EFFECT OF LATERAL WALKING TRAINING WITH VISUAL FEEDBACK ON GAIT IN CHILDREN WITH HEMIPARETIC CEREBRAL PALSY: A RANDOMIZED CONTROLLED TRIAL

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ABSTRACT

Purpose: To evaluate the impact of lateral walking training with mirror visual feedback on gait in children with hemiparetic cerebral palsy (CP).

Methods: Sixty children with hemiparesis and aged from 5 to 7 from both sexes recruited in the study according to the following inclusion criteria: grade 1+ to 2 of spasticity based on modified Ashworth scale and they were able to walk independently at level II based on Gross Motor Functional Classification System. They were randomized into two groups of equivalent number. The study group was given lateral walking training with mirror visual feedback as well as a specific physical treatment program as received by the control group. Prior to therapy and three months following treatment, children underwent gait spatiotemporal assessment using 3D-Gait Analysis. The outcome measures were swing phase, stance phase, double limb support period, gait speed and gait symmetry ratio.

Results: After training, both groups demonstrated a statistically significant improvement favoring the study group for all measured outcomes.

Conclusions: Along with the planned physiotherapy program, lateral walking training with mirror visual feedback is efficient in enhancing gait in children hemiparetic cerebral palsy.

Keywords: Cerebral palsy; Gait; Hemiparesis; Lateral Walking Training; Mirror Visual Feedback.

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INTRODUCTION

Cerebral palsy (CP) describes a collection of conditions marked by permanent impairments in motion and posture and caused by non-progressive injuries in the developing brain of the fetus or child **(1).** More than a third of all children with CP are hemiparesis and hemiplegia, and the subsequent impairments to the extremities have an impact on functional independence as well as quality of life **(2).** A weakening on one side of the body is known as hemiparesis. It is less severe than hemiplegia, which results in severe paralysis of one side of the body's arm, leg and trunk. The affected side of child with hemiparesis is able to be moved but with less muscle force **(1).**

Numerous neurological and muscular deficits have been identified in children with CP, including disorders in the muscle stretch reflex, excessive velocity-dependent resistance during motion, and an interruption in proprioceptive signals from the extremities. These inadequacies lead to a variety of functional challenges, such as limited range of motion, decreased muscle strength and tight joints **(3).** Additionally, children with hemiparesis have significant difficulties with postural stability, lower extremity strength and promoted gains in balance and gait **(4).**

According to spatiotemporal and kinematic data, patients with hemiparesis have an asymmetric gait pattern, which is accompanied by limitations in the gait cycle caused by muscle weakness, spasticity, poor joint and posture control, motor incoordination, abnormal muscle activation patterns and altered energy expenditure **(5).** They complain of difficulty performing functional tasks due to balance and gait issues, an increased risk of falling and a higher level of care dependence, thatimpact exploring their surroundings and engaging in social activities **(6).**

Ryu **(7)** stated that lateral walking exercises appear to increase muscular activity relative to effort, indicating a higher degree of energy expenditure in injured athletes and healthy people. Lateral walking training is also suggested to improve walking capabilities and reduce unequal weight bearing on the lower extremities as it ensureside stability during walking **(8,9,10).** In post-stroke patients, it is utilizedfor strengthening exercise for the lateral muscles of the hip as well as knee, especially the adductors in addition to abductors **(11).**

Visual feedback created during walking in front of a mirror can improve weight-bearing compliance during gait training **(12).** Without feedback, it is difficult to follow the prescribed weight-bearing regime. Correct visual feedback improves body image by reducing sensorimotor incongruence and increasing visual somatosensory input **(13).** In order to improve motor performance by raising self-awareness and spatial attention, mirror visual feedback is used in the rehabilitation of various neurological diseases, as stroke patients **(14).** As it has a positive impact on enhancing their hand functions and it is recommended for children with hemiparesis **(15).**

Previous studies showed the effectiveness of lateral walking training in post-stroke hemiplegic adult patients **(11,16,10).** However, no published data have yet documented the impact of lateral walking training in hemiparetic children. Based on the previous context, the present study was conducted to examine the impact of lateral walking training with visual mirror feedback on gait spatiotemporal parameters in children with hemiparesis.

