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Therapeutic Effects of a Short-Term Inpatient Functional Electrical Stimulation Protocol on Gait and Balance in a Heterogeneous Neurological Population

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Abstract

Background: Neurological patients presenting with foot drop suffer from profound mobility restrictions that severely impair daily activities, independence, and community reintegration. Traditional rehabilitation often overlooks the biomechanical quality of gait, leading to suboptimal compensatory strategies. Therefore, effective interventions must focus on enhancing walking speed and endurance while preserving gait quality and minimising pathological compensations. **Methods:** This facility-based pilot study involved a heterogeneous cohort of 18 hospitalised neurological patients with unilateral foot drop. The intervention consisted of 6 to 8 sessions of overground walking with a Functional Electrical Stimulation (FES) applied at a frequency of 2 to 3 times per week as an adjunct to standard intensive daily physiotherapy. Functional mobility was assessed at baseline and post-treatment (with FES turned off) using the 6-Minute Walk Test (6 MWT), Timed Up and Go (TUG) test, and the 10-Meter Walk Test (10 MWT) at preferred and fast speeds. Changes were benchmarked against established Minimal Clinically Important Difference (MCID) thresholds. **Results:** Post-treatment assessments revealed statistically significant improvements across all parameters ($p < 0.001$) with exceptionally large effect sizes. Submaximal walking endurance (6 MWT) improved by 62.16%, while dynamic balance (TUG) and gait velocities (10 MWT) improved by more than 30%. Clinical relevance was highlighted by substantial MCID responder rates ranging from 78% to 94% across all tested domains. **Conclusions:** Integrating a short-term, low-frequency FES protocol into standard inpatient rehabilitation significantly enhances both objective statistical and clinical gait parameters. Beyond biomechanical recovery, this scalable intervention facilitates greater autonomy, restores self-confidence, and supports successful com-

munity reintegration in mixed neurological populations.

Keywords

Functional Electrical Stimulation, Foot Drop, Neurological Rehabilitation, Gait Velocity

1. Introduction

Neurological conditions such as stroke and multiple sclerosis (MS) are leading causes of chronic disability worldwide, frequently resulting in profound and persistent mobility limitations [1] [2]. Up to 46% of individuals who survive a first-ever stroke are initially unable to walk, and gait impairment remains a primary complaint restricting independence and quality of life [1] [3]. A prevalent manifestation of these upper motor neuron lesions is foot drop, a severe motor deficit affecting approximately 20% to 30% of stroke survivors and a substantial proportion of patients with MS [2] [4] [5]. Foot drop is fundamentally characterized by an inability or reduced capacity to actively dorsiflex the foot during the swing phase of the gait cycle [1] [3].

The underlying pathophysiology of foot drop involves profound weakness or absent voluntary control of the ankle dorsiflexor muscles, frequently compounded by increased spasticity in the antagonistic plantar flexors [1] [6]. This imbalance directly impedes toe clearance during the swing phase and disrupts proper heel strike at initial contact [4] [7]. Instead of a physiological heel-to-toe progression, patients often land flat-footed or on the anterior and lateral edges of the foot [8]. In hemiparetic patients, where spasticity and primitive extensor synergies dominate, the ankle frequently assumes an equinovarus posture—a combination of excessive plantar flexion and inversion—which shifts weight-bearing forces unsteadily onto the lateral border of the foot [9].

To compensate for functional limb lengthening and to avoid dragging the toes, patients are forced to adopt undesirable kinematic strategies at proximal joints, such as excessive hip hiking and pelvic circumduction [3] [9]. Consequently, the gait cycle becomes highly asymmetrical, unstable, and metabolically inefficient [7] [9]. The extra mechanical work required to lift the body's center of mass and advance the paretic limb against gravity results in a significantly higher energy expenditure during walking [9]. Clinically, these biomechanical deviations manifest as drastically reduced walking speed, poor endurance, and an elevated risk of trips and falls [10] [11].

