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Impact of Eye Movement Exercise on Step Length and Step Width in Cerebral Palsy Spastic Diplegic Children: A Randomized Controlled Trial

Salma Mohammed*[1], Asmaa Osama Sayed[2], Kamal El-Sayed Shoukry[2]
[1]Department of Physical Therapy, Om Al-Atabaa Hospital, Dokki, Cairo City, Egypt
[2]Department of Pediatric Physical Therapy, Faculty of Physical Therapy, Cairo University, Egypt
***Corresponding author:** Salma Mohammed, **Mobile:** (+20)01065184515, **Email:** dr.salmaa90@gmail.com

ABSTRACT
Background: Cerebral palsy (CP) is a neuromuscular developmental disorder occurred due to non-progressive prenatal brain injury. It leads to permanent motor impairments affecting posture and movement. Spastic diplegic CP is the most common type (30-40%), characterized by difficulties with posture and gait control.
Purpose: To explore the effectiveness of eye movement training exercises on step length and step width in CP spastic diplegic children. **Patients and Methods:** This study included 42 children aged 4 to 7 years diagnosed with spastic diplegia. They were randomly allocated into two groups equal in number. Both groups underwent a selected gait training program, 4 times weekly for six consecutive weeks. While, the study group performed eye movement exercises alongside the gait training. Gait function and ocular movement for all participants were evaluated using footprint analysis and the Ocular Motor Score (OMS).
Results: Both groups showed significant improvements in step length and step width after treatment ($p < 0.05$). However, comparing both groups indicated significantly greater improvement after treatment in favor of the study group ($p < 0.001$).
Conclusion: This prospective study showed positive outcomes from six weeks of gait training combined with eye movement exercises in CP children with spastic diplegia.
Keywords: Diplegia, Gait, Eye movement exercises.

INTRODUCTION

Cerebral palsy (CP) is a non-progressive neurological developmental ailment brought on by early brain injury, affecting muscle tone, movement, and motor abilities, often accompanied by sensory, cognitive, communication, and musculoskeletal challenges[(1)].

CP is divided into four categories based on the topographical distribution of motor impairment: monoplegia, hemiplegia, diplegia, and quadriplegia, with spastic diplegia being the most prevalent type (30-40%), particularly associated with prematurity and periventricular leukomalacia[(2)].

Spastic diplegia primarily impacts posture, balance, and gait control[(3)]. It is characterized by abnormal gait patterns such as jump gait, equinus gait, and crouch gait[(4)], alongside reduced walking speed and increased energy consumption[(5)]. Gait assessment involves both spatial parameters (step length, stride length, step width, foot angle) and temporal parameters (step time, stride velocity), including the step length to leg length ratio[(6)].

Gait training programs focus on improving motor performance through neuroplastic mechanisms by incorporating motor and sensory stimulation. This includes visual stimuli, such as eye movement exercises[(7)]. Eye movements are closely related to the vestibulo-ocular reflex (VOR), which is essential for stability and body position awareness[(8)]. These ocular movements occur across three axes, controlled by seven extraocular muscles[(9)]. Visual abilities such as tracking, fixation, depth perception, and binocularity play a vital role in supporting functional gait[(10)].

Children with CP often experience visual system dysfunction, affecting both anterior structures (eyes, optic nerves) and posterior pathways (optic tracts, optic radiations, occipital cortex, lateral geniculate nuclei)[(11)]. Approximately 49.6% of CP children have ophthalmological problems, with common issues including abnormalities in gaze, saccades, smooth pursuit, strabismus, and other eye movement disorders[(12)].

Visual perception is crucial for postural adjustment and motor growth through its role in spatial orientation and objects recognition[(13)]. Eye movement control is fundamental to visual perception and is frequently impaired in central nervous system disorders[(14)]. Maintaining normal gait and balance involves the integration of multiple brain regions, including the cerebral cortex, cerebellum, and brainstem, and depends on musculoskeletal support, coordinated eye movements, and sensory integration[(15)].