METHODOLOGY

Study design and sampling method

This study is a convenient randomized control trial that was carried-out during the period from February 2021 to January 2022. The study was carried-out in the Outpatient Physical Therapy Clinic of Tukh Central Hospital and Qaha Central Hospital, Egypt.

Sample size calculation

The sample size was calculated by G*Power 3.1.9.7. using two-tailed independent t-test, based on a work of previous study evaluating the impact of lateral walking training on gait in post-stroke patients by assessing spatiotemporal parameters via 3-d gait analysis **(11).** At which the velocity post-treatment Mean±SD values were (79.54±10.54) and (88.11±7.91) for control and study group, respectively, with an effect size of 0.92. The test indicated a sample size of 26 for every group was sufficient to detect the difference between them, with an assumption of power of 0.9, a significance level of 0.05, and allocation ratio 1:1. This group number was raised to 30 in order to account for the anticipated patients’ dropout throughout the study.

Participants

Sixty children of both sexes (25 boys and 35 girls) with hemiparetic CP (HCP) were eligible for this study. All children were recruited either from Outpatient Physical Therapy Clinic of Tukh Central Hospital or Qaha Central Hospital, Egypt. They enrolled in this study if they had the following inclusion criteria: a) they were aged from 5 to 7 years; b) they were diagnosed with hemiparetic CP, whether right or left sided; c) grade 1+ to 2 of spasticity based on modified Ashworth scale **(17);** d) they were capable of walking independently at level II based on Gross Motor Functional Classification System **(18)** and e) they were capable of following instructions during assessment as well as treatment procedures. Children were excluded from this study if they had visual or visual perceptual disorders, evidenced seizures, sensory or hearing deficits, or had a history of previous surgeries or Botulinum injection.

Participants were randomized into two groups of equivalent number; a control group was given a specific physiotherapy program while the study group was given the same specific physiotherapy program of the control group as well as lateral walking training with mirror visual feedback.

Randomization

A blinded, unbiased research assistant, who was not engaged in patient selection, opened envelopes containing a computer-generated randomization card as well as randomly allocated the children to one of two groups with equal numbers. As shown in the flow chart in (Figure 1), 72 patients were eligible in this study and 12 patients dropped out due to their far residence. Block Stratified Randomization Software was used to randomly assign the remaining 60 patients (windows version 6.0 of randomization program (Rand.exe) to put the same number of samples in each of two groups when there are more than two stratified variables.

Ethical considerations

All procedures involving human participants were performed in compliance with the World Medical Association's Declaration of Helsinki on the ethics of medical research including humans. The study's project was given the approval by the Ethics Review Committee at Cairo University's Faculty of Physical Therapy (approval number: P.T.REC/012/002753). Approval from Tukh Central Hospital and Qaha Central Hospital, Egypt, were got. After providing a thorough explanation of the procedures, the consent forms were given out to the parents or caregivers. Before beginning the experiment, a consent form was collected.

Outcome measures

All children were evaluated prior to therapy (pre-treatment) as well as after three months of treatment (post-treatment).The following spatiotemporal gait parameters were assessed; swing phase, stance phase, double limb support period, gait speed and gait symmetry ratio.

Procedures

1. Evaluation

All children were assessed for eligibility. Each eligible child underwent gait analysis. Gait was assessed by 3D-Gait Analysis Qualysis Track Manager (QTM) operating system which is reliable and valid for kinetic and kinematic analysis in the sagittal plane of gait for linear motion analysis and spatiotemporal measurements. The gait evaluation was provided in a 3D-gait analysis lab and carried out by experienced and qualified physical therapist blinded to group allocation; children and caregivers were asked not to indicate their treatment to the gait analyzer.

