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A Video Game with Foot Switch for Walking and Balance Ability Improvement in Children with Cerebral Palsy

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Abstract

Background: Ankle dorsiflexion exercises are important for gait and balance abilities, and these walking abilities can be facilitated by repetition

Objectives: Video games for rehabilitation have been used to make home training accessible, with a mouse modified to a foot switch for children with CP.

Design: A randomized controlled trial.

Participants: The intervention group (n=24) received 15 weeks, of approximately 3.5 hours/week VG training using a pressure-activated electronic foot switch, in addition to routine after-school programs. The control group (n=24) received routine after-school activities only.

Main Outcome Measures: A force platform to measure Center of Pressure sway (sway path, area, rate), and two function test scores, Pediatric Balance Scale score and One-Meter Test of Walking score, were used to measure the standing balance and walking performance.

Results: In the analysis of covariance, there were significant improvements in the intervention group than those in the control group in Center of Pressure sway performance, and functional test.

Conclusions: Using this modified foot switch with video games may improve exercise compliance and enhance recovery of balance and walking performance.

Keywords: CP rehabilitation; Postural balance; Video games

Introduction

The restoration and improvement in walking and balance is highly important for the daily life of children with CP [1,2]. Walking performance, such as heel strike, requires ankle flexors to make coordinated movements [3]. Children with CP have to practice the movements repeatedly to promote the motor control of their lower limbs, especially ankle control. Increased tibialis anterior activation can overcome the plantar flexors spasticity and stiffness, during gait training for CP [2,4]. Ankle dorsiflexion exercises include muscle strengthening, and flexibility of the ankle joints to prevent plantar flexor contractures, which are important for gait and balance abilities, and these walking abilities can be facilitated by repetition [5,6].

Researchers are increasingly aware of the importance of functional abilities and of considering the effect of the intervention in children with cerebral palsy (CP) of differing ability levels. Dynamic systems theory posits that motor behaviors depends on interaction of factors within child, task and environment subsystems and that the specific motor solution is influenced from three sources, child characteristics; task demands; and environmental influences [7-8]. Child characteristics represent not only the traditional physical impairments considered in the rehabilitation of children with CP (e.g. muscle tone, range of motion, balance) but also non-physical characteristics such as motivation, attention, and cognition [9].

As postulated by the motor learning theory, repetition, feedback, and motivation are regarded key factors for improving movement [10,11]. Video games (VG) for rehabilitation may promote these key motor learning principles and have been found to be effective for improving balance and walking performance in children with CP [12,13]. As per a systematic review of 40 studies on motor learning through a virtual environment in children with CP, there were statistically significantly improved motor task learning, improved motor function, and positive transfer of motor abilities in natural environments [12]. The VG rehabilitation highlighted the role of ankle muscles in gait training, and these training programs included a promising, task-specific, repetitive treatment concept, such as standing up and walking [13].

Computer-based training has become more popular due to its low cost, potential for independent practice and use at home [14]. The VG technology incorporates interactive sensory information for therapy, such as balance training, for children with CP [15-16]. Instead of using complex and expensive equipment, this study used VG rehabilitation with a foot switch to improve participation and to increase ankle

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movements by changing the interface for playing online games and specifying movement requests. However, there is limited evidence showing the relationship between modified VG rehabilitation, balance control, and walking performance in children with CP. Therefore, the research question is: "Does balance control and walking performance improve more with additional modified VG training using a foot switch, compared with after school activities alone for children with CP?"

Methods

Design

In this randomized controlled trial, participants were allocated to the VG training and standard care conditions randomly. One research assistant who was in charge of the randomization and recruitment process. Randomization was accomplished by using computer-generated random numbers from a random number generator. The protocol for this trial followed CONSORT 2010 guidelines [17], and the participant flow was shown in Figure 1.

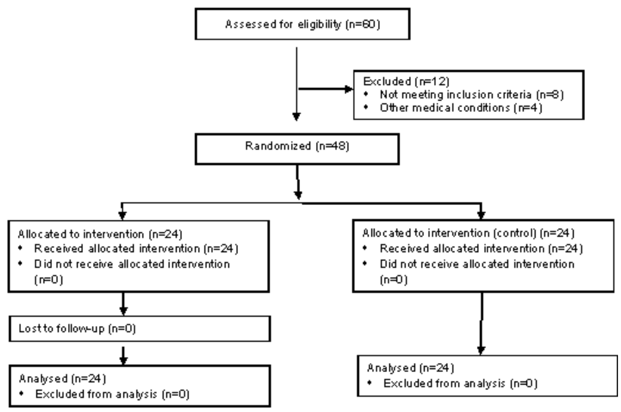

Figure 1: Participant flow in the trial.

