 8 weeks. The participants were randomly allocated to the virtual reality treadmill training (VRTT) group and the treadmill training (TT) group (n = 9 per group) by lots in order to control the extraneous age variable. Fig. 1 was shown study's process. The VRTT group performed treadmill gait training with virtual reality for 30 minutes per day 3 times per week for a total of 8 weeks, while the TT group performed treadmill gait training without virtual reality for the same frequency and period. In addition, all participants received general physical therapy 30 minutes per day 3 times per week for a total of 8 weeks.

Only the jogging program from the Nintendo Wii (Nintendo, Tokyo, Japan) was used in the virtual reality program. A remote control (133 g) with a 2.4-GHz radio with a wireless specification of Bluetooth version 1.2 was connected to the sensor bar on the body of the Nintendo Wii. The participant walked with the Nintendo Wii remote control at their waist. During exercise, information on body motion acceleration was recorded by a 3D accelerometer within the remote control and transmitted to the sensor bar via Bluetooth. Thus, the transmitted information on body acceleration affects the speed of the character displayed on a television (TV) monitor, making it walk according to the speed of the participant. The body of the Nintendo Wii was placed 1.5 m in front of the participant together with a 42-inch TV. For safety, the participants walked while holding onto a side bar placed at the height of the solar plexus; only stability was ensured, without partial weight support, by using a PneuLif Unweighting System (Pneumex Co., Sandpoint, ID, USA).

The participants were assessed by manual muscle testing, the Gross Motor Functional Measure (GMFM), the Pediatric Balance Scale (PBS), the 10-meter walk test (10MWT), and the 2-minute walk test (2MWT) before and after training in order to investigate the effects of virtual reality treadmill training. Two experimenters with at least 3 years of clinical experience and two evaluators executed this study. The two evaluators were blinded to the group allocation of the participants.

Table 1. Clinical Characteristics of the Participants in this study. (N = 18)

Variables	VRTT group (n = 9)	TT group (n = 9)	X^2/t	P
Age (yrs)	10.2 ± 3.4	9.4 ± 3.8	4.000	0.857
Gestational age (wks)	32.6 ± 4.8	31.4 ± 4.9	0.505	0.621
Height (cm)	129.9 ± 20.0	120.7 ± 21.7	1.556	1.000
Weight (kg)	29.0 ± 12.5	26.6 ± 13.1	0.889	1.000
Gross motor function system classification (I/II/III)	3/1/5	3/2/4	0.444	0.801
Gross motor functional measure –Standing (%)	63.1 ± 22.4	62.0 ± 27.3	0.094	0.926
Gross motor functional measure –Walking, running, jumping (%)	52.7 ± 24.9	47.1 ± 25.8	0.464	0.649
Pediatric balance scale	31.3 ± 13.0	28.1 ± 16.0	0.469	0.645
10-meter walk test	0.4 ± 0.2	0.5 ± 0.4	−0.478	0.639
2-minute walk test	54.8 ± 30.1	72.9 ± 45.2	−0.997	0.334
Muscle strength (kg)				
Left extension	18.9 ± 7.9	15.2 ± 5.0	1.166	0.261
Right extension	20.4 ± 9.0	14.3 ± 5.9	1.728	0.103
Left flexion	7.1 ± 3.3	6.7 ± 2.8	0.251	0.805
Right flexion	8.6 ± 3.7	6.9 ± 4.1	0.903	0.380

Values are expressed as mean ± SD.