The assessed spatiotemporal parameters were swing phase, stance phase and double limb support period, for each affected and unaffected leg in addition to gait speed and gait symmetry ratio.

Swing phase is the percentage of swing time representation in the cycle time (40% of gait cycle), as the swing time is the period of time in seconds the foot spends off the ground in the gait cycle, The period of time that one-foot travels from toe off to heel strike **(19,20).** Stance phase is the percentage of stance time representation in the cycle time (60% of gait cycle), as the stance time is the time in seconds throughout which the foot is in contact with the ground in the gait cycle, the time from the initial contact to toe off of the same foot **(19,20)** Double limb support period is the ratio at which both feet land during a single gait cycle(during stance there are two periods of double limb support, initial and terminal, each one represents 10% of the gait cycle time, 20% total) **(19,20).** Whereas, the gait cycle time, is the time in seconds takenamong the initial contact of a foot and the following initial contact of the same foot **(19,20).**

Gait speed (m/s) is the individual’s rate of walking by identifying the time in seconds required to cover a particular distance in meters. Gait symmetry ratio is the affected side gait cycle ratio multiplied by (affected swing time / affected stance time) divided by the unaffected side gait cycle ratio multiplied (unaffected swing time / unaffected stance time)(Patterson et al., 2008), it can be calculated by the following formula:

$$\text{Gait symmetry ratio} = \frac{\text{paretic cycle ratio }\left(\frac{\text{paretic swing time}}{\text{paretic stance time}}\right)}{\text{non-paretic cycle ratio }\left(\frac{\text{non-paretic swing time}}{\text{non-paretic stance time}}\right)}$$

The gait analysis system was initially calibrated using a wand. Then, the child's personal data, including name, sex, and date of birth as well as the child's weight and height were taken. Markers were subsequently applied to ASIS and PSIS, greater trochanters, lateral femoral epicondyles, heads of fibulae, tibialtuberosities, lateral malleolli, posterior aspect of calcaneus, 1stand 5thmetatarsals on both lower limbs. Throughout the static test, six markers were put on the medial femoral condyle, medial malleolus, as well as second metatarsal of both feet. The markings must be directly adhered to the skin and cannot be covered up by the child's clothing or made to move. After attaching the markers, a static trial was performed with the child standing on the first force plate for 10 seconds with both arms extended 90 degrees. The static trial was produced using a full-body dynamic and static model. The calibrating markers were then taken out. In order to maintain walking consistency, every child was encouraged to cross the walkway in bare feet for six trials at a speed of their choice. When necessary, a rest period was given in between trials **(21,22).**

2. Intervention

All children in the two groups were given a specific physiotherapy program for one hour to improve the gross motor functions, balance, and gait including; quadriped exercise, kneeling and half-kneeling, standing and step standing with the therapist assistance, standing on balance board, ascending and descending stairs and forward walking training on treadmill. All children were given three sessions a week under the therapist’s supervision for 3 successive months **(15).**

In addition to the previous mentioned treatments children in the study group were given lateral walking training on treadmill with mirror visual feedback. Each child was requested to walk laterally/sideway on treadmill while looking at his/her reflection in a long stand mirror in front to control his/her steps, the direction of walking towards the affected side, as the affected leg abducted to take the steps with the therapist encouraged and guided the child’s leg to the correct movement pattern, at walking speed of 1 kilometer per hour, for 20 minutes in four sets (5 minutes for each). Children were allowed to rest for one minute in between sets when needed **(23).**

