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Effect of Visual Cue Training on Spatiotemporal Parameters of Gait in Patients with Stroke: A Randomized Controlled Study

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Abstract:

Background: Patients who have suffered a stroke encounter gait disturbances for multiple reasons; therefore, the principal objective of rehabilitation is to restore independent walking. Visual cues would be more efficacious in triggering gait recovery post-stroke.

Purpose: The aim of this study was to find out the impact of visual cue training on spatiotemporal gait parameters in patients with stroke.

Methods: A randomized controlled trial was carried out on thirty stroke patients from both sexes aged 40-65 years. The participants were randomly assigned to the study and control groups, comprising 15 patients in each group. Patients in the control group underwent a designed physiotherapy program, while participants in the study group underwent the identical physiotherapy program plus visual cue training. The measured variables comprised 10MWT for evaluating gait velocity, kinovea software for measuring the spatiotemporal gait parameters. Evaluation of all variables took place before and following intervention

Results: All evaluated variables exhibited a statistically substantial improvement in both groups post treatment. There was a substantial decline in stepwidth score (p = 0.03) in addition a substantial improvement in walking speed, step length of the affected and non-affected sides (p=0.001) as well as cadence (p=0.002) in study group in comparison with that of control group post-treatment.

Conclusion: The findings of this study indicate that incorporating visual cue training together with a physiotherapy program is beneficial for improving spatiotemporal gait parameters as step length, step width, velocity and cadence among stroke patients.

Key words: Stroke, spatiotemporal parameters of gait, visual cue training.

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Introduction:

Stroke is a neurological condition caused by a partial or total deprivation of blood flow to any region of the brain. The deficiency in blood supply frequently results from impeded blood circulation (ischemic stroke) or blood extravasation due to a ruptured brain vessel (hemorrhagic stroke).[1]

Hemiplegia brought on by a stroke has issues such asymmetries in posture, unsteady bodily balance, difficulty shifting weight, and difficulty walking, which raises the risk of falling and slows recovery.[2]

Over 80% of stroke survivors encounter walking disabilities[3]. The paretic side typically exhibits a reduced stance phase along with an extended swing phase. Additionally, the walking speed is diminished in addition the stride length is reduced[4]. Stroke survivors are at an increased risk of falling due to these irregularities in gait and muscle weakness.[5,6]
Gait recovery is the main goal of rehabilitation for stroke patients, taking precedence over all other issues in order to reduce patients' dependence on ADLs[7]. Gait recovery and adaptability after a stroke would be sparked more by visual cues than by non-visual cue therapies. One of the key components of dynamic balancing control is the ability to manage the changes in the connection between the base of support as well as the center of mass that occur as step widths and lengths change. This practice is task-specific and is believed to contribute to the predicted improvements in functional gait[8].
Visual cues indicate calibrating the step on a particular and constant length (the distance between tapes) may act through a less automatic, more "corticalized," mode of training that causes the patient to pay more attention throughout the swing phase in order to hit the target distance[9].
It has been suggested that visual cues could aid in directing attention onto task-relevant visual processing, which could help in gait. For example, focusing on the floor and stepping over lines instead of trying to process the full visual environment[10].
Visual cues are more successful in facilitating gait recovery as well as adaptability post-stroke compared to therapies that do not incorporate visual cues. It is hypothesised that expected enhancements in functional gait may result from task-specific practice in managing the relationship between the base of support and the centre of mass during variations in step widths and lengths, which is essential for dynamic balance management[8].
To the best of our knowledge, there are only a few studies[1,12,13] that have been done to find out the impact of visual training on gait on chronic stroke. Therefore, the goal of our study is to find out the impact of visual training on spatiotemporal gait parameters in patients with stroke.

Materials and Methods:

Study design: A Randomized controlled trial (RCT) was conducted at the Outpatient Clinic of Faculty of Physical Therapy, Cairo University and Cairo University Hospitals in the period from December 2022 to May 2023. The study was approved by the Ethical Committee of Faculty of Physical Therapy, Cairo University (P.TREC /012/005094). This trial followed the Declaration of Helsinki's Principles for
the Conduct of Human Research. Before the initial assessment and recruitment into the study, every patient was provided with a thorough elucidation regarding the study aims, methodology and possible benefits. Every participant signed a consent form authorized by the institution. A written consent was signed from all patients.