Recent research emphasizes the role of eye movement training with visual feedback in enhancing balance and movement patterns in individuals with visual system impairments[(10)]. Additionally, postural control and visual stability are facilitated by the vestibular system through various processes, such as the vestibulo-spinal reflex (VSR) and the VOR[(16)]. The VOR helps maintain stable retinal images throughout head motions by generating compensatory eye movements, operating even without direct visual input[(9)].

The step length (cm) is the linear distance, recorded while walking, between the heel contact point of one foot and that of the other foot. Step width (cm) represents the lateral distance between the centerlines of both feet during the double support phase of the gait

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cycle[17]. Our study aimed to examine the effectiveness of eye movement training exercises on step length in CP spastic diplegic children.

PATIENTS AND METHODS

Subjects:

This prospective randomized clinical trial was conducted at Dr. Kamal Shoukry Center, Cairo, Egypt between February 2024 and March 2025. A total of 42 children, both boys and girls, diagnosed with spastic diplegic CP and aged from 4 to 7 years, took part in the study.

Their eligibility criteria were:

(1) spasticity graded as 1 or +1 on the Modified Ashworth Scale (MAS), (2) Gross Motor Function Classification System (GMFCS) levels I or II [2], and (3) the capability to understand and adhere to verbal instructions during assessments and treatment.

Children were excluded if they had visual or hearing impairments[12], fixed structural deformities in the lower limbs[4], cognitive disorders[1], or a history of lower limb fractures, surgical interventions, or Botox injections within the previous six months.

The study's proper sample size was estimated to be 42 children, utilizing the G*Power software version 3.1.9.2 (**Franz Faul**, University of Kiel, Germany). Spastic diplegic CP children were randomly allocated into two groups equal in numbers (21 for each); the control group or the study group, using block randomization following an AAABBB distribution pattern (A = control group, B = study group).

Fifty-four diplegic children with CP were assessed for eligibility. Eight of them weren't included as they didn't fulfill the eligibility criteria and four of them declined to participate. The remaining 42 children were split into two groups; study group (A) and control group (B), as displayed in figure (**1**).