The conventional standard of care for persistent foot drop relies primarily on the prescription of an ankle-foot orthosis (AFO) [5] [10]. While AFOs successfully maintain the ankle in a neutral position to prevent toe drag, they rely on a purely passive mechanical mechanism [12]. By restricting natural arthrokinematic motion at the ankle, AFOs can hinder dynamic balance-recovery strategies, lead to

patient discomfort, and predispose the joint to plantar-flexion contractures [2] [10] [12]. Crucially, because AFOs do not facilitate active muscle contraction, they fail to promote motor relearning and can contribute to disuse atrophy in the affected musculature [3] [12].

In contrast, Functional Electrical Stimulation (FES) has emerged as a dynamic alternative. These neurostimulators apply timed electrical impulses to the common fibular nerve and the tibialis anterior muscle [3] [13]. Synchronized with the swing phase of gait, this stimulation elicits active dorsiflexion and eversion, mimicking physiological movement and enabling safe foot clearance [6] [14]. The clinical efficacy of FES is conceptualized through two distinct mechanisms. The orthotic effect refers to the immediate improvement in gait kinematics, speed, and stability observed while the device is actively functioning. More importantly, prolonged use of FES can induce a therapeutic (or carry-over) effect, where improvements in voluntary gait and unassisted muscle control persist even when the device is turned off [5] [13]. This therapeutic phenomenon is attributed to the fact that FES combines active peripheral muscle contraction with proprioceptive sensory feedback, promoting activity-dependent neuroplasticity and the reorganization of central motor networks [13] [15].

While the orthotic and therapeutic benefits of FES are well-documented, the literature is dominated by specific application protocols. Evidence of FES efficacy is largely derived from high-intensity regimens, such as continuous, all-day home use in chronic community-dwelling patients, or intensive daily training within specialized research facilities [6] [7] [13] [16]. Conversely, in standard real-world facility-based rehabilitation, logistical and financial constraints typically limit therapy to moderate frequencies [13] [17]. There is a pronounced lack of evidence regarding the feasibility and clinical impact of a short-term, facility-based FES program applied at a frequency of 2 to 3 times per week. Furthermore, while most FES trials isolate subjects by single etiologies - studying only post-stroke or only MS patients—clinical rehabilitation departments routinely manage heterogeneous neurological populations simultaneously [13] [16].

Therefore, the primary objective of this clinical study is to evaluate the therapeutic and orthotic effects of the FES on a mixed cohort of hospitalized neurological patients presenting with foot drop. Specifically, this study aims to determine whether integrating FES into a standard inpatient rehabilitation protocol at a low frequency yields significant improvements in objective functional mobility parameters.

2. Materials and Methods

2.1. Study Design

The study was conducted as part of the routine rehabilitation care provided at the Semily Rehabilitation Center, spanning the period from May 2025 to May 2026. Evaluated data were gathered during standard, non-experimental clinical care and involved no non-standard invasive procedures. The study was conducted in ac-

cordance with the ethical standards set forth in the Declaration of Helsinki. Prior to inclusion, all participants were thoroughly informed about the possible risks and benefits and provided written informed consent for their participation and the potential publication of the results.

2.2. Study Population

The investigated study population consisted of adult in patients who received conventional rehabilitation due to mobility restrictions caused by upper motor neuron damage. For inclusion in the trial, individuals had to demonstrate clear signs of unilateral foot drop, which was identified by the compromised ability to actively lift the foot and safely clear the toes while the leg was in the swing phase. Additionally, subjects needed the baseline ambulatory ability to walk at least ten meters with or without a single-sided walking aid, and they were required to show a functional muscle contraction during initial common fibular nerve stimulation without undue pain. To guarantee active engagement in the therapy sessions, patients also had to possess sufficient cognitive awareness to understand complex commands and grant informed consent. Individuals were deemed ineligible if their gait abnormalities stemmed primarily from severe peripheral nerve damage, lower motor neuron disorders, or major structural joint issues like permanent ankle plantar-flexion contractures. Further grounds for exclusion involved having active electronic implants such as cardiac pacemakers, severe cardiovascular disease, unmanageable leg spasticity, or having received botulinum toxin treatments in the affected leg within the prior six months.