Participants: Thirty patients from both sexes were included in this trial. All participants were diagnosed as stroke by an experienced neurologist thorough full neurological evaluation as well radiological investigations using the computed axial tomography (CT) and/or the magnetic resonance imaging (MRI) of the brain. To be a part of the study, participants should be diagnosed as stroke with a duration of illness ranged from six to eighteen months, aged between 40 and 65 years old, On the Modified Ashworth Scale (MAS), patients experiencing lower limb spasticity ranged from 1 to 1+, able to walk 10 meters on their own, medically stable with sufficient cognitive capabilities to adhere to instructions.
Patients who have any neurological problems other than stroke that could affect lower limbs function (e.g., multiple sclerosis, peripheral neuropathy, etc.); Severe spasticity of the affected lower limb; Hearing or vision loss, or language difficulties that could interfere with patient's cooperation; Cognitive disability with a Mini mental state examination (MMSE) score ≤ 25; Patients who were medically or psychologically unstable; Orthopedic conditions such as severe arthritis or fixed lower limb's contractures; Pulmonary disorders or cardiovascular conditions (angina, recent myocardial infarction in the previous three months, congestive cardiac failure, or unsteady hypertension), were excluded.

Randomization: By an assistant researcher who was blinded, the sealed envelope technique was utilized to randomly assign patients into either the study or control group, with 15 patients in each group

Interventions: They were all treated three times weekly, every other day for four successive weeks by the same qualified physiotherapist who conducted all therapeutic sessions. Patients in the control group underwent a designed physiotherapy program, while participants in the study groups underwent the identical physiotherapy program and visual cue training.

Visual cue Training: Stripes were utilized on the floor in parallel lines, each measuring 2.5 cm in width and 90 cm in length, were drawn on a 10-meter walkway to create visual cues. The interline distance was maintained at 110% of the baseline step length (14). The interline distance was progressively augmented to 120%, 130%, and 140% of the baseline step length during the 2nd, 3rd, and 4th weeks, respectively. Participants were directed to place any part of their foot on the stripe. The position of the stepping stripe is established based on objectives for 10% increments in enhanced symmetry and is modified as therapy advances to elevate intensity. The positions of the stripes were determined after an analysis using Kinovea software and before the commencement of training. Visual cue training was administered for 20 minutes, three sessions each week, over duration of four weeks.

The designed physical therapy program: The physiotherapy program focused on controlling spasticity through muscles elongation and activation. Stretching exercises were applied to the planter flexors, knee flexors, hip adductors and flexors. Activation of weak muscles; hip flexors, extensors, and abductors, knee flexors and ankle dorsiflexors, was also applied using different facilitatory techniques (extroceptors and proprioceptors), Bobath approach for movement control, and Proprioceptive Neuromuscular Facilitation technique (PNF) "Flexion, adduction, lateral rotation with knee bending" was also applied for the weak lower limb muscles.

The outcome measures: For all subjects in both groups, the subsequent measures were completed before and after treatment.

1-**The Ten-meter walk test (10MWT):** It is a performance metric utilized to evaluate walking speed in meters per second throughout a brief distance. It can be utilized to assess functional mobility, gait, as well as vestibular function. The ten-meter walk test is frequently utilized to assess walking speed, health status, and functional capability in various individuals. Nonetheless, the test is being administered utilizing different timing protocols as well as distances covered, which may influence data interpretation against a standard value and hinder comparisons between research[15].