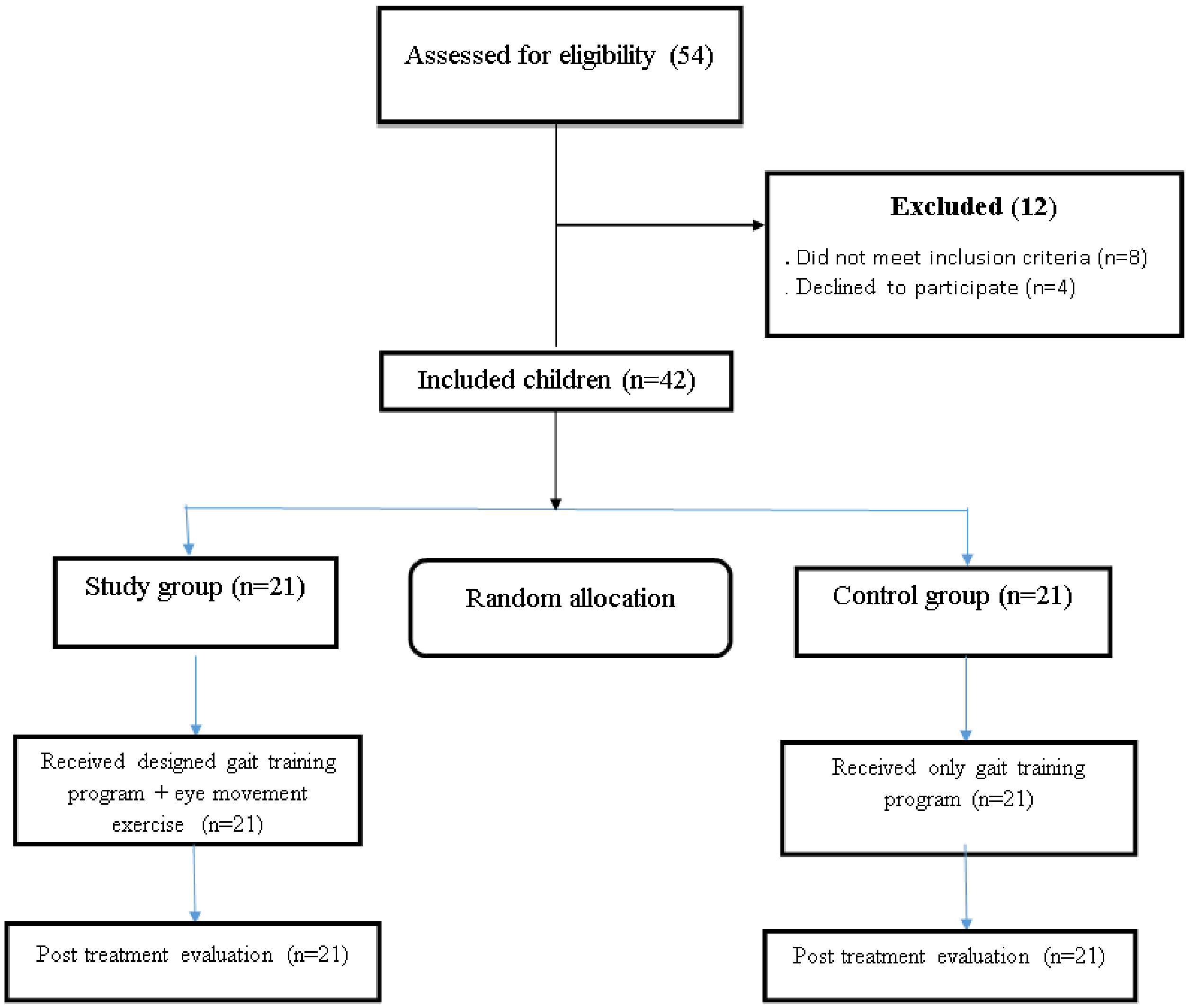

Fig. (1): Participants flow chart.

Procedures:

Group A followed a selected gait training program using a motorized treadmill[5], while Group B received the same gait training combined with an eye movement exercise program[18,19]. Gait performance and ocular motor function were evaluated using footprint analysis and the Ocular Motor Score (OMS), respectively[20-22]. The treatment protocols were designed following established guidelines for the control group and validated protocols for the study group.

There were three stages to the treadmill training: a 5-minute warm-up, 30 minutes of main exercises, and a 5-minute cool-down[5]. In the main training phase, participants walked at a speed tailored to each child's capabilities on a treadmill without body weight support[5].

Eye training exercises were as follows[18,19]:

1. After showing the child an image card, twenty other cards were combined and laid out face up on a desk. The child, covering one eye at a time, was asked to find the target card. Repeat this task for 10 times.
2. The therapist made three slow movements with a pencil, first up and down, then right to left three times, while the child focused on the pencil tip from a distance of approximately 1 meter.
3. The therapist moved the pencil in slow circular motions, instructing the child to fix their gaze on the tip, maintaining a 1-meter distance.
4. The therapist moved the pencil in a large figure-eight pattern for about 30 seconds in each direction, while the child kept focusing on the tip from a 1-meter distance.
5. The therapist presented two pencils, one on the right and one on the left, switching their positions. The child was instructed to shift focus between them repeatedly.
6. The child was asked to shake his head quickly side-to-side while identifying letters on a small upside-down card. This was repeated about 10 times.
7. The therapist asked the child to follow the pencil with their eyes as it moved slowly from a five cm point from his/her head to roughly 50 cm away.
8. The child walked while focusing on a fixed target object placed 1 meter away at eye level for approximately five minutes.

The study noted limitations, including possible lack of cooperation from some children and measurement errors, while assuming consistent procedures, participant effort, and controlled environmental conditions.

Ethical Approval

The Ethical Committee of Cairo University's Faculty of Physical Therapy in Egypt gave its approval to the study (P.T.REC/012l004463). Before beginning the study procedures, the parents of each subject gave their informed consent. Throughout its implementation, the study complied with the Helsinki Declaration.

