International Journal of Multidisciplinary Research and Development
www.allsubjectjournal.com
ISSN Online: 2349-4182 ISSN Print: 2349-5979
Received: 30-09-2025, Accepted: 29-10-2025, Published: 14-11-2025
Volume 12, Issue 11, 2025, Page No. 105-109

Impact of electromyographic biofeedback on gait parameters in hemiparetic chronic stroke patients

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Abstract

Background: Gait asymmetry is a common and disabling consequence of stroke, often resulting in reduced mobility and independence. Surface electromyographic (EMG) biofeedback has emerged as a promising tool to enhance motor relearning and improve gait performance by providing real-time visual feedback on muscle activation.

Objective: To evaluate the effect of EMG biofeedback training on gait parameters in individuals with chronic stroke.

Methods: Forty stroke survivors aged 40–60 years were randomly divided into two groups: Group A (EMG biofeedback + conventional circuit gait training) and Group B (conventional training only). Both groups underwent 20 sessions over four weeks. Gait parameters—stride length, step length, stride width, degree of toe-out, and cadence were measured before and after intervention using the clinical footprint method. Data were analysed using SPSS v25, with $p > 0.05$ considered significant.

Results: Post-intervention, Group A showed significant improvements in stride length, stride width, step length, and degree of toe-out compared to Group B ($p < 0.05$). Cadence improved in both groups, though not clinically significant.

Conclusion: EMG biofeedback combined with conventional gait training enhances neuromuscular control and gait symmetry in stroke survivors. It serves as an effective adjunct to conventional therapy, promoting functional mobility and facilitating motor relearning in stroke rehabilitation.

Keywords: EMG biofeedback, stroke, gait parameters, rehabilitation; stroke, walking independence

Introduction

EMG Biofeedback technology has become an increasingly recognized and scientifically supported approach for enhancing the recovery of motor functions, particularly walking ability, following neurological injuries such as cerebral stroke [1, 3]. The principle underlying biofeedback involves recording a physiological or biomechanical parameter and converting it into a perceivable signal—visual, auditory, or tactile—allowing the patient to consciously monitor and modify their own motor performance in real time. This process transforms the traditionally passive rehabilitation experience into an active, participatory one, empowering patients to engage directly in their recovery process. Through the use of EMG Biofeedback, individuals can better understand their own movement errors, adjust them voluntarily, and reinforce correct motor patterns through repetition and feedback-based learning. Consequently, this technology helps to activate the body's inherent neuroplastic potential and supports motor re-learning during rehabilitation.

Biofeedback systems can be integrated with conventional physiotherapy protocols or utilized as independent therapeutic modalities. Depending on the type of feedback provided, EMG Biofeedback systems may target visual, auditory, or somatosensory channels. Among these, visual feedback is the most frequently employed because it allows patients to easily interpret performance changes through graphical or numerical displays. Auditory feedback, either alone or combined with visual cues, is also commonly used, while kinesthetics or tactile forms of feedback—such as vibration or haptic stimulation are less common but are gaining research interest for their potential in engaging proprioceptive control mechanisms [1, 4].

Walking dysfunction is one of the most disabling sequelae following a cerebral stroke. A stroke typically affects one cerebral hemisphere, leading to hemiplegia or hemiparesis, which results in characteristic asymmetries in gait performance [5]. Post-stroke gait is often marked by reduced velocity, an increased duration of the double-support phase, and limited range of motion at the hip, knee, and ankle joints [6, 8]. In addition, four primary gait abnormalities are typically described in hemiplegic patients: drop-foot gait, caused by dorsiflexor weakness; circumduction gait, in which the affected leg swings outward due to limited knee flexion; hip hiking gait, characterized by exaggerated pelvic elevation on the affected side; and back-knee gait, involving excessive knee extension during stance [9]. These impairments not only compromise mobility but also increase energy expenditure and risk of falls, thereby affecting functional independence and quality of life.