Participants

A total of 60 children from the rehabilitation outpatient clinics in Taiwan were screened by research assistants and 12 children with CP were excluded as they did not meet the inclusion criteria (n=9) and had coexisting medical conditions (n=3). The inclusion criteria for CP participants were: a clinical diagnosis of spastic CP, Gross Motor Function Classification System (GMFCS) Levels I-III, with slight active ankle dorsiflexion, and ability to walk with or without an assistive device. Children with additional significant medical or severe walking problems were excluded. Forty-eight children were assigned randomly to either the intervention group or a control group (24 in each group).

Procedure

The VG intervention with foot switch informed the hypothesized mediators of physical activity and motivation that were targeted in the program: repeated practice, positive attitude, and perceived ankle control on screen. In the intervention group, ankle plantar flexion was performed by pressing the foot switch (the mouse), and ankle dorsiflexion occurred by releasing the foot switch. The participants in the intervention group had to use their feet to control the computer instead of using a computer mouse to play the online games (Figure 2).

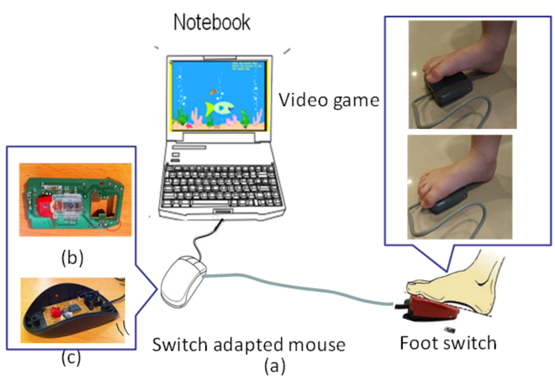

Figure 2: (a) Schematic diagram of switch adapted mouse, foot switch and video game (b) Top side of printed circuit board inside the mouse. In this procedure, fastening screws on the mouse are removed using a screw driver and the solder points on the circuit board for the left click buttons on the mouse are identified. (c) Two wires are soldered to prongs of the micro switch on the bottom side of the printed circuit board. Each wire is attached to the single-core shielded wire, and after the wire is attached, the circuit board is placed back into the mouse.

In the intervention group, ankle plantar flexion was performed by pressing the foot switch (the mouse left click), and ankle dorsiflexion was done by releasing the foot switch. Each session included passive stretching (5 min), active movements with PC games (15 min), rest (5 min), and active movements with PC games again (15 min), followed by a cool-down period involving passive stretching (5 min). The online games chosen for this study required participants to use the left button of the mouse to operate the games; the free online games used in this study were selected from the following address: http://www.gamesmomo.com. The VG intervention was delivered by a paediatric physical therapist with 5 years' experience. For the intervention group, the researcher set up the VG rehabilitation with the modified foot switch in the participants' schools. This intervention group received 45 min of VG rehabilitation with a modified foot switch at their school during after-school sessions once a day for a 15-week period. In contrast, the children in the control group received only after-school activities. The after-school programs in Taiwan include academic enrichment and test preparation.

Training device

The researcher connected the left button of the mouse to a foot switch, as the proposed device to modify computer access, as shown in Figure 2. Twenty-four foot switches were modified for the intervention group. The foot switch made up of a mouse interface that allows the user to simulate left click selection using the foot switch. Works with single foot switch that utilizes a left mouse click for activation or for PC games and the user can activate their foot switch to select an item. The mechanism of foot switch action is to facilitate active ankle dorsiflexion for children with CP, because their ankles are often in a plantar flexion position which diminishes the normal heel strike. The material cost of a modified foot switch was 12.5 USD. The goal of using a modified foot switch and free internet games was to provide inexpensive rehabilitation. This foot switch was activated by pressing and released by ankle dorsiflexion (>10°). Literature showed that the normal range of motion in the ankle is from 0° to 13° ~33° dorsiflexion, and 10° dorsiflexion is used during walking [18,19]. After the clinical training, the patient in the intervention group operated the foot switch to play games via ankle dorsiflexion and plantarflexion at home to improve walking abilities, as shown in Figure 2.