Statistical analysis

The SPSS version 23.0 was utilized. The data's normality was verified and group homogeneity was evaluated using Shapiro-Wilk and Levene's tests for homogeneity of variances. The variance was homogeneous, and the data had a normal distribution. Quantitative data were presented as mean $\pm$ standard deviation (SD), while qualitative data were presented as frequency and percentage. The unpaired t-test was applied when groups were compared according to all demographic quantitative variables. Using two-way MANOVA, the impacts of treatment on all measurable variables were examined. The MANOVA was followed by several univariate ANOVAs when the findings were significant. Post-hoc analysis was performed utilizing the Bonferroni correction for multiple comparisons. Chi Square test was used to compare qualitative data. The significance limit was set at p-value = 0.05 for all statistical analyses.

RESULTS

I. Demographic Characteristics

The experimental and control groups' patient characteristics were displayed in **table 1**. Regarding their general characteristics, there were no statistically significant variations across the two groups (p-value $\geq$ 0.05).

Table (1): General characteristic of patients (N=42)

	Control group	**Experimental group**	**t-value**	**p-value**
	$\overline{X}$ **±SD**	$\overline{X}$ **±SD**		
Age (years)	5.71±0.94	5.52±1.16	0.58	0.56[a]
Weight (kg)	18.9±1.92	19.3±1.2	-0.87	0.39[a]
Height (cm)	110.47±4.35	110.54±3.28	-0.05	0.96[a]
BMI (kg/m²)	15.47±0.67	15.81±0.97	-1.36	0.18[a]
Gender, n (%)				
Girl	10 (47.62%)	12 (57.14%)	χ^2=0.38	0.54[a]
Boy	11 (52.38%)	9 (42.86%)		
Degree of spasticity, n (%)				
1	12 (57.14%)	8 (38%)	χ^2=1.53	0.22[a]
1+	9 (42.86%)	13 (62%)		
GMFCS, n (%)				
1	11 (52.38%)	7 (33.33%)	χ^2=1.56	0.21[a]
2	10 (47.62%)	14 (66.67%)		

Data are expressed as mean ± standard deviation; or as N (%); N: number; BMI: body mass index; [a]: non-significant difference, X^2: Chi Square; GMFCS: gross motor function classification system.

Two-way MANOVA was conducted to investigate the effect of treatment on the measured outcomes. There was a statistically significant variations across groups (**Wilk's** Λ = 0.27, F (19, 22) = 3.09, P-value < 0.001, Partial Eta Squared (η^2) = 0.73).

Also, a statistically significant effect on time was detected (**Wilk's** Λ = 0.002, F (19, 22) = 619.66, p-value < 0.001, η^2 = 0.99), and for the interaction across groups and time (**Wilk's** Λ = 0.02, F (19, 22) = 47.9, p-value < 0.001, η^2 = 0.98).

II. Between-groups Comparison: Before and After Six Weeks of Treatment

According to table 2, all assessed variables indicated no statistically significant changes among the experimental and control groups at baseline (P-value ≥ 0.05).

After treatment, a statistically significant change was detected across both groups in step length right and left leg and step width with the superiority of the experimental group (P-value < 0.05).

III. Within-groups Comparison

When comparing before and after treatment results, there were statistically significant variations in step width and step length in the right and left legs (p-value < 0.05) in both groups, with the superiority of the experimental group as displayed in table **2**.

Table (2): Within and between group analysis for all outcome measures (N=42)

Variables	Control Group	Experimental Group	MD (95% CI)	P-value (between groups)	η^2
Step length right leg (cm)					
Pre-treatment	**22.04±0.99**	**22.4±1.26**	-0.36 (-1.06 to 0.34)	0.3[a]	
Post-treatment	**24.27±1.1**	**26.4±1.19**	-2.14 (-2.86 to -1.42)	0.001 [b]	0.48
P-value (within-group)	0.001 [b]	0.001 [b]			
MD (95% CI)	-2.22 (-2.31 to -2.13)	-4 (-4.1 to -3.91)			
Step length left leg (cm)					
Pre-treatment	**21.2±1.07**	**21.49±0.96**	-0.29(-0.92 to 0.35)	0.37[a]	
Post-treatment	**23.51±1.16**	**25.88±1.16**	-2.37 (-3.1 to -1.64)	0.001 [b]	0.52
P-value (within-group)	0.001 [b]	0.001 [b]			
MD (95% CI)	-2.31 (-2.68 to -1.94)	-4.37 (-4.76 to -4.02)			
Step width (cm)					
Pre-treatment	**18.05±0.93**	**17.86±0.77**	0.19 (-0.34 to 0.73)	0.46 [a]	
Post-treatment	**17.13±0.8**	**16.09±0.6**	1.04 (0.6 to 1.48)	0.001 [b]	0.36
P-value (within-group)	0.001 [b]	0.001 [b]			
MD (95% CI)	0.92(0.57 to 1.27)	1.77 (1.42 to 2.12)			