Initially, the clinical application of EMG Biofeedback in gait training was restricted by technological limitations in capturing and processing gait parameters. Earlier systems could measure only a few global outcomes—such as walking speed, stride length, or cadence—which are influenced by a variety of factors and are not disease-specific [1]. Walking speed, for instance, reflects overall locomotor performance but can be affected by pain, spasticity, muscle weakness, joint stiffness, or postural instability, and therefore cannot accurately pinpoint the nature of motor impairment. Similarly, cadence (steps per minute) offers a general measure of gait rhythm but provides limited insight into side-specific asymmetry. Stride length, on the other hand, may reveal inter-limb discrepancies, making it more sensitive to unilateral impairments. Nevertheless, these outcome parameters, while clinically valuable, do not fully describe the underlying temporal and spatial characteristics of gait affected by stroke [8, 10]. Determinant parameters such as gait cycle duration, stance and swing phase proportions, double and single support periods, and temporal symmetry between limbs are increasingly recognized as critical indicators for understanding and correcting abnormal gait patterns.

In recent years, more sophisticated EMG Biofeedback systems have emerged that allow for monitoring and training based on selective gait parameters. Some systems focus on kinetic parameters, such as ground reaction force or limb loading patterns [11, 12], while others use kinematic or spatiotemporal parameters, including step length or foot clearance during the swing phase [13]. Electromyography (EMG)-based biofeedback has also been employed, particularly for retraining the activation of the triceps and other lower limb muscles involved in propulsion. Such approaches have shown potential for improving both gait symmetry and muscle coordination.

The development of wearable inertial measurement unit (IMU) technology has greatly advanced the feasibility of biofeedback in gait rehabilitation. IMUs comprising accelerometers, gyroscopes, and magnetometers allow continuous, real-time monitoring of body segment movements in natural environments. Their lightweight and portable nature has enabled the collection of spatiotemporal and kinematic data outside traditional laboratory settings. Validation studies on IMU-based systems in healthy adults have confirmed high reliability and accuracy for a variety of gait parameters [14]. Moreover, recent innovations have combined IMU technology with artificial intelligence and neural networks to automatically classify post-stroke gait patterns [15]. Despite these advances, evidence regarding the effectiveness of IMU-based EMG Biofeedback for improving walking function in stroke patients remains limited. Systematic reviews suggest that while IMU-based feedback has shown encouraging results for balance training, its application in gait training is still in the early stages of research [16].

Existing literature presents inconsistent findings concerning the benefits of EMG Biofeedback for gait restoration following stroke. For instance, Druzbicki *et al.* [17] reported no significant improvements in walking function after EMG intervention, whereas their earlier study indicated notable positive outcomes [17]. Gente *et al.* [12] observed that a brief six-minute EMG session, using ground reaction force data with both visual and auditory cues, resulted in increased limb loading capacity. Similarly, another study [17] that utilized stance-phase duration as a feedback parameter found greater improvements when using vibrotactile feedback compared to visual cues, emphasizing that parameter specificity may influence training outcomes.

One major challenge in interpreting existing research is the lack of standardization in BFB training protocols. Studies vary widely in terms of the frequency, duration, and total number of training sessions, as well as the feedback modality and the target parameter. In the analytical review by Spencer *et al.* [3], training frequencies ranged from three times per week to twice daily, with total sessions spanning from three to eighteen. Session durations varied from 10 to 30 minutes across different studies [3, 12, 13, 17]. This heterogeneity makes it difficult to establish optimal therapeutic parameters or to compare findings across studies. Moreover, most existing studies have employed global gait measures rather than parameter-specific feedback, potentially limiting their ability to target asymmetrical deficits characteristic of post-stroke gait.

Overall, while most authors agree that EMG Biofeedback is a promising adjunct to conventional gait rehabilitation, the field lacks consensus regarding which gait parameters should be prioritized, how feedback should be delivered, and how training protocols should be structured. The application of highly selective feedback parameters, such as stance phase duration, is particularly underexplored, mainly due to the technological demands of precise data acquisition and real-time feedback integration. Nevertheless, targeting such parameters may be critical for improving gait symmetry and overall functional mobility in stroke survivors.