2.3. Intervention

All participants received the standard, comprehensive inpatient rehabilitation program provided by the facility. This baseline treatment was administered daily and consisted of individualized physical therapy sessions (approximately 45 - 60 minutes per day) focusing on neurodevelopmental treatment, sensory-motor stimulation, progressive resistance strength training of the lower paretic limb, and core stabilization. FES intervention using the BTL Walk Pro stimulator (BTL Industries Ltd., Prague, Czech Republic), a portable wireless system designed for correction of unilateral foot drop, was integrated into the overground walking component of physical therapy sessions 2 - 3 times per week.

A stimulation belt was applied to the paretic lower leg, positioned on either the medial or lateral side of the patient's shin. The position of the belt was then carefully adjusted to ensure the electrodes effectively stimulated the common fibular nerve and the tibialis anterior muscle. The device delivered rectangular, biphasic electrical impulses at a frequency of 35 Hz and a pulse duration of 300 μs. During the initial fitting, the stimulation intensity was gradually increased while the patient was in a seated position with the hip, knee, and ankle at a 90-degree angle until a visible and sufficient ankle dorsiflexion was elicited. Electrode placements and stimulation intensities were then continuously adjusted to maintain the foot

in a neutral alignment, thereby preventing excessive ankle inversion or eversion.

During gait training, the stimulation was synchronized with the swing phase of the gait cycle to facilitate active dorsiflexion and safe toe clearance, mimicking a more physiological walking pattern. The FES was delivered as the standard rehabilitation protocol and was applied during level overground walking. Treatment sessions lasted between 10 and 30 minutes and were administered at a frequency of two to three times per week. Depending on the condition, the total number of sessions ranged from 6 to 8.

2.4. Outcome Measures

To evaluate the therapeutic efficacy of the FES intervention, objective functional mobility parameters—focusing on walking speed, endurance, and dynamic balance—were assessed. All clinical tests were performed at two distinct time points: at baseline (pre-treatment) and immediately after finishing the treatment course (post-treatment). To isolate the therapeutic carry-over effect of the training program and assess unassisted functional recovery, all post-treatment assessments were performed with the FES stimulator turned off and removed. Participants wore the same footwear and used their individually required walking aids during both testing sessions to ensure consistency. The clinical outcome measures included the following standardized assessments:

- 6-Minute Walk Test (6 MWT): Patients were instructed to walk as far as possible along a flat, unobstructed 30-meter hallway for a total duration of 6 minutes. The total distance covered was recorded in meters (m). Rest breaks were permitted if necessary, though the timer ran continuously [18].
- Timed Up and Go (TUG) Test: Patients were timed while rising from a standard armchair (seat height approximately 45 cm), walking at a safe and comfortable pace to a line marked 3 meters away, turning around, walking back to the chair, and returning to a seated position. To ensure strict methodological consistency and eliminate confounding environmental variability, the exact same armchair was used for all assessments across all participants and testing sessions. The total time from the command "Go" until the patient's backside touched the chair seat was recorded in seconds (s) [19].
- 10-Meter Walk Test (10 MWT): Patients were instructed to walk along a straight 14-meter marked pathway. The time taken to cover the central 10 meters was recorded using a stopwatch, allowing 2 meters at the start and end of the course for acceleration and deceleration. The test was performed under two distinct conditions: walking at the patient's preferred speed and walking at a fast (maximum safe) speed. Walking speed was calculated in meters per second (m/s) [20].

