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Research Article

Functional Balance and Electrophysiological Responses to Synchronized Lifestyle Modification and Physiotherapy in Type 2 Diabetic Peripheral Neuropathy

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ABSTRACT
Background: Diabetic peripheral neuropathy impairs proprioception, postural control, and mobility. Functional recovery may occur before measurable normalization of large-fiber electrophysiology, but few trials have evaluated balance and nerve-conduction outcomes together.
Objective: To compare the effects of synchronized lifestyle modification, supervised physiotherapy, and their combination on functional balance and lower-limb sensory and motor nerve-conduction parameters in adults with type 2 diabetic peripheral neuropathy.
Methods: In this four-arm randomized controlled trial, 120 adults aged 40–75 years were allocated to control (n=60), synchronized lifestyle modification (n=20), synchronized lifestyle modification plus physiotherapy (n=20), or physiotherapy (n=20). Interventions continued for 12 weeks. Balance was assessed using the Berg Balance Scale (BBS). Bilateral sural and peroneal sensory and peroneal and tibial motor nerve peak latency, amplitude, and conduction velocity were evaluated. BBS change scores were compared by one-way analysis of variance followed by Tukey testing. Nerve-conduction outcomes were assessed using the original repeated-measures analysis.
Results: Mean BBS change was −0.13±0.79 in control, +1.70±0.47 with lifestyle modification, +1.95±0.51 with the combined intervention, and +2.40±0.82 with physiotherapy. The between-group difference in change was significant ($F(3,116)=94.37$, $p<0.001$, $\eta^2=0.709$); every active intervention outperformed control. Physiotherapy produced a greater improvement than lifestyle modification alone (mean difference 0.70 points, 95% CI 0.11–1.29; $p=0.013$), whereas the combined intervention did not differ significantly from either active intervention. Nerve-conduction measures showed small favorable directional changes in active groups, but no statistically significant between-group electrophysiological effects were detected.
Conclusion: Twelve weeks of synchronized lifestyle modification and/or physiotherapy improved balance, while nerve-conduction parameters remained statistically unchanged. Functional gains may precede detectable electrophysiological recovery, although the absolute BBS changes were modest.

Keywords: Berg Balance Scale, Diabetic Peripheral Neuropathy, Nerve Conduction, Physiotherapy, Randomized Controlled Trial, Synchronized Lifestyle Modification.

INTRODUCTION

Diabetic peripheral neuropathy (DPN), most commonly expressed as distal symmetric polyneuropathy, is among the most prevalent and disabling chronic complications of diabetes. Its pathogenesis is multifactorial: sustained hyperglycemia interacts with dyslipidemia, mitochondrial dysfunction, oxidative stress, inflammation, and microvascular injury to damage peripheral axons, Schwann cells, and

their supporting microenvironment. [1,2] The resulting clinical phenotype ranges from neuropathic pain and paresthesia to numbness, loss of protective sensation, weakness, and impaired mobility. Contemporary guidance therefore emphasizes routine assessment of neuropathic symptoms, distal sensation, reflexes, and foot risk in people with type 2 diabetes. [3,4]

The functional consequences of DPN extend beyond pain. Loss of plantar cutaneous feedback and impaired joint-position sense reduce the accuracy of sensory information available for postural control, while distal weakness, restricted ankle mobility, and slower corrective responses constrain the motor strategies used to recover stability. Visual and vestibular information may partly compensate, but this compensation becomes less reliable during transfers, narrow-base standing, turning, or walking on uneven or poorly illuminated surfaces. [5] Systematic-review evidence links DPN with poorer postural stability, limitations in activities of daily living, altered gait, and a greater risk of falls.[6] Balance is therefore a clinically meaningful outcome in its own right rather than merely a surrogate for nerve damage. The proposed pathway from cardiometabolic disturbance to peripheral nerve injury and balance impairment is summarized in Figure 1.

Functional balance and peripheral nerve electrophysiology represent related but non-equivalent domains. The 14-item Berg Balance Scale (BBS) samples performance during sitting, standing, transfers, reaching, turning, and progressively demanding stance tasks. Nerve-conduction studies (NCS), in contrast, quantify large-fiber sensory and motor physiology through latency, amplitude, and conduction velocity. Clinical examination and NCS are valuable for characterizing DPN, but neither captures the full multisystem process that determines balance. [3,4] A patient may function better through strength gains, motor learning, improved use of residual sensory information, or greater confidence without demonstrable recovery of distal large-fiber conduction over the same interval. Measuring BBS and NCS together can therefore show whether a treatment produces parallel or dissociated functional and electrophysiological responses.

