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Original Article

Effect of simultaneous proprioceptive-visual feedback on gait of children with spastic diplegic cerebral palsy

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Abstract

Objective: to evaluate the effect of simultaneous proprioceptive - visual training on gait parameters in children with spastic diplegic cerebral palsy. **Background:** Feedback is a very crucial feature of motor control via motor learning. The visual and proprioceptive information are important regulatory mechanisms of motor control, functional activities and participation in daily activities in children with cerebral palsy. **Method:** gait parameters of 30 spastic diplegic children (age range 4-6 years) were evaluated before and after treatment by Tekscan's Walkway Pressure system. They were randomly and equally assigned into two groups (study and control). All children received regular therapeutic exercise program for one hour. In control group walked for 30 minutes without feedback, while those in study group walked for 30 minutes with proprioceptive-visual feedback. Duration of treatment was 3 times/week for 8 successive weeks. **Results:** There were significant differences after treatment in spatial parameters and temporal parameters of both groups with more improvement in study group than control one, and insignificant difference in kinetic gait parameters. **Conclusion:** the simultaneous proprioceptive - visual training might improve spatial and temporal gait parameters with no effect on kinetic gait parameters of children with spastic diplegic cerebral palsy.

Keywords: Spastic Diplegia, Visual Feedback, Proprioceptive Stimulation, Gait, Tekscan Walkway

Introduction

Cerebral palsy (CP) is the common neuropediatric disorder that affects development of posture and movement, such as gait[1]. CP is caused by lesion in early life either in pregnancy or after birth to the developing nervous system[2], that may affect 1.5 and more than 4 per 1000 live births[3]. Cerebral palsy is difficult to be classified because a wide range of independent severity as the etiology (causation and timing), the findings either anatomical or radiological, and the associated impairments[4], while in past the classification systems have focused principally on the type of tone or movement abnormality (e.g. spastic, ataxic) and the distributional pattern of motor impairments (e.g. diplegia, hemiplegia)[4-5]. Children with cerebral palsy often demonstrate different motor learning strategies due to their sensory, motor execution, and cognitive impairments[6]. The motor impairments in CP are secondary to lesions or anomalies in brain development, it inhibit normal automatic and voluntary responses and also allow development of dysfunctions[4]. Spastic diplegia is the most common type of CP that gives rise to difficulties in posture, balance, and gait control[5]. 30.6% of the children having CP had walking disorders as toe walking, foot drop, and walking manipulation[3,7]. Feedback is defined as sensory or perceptual information received from any sensory source either from inside the body such as a result of movement from proprioceptors (intrinsic feedback) or from extra or augmented sensory information (extrinsic feedback)[8]. Feedback can be used to detect errors in movement, and to provide a mean to understand the process of self-control, and the fundamental process for learning new motor skills[9]. Compared with the other senses, vision plays a crucial role in the acquisition and control of human locomotion[10]. The beneficial rehabilitation programs used in cerebral palsy treatment should be based on concepts of motor learning, such as active participation of the person with the disability, functional restoring of the paretic

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limb, and repetition of voluntary movements[11]. Training with visual feedback has been found to improve motor function, but maintenance strategies for this effect are yet to be determined[12]. Balance training with visual feedback was found to improve stance in CP, with a secondary positive effect on gait[13]. Tekscan digital pressure sensors (Tekscan, Inc., South Boston, MA, USA) are one of the available technologies for quantification of pressure force[14]. It provides barefoot static and dynamic gait data; the repeatability and reproducibility study in children showed 'good' Interclass Correlation Coefficient (ICC) scores in most of the anatomical areas investigated with the HR Walkway system[15]. One of the advantages of the barefoot analysis system is that the pressure sensors that always positioned parallel to the supporting surface provide a 'true' vertical force measurement[16]. Also, it enables collection of data without the influence of footwear hence, compensations for true deformities may be assessed and the long term effects of the intervention. Also it allows gait recording over several steps using a low profile floor walkway (5 mm) equipped with 4 sensels/cm^2. Hence the HR Walkway system can be used for recording walking and various sport activities[17]. Few studies that had examined the regulation of motor activity by manipulating tactile sensory cues concerning children with CP, especially while performing dynamic activities such as postural transition tasks and gait. So the hypothesis of study was that simultaneous proprioceptive and visual feedback during gait training in children with spastic cerebral palsy would improve gait parameters either kinematic and/or kinetic.