The 10MWT was employed to evaluate walking velocity by directing the patient to traverse a distance of ten meters. Participants were assessed using the 10MWT at two times: during admission and following the intervention. The participants conducted the 10MWT on a level, flat surface, with the starting and ending locations of the pathway clearly indicated on the floor for the examiners' observation. The standardized verbal directive was "1, 2, 3, go!". While walking the predetermined distance, time is recorded; frequently, the person is allowed to accelerate to his or her desired walking speed pace. The distance covered is divided by the duration taken by the individual to walk that distance[16]

2- **Kinovea software:** This software is a 2D motion analysis program for computers that can be employed to measure kinematic parameters. This software facilitates video analysis devoid of markers[17]. It assesses gait kinematics through two steps:

A-Gait video recording: Patient was asked to walk on even surface in an illuminated room. Video recording was done during the patient walking and two views were captured: a) Sagittal plane view: in which the first camera was positioned to the side of the patient, b) Frontal plane view: in which the second camera positioned in front of the patient. Standardization of the position of the video cameras (usually 90 degrees to the sagittal or frontal plane).The camera was positioned on a carrier to be at the level of the lower limbs. Video recording was continued until all views are captured[18].

B-Data analysis: The kinovea software was used for analysis of the videos, the videos were uploaded to the program for each view, and then the video was analyzed. The initial positions of the markers are documented. The actual coordinates of the marker were determined by comparing the positions at which the two cameras viewed it. A coordinate system was concurrently documented using reference markers[19]. The operator calibrated the recorded videos utilizing a measured line from reality (walkway length) to enable the Kinovea software to reliably determine velocity as well as distance. The operator applied a marker on the patient's hips, knees, and ankles to accurately track the motion path. The average of the recorded trails was used for each variable[20].

Sample Size: Sample size determination is conducted utilizing G*POWER statistical software (version 3.1.9.2) for a comparison analysis among two groups. According to the 10-MWT data from Upadhyay & Verma (21), which identified a substantial difference in 10-MWT among groups, the calculation determined that the necessary sample size for this investigation was 15 patients per group. Calculations were conducted utilizing α=0.05, power of 80%, effect size of 1.06, and an allocation ratio of N2/N1 = 1.

Statistical analysis:

- An unpaired t-test was performed to compare age, weight, height, as well as BMI among the groups.
- A chi-squared test was performed to compare the distribution of sex, affected side, as well as spasticity grades among groups.
- A mixed MANOVA was performed to assess the impact of time (before versus post) as well as treatment (across groups), along with the interaction among time and treatment, on step length, step width, velocity, as well as cadence. Post-hoc analyses employing the Bonferroni correction were conducted for subsequent multiple comparisons.
- The significance criterion for all statistical tests was established at $p < 0.05$.
- Statistical analyses were conducted using the Statistical Package for the Social Sciences (SPSS) version 25 for Windows.

Results:

Subject characteristics: Comparison of subject characteristics across groups

Table 1. Comparison of age, weight, height and BMI between group A and B.

	Group A	Group B	MD	t- value	p-value	Sig
	$\bar{X}$ ± SD	$\bar{X}$ ± SD				
Age (years)	52.80 ± 5.36	51.33 ± 6.42	1.47	0.68	0.50	**NS**
Weight (kg)	77.67 ± 9.22	76.93 ± 8.36	0.74	0.23	0.82	**NS**
Height (cm)	164.93 ± 7.53	166.73 ± 8.36	-1.8	-0.62	0.54	**NS**
BMI (kg/m²)	28.56 ± 2.71	27.80 ± 3.62	0.76	0.65	0.52	**NS**

Table 2. The frequency and chi squared test for comparison of sex distribution between group A and B.

	Group A	Group B	χ^2 value	p-value	Sig
Females	6 (40%)	8 (53%)	0.54	0.46	**NS**
Males	9 (60%)	7 (47%)			

Table 3. The frequency and chi squared test for comparison of affected side distribution between group A and B.

	Group A	Group B	χ^2 value	p-value	Sig
Right side	10 (67%)	9 (60%)	0.14	0.71	**NS**
Left side	5 (33%)	6 (40%)			

Table 4. The frequency and chi squared test for comparison of spasticity grades distribution between group A and B

- Effect of treatment on gait spatiotemporal parameters:

	Group A	Group B	χ^2	p-value	Sig
Grade I+	11 (73%)	8 (53%)	1.29	0.26	**NS**
Grade I	4 (27%)	7 (47%)			

A mixed MANOVA was performed to examine the impact of treatment on gait spatiotemporal characteristics. The interaction between treatment and time was significant (p = 0.001). A substantial primary effect of therapy was observed (p = 0.02). There was a significant main effect time (p = 0.001). (Table 5).