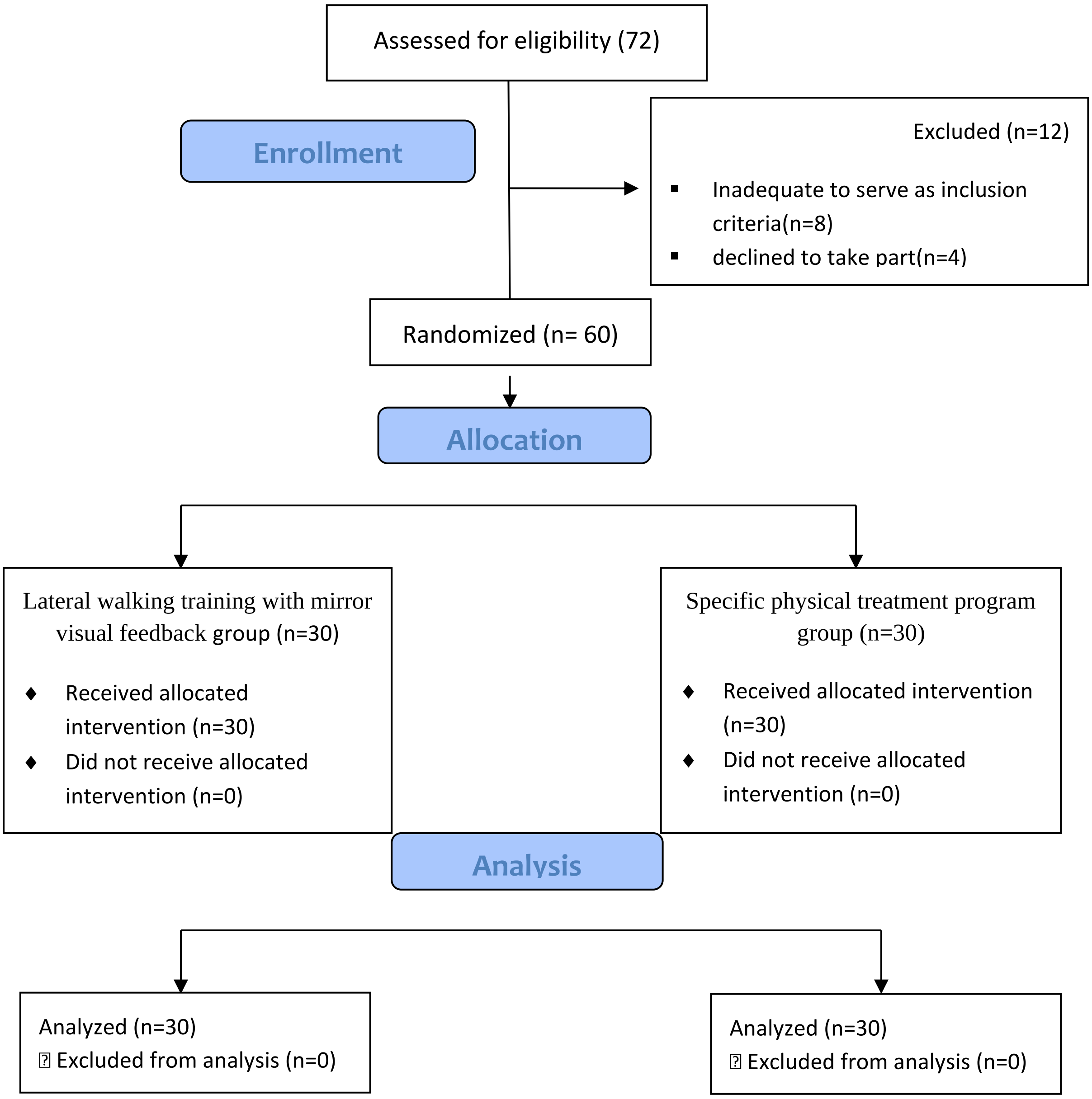

Figure (1): The flow chart of the study.

Statistical analysis

All statistical analysis was conducted by the Statistical Package of Social Studies (SPSS) version 23 for Windows (IBM Co., Armonk, NY, USA). The Shapiro-Wilk test was utilized to determine whether or not the data was normally distributed. The mean as well as standard deviation was calculated for all outcome measures as descriptive statistics. The pre- and post-treatment means of all outcomes were compared across groups using the paired t-test. Independent t-test was conducted to compare the mean values between groups before as well as after intervention. Chi-square test was used to compare gender and paretic side distribution between groups and was expressed as number and percentage. P-values ≤0.05 were considered to indicate statistical significance.