Hence, the present study was designed to examine the feasibility and effectiveness of EMG Biofeedback training focused on Gait Parameters in individuals during the early recovery phase following stroke. It was hypothesized that providing EMG Biofeedback would enable patients to consciously adjust and improve Gait parameters, leading to better gait symmetry and functional walking performance.

Methodology

A total of forty stroke subjects presenting with gait abnormalities, who satisfied the inclusion criteria, were recruited from the Govt. hospital, Ahmedabad, Gujarat. Individuals aged between 40 and 60 years who were able to ambulate independently for a distance of 10 metres without assistance were considered eligible for participation. Subjects with a Brunnstrom stage of motor recovery of IV or above, a Mini-Mental State Examination (MMSE) score of 24 or higher, and without any deformities or contractures were randomly assigned to either Group A or Group B.

Participants with a history of previous similar interventions, those exhibiting cognitive or visual deficits, and individuals who were unable to comply with the treatment procedures were excluded from the study to ensure homogeneity within the sample population. Written informed consent was obtained from all eligible participants prior to the commencement of the study.

Intervention Protocol

- **Experimental Treatment (Group A):** Participants received surface electromyographic (EMG) biofeedback training in addition to conventional therapy.

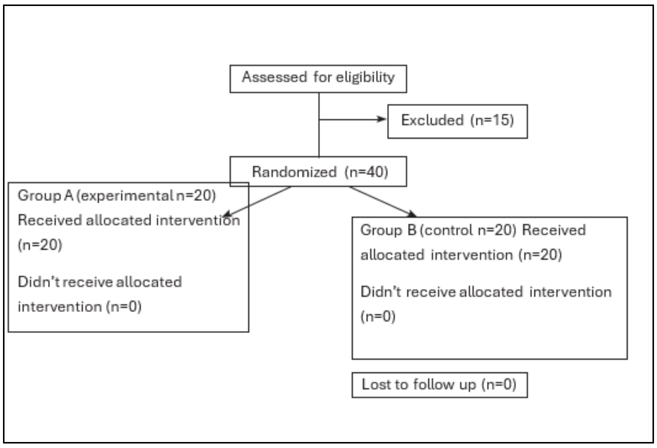
- **Conventional Treatment (Group B):** Participants received circuit gait training along with functional activities such as reaching in sitting and standing positions, sit-to-stand exercises, heel lifts, Backward walking, step-over training, and isokinetic strengthening exercises.

Outcome Measures

- **Stride Length:** Defined as the linear distance between two successive heel strikes of the same foot.

- **Step Length:** Defined as the distance between the heel strike of one foot and the subsequent heel strike of the contralateral foot.

- **Degree of Toe-Out:** Refers to the angle formed between the longitudinal bisection of the footprint and the line of progression during gait.
- **Stride Width:** Measured as the lateral distance between predetermined landmarks on one footprint and the ipsilateral line of progression of the opposite foot.
- **Cadence:** Denotes the number of steps taken per minute, representing the rate of ambulation.



Intervention

Control Group : Participants allocated to the control group received a structured circuit training program comprising functional and strengthening exercises. The circuit included activities such as reaching in both sitting and standing positions, sit-to-stand transfers, step-ups, heel raises, isokinetic strengthening exercises, walking over obstacles, and ambulation on inclined and declined surfaces. Each activity was performed for 4 minutes, with a 1-minute rest interval between exercises. Training sessions were conducted five times per week for four consecutive weeks, resulting in a total of 20 sessions. The total duration of each circuit training session was approximately 60 minutes.

Experimental Group: Participants in the experimental group received electromyographic (EMG) biofeedback training in addition to the circuit training described above. For electrode placement, the gluteus medius muscle was identified by locating the region between the iliac crest and the greater trochanter, and palpated during active hip abduction to confirm contraction. Adhesive surface EMG electrodes were positioned approximately 10 mm between the innervation zone and the tendon insertion point. During gait training, participants were provided with wireless visual biofeedback of their EMG activity, enabling real-time monitoring of muscle activation amplitude displayed as graphical feedback. The EMG biofeedback intervention was administered for 20 sessions, conducted five days per week for four weeks, with each biofeedback session lasting 20 minutes including rest intervals. The overall training duration for each session was one hour.