Table 5. Mixed MANOVA for the effect of treatment on gait spatiotemporal parameters.

Mixed MANOVA		
Interaction effect (treatment * time)		
F = 24.92	***p = 0.001***	***Partial Eta Squared = 0.84***
Effect of treatment (group effect)		
F = 3.23	***p = 0.02***	***Partial Eta Squared = 0.40***
Effect of time		
F = 202.51	***p = 0.001***	***Partial Eta Squared = 0.98***

F value: Mixed MANOVA F value p value: Probability value

Table 6. Mean step length of the affected side pre and post treatment of group A and B.

Step length of the affected side (cm)	Pre treatment	Post treatment	MD	% of change	P-value	Sig
	$\bar{X}$ ±SD	$\bar{X}$ ±SD				
Group A	50.28 ± 3.45	63.23 ± 4.05	-12.95	25.76	0.001	**S**
Group B	49.72 ± 4.31	56.99 ± 3.33	-7.27	14.62	0.001	**S**
MD	0.56	6.24				
P-value	0.69	0.001				
Sig	**NS**	**S**				

$\bar{X}$: Mean **SD: Standard deviation** **MD: Mean difference**
p value: Probability value **S: Significant** **NS: Non significant**

Table 7. Mean step length of the non affected side pre and post treatment of group A and B.

Step length of the non affected side (cm)	Pre treatment	Post treatment	MD	% of change	P-value	Sig
	$\bar{X}$ ±SD	$\bar{X}$ ±SD				
Group A	45.88 ± 4.38	56.94 ± 4.65	-11.06	24.11	0.001	**S**
Group B	46.23 ± 3.21	53.26 ± 3.76	-7.03	15.21	0.001	**S**
MD	-0.35	3.68				
P-value	0.81	0.02				
Sig	**NS**	**S**				

$\bar{X}$: Mean **SD: Standard deviation** **MD: Mean difference**
p value: Probability value **S: Significant** **NS: Non significant**

Table 8. Mean step width pre and post treatment of group A and B.

Step width (cm)	Pre treatment	Post treatment	MD	% of change	P-value	Sig
	$\bar{X}$ ±SD	$\bar{X}$ ±SD				
Group A	15.66 ± 4.41	12.92 ± 3.50	2.74	17.50	0.001	**S**
Group B	16.94 ± 2.42	15.22 ± 2.10	1.72	10.15	0.001	**S**
MD	-1.28	-2.3				
P-value	0.33	0.03				
Sig	**NS**	**S**				

$\bar{X}$: Mean **SD: Standard deviation** **MD: Mean difference**
p value: Probability value **S: Significant** **NS: Non significant**

Table 9. Mean velocity pre and post treatment of group A and B.

Velocity (m/s)	Pre treatment	Post treatment	MD	% of change	P-value	Sig
	$\bar{X}$ ±SD	$\bar{X}$ ±SD				
Group A	0.51 ± 0.08	0.69 ± 0.08	-0.18	35.29	0.001	**S**
Group B	0.52 ± 0.06	0.57 ± 0.06	-0.05	9.62	0.001	**S**
MD	-0.01	0.12				
P-value	0.65	0.001				
Sig	**NS**	**S**				

$\bar{X}$: Mean **SD: Standard deviation** **MD: Mean difference**
p value: Probability value **S: Significant** **NS: Non significant**

Table 10. Mean cadence pre and post treatment of group A and B.

Cadence (steps/min)	Pre treatment	Post treatment	MD	% of change	P-value	Sig
	$\bar{X}$ ±SD	$\bar{X}$ ±SD				
Group A	73.67 ± 5.49	95.33 ± 7.33	-21.66	29.40	0.001	**S**
Group B	75.20 ± 6.54	86.47 ± 6.63	-11.27	14.99	0.001	**S**
MD	-1.53	8.86				
P-value	0.49	0.002				
Sig	**NS**	**S**				

$\bar{X}$: Mean **SD: Standard deviation** **MD: Mean difference**
p value: Probability value **S: Significant** **NS: Non significant**

Discussion:

Patients who have suffered a stroke encounter gait abnormalities attributable to multiple factors, such as sensory deficits, muscle weakness, and spasticity. The principal objective of rehabilitation is to restore independent walking[22]. Visual cues would be more efficacious in eliciting gait recovery post-stroke[8].