Exercise and physical activity are central components of type 2 diabetes management, and current recommendations include aerobic, resistance, flexibility, and balance exercise, adapted to the individual's comorbidities and foot-safety profile.[7] Recent systematic reviews in DPN generally report improvements in balance or related functional outcomes after physical rehabilitation, particularly when programs include balance, strengthening, gait, foot–ankle mobilization, or multicomponent training.[8–10,16–18,20] Nevertheless, the evidence base remains heterogeneous in intervention content, intensity, duration, outcome selection, and risk of bias.[8–10,16–18] Improvements observed on a balance scale should consequently be interpreted alongside their magnitude, clinical relevance, and transfer to outcomes such as falls and community mobility.

Whether exercise produces measurable electrophysiological recovery over a brief intervention is less certain. Recent evidence syntheses suggest that exercise may improve selected neuropathy measures and, in some studies, lower-limb conduction velocity; however, findings vary substantially by nerve, exercise prescription, disease duration, and study quality. [11,12,15,18,19] Structural axonal or myelin recovery may also require more time than neuromuscular adaptation. Short trials may therefore detect changes in balance before they detect stable between-group changes in NCS parameters.

Lifestyle programs may complement supervised rehabilitation by addressing diet, daily activity, hydration, sleep, and the regularity of health behaviors. The timing of sleep, meals, and activity has attracted interest because circadian misalignment and irregular sleep are associated with adverse glycemic and cardiometabolic profiles. [13,14] Yet human intervention evidence on deliberately changing sleep timing remains limited and inconsistent. [13] Accordingly, a timing-conscious lifestyle intervention should be viewed as a pragmatic behavioral package unless circadian phase, sleep timing, meal timing, and adherence are measured directly.

Pancreatic β cells also contain cell-autonomous molecular clocks that organize the daily timing of glucose-stimulated insulin secretion. In an experimental model of circadian disruption, disturbed feeding-fasting cycles impaired β-cell transcriptional and epigenetic identity and insulin secretory function, whereas restoring food intake to the active phase preserved these processes.[21] In a controlled human night-work model, daytime rather than nighttime eating maintained alignment of endogenous glucose and insulin rhythms and prevented

deterioration in glucose tolerance and β-cell function.[22] These findings provide a physiological rationale for regular daytime meals and avoidance of eating close to the biological night, although they do not establish one universally optimal clock time for eating.

Few randomized studies have concurrently compared a timing-conscious lifestyle program, supervised physiotherapy, and their combination while assessing both functional balance and lower-limb nerve conduction in adults with established DPN. This secondary-outcome report therefore evaluated 12-week changes in BBS scores and bilateral sensory and motor NCS parameters across four randomized groups. We hypothesized that each active intervention would improve BBS performance relative to standard care. NCS outcomes were examined as complementary electrophysiological endpoints, with the expectation that their response might be smaller or slower than the functional response.

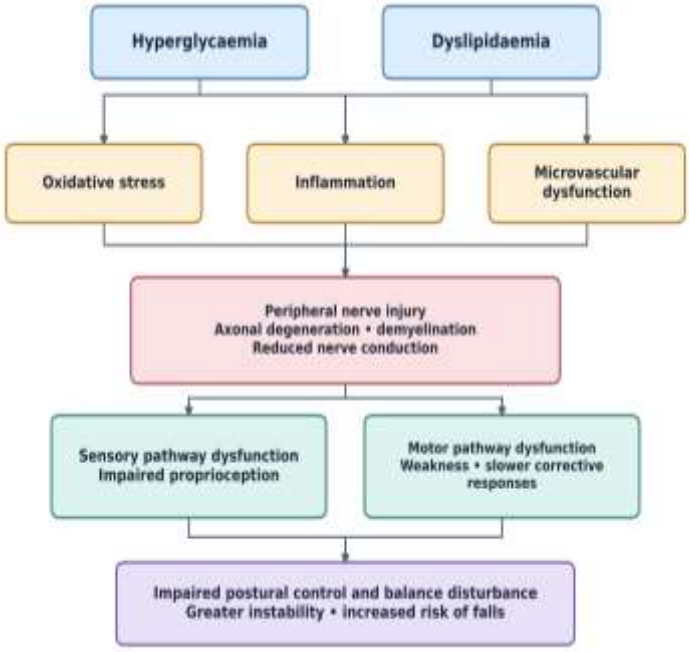

Figure 1. Proposed Mechanistic Pathway Linking Cardiometabolic Abnormalities to Balance Disturbance in Diabetic Peripheral Neuropathy.