Subjects

This study was conducted on 30 children who were recruited from out- patient clinic, Faculty of Physical Therapy, Cairo University. The selection criteria for the children were as follows: a; diagnosed with diplegic CP from 4 -6 years old, b; spasticity grades were 1 and 1+ according to modified Ashworth Scale, c; gross motor function classification system. at level II and III The children who had visual impairments, hearing damage, fixed deformities at lower limbs or inability to understand the task were excluded. Prior to participation in the study, parents of selected children signed the written informed consent - ethical committee- faculty of physical therapy. The purpose and steps of the task were explained to them.

Experimental setup

Children were randomly and equally assigned by computer program into two groups (control and study). Control group (twelve boys and three girls) received the regular therapeutic exercise program (stretching and strengthening exercises) and traditional gait training. Study group (thirteen boys and two girls) received the same therapeutic exercise and gait training on TekscanK-Scan Sensors. All children received the treatment program for one hour and gait training for 30 minutes, three times per week for two successive months.

Tekscan Walkway system

It consists of a digital mat (195.5 cm length, 44.2 width) inserted in wooden walkway , sensors (4 sensels/cm^2) equipped in the mat, with resolution up to 185 Hz , and a pressure (1 to 862 kPa). Plasma screen is facing walkway; at distance 7 meters and height 1.5 meters. It shows image which is light reflected from seven pressure areas (taking shape of foot). if the seven regions of pressure on the foot are Heel, Midfoot, Forefoot, 5th metatarsal, 3rd-4th metatarsals, 2nd metatarsal, and 1st metatarsal[15]. Computer with The Tekscan Software (version 7) was utilized for data extrapolation such as: maximum peak pressure (kPa), stance time (s), cadence, gait time (s), distance (cm), velocity (cm/s), and a transmission hardware (cable and sensor-interface or so called handle).

Procedures

Anthropometric measures

A valid and reliable weight and height scale was used to assess children's weight and lower extremity length. Lower extremity length was the distance measured from the greater trochanter to the floor, while the child stands upright with straight knees and barefoot.

Gait analysis

Calibration

Calibration procedure was carried out prior to any step recordings by asking the child to stand for few seconds on one leg and then change foot of other leg (5-6 s). The subject was constantly monitored to recognize any possible issues related to balance. If the calibration was carried out correctly, the software informed the user that the procedure was successfully completed. We determine the starting and the finishing point on walkway (7 m). Tekscan Walkway platform was in the middle of walkway. In order to familiarize with the equipment, each patient performed two walks along the length the gait laboratory prior to starting the recording. Each child walked a total distance and record 6 steps (3 strides) in each time, a total of three trials recordings were taken and saved with their anonymous code number. The gait analyzed before and after two months of treatment program.

Gait training

1. Without feedback

In control group, each child walked for 30 minutes on open environment using obstacles, steppers, and balance board.

2. With simultaneous proprioceptive - visual feedback

In study group, children walked on mat of tekscan walkway platform and pay attention to image of his/her foot (the light of various colors of seven pressure points taking foot shape) on the screen, front of his/her scene. Child should concentrate during walking accurately because the image

Table 1. Descriptive data.

		Control group	Study group	MD	t- value	p-value
		x̄±SD	x̄±SD			
Age (years)		5.27 ± 0.77	5.23 ± 0.52	0.04	0.16	0.86
Weight (kg)		16.8 ± 2.95	15.86 ± 1.35	0.94	1.11	0.27
Height (m)		0.81 ± 0.07	0.79 ± 0.04	0.02	1.24	0.22
BMI (kg/m²)		24.97 ± 1.56	25.48 ± 2.03	-0.51	-0.77	0.44
Leg length	right	0.5 ± 0.04	0.49 ± 0.03	0.01	1.22	0.23
	left	0.5 ± 0.04	0.49 ± 0.03	0.01	1.22	0.23
Spasticity	I	7 (47%)	6 (40%)			
	I+	8 (53%)	9 (60%)			

x̄: mean; SD: Standard deviation; MD: mean difference; t value: Unpaired t value; p value: Probability value.