RESULTS

Sixty children with HCP participated in this study. There were no significant differences between the two groups with concerning demographic characteristics in terms of age, weight, height and BMI (P>0.954) (Table 1). Furthermore, non-significant differences were observed among groups regarding pre-treatment mean values of gait spatiotemporal parameters (Table 2).

Results revealed statistically significant improvements when comparing pre-treatment as well as post-treatment mean values of all outcome measures in every group (Table 3). Comparisons of gait spatiotemporal parameters between groups' post-treatment mean values indicate statistically significant differences between groups in all outcome measures favoring the study group (Table 4).

Table (1): Demographic characteristics of all participated children of both groups.

Variable		Control group (n=30)	Study group (n=30)	*P*-value
Gender	Boy	14 (47%)	11 (37%)	0.432[a)]
	Girl	16 (53%)	19 (63%)	
Paretic side	Right	8 (27%)	5 (17%)	0.347[a)]
	Left	22 (73%)	25 (83%)	
Age		5.93±0.78	6.26±0.78	0.105[b)]
Weight		20.5±1.83	21.1±1.26	0.129[b)]
Height		113.06±3.03	114.46±3.74	0.117[b)]
BMI		16.18±1.5	16.16±1.63	0.954[b)]

Values are presented as mean±standard deviation or number (percentage %), BMI: Body mass index, [a)]Chi-square test.[b)]Independent t-test.

Table (2): Comparisons of pre-treatment mean values of gait spatiotemporal parameters between groups.

Variable	Assessed Leg	Pre-treatment		*P*-value
		Control group (n=30)	Study group (n=30)	
Swing phase (%)	AL	46.83±1.49	46.77±1.48	0.878[a)]
	UL	23.11±1.18	22.77±1.06	0.245[a)]
Stance phase (%)	AL	53.16±1.49	53.22±1.48	0.878[a)]
	UL	76.88±1.18	77.22±1.06	0.245[a)]
DLS period (%)	AL	36.30±2.35	35.73±2.24	0.340[a)]
	UL	28.63±1.56	28.02±1.69	0.152[a)]
Speed (m/s)		0.703±0.052	0.684±0.049	0.162[a)]
Gait symmetry ratio		2.944±0.269	2.990±0.223	0.480[a)]

Values are presented as mean±standard deviation, AL: Affected leg, UL: Unaffected leg, DLS: Double limb support, %: Percentage, m/s: Meter/second, [a)] Independent t-test.

Table (3): Comparisons of mean values of gait spatiotemporal parameters within each group.

Variable	Assessed Leg	Control group (n=30)		*P*-value	Study group (n=30)		*P*-value
		Pre-treatment	Post-treatment		Pre-treatment	Post-treatment	
Swing phase (%)	AL	46.83±1.49	43.72±1.06	0.000[a),*]	46.77±1.48	41.44±1.14	0.000[a),*]
	UL	23.11±1.18	32.10±1.16	0.000[a),*]	22.77±1.06	38.90±1.33	0.000[a),*]
Stance phase (%)	AL	53.16±1.49	56.27±1.06	0.000[a),*]	53.22±1.48	58.55±1.14	0.000[a),*]
	UL	76.88±1.18	67.89±1.16	0.000[a),*]	77.22±1.06	61.09±1.33	0.000[a),*]
DLS period (%)	AL	36.30±2.35	29.10±1.68	0.000[a),*]	35.73±2.24	24.96±1.99	0.000[a),*]
	UL	28.63±1.56	26.99±1.50	0.000[a),*]	28.02±1.69	24.39±2.15	0.000[a),*]
Speed (m/s)		0.703±0.052	0.903±0.058	0.000[a),*]	0.684±0.049	1.133±0.018	0.000[a),*]
Gait symmetry ratio		2.944±0.269	1.648±0.118	0.000[a),*]	2.990±0.223	1.114±0.084	0.000[a),*]

Values are presented as mean±standard deviation, AL: Affected leg, UL: Unaffected leg, DLS: Double limb support, %: Percentage, m/s: Meter/second, [a)]Paired t-test, [*]P<0.05.