Gait impairment is a prevalent and disabling consequence of stroke, often characterized by deficits in spatiotemporal parameters such as step length, cadence, gait speed, and symmetry. Traditional rehabilitation approaches have had limited success in fully restoring gait function, prompting the exploration of adjunctive interventions like visual cue training (VCT)[8,21,23].

The current study was conducted to find out the impact of visual cue training on spatiotemporal gait parameters among patients with stroke

The findings revealed no substantial difference among groups regarding age, weight, height, BMI, sex, affected side as well as spasticity grades distribution ($p > 0.05$) in addition a substantial improvement in step length of affected as well as nonaffected sides along with a substantial reduction in step width in both groups following treatment in comparison with pretreatment ($p < 0.001$). As well there was a substantial increase in velocity as well as cadence in both groups following treatment in comparison with pretreatment ($p < 0.001$).

In agreement with[24], the visual cue training effectively improves spatiotemporal gait parameters including step length, gait velocity, as well as symmetry in stroke patients by enhancing motor control and coordination through visual feedback

mechanisms. This training activates brain areas like the cerebellum and basal ganglia, improving automatic motor processes and muscle coordination, which leads to better gait performance and reduced postural sway.
Studies indicate that integrating visual cue training with traditional therapy yields superior enhancements in gait velocity, step length, and dynamic gait index compared to traditional therapy alone. Visual feedback also enhances accuracy and precision of foot placement and promotes controlled gait movement by linking oculomotor and locomotor pathways. These findings support the use of visual cue training as an adjunct to conventional rehabilitation for gait recovery after stroke[21].
Visual cues serve as important sensory inputs to guide walking and balance, especially since stroke survivors often become more dependent on vision to maintain dynamic stability. Training that incorporates stepping to visual targets can improve gait symmetry and speed as well as turning ability[24].
In a quasi-experimental study, stroke patients receiving visual cue training in addition to conventional therapy showed significantly greater improvements in dynamic gait index (DGI) and walking velocity than those receiving conventional therapy alone, indicating enhanced functional gait parameters post-intervention[21]
Moreover, Hollands, et al.,[8] showed that ongoing trials and feasibility studies indicate that visual cues can improve gait adaptability, step length symmetry, and turning ability in stroke patients. These studies emphasize the importance of treatment adherence and the potential for Visual cue training to be integrated into routine rehabilitation
Visual cue training (VCT) has been shown to help patients to regulate step length and improve symmetry between paretic and non-paretic limbs, thereby reducing compensatory gait patterns and fall risk[25]
By providing clear targets for foot placement, visual cue training (VCT) can help increase stride length and overall walking speed, which are critical for community ambulation and independence. However, evidence suggests that visual cues alone may increase stride length but can actually reduce cadence compared to other cue types like auditory or visuotemporal cues[26]
The results of the current study align with (Upadhyay, S., and Verma, S.)[21] The investigation of the impact of visual cue training on gait as well as walking velocity among patients with chronic stroke revealed that the combination of visual cue training in addition conventional training yielded promising outcomes for gait as well walking velocity in these patients.
Furthermore, prior studies examining the impact of visual cue training on various neurological disorders corroborate the findings of the present study[11,9]. Another study conducted on forty-five acute stroke patients indicates that cuing training is more beneficial than conventional training alone[21].
Consistent with Heeren et al.[27], the incorporation of visual cues in treatment options designed to enhance gait coordination has been suggested. Similarly to auditory cueing, the purpose of these visual cues is to promote a more symmetrical gait pattern in patients.
Furthermore, the visual cues offered by the wearable laser device, acting as an effective alternative to ground lines, enhanced toe clearance, improved ankle dorsiflexion during the swing phase, in addition reduced Centre of Pressure (COP) deviations in the anterior-posterior direction. This suggests that such visual feedback can improve gait mechanics and stability by encouraging higher foot lift and better ankle movement, along with more controlled COP progression during walking. These improvements are beneficial for gait rehabilitation and fall prevention, as they enhance foot clearance and reduce instability during walking[28].
Visual cues help focus attention on stepping, bypassing impaired automatic motor control, and may engage alternative visual-motor circuits to facilitate better gait execution. This compensatory mechanism reduces gait variability and risk of falls, making walking patterns more stable and closer to normal[29]
Real-time visual feedback has been employed for gait rehabilitation among stroke patients. Begg et al.[30] found that stroke patients' foot trajectory regulation was significantly altered by treadmill training that included visual input on the lower extremities.
Furthermore, Lewek et al.[31] indicated that treadmill training incorporating visual as well as proprioceptive feedback for individuals with chronic stroke resulted in enhancements in gait velocity and symmetry. Consequently, the utilization of visual as well as proprioceptive feedback for gait symmetry significantly enhances walking among stroke patients.
The current study aligns with the findings of Zhang Wei et al.[29], who proposed that visual cueing may serve as an effective physiotherapeutic intervention for enhancing gait as well as stability among individuals having Parkinson's disease. Moreover, visual cues may enhance functional mobility as well as overall quality of life.
The potential neurophysiological mechanism underlying the enhancement in the visual training group may include the allocation of attention throughout walking, which significantly influences gait control[32]. Stepping on a line at a specific distance enhances focus and creates a dynamic visual flow that helps maintain locomotor pattern[33].
As attention enhances, it transitions to a corticalized task (Lewis etal.[34]. The transformation of visual information into action is termed the visual motor process. The sensory information acquired during visually directed movement is