Table 2. Comparison of mean values of gait spatial parameters.

Spatial parameters			Control group	Study group	MD	p-value
			x̄±SD	x̄±SD		
Step length (cm)	Right	Pre	20.26 ± 9.82	19.73 ± 4.65	0.53	0.85
		Post	22.98 ± 9.52	29 ± 5.31	-6.02	0.04*
		MD % of change p	-2.72 13.42 0.0001*	-9.27 46.98 0.0001*		
	Left	Pre	21.2 ± 7.21	20.2 ± 3.52	1	0.63
		post	24.13 ± 6.79	29.66 ± 3.13	-5.53	0.03*
		MD % of change p	-2.93 13.82 0.0001*	-9.46 46.83 0.0001*		
Step width (cm)	Right	pre	5.86 ± 1.4	6.39 ± 1.69	-0.53	0.36
		Post	6.34 ± 1.37	7.31 ± 1.02	-1.16	0.02*
		MD % of change p	-0.48 8.19 0.001*	-0.92 14.39 0.002*		
	Left	Pre	5.6 ± 1.63	5.8 ± 1.14	-0.2	0.7
		Post	5.94 ± 1.64	7.1 ± 0.87	0.002*	
		MD % of change p	-0.34 6.07 0.01*	-1.3 22.41 0.002*		
Foot angle (degree)	Right	pre	18.6 ± 5.8	17.33 ± 7.34	1.27	0.6
		Post	22 ± 5.14	27.46 ± 3.62	-5.46	0.002*
		MD % of change p	-3.4 18.27 0.0001*	-10.13 58.45 0.0001*		
	Left	Pre	16.66 ± 5.55	16.26 ± 7.35	0.4	0.86
		Post	21.33 ± 6.39	26.93 ± 8.29	-5.6	0.04*
		MD % of change p	-4.67 28.03 0.01*	-10.67 65.62 0.003*		

x̄: Mean; MD: Mean difference; p value: Probability value; SD : Standard deviation; *: significant.

Table 3. Gait temporal parameters of both groups (control &study).

Temporal parameters		Control group x̄±SD	Study group x̄±SD	MD	p-value
Cadence (steps/min)	Pre	74.57 ± 10.44	76.09 ± 12.16	-1.52	0.71
	Post	80.5 ± 9.74	88.48 ± 9.54	-7.98	0.03*
	MD % of change p	-5.93 7.95 0.0001*	-12.39 16.28 0.0001*		
Gait velocity (cm/sec)	Pre	37.2 ± 9.79	39.36 ± 14.7	-2.16	0.64
	Post	39.89 ± 10.2	48.96 ± 12.53	-9.07	0.03*
	MD % of change p	-2.69 7.23 0.0001*	-9.6 24.39 0.0001*		
Gait time (sec)	Pre	6.43 ± 1.04	6.34 ± 1.28	0.09	0.84
	Post	5.89 ± 1.02	5.03 ± 1.22	0.86	0.04*
	MD % of change p	0.54 7.09 0.0001*	1.31 20.66 0.0001*		

x̄: Mean; MD: Mean difference; p value: Probability value; SD :Standard deviation; *: significant.

didn't appear if he/she presses improperly on fitted 7 points (sensors). We can keep the task be motivated by changing the light color. All children (in both groups) were evaluated prior to the commencement of baseline training and at the end of the two-month training period (post-treatment). The gait parameters were spatial (step length, stride width, and foot angle), temporal (cadence, gait velocity, and gait time), and kinetic parameters (maximum force and peak pressure).

Data analysis

For data analysis, all statistical measures were performed through the Statistical Package for Social Studies (SPSS) version 19 for windows, (SPSS, Inc., Chicago, IL). Data obtained from both groups pre and post treatment regarding gait parameters were statistically analyzed and compared using paired and unpaired T- test to detect level of significance within and between groups respectively.