All clinical assessments at baseline and post-treatment were conducted by the same physiotherapist, who was independent of therapy delivery and unaware of specific study hypotheses, to ensure measurement consistency. To determine whether the observed post-treatment changes reflected meaningful clinical improvements

rather than measurement error, the absolute change between baseline and post-treatment scores (Δ) was benchmarked against established Minimal Clinically Important Difference (MCID) thresholds derived from validated literature on neurological populations [21]-[23]. Given the heterogeneous cohort, these values were applied as approximate, standardized anchors rather than disease-specific cut-offs. A patient was classified as a clinical responder in walking endurance if they demonstrated an increase of ≥19.7 m on the 6 MWT [21]. For dynamic mobility and balance, responsiveness on the TUG test was defined as a reduction in time of ≥2.1 s [22]. Regarding short-distance gait velocity, the threshold for a meaningful clinical improvement was established as an increase of ≥0.05 m/s for both the 10 MWT at preferred speed and the 10 MWT at fast speed [23]. Participants who met or exceeded these specific thresholds in the unassisted post-treatment assessments were categorized as clinical responders for that respective mobility domain.

2.5. Statistical Analysis

Statistical analysis and data visualization were performed using a custom-written script in R Project (version 4.5.2, R Foundation for Statistical Computing, Vienna, Austria). Descriptive statistics were used to characterize the study population's baseline demographics and clinical features; continuous variables were expressed as Mean ± Standard Deviation (SD) or Median [Interquartile Range (IQR)], while categorical variables were expressed as frequencies and percentages (n, %).

Due to the exploratory nature of this study and the logistical constraints of a hospitalized setting, the sample size was determined post-hoc based on patient availability during the study period rather than calculated a priori.

The normality of the data distribution for all functional gait parameters was evaluated using visual inspection and formal normality testing. For normally distributed continuous data (6 MWT and TUG), a paired t-test was employed to evaluate differences between baseline and post-treatment scores. For non-normally distributed data (10 MWT Preferred and Fast speeds), a non-parametric Wilcoxon signed-rank test was applied. To quantify the magnitude of the treatment effect, effect sizes were calculated. Cohen's d was computed for parametric comparisons (with values of 0.2, 0.5, and 0.8 representing small, medium, and large effects, respectively), and the Wilcoxon r was calculated for non-parametric comparisons (with values of 0.1, 0.3, and 0.5 representing small, medium, and large effects, respectively). Mean improvement percentages were calculated as the average of individual percentage changes across all participants. For all statistical tests, the significance threshold was set a priori at $p = 0.05$.

3. Results

Participants were consecutively screened upon admission to the inpatient unit. Out of 22 screened patients presenting with unilateral foot drop, 20 met the inclusion criteria and were enrolled, while 18 completed the full protocol. Two patients

dropped out of the study prior to completion due to personal reasons unrelated to the intervention or its therapeutic effects. At baseline, all patients presented with acute to subacute upper motor neuron deficits and required a single-sided walking aid or ankle support for overground ambulation. The FES treatment program was well tolerated by all completing participants, and no adverse events or device-related complications were reported during the study period. The baseline demographic and clinical characteristics of the final analyzed cohort are summarized in Table 1.

Table 1. Baseline demographic, clinical characteristics, and fes treatment dosage of the study population (N = 18).

Characteristic	Value (N = 18)
Age (years), Mean ± SD	58.4 ± 13.4
Sex, n (%)	
Female	8 (44.4%)
Male	10 (55.6%)
Primary diagnosis, n (%)	
Stroke (Hemiplegia)	12 (66.7%)
Multiple sclerosis	4 (22.2%)
Cerebral palsy	2 (11.1%)
Delivered FES dosage	
Completed sessions (n), Mean ± SD [Range]	6.8 ± 0.9 [6]-[8]
Session duration (min), Mean ± SD [Range]	17.1 ± 5.1 [10]-[25]
Total cumulative FES time (min), Mean ± SD	118.8 ± 41.2

Note: SD = Standard Deviation.