Results

		Range	Mean ± SD	Rang	Mean ± SD	
1	**Age in years**	40-70	49.73±5.66	43-60	51.82±6.34	t=0.448, p>0.05, NS
2	BMI	21.02-27.03	24.07±2.49	19.70-33.90	24.13±3.82	t=0.942, p>0.05, NS
3	Right limb length	77-88	81.73±3.03	75-89	81.60±3.52	t=0.402, p>0.05, NS
4	Left limb length	78-88	81.60±2.89	76-90	81.80±3.46	t=0.048 p>0.05, NS

S no	Outcome measures	Group-A Mean ±SD	Pre-test	Group-B Mean ±SD	Group-A Mean ±SD	Post-test	Group-B Mean ±SD
1	Stride length	32.90±8.79		37.64±9.19	36.63±5.23		38.21±7.83
2	Stride width	12.42±3.48		11.38±3.88	9.55±2.19		10.85±3.43
3	Step length	23.59±5.91		26.94±5.08	29.17±5.02		27.74±5.02
4	Degree of toe out	10.70±2.35		10.93±2.34	8.63±1.65		10.38±2.36
5	Cadence	51.47±11.42		56.07±11.01	65.00±9.53		60.00±10.31

Statistical analysis was done using SPSS version 25 for windows software. Descriptive statistics are presented as means [standard deviations (SD)].

On comparison of the pre-and post-test outcomes between the groups, stride length, stride width, step length, degree of toe out and cadence among stroke subjects showed statistically significant differences. It was observed that initially before the intervention, the stroke subjects were similar in both the groups. After the intervention, significant differences were observed in the variables in between the groups at p value
>0.05.

Discussion

The present study aimed to determine the effect of surface EMG biofeedback on gait parameters in individuals with chronic stroke. The experimental group received surface EMG biofeedback combined with conventional circuit gait training, whereas the control group underwent only conventional therapy. Both groups participated in 20 treatment sessions over four weeks (five sessions per week). Gait parameters were evaluated before and after the intervention using the clinical footprint method. Statistical analysis was performed using paired and unpaired *t*-tests for normally distributed data, the Wilcoxon test for skewed data, and the chi-square test for categorical variables. A *p*-value of >0.05 was considered statistically significant.

Gait deviations observed in the participants included lack of smooth forward progression, asymmetry in stance and swing phases, and step-length variability. These inconsistencies were most likely related to balance deficits and difficulties in transferring body weight over the paretic limb. Similar findings have been documented previously, where altered gait patterns were considered compensatory strategies due to impaired motor control. A study by Tunc Akbas *et al.* reported that stiff-knee gait following stroke results not only from compensation for reduced knee flexion but also from abnormal coordination between the gluteus medius and rectus femoris, which disturbs gait symmetry.

In the present research, EMG electrodes were placed over the gluteus medius to reduce abnormal co-activation with the rectus femoris. This approach aligns with findings by D.

Intiso *et al.*, who demonstrated that EMG biofeedback applied to the spastic gastrocnemius and soleus can reduce muscle overactivity and prevent foot drop after stroke.

Stride Length

The pre-test stride length of participants in the experimental group ranged from 22.0 cm to 47.4 cm. Twelve participants demonstrated stride lengths roughly double their step length, predominantly among those with left-sided involvement and right-side dominance. Others displayed smaller differences between stride and step lengths. Previous studies have also shown that left-hemisphere lesions tend to produce more asymmetrical gait, especially during the swing phase, affecting propulsion of the paretic limb. Although stride length increased following intervention, the change was statistically significant. This may have resulted from variations in ground clearance, plantar-flexor spasticity, and fear of falling due to balance impairments. G. Katlin *et al.* previously highlighted the importance of plantar-flexor function in forward propulsion during gait, with increased spasticity reducing stride length. Additionally, limited pelvic rotation and hip extension during pre-swing may have further restricted stride length improvement.