transmitted to the dentate nucleus of the cerebellum for the execution of movement Allen et al.[35]. This focus on visual stimuli engages the cerebellum and basal ganglia, which have reciprocal connections with the brainstem and cerebral cortex for the regulation of automatic motor processes[36].

Another factor contributing to the substantial improvement in gait as well as velocity may be the enhancement of motor function through visual feedback[37]. The connection between the oculomotor as well as locomotor pathways results in altered muscle coordination patterns, facilitating regulated gait movement[38]. The postural sway of the paretic leg diminishes while ankle mobility enhances to facilitate body control. Moreover, visual movements enhance the accuracy and precision of foot positioning[39].

Nevertheless, the findings of this study are inconsistent with those of Nam & Lee,[40], who proposed that visual cue deprivation balancing training effectively enhances the balance as well as walking of stroke patients. Specifically, balance training that incorporates head control while depriving visual cues is useful in enhancing dynamic balance capabilities. Consequently, it is crucial to preserve head orientation during visual cue deprivation balance training. Accurate vestibular input is essential for sustaining balance. Consequently, it is essential to consistently regulate head orientation through feedback and to accurately manage head movement.

The findings of this study contrast with those presented by Jeong & Chung[41], who proposed that balance training depending on visual deprivation is beneficial for enhancing static and dynamic balance as well as gait in stroke patients. Patients who have experienced a stroke should aim to decrease their dependence on visual information.

Furthermore, the findings of this study are inconsistent with those of Bonan et al.[42], which indicated that balance rehabilitation among patients with longstanding hemiplegia might be more effective under conditions of visual deprivation compared to free vision. Deprivation likely prompts patients to enhance their reliance on somatosensory as well as vestibular information to compensate for the lack of a visual strategy.

The current study exhibited certain limitations. Firstly, there was no follow up to evaluate how the employed intervention affected the research variables in the long term. Secondly, psychosocial factors could influence patients' performance during the treatment and evaluative sessions. Nonetheless, this study could contribute to future investigations aimed at improving the walking function in stroke patients.

Conclusion:

The findings of this study indicate that incorporating visual cue training together with a physiotherapy program is beneficial for improving spatiotemporal gait parameters as steplength, stepwidth,velocity and cadence among stroke patients.

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