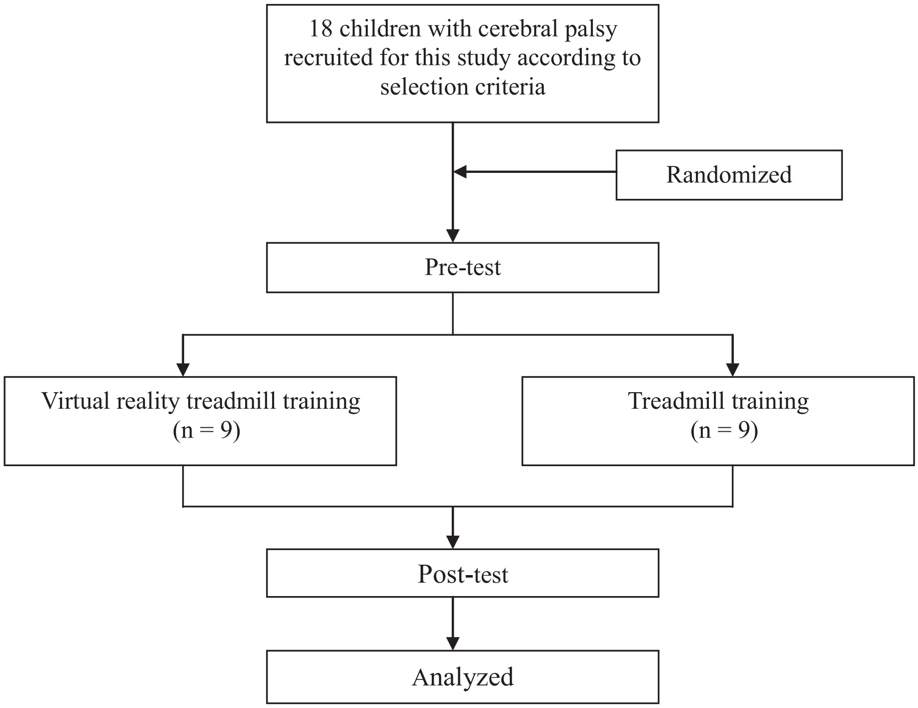

Fig. 1. Enrollment of children with cerebral palsy.

Intervention

The VRTT group performed treadmill gait training connected to a videogame-assisted program (Fig. 2). Before the training, the average walking speed of a participant was calculated using the results of the 10MWT. The participant then started TT at a walking speed equivalent to 60% of their target heart rate based on the calculations described below; walking speed was increased by 0.1 mph every 5 minutes if the heart rate did not exceed the target heart rate; exercise was performed at the previous speed if the heart rate exceeded the target heart rate (Dodd and Foley 2007; Fowler et al. 2010). The target heart rate was calculated using the Karvonen formula as follows: (maxHR − resting HR) × exercise intensity + resting HR (Whaley et al. 2006). Each participant wore a heart rate monitor during exercise. The two experimenters monitored their heart rate in order to adjust exercise intensity such that the heart rate stayed close to the target.

The jogging program of Nintendo Wii Fit Plus was used to provide the virtual reality for the VRTT group. Each participant was treated for 30 minutes per day 3 times per week for a total of 8 weeks. Each treatment session included a 5-minute warm-up, 10 minutes of exercise, a 5-minute rest, and 10 minutes of exercise. Participants were educated about the exercise 1 week before the start of the experiment.

Children in the TT group performed gait training on a treadmill without the application of virtual reality. The average walking speed of the children was calculated using the results of the 10MWT, and the children then started a treadmill gait exercise at a walking speed equivalent to 60% of the target heart rate calculated as described above. Walking speed was increased by 0.1 mph every 5 minutes if their heart rate did not exceed the target heart rate; exercised was conducted at the previous speed if their heart rate exceeded the target.

In addition, the participants received the same general physical therapy that consisted of range-of-motion exercise and neurodevelopment treatment for 30 minutes per day 3 times per week for 8 weeks.

Fig. 2. Virtual reality treadmill training.

Outcome measure

The following were evaluated before and after the interventions: the Manual Muscle Test, GMFM, PBS, 10MWT, and 2MWT. Muscle testing was performed by using a digitalized manual muscle tester (Commander Muscle Testing, JTECH Medical, Midvale, UT, USA); this instrument has a range of 0-125 lbs. and a measurement error of 1%. Both knee extensors and flexors were assessed. The average values of 3 measurements during one exercise were recorded and analyzed.

The GMFM is used to determine the gross motor function of children with cerebral palsy. The evaluation items cover 5 fields: (A) lying down and rolling; (B) sitting; (C) crawling on hands and knees, and kneeling; (D) standing; and (E) walking, running, and jumping. Items are scored on a 4-point scale (0-3 points). The inter-rater reliability of GMFM is 0.99, demonstrating excellent reliability; the construct validity is confirmed by very a strong correlation with the GMFM. Standing (D field) as well as walking, running, and jumping (E field) were assessed before and after treatment (Russell et al. 1989).

The PBS is used to determine the dynamic balancing abilities of children with cerebral palsy. It consists of 14 items evaluated on a 5-point scale (0-4); the maximum score is 56. The inter-rater reliability is 0.99, demonstrating excellent reliability of this instrument (Franjoine et al. 2003). The 10MWT is a measure of walking speed. The children were instructed to walk 14 m, and speed was measured at 10 m in order to exclude acceleration at the beginning of walking and deceleration at the end of walking. The inter-rater reliability of this instrument is very high between 0.89 and 1.00 (Thompson et al. 2008). The 2MWT is a measure of walking endurance; it is used to evaluate the cardiopulmonary endurance of children by measuring the maximum distance walked in 2 min in a silent hallway. The inter-rater reliability is very high: between 0.93 and 0.95 for children with cerebral palsy (Slaman et al. 2012)

Data analysis

The data were analyzed using PASW version 18.0 for Windows (SPSS Inc., Chicago, IL, USA). Paired *t*-tests were used to evaluate differences before and after treatment, because the result of the test of normality showed the data met the assumption of a normal distribution. Meanwhile, independent *t*-tests were performed to determine the significance of differences between groups. The level of significance was set at $P < 0.05$.