Table 4: Comparisons of post-treatment mean values of gait spatiotemporal parameters between groups.

Variable	Assessed Leg	Post-treatment		*P*-value
		Control group (n=30)	Study group (n=30)	
Swing phase (%)	AL	43.72±1.06	41.44±1.14	0.000[a),*]
	UL	32.10±1.16	38.90±1.33	0.000[a),*]
Stance phase (%)	AL	56.27±1.06	58.55±1.14	0.000[a),*]
	UL	67.89±1.16	61.09±1.33	0.000[a),*]
DLS period (%)	AL	29.10±1.68	24.96±1.99	0.000[a),*]
	UL	26.99±1.50	24.39±2.15	0.000[a),*]
Speed (m/s)		0.903±0.058	1.133±0.018	0.000[a),*]
Gait symmetry ratio		1.648±0.118	1.114±0.084	0.000[a),*]

Values are presented as mean±standard deviation, AL: Affected leg, UL: Unaffected leg, DLS: Double limb support, %: Percentage, m/s: Meter/second, [a] Independent t-test, *P<0.05.

DISCUSSION

The present study was conducted to examine the impact of lateral walking training with mirror visual feedback in improving gait in children with HCP. Up to the author's knowledge, no study has investigated the effect of lateral walking training in the treatment of children with hemiparesis. The findings of this study supported the usage of lateral walking training with mirror visual feedback in children with HCP.

The baseline pre-treatment values demonstrated altered gait; this affection differs from affected limb to unaffected limb, resulting in unbalanced asymmetrical gait. This is consistent with Choi et al. **(5)**, who found that children with HCP experienced different adaptation mechanisms in their affected and unaffected legs while walking on various surfaces. According to 3-D gait analysis, children with HCP walk more slowly, with shorter strides than typically-developing peers, with the unaffected limb having a longer stance time and a higher stance phase than the affected leg **(24,25,26).**

After completing the treatment period, both groups revealed significant improvements in all outcome measures. This could be related to the impact of the specific physiotherapy program, which plays an essential role in enhancing gross motor functions, balance and gait abilities. These findings are in line with those of Sethy et al. **(10)**, who stated that post-stroke hemiplegic patients who underwent physical therapy training significantly improved in terms of walking speed and endurance. Additionally, Liang et al. **(27)** noted that numerous randomized trials shown the favorable benefit of exercise therapies in enhancing muscle strength and walking speed in children with CP.

In comparing pre and post-treatment data in both groups, we found improvement of spatiotemporal parameters. According to the normal representation of the gait cycle time, which consists of 40% swing phase, 60% stance phase, and 20% double limb support period, the evaluated spatiotemporal parameters post-treatment in both groups showed that the affected leg swing phase decreased but increased in the unaffected leg, in contrary the affected leg stance phase which increased and decreased in the unaffected leg, the percentage representation of the double limb support period decreased in both groups, whether assessed in relation to affected leg cycle time or to unaffected leg cycle time. Based on these findings, we deduced that the swing and stance phases for the affected and unaffected legs both improved towards normal representation, for a more symmetrical and balanced gait with more and longer steps in a shorter cycle time. This symmetrical balanced gait enhanced the speed of gait after treatment, as well as the gait symmetry ratio dropped as a result of the spatiotemporal parameters' improvement, with more improvement in the study group for all assessed spatiotemporal parameters.

When comparing post-treatment values between groups, a more significant improvement was reported for study group in all measured variables for gait spatiotemporal parameters. This improvement may be attributable to lateral walking training, as demonstrated by the work of Fujisawa and Takeda **(9)**, who found that lateral walking effectively enhances walking capabilities and decreases unequal weight bearing on the lower extremities because it establishes a greater emphasis on side stability than forward or backward walking.