[a]: non-significant difference; [b]: significant difference; CI: confidence interval; MD: mean difference, η2: eta square; η^2 = 0.14 indicates a large effect.

DISCUSSION

In this study, participants' ages ranged from 4 to 7 years, as this developmental period is considered critical for treatment in spastic diplegic children[23]. Prior research indicated that CP diplegic children who gained intensive therapy within this age range demonstrated a higher likelihood of achieving independent walking compared to those treated at younger or older ages. These findings are corroborated with **Samsir *et al.*** [15] who indicated that children receiving therapy between 4 and 7 years showed better balance and coordination outcomes.

Children with cerebral palsy face complex challenges that extend far beyond motor impairment, affecting multiple physiological systems in ways that significantly impact their daily functioning and quality of life. This multisystem nature of cerebral palsy has prompted researchers to explore therapeutic approaches that address the interconnected relationship between visual and motor control systems. Research demonstrates that eye movement training can improve gait function in neurological cases, which is supported by **Kang and Yu** [18] who found that eye movement training significantly improved gait pattern in stroke patients.

Similarly, **Elhamrawy *et al.*** [19] reported that eye movement training had positive effects on balance in post-stroke patients with unilateral spatial neglect, providing evidence for the effectiveness of visual interventions in neurological rehabilitation. These findings from adult populations provide a strong theoretical foundation for implementing similar interventions in pediatric populations with cerebral palsy.

The present study investigated whether combining eye movement exercises with traditional treadmill-based gait training could enhance functional capabilities in spastic diplegic CP children compared to gait training alone. The study employed a controlled experimental design with 42 children aged four to seven years, divided into two comparable groups. The control group received established treadmill-based gait training, while the study group received identical treadmill training supplemented with structured eye movement exercises. This methodological approach was designed to isolate the specific contribution of visual interventions while maintaining the established benefits of motor training that previous researchers have documented.

All assessments were conducted during barefoot walking at self-selected speeds, following recommendations by **Paterson *et al.*** [24] who validated the clinical relevance of barefoot measurements for capturing natural gait patterns. The evaluation protocol emphasized dynamic measurements during ambulation rather than static assessment, an approach that **Paterson *et al.*** [17] demonstrated as superior for capturing functional pathology in neurological conditions. Primary outcome measures included the Ocular Motor Score following validation studies by **Mucha *et al.*** [20] and **Olsson *et al.*** [21], with specific application to spastic cerebral palsy populations as described by **Jeong and Oh** [22]. Spatial gait parameters were assessed through detailed footprint analysis using conventional methodologies described by **Kaur and Singh** [6].

Based on the current findings, there was a significant improving in both step length and step width within the study group after treatment compared to before treatment. These findings align with those of **Kang and Yu** [18], who observed that eye movement training significantly enhanced gait parameters in stroke patients. Similarly, **Elhamrawy *et al.*** [19] found that eye movement training positively influenced balance in stroke survivors who had unilateral spatial neglect. Such evidence from adult neurological rehabilitation supports the theoretical rationale for applying similar visual interventions in pediatric cerebral palsy populations. The investigation revealed that both treatment approaches produced significant improvements across all measured parameters, with the combined intervention group demonstrating consistently superior outcomes. The most remarkable result was the dramatic enhancement in ocular motor function, with the study group achieving a 65.6% improvement in OMS scores compared to 20.22% in the control group. This substantial difference extends beyond statistical significance to represent a clinically meaningful transformation in visual-motor integration capabilities.

The study group achieved substantial improvements in ocular motor function, with OMS scores decreasing from 6.57±1.06 to 2.26±0.56, representing enhanced visual-motor integration capabilities. The control group also showed meaningful improvements, with scores decreasing from 6.33±1.49 to 5.05±1.79, indicating that traditional gait training alone can positively influence visual-motor function.