Following completion of the treatment course, statistically significant improvements were observed across all functional mobility and gait outcome measures ($p < 0.001$, Table 2). The most pronounced advancement was demonstrated in submaximal walking endurance via the 6 MWT with the mean distance covered increased by 62.16%. The remaining functional parameters—dynamic balance (TUG) and short-distance gait velocity (10 MWT Preferred and Fast)—all followed a remarkably consistent trend, demonstrating robust improvements exceeding 30%. Notably, every single outcome reached an exceptionally large effect size (Cohen's $d > 1.45$; Wilcoxon $r > 0.88$). When benchmarked against established MCID thresholds, the intervention demonstrated substantial clinical relevance. The overall responder rate exceeded 77% across all tested domains, indicating that the vast majority of patients experienced a meaningful functional recovery. Individual patient trajectories relative to the MCID lines are graphically displayed in Figure 1, and a direct comparison of the overall responder rates is presented in Figure 2.

Table 2. Changes in functional gait parameters following treatment program.

Outcome measure	Baseline	Post-treatment	Mean improvement (%)	P -value	Effect size
6 MWT (m)	218.7 ± 106.3	326.4 ± 108.0	**62.16%**	<0.001*	$d = 1.45$
TUG (s)	17.9 ± 7.0	12.1 ± 5.2	**31.17%**	<0.001*	$d = 1.63$
10 MWT preferred (m/s)	0.58 [0.47 - 0.77]	0.81 [0.77 - 1.12]	**30.48%**	<0.001†	$r = 0.88$
10 MWT fast (m/s)	0.74 [0.52 - 0.97]	1.09 [0.80 - 1.27]	**30.65%**	<0.001†	$r = 0.88$

* Normally distributed data (6 MWT, TUG) are presented as Mean ± Standard Deviation and were analyzed using the Paired t-test. † Non-normally distributed data (10 MWT Preferred and Fast speeds) are presented as Median [Interquartile Range] and were analyzed using the Wilcoxon signed-rank test. Effect sizes are reported as Cohen's d for parametric tests and Wilcoxon r for non-parametric tests. The mean improvement (%) was calculated as the mean of the individual percentage changes across all patients.