Ethical approval

Ethical committee approvals of the faculty of physical therapy, Cairo University, Egypt (no: P.T.REC/012/001359) a signed written consent form with parent acceptance for participation in the study and publication of the results was obtained before starting procedure.

Results

30 (15 boys and 15 girls)children with spastic diplegic cerebral palsy were recruited and assigned into two groups (control& study). Their age range 4-6 years, and median of GMFCS was II Table 1.

Spatial parameters

There were significant differences in step length, step width and foot angle (Foot Angle (degree): means the angle between the line of progression and the foot axis. Foot angle is zero when the foot axis is parallel to the line of progression. The foot angle is positive when the foot axis points lateral to the line of progression. The foot angle is negative when the foot axis points medial to the line of progression) of both right and left sides between the control and study groups post treatment ($p>0.05$). Percentage of change showed increase in all variables after treatment program in control and study group with significant difference ($p>0.05$) Table 2.

Temporal parameters

The mean values of cadence (steps/min), gait velocity (cm/sec) and gait time (sec) showed significant difference within control and study groups after treatment ($p>0.05$). They change in study group as (16.28, 24.39, and 20.66 respectively) more than in control group as (7.95, 7.23, and 7.09 respectively) with significant difference Table 3.

Kinetic parameters

These parameters showed non-significant difference either in right and left sides between and within control and study groups ($p=0.45$) Table 4.

Discussion

This study is conducted to determine if gait training with simultaneous (dual) proprioceptive - visual feedback influences spatial, temporal, and kinetic gait parameters in

Table 4. Gait kinetic parameters of control and study groups.

Kinetic parameters			Control group x̄±SD	Study group x̄±SD	MD	p-value
Maximum force (N)	Right	Pre	15.58 ± 2.35	16.19 ± 1.98	-0.61	0.45
		Post	16.71 ± 2.69	17.91 ± 3.79	-1.2	0.32
		MD % of change p	-1.13 7.25 0.14	-1.72 10.62 0.11		
	Left	Pre	16.38 ± 2.4	16.73 ± 2.02	-0.35	0.67
		Post	17.17 ± 2.5	19.3 ± 5.48	-2.13	0.18
		MD % of change p	-0.79 4.82 0.1	-2.57 15.36 0.11		
Maximum peak pressure (KPa)	Right	Pre	12.35 ± 4.05	12.86 ± 5.01	-0.51	0.76
		Post	13.83 ± 4.6	14.73 ± 5.43	-0.9	0.62
		MD % of change p	-1.48 11.98 0.23	-1.87 14.54 0.28		
	Left	Pre	12.66 ± 4.54	13.26 ± 5.65	-0.6	0.75
		Post	13.13 ± 5.05	15.13 ± 5.2	-2	0.29
		MD % of change p	-0.47 3.71 0.71	-1.87 14.1 0.14		

x̄: Mean; MD: Mean difference; p value: Probability value; SD : Standard deviation; *: significant.

children with spastic diplegic CP. As the children with CP have difficulties in planning and organizing motor behavior which are attributed to problems of processing sensory inputs within the CNS, including vestibular, proprioceptive, tactile, visual, and auditory, and disturb their motor control and balance ability[7]. In our study, when the child walks on Tekscan walkway platform receives proprioceptive information (motor task) and visual feedback through appeared light on the screen (cognitive task) to correct the foot alignment because the gait has recently been required various attentional resources using a dual-task paradigm[18,19]. The baseline of all measuring variables of both (study and control) groups are consistent and homogenous as there were no significant differences between them. The results of the spatial and temporal parameters (step length, step width, foot angle, cadence, velocity, and gait time) showed significant improvement within and between groups after treatment program. While the post treatment results of kinetic parameters showed no significant differences within and between groups.

The improvement of gait parameters may be due to physical therapy interventions including a variety of activities that require strength, endurance, balance and coordination during standing and walking. That comes in agreement with Dodd et al.[20] who stated that a common goal of rehabilitation program and activities, improve physical capacity and functional abilities of children with CP. Furthermore, improvement of postural control during gait enables children with CP to increase gait velocity. Also repetition of the desired movement of the involved lower extremities as in gait training could increase neural plasticity and improve the walking performance of children with CP by facilitating motor relearning[21].