Results

General characteristics and homogeneity test of participants

A total of 18 participants were tested. The mean ages of the VRTT and the TT groups were 10.2 and 9.4 years, respectively. The mean height and weight of the VRTT and TT groups were 129.9 and 120.7 cm, and 29.0 and 26.6 kg, respectively. In the VRTT group, the scores of the GMFM-standing and the GMFM-walking, running, jumping were 63.1 and 52.7 respectively. In the TT group, the scores of the GMFM-standing and the GMFM-walking, running, jumping were 62.0 and 47.1 respectively. The homogeneity test of each measurement item showed no significant differences in any items (Table 1).

Changes in muscular strength of knee extension

The muscular strength of left knee extension increased significantly from 18.9 to 29.1 in the VRTT group and from 15.2 to 18.2 in the TT group, after training ($P < 0.05$). Left knee extension strength was significantly greater in the VRTT group than the TT group after training ($P < 0.05$). Right knee extension strength increased significantly from 20.4 to 30.2 in the VRTT group and from 14.3 to 18.5 in the TT group, after training ($P < 0.05$). The change in the muscular strength of right knee extension after training was significantly greater in the VRTT group than the TT group ($P < 0.05$) (Table 2).

Changes in muscular strength of knee flexion

The muscular strength of left knee flexion increased significantly from 7.1 to 11.5 in the VRTT group and from 6.7 to 7.9 in the TT group, after training ($P < 0.05$). Right knee flexion strength increased significantly from 8.6 to 11.9 in the VRTT group and from 6.9 to 8.3 in the TT group after training ($P < 0.05$). However, after training, right knee flexion strength was not significantly different between groups (Table 2).

Changes in gross motor function

In the field of standing, gross motor function increased significantly from 63.1 to 72.2 in the VRTT group and from 62.0 to 65.2 in the TT group after training. In addition, the change in gross motor function in the field of standing was significantly greater in the VRTT group than the TT group after training ($P < 0.05$). In the field of walking, running, and jumping, gross motor function increased significantly from 52.7 to 57.9 in the VRTT group and from 47.1 to 51.2 in the TT group after training ($P < 0.05$). However, the change in gross motor function in the field of walking, running, and jumping did not differ significantly between groups (Table 3).

Table 2. Changes in muscle strength on knee joint of the participants in this study. (N = 18)

	VRTT group (n = 9)		TT group (n = 9)		t	P
	Pre-test	Post-test	Pre-test	Post-test		
Extension						
Left	18.9 ± 7.9	29.1 ± 12.6	15.2 ± 5.0	18.2 ± 4.8	3.769	0.002
Right	20.4 ± 9.0	30.2 ± 12.6	14.3 ± 5.9	18.5 ± 5.5	2.662	0.017
Flexion						
Left	7.1 ± 3.3	11.5 ± 5.3	6.7 ± 2.8	7.9 ± 2.6	2.701	0.016
Right	8.6 ± 3.7	11.9 ± 4.4	6.9 ± 4.1	8.3 ± 4.5	1.868	0.080

Values are expressed as mean ± SD.
VRTT, virtual reality treadmill training; TT, treadmill training.

Table 3. Changes in clinical functional measures of the participants in this study. (N = 18)

	VRTT group (n = 9)		TT group (n = 9)		t	P
	Pre-test	Post-test	Pre-test	Post-test		
Gross motor functional measure						
Standing (%)	63.1 ± 22.4	72.2 ± 21.5	62.0 ± 27.3	65.2 ± 27.0	3.120	0.007
Walking, running, jumping (%)	52.7 ± 24.9	57.9 ± 24.8	47.1 ± 25.8	51.2 ± 26.0	0.793	0.440
Pediatric balance scale	31.3 ± 13.0	34.6 ± 13.5	28.1 ± 16.0	30.2 ± 15.6	2.917	0.010
10 meter walk test	0.4 ± 0.2	0.9 ± 0.2	0.5 ± 0.4	0.7 ± 0.4	4.169	0.001
2 minute walk test	54.8 ± 30.1	116.1 ± 27.7	72.9 ± 45.2	88.9 ± 50.8	5.058	<0.001

Values are expressed as mean ± SD.
VRTT, virtual reality treadmill training; TT, treadmill training.