Outcome assessment

All the testing sessions were conducted by one occupational therapist and one physical therapist. Both evaluators were blinded to the assignment. There were five primary outcome variables to measure balance performance and walking abilities, which were sway path, sway area, sway rate, PBS score, and 1MWT score. The study used the results of the Midot Posture Scale Analyzer (MPSA-QPS200; a force platform) to evaluate sway path, sway area, and sway rate. Each patient then performed three trials standing still (30 s each) with eyes open. The CoP trajectory of the quiet stand trial was computed and delineated into rambling and trembling trajectories, measured as quantification of center-of-pressure sway (CoP Sway), ellipse sway area, CoP path lengths, and sway rate. The ellipse sway area (mm^2) was defined as a 95 % confidence ellipse for the mean of the CoP anterior, posterior, medial and lateral coordinates [20,21]. The CoP path length (mm) was defined as the absolute length of the CoP path movements throughout the testing period. The sway rate (mm/s) was defined as the mean speed of movement of the CoP throughout the testing period.

The Pediatric Balance Scale (PBS), a modification of Berg's Balance Scale, was developed as a balance measure for school-age children with mild to moderate motor impairments [22]. A study on minimal clinically important change (MCID) of PBS in 45 children with CP (age range: 19-77 months), the MCID ranges on the PBS-static, PBS-dynamic, and PBS-total were 1.47-2.92, 2.23-2.92, and 3.66-5.83 respectively. The data and MCID values can assist clinicians in interpreting changes over time and in assessing interventions [23]. The PBS has been demonstrated to have good test-retest and interrater reliability in school-age children with mild to moderate motor impairments (ICC 3.1=0.998) [24].

A viable low-cost alternative for gait assessment in children with CP is walking tests with good validity and reliability, such as the one-minute walking test (1MWT). During the 1MWT, participants were instructed to start walking when the signal was given and continue walking around a track with markings at each meter, for one minute. The distance was measured with a manual tape measure using the markings on the track and the MCID range on the 1MWT was 3.8~5.6 [25].

Interviews for participant feedback were conducted to understand the psyche and the progress of the children with respect to the issues faced in participating in the therapy (e.g., "How did you feel while training with the modified foot switch?".

Data analysis

Several kinds of data were collected in the pre-test and post-test phases: Sway path, Ellipse area, sway rate, distance of 1MWT, PBS static, PBS dynamic, PBS total score, and children's feedback. The analysis of covariance (ANCOVA) was used to identify children who had benefited the most from the treatment, with pre-treatment scores serving as covariates. The ANCOVA allowed adjustment for initial differences between the control and experimental groups for some of the prognostic factors, as well as for the identification of differences between the 2 study groups after the therapeutic intervention had started. The software program SPSS (SPSS Inc., Chicago IL, USA) for Windows was used to perform statistical analysis. Partial eta squared (η^2) values were used as the effect size of significant findings. Statistical significance was assumed for p<.05. The power analysis results are listed in Table 1 to provide the readers a visible representation of the probability of rejecting the null hypothesis when incorrect.

	Intervention group(N=24)		Control group (N=24)		ANCOVA			
	pre-test	post-test	pre-test	post-test	F	p	partial η^2	1-β
CoP sway performance	M ± SD	M ± SD	M ± SD	M ± SD				
Sway Path (mm)	218.0 ± 36.9	185.8 ± 37.0	224.7 ± 31.9	212.7 ± 29.3	12.54*	0.001	0.218	0.934
Ellipse Area (mm^2)	186.3 ± 43.0	149.0 ± 29.1	177.0 ±36.8	160.5 ± 19.5	6.74*	0.013	0.13	0.719
Sway Rate (mm/sec)	18.1 ± 2.6	16.2 ± 2.8	18.0 ± 3.0	17.3 ± 2.4	4.94*	0.031	0.099	0.585
Functional test								
1MWT(m)	61.0 ± 11.6	66.5 ± 11.1	64.1 ± 12.6	65.7 ± 12.9	5.72*	0.021	0.113	0.648
PBS static (scores)	13.9 ± 3.1	15.0 ± 2.0	13.0±3.6	13.5 ± 2.3	7.06*	0.011	0.136	0.739
PBS dynamic (scores)	22.1 ± 4.2	23.7 ± 4.0	21.9 ± 4.6	22.5 ± 4.2	5.70*	0.021	0.113	0.647
PBS total (scores)	36.0 ± 7.0	38.7 ± 5.7	35.3 ± 7.4	36.1 ± 6.2	9.57*	0.003	0.176	0.857

Table 1: Descriptive statistics and ANCOVA of test results.