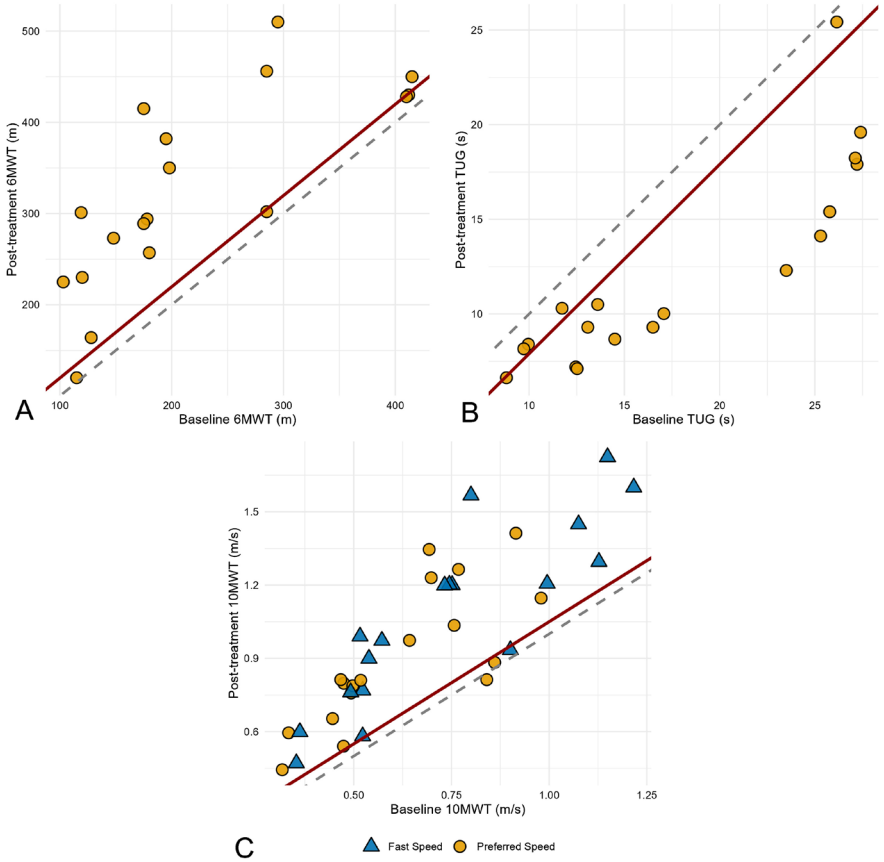

Figure 1. Individual responder plots for functional gait parameters. Baseline (x-axis) versus post-treatment (y-axis) scores for each patient. The dashed gray line denotes no change, and the solid bordeaux line represents the Minimal Clinically Important Difference (MCID). (A) 6 MWT: Points above the MCID line (+19.7 m) signify clinically meaningful improvement. (B) TUG: Points below the MCID line (−2.1 s) signify clinically meaningful improvement (decreased time). (C) 10 MWT: Preferred (yellow circles) and fast gait speeds (blue triangles). Points above the MCID line (+0.05 m/s) signify clinically meaningful improvement.

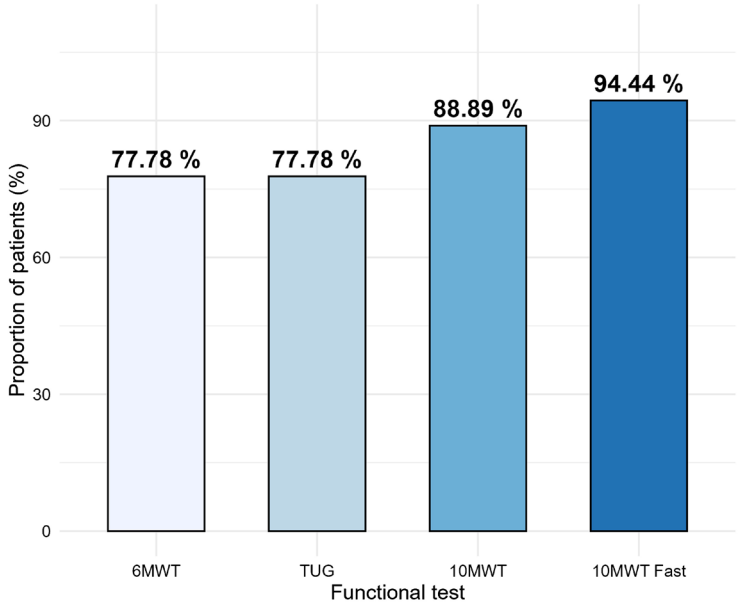

Figure 2. Proportion of patients achieving the Minimal Clinically Important Difference (MCID) following BTL walk therapy. The bar chart displays the percentage of patients who demonstrated clinically meaningful improvements across four functional gait assessments.

4. Discussion

Our study demonstrates that a short-term, low-frequency inpatient FES program yields highly significant and clinically meaningful improvements across walking endurance, speed, and dynamic balance. Crucially, because all post-treatment assessments were performed with the FES device removed, these findings reflect a true therapeutic carry-over effect (voluntary motor recovery) rather than a temporary orthotic substitution.

From a clinical perspective, these objective biomechanical improvements may translate directly into enhanced functional independence and quality of life. In daily life, restricted walking speed and poor endurance represent the most profound barriers to patient autonomy. By significantly increasing velocity (10 MWT) and submaximal walking capacity (6 MWT), patients gain the physical capability to navigate home and community environments more efficiently [24]. Furthermore, improved dynamic balance (TUG) directly correlates with increased safety during transitional movements and a reduced fear of falling [25]. While quality of life and community reintegration were not directly measured in this pilot trial, reversing these functional gait restrictions provides the biomechanical foundation required for unassisted daily activities [24].