These results are in accordance with those of Kim et al. **(16)**, who stated that lateral walking training might ameliorate the asymmetric gait patterns in post-stroke patients, rather than conventional and backward training. In comparison to backward walking, where the cadence only slightly increased, they found that lateral walking significantly improved gait velocity, cadence, stride length, gait symmetry as well as double limb support.

The findings of this study are similarly in line with Lee et al. **(16)**, who demonstrated that lateral walking therapy significantly improved the gait speed, stride length and balance in chronic stroke patients. Sethy et al. **(10)**, also came to the conclusion that in post-stroke hemiplegic patients, lateral and backward walking training significantly improved walking speed and endurance more than traditional treatment.

Walking speed has become an important and sensitive measure of gait abilities. The enhanced symmetry of gait may be responsible for the increase in speed. This might be described by the active involvement of the hip adductors as well as abductors along with hip extension throughout lateral walking, as it's a useful exercise for improving balance and flexibility in hemiplegic patients using body weight-bearing exercise, while shifting weight from one foot to the other, as well as mediolateral plane posture training with an adjustable tilt **(28).** As a crucial essential point in the mobilization of body weight during walking, the hip abductor muscles have a significant biomechanical role **(29).**

Furthermore, Liu et al. **(30)** shown through the use of mathematical models which the gluteus medius muscle is essential to the body's forward propulsion as well as support during the stance phase. Training in lateral walking may have increased the gluteus medius strength. It's possible that these muscles from the hip stabilizers and their increased strength helped to increase hip stability and walking speed. Lateral walking provides mediolateral tilting posture training for improving balance as well as walking abilities and decreasing unequal weight bearing during foot shifts due to its greater emphasis on side stability and encouragement of more dynamic weight shifts to the involved side in the coronal plane **(31).** As a result, the study group saw greater increases in walking speed.

The timing of the single-limb supporting of the affected and unaffected legs is unequal in the typical hemiparetic/hemiplegic gait **(32).** According to Nyberg and Gustafson **(33)**, this asymmetrical gait pattern increases energy consumption and increases the risk of falling. Whereas, lateral walking has been reported to need more energy expenditure, oxygen consumption, as well ascardiorespiratory and metabolic responses than forward and backward walking **(34,7).** It may seem to require better functional gait performance by generating more muscle activation proportionate to effort; the body spends a large amount of its energy in the frontal plane of the hip to hold the pelvis as well as trunk versus the pull of gravity **(35).**

The significant improvement of all outcome measures after treatment in the study group may also related to the effect of visual mirror feedback used during lateral walking training, which is confirmed by the work of Abo-zaid et al. **(36)**, who found that lower extremity mirror visual feedback had a major effect on balance in children with HCP. This is because it helps to create a correct body image by raising self-awareness and spatial attention while walking, which improves weight-bearing symmetry and motor abilities. In addition, Kundi and Spence (2023) **(37)** also reported that mirror visual feedback significantly improved balance, gait and lower limb motor recovery in post-stroke patients with hemiplegia.

Lateral walking training with mirror visual feedback may enhance gait as a result of strengthening the hip abductor muscles, which can function as a counterbalance to adductor spasticity, and balance side to side base of support during standing and walking. In post-stroke adult patients with hemiplegia, mirror visual feedback has been shown to improve lower limb functioning **(37).** The current study would benefit from using mirror visual feedback since it would increase the effect of training and make it more entertaining and enjoyable for the child.

The current study has a limitation that the combination of lateral walking training and mirror visual feedback for the study group limits the ability to identify each effect on its own.

Conclusions

Lateral walking training with mirror visual feedback is an effective rehabilitation strategy that can be accompanied with the physiotherapy rehabilitation program forchildren with hemiparetic cerebral palsy to improve gait.

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