The participant interviews were systematically coded and analyzed, and the parent feedback was used in this study.

Results

Twenty-four children with CP in the intervention group were trained for intensive active dorsiflexion to play online games with foot switch for a 15-week period. The background information for the 48 participants is listed in Table 2.

	Intervention group (N=24)	**Control group (N=24)**
Age(SD)	8.62 (1.43)	8.70(1.42)
Gender		
Male	18(75%)	17(71%)
Female	6(25%)	7(29%)
CP subtype		
Spastic quadriplegia	9(38%)	10(42%)
Spastic hemiplegia	4(16%)	5(21%)
Spastic diplegic	6(25%)	5(21%)
Athetoid	3(13%)	2(8%)
Ataxic	2(8%)	2(8%)
GMFCS Level		
UE		
UE Level I	6(25%)	5(21%)
UE Level II	8(33%)	9(38%)
UE Level III	7(29%)	8(33%)
UE Level IV	3(13%)	2(8%)
LE		
LE Level II	10(42%)	10(42%)
LE Level III	10(42%)	9(37%)
LE Level IV	4(16%)	5(21%)

Table 2: Demographic data of participants (Note: The Gross Motor Function Classification System (GMFCS) provides for the classifying of children with CP. The five levels of classification are based on self-initiated movement. Level I represent children who move without restriction, but have limitations in advanced skills, while Level V represents children with severe movement restrictions.)

Performance on MPSA and functional tests

Test results of ANCOVA are listed in Table 2 and bar charts are list in Figure 3. The bar charts provide a visual presentation of the test scores between the intervention group and the control group.

The effectiveness of the intervention was explained in the bar chart, indicating that the VG foot switch intervention can improve ankle movements and test performance (rectangular bars were used for the comparison between the two groups). In the post-test, the two groups showed significant difference in the CoP sway performance (sway area, F=12.54, p=0.001; ellipse area, F=6.74, p=0.013; sway rate, F=4.94, p=0.031). Group differences also show significant difference in functional tests (1MWT, F=5.72, p=0.021; PBS static, F=7.06, p=0.011; PBS dynamic, F=5.70, p=0.021; PBS total score, F=9.57, p=0.003), and performance also revealed that children in the intervention group showed improvement in functional balance after VG training.

The ANCOVA result showed that the VG rehabilitation sessions appeared to influence the walking performance and balance control of children in the intervention group.

Participant interview results

All the experimental participants indicated that they found the VG exercises fun and interesting, making statements such as "it's fun and interesting". Playing VG exercise that triggers positive emotional impact (emotional stability, optimism), and positive functioning (engagement, positive relationships, competence & achievement). Participating in the VG rehabilitation, allowed children with CP to actively participate in and to gain control over the games, instead of boring routine practice.