Following treatment, there were also statistically significant improvements in the control group. The impacts of the six-week treadmill-based gait training program are probably contributing to this improvement. These results are consistent with **Ameer *et al.*** [5] who demonstrated that treadmill training alone can improve proprioceptive input, muscular strength, and cardiovascular endurance, contributing to meaningful functional improvements in children with CP. The underlying mechanisms likely involve enhanced neuroplasticity within the visual-vestibular networks, as 1described by **Somisetty and Das** [9] who established the vestibulo-ocular reflex as fundamental to postural stability during ambulation.

The neuroplasticity concept is particularly relevant given our target population's age range (4-7 years), which **Adolph and Franchak** [23] identified as a critical period for motor behavior development. During this developmental window, the brain's capacity for reorganization is heightened, potentially explaining why the eye movement interventions produced such pronounced effects. The visual system's role in motor control, as documented by **Fazzi *et al.*** [12] in approximately 50% of CP children, suggests that targeted visual interventions can activate compensatory mechanisms that traditional motor training alone cannot fully address.

From the present findings, it can be concluded that combining eye movement exercises with a structured gait training program is more effective in enhancing both spatial gait variables in spastic diplegic children compared to gait training alone. Normal gait balance relies on musculoskeletal support, coordinated ocular motor function, and sensory integration. Through processes like the vestibulo-ocular reflex (VOR) and vestibulo-spinal reflex (VSR), the vestibular system plays a central role in stabilizing posture and vision. Eye movement training with visual feedback appears to enhance balance control, particularly in individuals with visual system dysfunction. This mechanism likely underlies the significant improvements observed in gait parameters across children in the study group who received both gait and eye movement interventions. The unexpected improvement in ocular motor function observed in the control group, despite receiving no direct visual intervention, reveals important insights about the interconnected nature of motor and visual systems. This finding challenges previous assumptions about the necessity of direct visual system targeting in cerebral palsy rehabilitation and suggests that motor training itself may have indirect benefits for visual function. **Gulati and Sondhi** [1] emphasized that cerebral palsy affects multiple aspects of neurological development, and these results support the concept that interventions targeting one system may have positive effects on related systems through improved neurological integration and enhanced proprioceptive feedback.

The spatial gait improvements observed in this study reveal important insights about the relationship between visual processing and locomotor function. Both groups demonstrated significant improvements in step length, with the study group achieving approximately double the improvements seen in the control group across most parameters. For instance, the study group's step length improvements (17.86% right, 20.43% left) substantially exceeded the control group's gains (10.07% right, 10.89% left). These findings are particularly meaningful because spastic diplegic CP children typically have with reduced step and stride lengths due to muscle spasticity and impaired motor control, as reported by **Ameer *et al.*** [5]. These findings align with the work of **Carcreff *et al.*** [25] who emphasized the importance of connecting laboratory findings with real-world functional mobility. The enhanced spatial parameters likely reflect improved motor planning and execution, mediated by better visual feedback processing. The greater improvements in spatial parameters observed in the study group can be attributed to enhanced visual-motor integration, as visual feedback plays a crucial role in motor planning and execution. The reduction in step width (9.91% in the study group versus 5.09% in controls) represents a particularly meaningful clinical outcome. Narrower step width indicates improved balance confidence and postural control, suggesting that the visual interventions enhanced the integration of sensory information crucial for dynamic stability. A narrower step width is associated with more mature gait patterns and improved stability, representing a positive adaptation in motor control that directly impacts functional mobility. This finding supports the theoretical framework proposed by **Kang and Yu** [18] who identified effective eye movement as essential for balance maintenance during locomotion.

LIMITATIONS

A key limitation of this study was the extended duration required for data collection, primarily due to some parents declining their children's participation, which affected the recruitment timeline.

CONCLUSION

Integrating eye movement exercises may enhance step length and step width in CP children. Pediatric physiotherapy clinics are encouraged to include eye movement exercises as part of their rehabilitation programs, as it offers a practical, effective, and non-invasive intervention.

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