These results strongly align with recent evidence indicating that short-term, facility-based FES protocols significantly enhance gait parameters in neurological patients [13]. However, two major distinctions set our findings apart. First, while earlier research isolated its sample strictly to chronic stroke survivors, our study expands this evidence to a heterogeneous cohort comprising stroke, MS, and Cer-

ebral Palsy [13]. This demonstrates that the therapeutic mechanism of FES is robust across diverse upper motor neuron etiologies, making it a highly versatile tool for mixed clinical populations [1] [16]. Second, the magnitude of functional improvement in our study substantially exceeded these prior benchmarks, yielding markedly higher percentage changes in both TUG and 10 MWT, alongside superior MCID responder rates. This disparity is likely driven by differences in chronicity; while previous work focused exclusively on chronic patients, our cohort predominantly consisted of individuals in the acute or subacute phases of recovery. During these early stages, the central nervous system exhibits a heightened capacity for spontaneous neuroplasticity, which was likely synergistically amplified by the FES intervention [26].

The rapid recovery observed after only 6 to 8 sessions contrasts with traditional high-intensity protocols that require continuous home use [6] [14]. This efficiency can be attributed to active neuroplasticity driven by synchronous sensorimotor feedback. Unlike passive AFOs that immobilize the joint and risk disuse atrophy [10] [12], FES dynamically pairs the patient's voluntary movement intention with precise, phase-synchronized electrical stimulation of the tibialis anterior [15]. By immediately clearing toe drag and correcting proximal gait compensations like circumduction, FES breaks the energy-inefficient "vicious cycle" of hemiparetic walking [9]. This allows patients to execute a high volume of high-quality, symmetrical steps during every 10-to-30-minute session, maximizing motor relearning within a remarkably short clinical window.

This study has several limitations that should be considered when interpreting the results. First, the modest sample size, the single-assessor design, and the inherent unblinded nature of a single-group study without a control group limit the ability to isolate the independent effect of FES from concurrent daily rehabilitation and natural recovery. Additionally, baseline disease chronicity (time since injury) and foot-drop severity were not stratified in the analysis, which should be addressed in future trials. However, our findings demonstrate that the targeted addition of FES even at a moderate weekly frequency serves as a powerful adjuvant catalyst enabling substantial functional gains.

Given that patient enrollment was determined by clinical availability within a standard hospital setting rather than an a priori power analysis, there is a possibility that part of the observed recovery may be attributed to natural neurological healing or the intensive nature of the standard care program itself. Our study focused on a short-term, inpatient timeframe, and we did not perform long-term follow-up assessments to determine the durability of the therapeutic carry-over effect after patients returned to their home environments. Finally, the heterogeneous nature of the study population, while reflecting real-world clinical practice, introduces variability in disease progression and pathophysiology between stroke, MS, and Cerebral Palsy patients, which may influence individual responses to neuroprosthetic training.

Future research should prioritize larger, multicenter randomized controlled tri-

als incorporating a control group receiving conventional gait training without FES alongside stratified analyses based on etiology and chronicity. Furthermore, longitudinal studies with long-term post-discharge follow-ups are essential to evaluate whether the gains achieved during this short-term facility-based program can be maintained through home-based maintenance protocols, ensuring sustained functional independence for patients after discharge.

5. Conclusion

Our results suggest that even a short-term, low-frequency inpatient FES program can serve as a potent catalyst for motor relearning in patients with foot drop. By integrating phase-synchronized neurostimulation into standard clinical care, statistically significant and clinically meaningful gait improvements were observed across the majority of our mixed-population cohort. While subjective psychological and social domains were not directly measured, such biomechanical advancements carry the theoretical potential to indirectly support functional independence, confidence during mobility, reduce the fear of falling, and ultimately foster better community reintegration among neurological populations. Consequently, this pilot study supports further clinical implementation and investigation of facility-based FES, highlighting it as a promising, scalable strategy to enhance functional outcomes and quality of life in neurological rehabilitation.

Author Contributions

Lenka Hladíková: Conceptualization, methodology, formal analysis, investigation, writing—original draft, writing—review & editing, visualization, project administration.

Marie Listoňová: Methodology, investigation, data curation, writing—review & editing, supervision.

All authors have read and agreed to the published version of the manuscript.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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