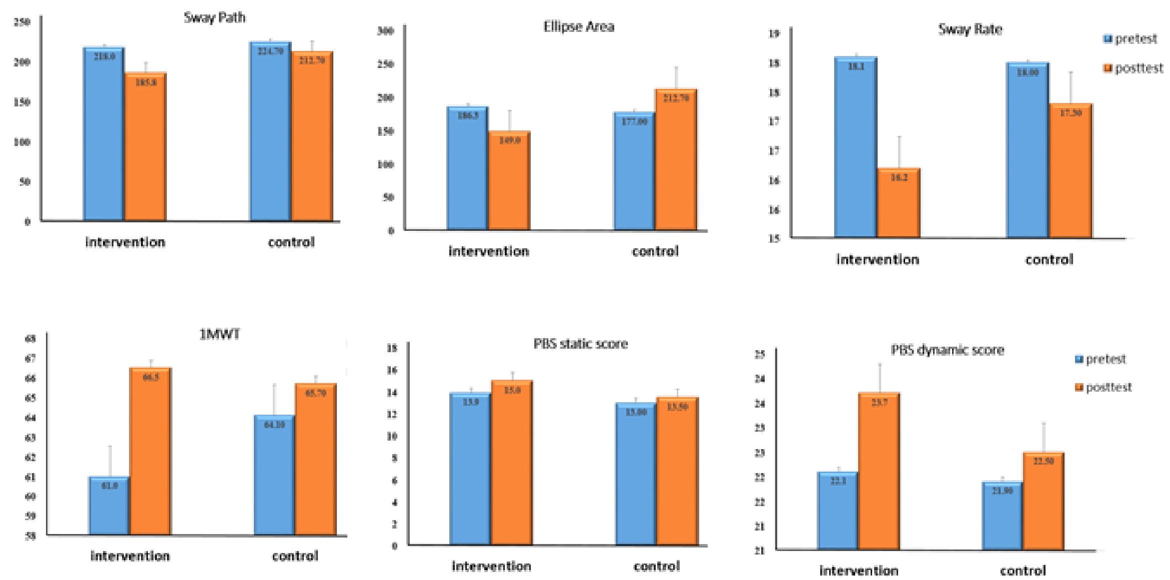

Figure 3: Pre-test and post-test scores between intervention and control group in sway performance, 1MWT, and PBS.

Discussion

The VG foot switch intervention was more effective in improving walking and balance than only regular after-school activities. The improvement in gait speed may be due to increased active ankle control and speed of movement. When performing the VG exercises, the children had to perform ankle dorsiflexion quickly in order to generate the next action of ankle plantar flexion. A previous study has also supported the finding that the assistive technology enhanced participation during VG activities [12,15].

The mean Minimally Clinically Important Difference (MCID) of 1MWT was 4.8 m in the study by Hassani et al (2014). The changes in 1MWT between pre-test and post-test in the intervention group was 5.4 m which was higher than 4.8 m, and the changes in the control group were 1.4 m which was lower than 4.8 m. This indicated that improvement in the intervention group after VG training was clinically significant in the 1MWT. However, the mean Minimally Clinically Important Difference (MCID) of PBS was 1.47 points for PBS static balance, 2.23 for PBS dynamic balance, and 3.66 for PBS total in the study by Chen et al [23]. The PBS changes in Chen's study were more than the MCID found in our study (1.1 points for PBS static balance, 1.6 for PBS dynamic balance, and 2.7 for PBS total).

In this study, a playful environment was created in which the participants actively pursued achievable challenges, such that they did not express fatigue and stayed motivated during the entire intervention period. This VG training protocol with the foot switch also included key components of balance control: repetition- and task-specific activities within a multisensory environment. The finding was also in agreement with that of previous studies, and indicated that exercise practice had a training effect on motor control and the speed of gait is import for children with CP [26-27]. The children had a goal to attain (i.e., scoring the greatest number of points) while participating in the VG exercises, whereas with the traditional walking exercises, children received no feedback on ankle range. A study by Barlett et al. [28] indicates that motivational variables play a predominant role in controlling performance on rehabilitation tasks. The VG training effect of the foot switch was consistent with Barlett's study, both showing that biofeedback and learning motivation can improve motor control. This finding indicates that interactive games could improve motor abilities of children with CP through VG rehabilitation.

Limitations and future direction

The study has several limitations, which should be considered when interpreting the findings. Longitudinal studies may be needed to explore cause-and-effect relationships and confirm whether the VG foot switch intervention enhances ankle control as indicated above. This study focused only on 24 children with spastic CP who were able to control environmental stimulation through the modified foot switch by performing ankle dorsiflexion/plantar-flexion. Future studies regarding VG rehabilitation should focus on establishing movement training through the modified foot switch in larger clinical populations, and use of various outcome measures that are associated with optimal transfers to real-world functions. Future studies might also focus on systems that could target multiple joints in CP population and investigate their training effects.

Conclusion

In this study, children with CP in the experimental and control groups used the same type of video games with varying gaming platforms. The results showed differences between the two devices (mouse vs. adaptive foot switch) without any further interference from the motivational characteristics of different games. The foot switch-controlled VG system may provide an effective means of training ankle dorsiflexion/plantar-flexion in home environments. Children with CP demonstrate better control of balance and walking performance and also greater interest in doing the same exercise (ankle dorsiflexion and plantar flexion) through a VG system than as a daily walking exercise.

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