Stride Width

In the experimental group, stride width before intervention ranged from 6.6 cm to 18.3 cm. Post-intervention analysis revealed a significant reduction, suggesting improved gait stability and confidence. EMG biofeedback provides real-time, objective feedback, enabling patients to visualize and correct movement patterns. Rosalyn Stanton reported improved standing and walking performance following biofeedback training. Similarly, A.N.M. Qurat-ul-Ain found that enhanced balance and step length contribute to a narrower base of support and higher cadence, findings that align with our results.

Step Length

Participants initially presented with reduced step length (14.1–34.2 cm in the experimental group and 17.0–35.0 cm in the control group). Subjects initiating gait with the unaffected limb had shorter steps, while those starting with the affected limb showed improvement. Post-intervention data demonstrated significant improvement within the experimental group. Stefan Hesse *et al.* observed similar outcomes, indicating that increased symmetry during gait initiation improves step length and center-of-pressure dynamics. Enhanced lower-limb kinematics, increased single-limb support time, and improved gait speed likely contributed to these results. Through EMG biofeedback, participants may have learned to utilize preserved neural pathways, facilitating motor relearning and recovery of function.

Degree of Toe-Out

Before intervention, the degree of toe-out ranged from 7° to 15°. Excessive external rotation of the foot is common post-stroke and disrupts normal gait alignment. Previous evidence indicates that stroke survivors do not consistently regulate medio-lateral foot placement in response to shifts in the center of mass. In our study, excessive gluteus medius activity initially caused the center of mass to deviate toward the stance foot, leading to poor foot alignment. Post-treatment analysis revealed improved control and alignment, suggesting that inhibiting abnormal muscle coordination through EMG biofeedback contributed to better weight distribution and reduced toe-out angle.

Cadence

Baseline cadence ranged from 30 to 76 steps/min in both groups. Although cadence improved in both groups after treatment, the change was not clinically significant, as it did not meet the minimal clinically important difference (MCID) of 17.1 steps/min. Step length improvements are known to influence cadence positively. Circuit gait training, which incorporated stepping and obstacle-walking tasks, may have contributed to these gains. In experimental group improvements were reported in studies utilizing visual biofeedback during gait training.

Overall Interpretation

Participants in the experimental group may have achieved better neuromuscular control around the hip joint, even though knee and ankle parameters showed more marked improvement. Studies on EMG-based gait rehabilitation have confirmed that biofeedback enhances muscle recruitment and locomotor recovery in hemiparetic individuals. Dean *et al.* also demonstrated that circuit-based, task-oriented training yields superior functional outcomes.

Trowbridge and Casen emphasized that specific, corrective feedback promotes better motor learning compared with general motivational feedback. EMG biofeedback facilitates neural plasticity by unmasking latent pathways, reorganizing neural circuits, and reinforcing new motor strategies. Continuous visual EMG input processed through the cerebellum and motor cortex helps establish new sensory engrams and improve voluntary control.

Study Limitations

Certain factors may have influenced the outcomes, including environmental distractions during training, the cognitive challenge of dual-tasking (walking while observing the display), and variability in stroke duration, lesion location, and severity. Most participants in our study also had left-hemisphere involvement, possibly contributing to limited improvements. Moreover, as subjects were in the chronic phase (6 months to 3 years post-stroke), neural recovery may have plateaued, with gains primarily reflecting compensatory mechanisms rather than neuroplastic changes.

Conclusion

The present study concludes that surface electromyographic (EMG) biofeedback, when combined with conventional circuit gait training, significantly improves gait parameters such as stride length, step length, stride width, and degree of toe-out in individuals with chronic stroke. The integration of real-time visual feedback enabled participants to actively monitor and modify their muscle activation patterns, thereby enhancing gait symmetry and neuromuscular coordination. Although cadence showed improvement in both groups, it did not reach clinical significance. Overall, EMG biofeedback proved to be an effective adjunct to conventional physiotherapy, facilitating motor relearning and promoting functional recovery of gait. Future studies with larger sample sizes, longer follow-up periods, and standardized protocols are recommended to validate these findings and optimize biofeedback-based rehabilitation strategies for stroke survivors.

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