The significant improvement in gait parameters of the study group than that of the control group ($p \leq 0.05$) could be attributed to the effect of visual feedback during walking which may increase the brain capacity of coordinated sensory signals. A neural network can be modulated through visual stimulation in the motor, premotor, and parietal cortex; in hence it can promote cortical reorganization[22], and it provides the child with a unified percept of the world that essential for directing attention and controlling movement within it[23]. Some authors also indicated that the visual feedback may generate an immediate self-correction in the patient, thereby facilitating the activation of neuronal plasticity which increases its clinical applicability[24]. Increased gait velocity and cadence could provide by high attention requires in study group, as attention plays a major role in postural stability, however healthy children that performing eye movements during a postural task is a quite difficult attention-demanding duty leading to a change of the postural sway and increase postural stability. By encouraging more attention on the task, it could increase motor learning and enhance the physical performance of individuals with neurological problems during activities of daily living[25-26]. the visual movement of eyes towards the screen during walking on the tray provided a more facilitation on-line corrections and gait modifications to aid success to appear light on screen. this could impact on only spatial and temporal gait parameters . The task does play a role in dual-task interference. it was contradicted with other researches as when the complexity of motor tasks is manipulated the costs appear to be more pronounced[27]. The proprioceptive training could increase gait velocity and step length as proprioception may enhance the acquisition of more postural control strategies and in hence, helps the child to gain more functional movement. This consistent with Young D[28] who concluded that sensory processing play in the framework together to develop and maintain postural control. During a dual task, children have to share their attention between the two distinct tasks, by dedicating more attention to the most challenging one. In our study, they mainly focused their attention to visual cues as the memory-guided saccades task than the proprioceptive task which could be executed in an automatic way during walking that demonstrated that walking while performing a cognitive task caused reductions in gait velocity, cadence and stride-length, and increases in double-limb support time and base-of-support[29-30]. it may suggested by the absence of gait parameters influenced by memory-guided saccade task when using a visual, an auditory and a memorization task as the cognitive task during performance[30]. Additionally, Cherng et al[30] reported that when the balance requirements for gait increase in people with physical delay (i.e; cerebral palsy) during secondary tasks, the gait velocity and stride-length decreased, and double support time and base-of-support increased because of more time devoted for balancing the head, arms, and trunk over the stance leg[31]. In current study, the task of simultaneous proprioceptive -visual feedback during gait training did yield small changes in the kinetic parameters of gait after 8 weeks of treatment program about 7.25% to 14.54% of maximum force, and peak foot pressure respectively with insignificant difference between study and control groups that reinforced by O'shea and colleagues[32] who determined that the effect of secondary task motor versus cognitive had a negligible effect on gait determinants[33]. Also according to a pervious evidence of proprioceptive training regimens should last longer to yield relatively higher improvements in proprioceptive and/or motor function[34]. There is a little clarity on what constitutes of an optimal training, the best practices for session duration, number of weekly sessions, and overall duration of the intervention[35].

The findings suggested a cognitive task might interfere with the proprioceptive training; however few studies had investigated cognitive-gait interference in typically developing children that have converged a greater vulnerability to dual-task effects in children versus older adults[36]. In children, developing higher cognitive abilities or attentional resources are leading to a greater degree of cognitive-gait interference[37]. That means the children with spastic diplegic cerebral palsy seem more dependent on visual feedback neglecting proprioception information for postural control during functional activities.

Conclusion

According to the results of this study, it can be concluded that proprioceptive training through visual feedback during gait training in children with diplgic cerebral palsy is effective than traditional gait training on improvement of the spatial and temporal gait parameters while the kinetic parameters need further studies. Also, the effect of dual task on symmetry of gait in children with cerebral palsy can be studied next.

Limitation of study

The duration of cognitive training might be little to produce change on foot pressure and forces while the gait corrections that occurred on both groups. Also we can't generalize the effect on spatial or temporal gait parameters due to small sample size. The effect of psychological factors which may reflect on the treatment program is not evaluated.

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