Changes in dynamic postural control, walking, and endurance

The PBS score increased significantly from 31.3 to 34.6 in the VRTT group and from 28.1 to 30.2 in the TT group after training ($P < 0.05$). The change in PBS score was significantly greater in the VRTT group than the TT group ($P < 0.05$). Walking speed increased significantly from 0.44 to 0.89 in the VRTT group and from 0.51 to 0.69 in the TT group after training ($P < 0.05$). The change in walking speed after training was significantly greater in the VRTT group than the TT group ($P < 0.05$). The distance traveled in the 2MWT increased significantly, from 54.83 to 116.07 m in the VRTT and from 72.87 to 88.87 m in the TT group after training ($P < 0.05$). The change in the 2MWT was significantly greater in the VRTT group than TT group ($P < 0.05$) (Table 3).

Discussion

This study examined the effects of treadmill gait training with or without virtual reality on muscular strength, gross motor function, dynamic postural control, walking speed, walking endurance, and satisfaction in children with spastic cerebral palsy.

Virtual reality is a safe, pleasant, and educational therapeutic program, provides strong motivation, and improves concentration for participants. Furthermore, the advantage of a virtual reality program is that it is a simulating and intriguing therapeutic program for children with cerebral palsy (Harris and Reid 2005). The brain plasticity and behavioral changes of children with cerebral palsy are enhanced when they are given tasks or treated with a therapeutic method that requires troubleshooting ability (Bower and McLellan 1992; Ketelaar et al. 2001). Thus, in the present study, the VRTT group walked on a treadmill more actively than the TT group because of the use of the virtual reality program, which encouraged them to compete with virtual characters.

VRTT is reported to be significantly more effective than TT alone in enhancing the muscular strength of children with cerebral palsy. Schlough et al. (2005) report that the muscular strength of children with cerebral palsy increases significantly after aerobic exercise together with treadmill gait training. Burdea et al. (2013) report significant increases in the muscular strength of ankle dorsiflexion and plantarflexion in children with cerebral palsy who played a block break game and an airplane game using robotics in virtual reality 3 times per week for 12 weeks. The present study used treadmill gait training without partial body weight support, because the children were able to walk independently with walkers. Walking without partial body weight support would require muscular function in order to maintain proper posture. As walking speed increases, the heavier the weight bearing of the limbs becomes; accordingly, muscular function is enhanced to maintain proper posture. This is the basis on which rapid gait training enhances the muscular strength of the lower limbs. In the present study, the improvement in the muscular strength of the bilateral knee extensors was significantly greater in the VRTT group than the TT group. Task-oriented gait training improves the motor function of patients with neurological impairments. The virtual reality treatment is as dynamic as walking in daily life and provides patients with more intensive task-oriented real-time activities. Treadmill gait training is effective for increasing the muscular strength of the knee extensors and flexors as well as enhancing balance activities. Thus, it plays an important role in improving the functional activities of children with cerebral palsy. Virtual reality enabled body weight to be evenly distributed on the lower limbs by improving symmetry; this consequently increased stability while standing and thus improved ability to adjust posture.

Gait velocity and walking endurance improved to greater extents in the VRTT group than the TT group. The VRTT was conducted without partial body weight support, and treadmill speed was progressively increased during training. The results of this study show the training enhanced muscular strength in the lower limbs, consequently enhancing the participants' ability to adjust posture, improving dynamic postural stability, and ultimately improving walking. In general, in order to walk, a person needs approximately 38 percent of VO2max of cardiopulmonary function for gait endurance, and muscle performance consists of muscle strength, endurance, and power. Therefore, improved walking endurance and muscle strength has led to improved gait performance after treadmill training with virtual reality in this study. The walking activities of the VATT group improved significantly, because the skills learned walking training in virtual reality were transferred to real walking environments. The score of standing in the GMFM improved significantly in both groups after training. Harris and Reid (2005) report virtual reality games properly motivate children with cerebral palsy and thus represent a therapeutic method that can be used to facilitate rehabilitation training.

In summary, the results of this study suggest some beneficial effects of virtual reality treadmill training on functional activities in children with cerebral palsy are as follows: the primary endpoint is that VRTT has a therapeutic effect on gait performance after training. The secondary endpoint is that the treadmill gait training with virtual reality is very effective for improving the balance abilities in children with spastic cerebral palsy. A minor endpoint is that treadmill gait training with virtual reality is very effective for improving muscular strength of the lower limbs and gross motor function in children with spastic cerebral palsy. However, the results do not necessarily demonstrate potential long-term therapeutic efficacy, because the intervention period was relatively short at only 8 weeks. Furthermore, future studies should include larger sample sizes. Moreover, this study only included children with spastic cerebral palsy. Therefore, future studies should employ VRTT for children with various types of cerebral palsy such as athetosis, ataxia, and so on. This training method is expected to be used by physical therapists in clinical settings.

Conflict of Interest

The authors declare no conflict of interest.

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