Hyperglycaemia and dyslipidaemia may promote oxidative stress, inflammation, and microvascular dysfunction, contributing to peripheral nerve injury, impaired proprioception, motor dysfunction, postural instability, and increased fall risk. Adapted and simplified from Yang et al. [2] under the Creative Commons Attribution 4.0 International License (https://creativecommons.org/licenses/by/4.0/); the balance-related pathway was added. This conceptual pathway summarizes biologically plausible mechanisms and should not be interpreted as a causal model tested in the present trial.

METHODS

Study Design and Setting

This parallel, four-arm randomized controlled trial was conducted from October 2020 to October 2021 in the Department of Physiology and Multidisciplinary Laboratory of Islamic International Medical College, in collaboration with the Physiotherapy Department of Railway Hospital, Rawalpindi, Pakistan. The trial was registered at ClinicalTrials.gov (NCT04813146).

Participants

Adults of either sex, aged 40–75 years, with at least five years of clinically diagnosed type 2 diabetes, diabetic peripheral neuropathy, and treatment with oral hypoglycemic agents and a glucagon-like peptide-1 receptor agonist were eligible. Diabetic peripheral neuropathy was confirmed using the Michigan Neuropathy Screening Instrument physical examination score (>2.5). Exclusion criteria included type 1 diabetes, insulin therapy, neuropathy from other causes, major cardiac, hepatic, renal, ophthalmic, vascular, orthopedic, or lower-limb surgical disorders, active foot ulceration, inability to walk independently, concurrent structured physiotherapy, and pregnancy.

Randomization and Study Groups

A total of 120 participants were randomized using a computer-generated sequence in a 3:1:1:1 allocation ratio: control (Group A, n=60), synchronized lifestyle modification (Group 1, n=20), synchronized lifestyle modification plus physiotherapy (Group 2, n=20), and physiotherapy (Group 3, n=20). Baseline clinical, balance, biochemical, and electrophysiological evaluations were completed before intervention.

Baseline Lifestyle Assessment

Before randomization, trained healthcare professionals administered an investigator-developed lifestyle questionnaire in a face-to-face interview. The form recorded wake and sleep times; the timing and composition of breakfast, snacks, lunch, and dinner; water intake and its timing relative to meals; junk-food frequency and food cravings; walking or exercise; tobacco and other addictions; and daily screen time. Responses were used descriptively to characterize baseline routines and to individualize counseling within the standardized SLP framework; no composite lifestyle score was used in this analysis.

Interventions

The control group continued standard medical care without an additional study intervention. Participants allocated to SLP received the same written core protocol, with counseling tailored to routines identified by the baseline questionnaire. The 12-week program coordinated hydration, meal and snack timing, physical activity, and sleep. Core food options included whole-wheat or gram-flour flatbreads, lentils, eggs, chickpeas, vegetables or curries, yogurt, and fruit.

The written material was reinforced during follow-up visits and weekly telephone calls. Participants continued prescribed diabetes treatment and were instructed to report hypoglycemia, dizziness, or other adverse symptoms.

Supervised physiotherapy comprised aerobic, resistance, flexibility, and balance training. Exercise capacity was assessed before training. Sessions began at low intensity and progressed according to tolerance, reaching approximately 60 minutes per session, three sessions per week, for 12 weeks. Aerobic exercise included treadmill or cycling activity; resistance exercise used dumbbells at a moderate intensity; flexibility training included hamstring and calf stretching; and balance training included single-leg stance exercises. Participants assigned to the combined group received both programs.

Outcome Measures

Functional Balance

Balance was evaluated using the 14-item BBS. Each item is scored from 0 to 4, producing a total score from 0 to 56, with higher scores indicating better balance performance. [8,9] Assessments were completed at baseline and after 12 weeks.

Nerve-Conduction Studies

Nerve-conduction studies were performed by a neurophysiologist using a Keypoint workstation (Medtronic, France). Bilateral sural and peroneal sensory nerves and bilateral peroneal and tibial motor nerves were assessed. Recorded parameters included peak latency (ms), sensory amplitude (μV), motor amplitude (mV), and conduction velocity (m/s). Measurements were obtained at baseline and after 12 weeks. NCS results were interpreted as measures of large-fiber sensory and motor physiology. [3,4]

Statistical Analysis

Continuous outcomes are reported as mean±standard deviation. For this secondary-outcome manuscript, BBS participant-level records were verified against the prespecified baseline and 12-week summaries. Within-group changes were assessed using paired t tests. Change scores (12 weeks' minus baseline) were compared across the four groups using one-way analysis of variance; with two repeated observations, this evaluates the group-by-time difference in change. Tukey's honestly significant difference test was used for pairwise comparisons, and eta squared (η^2) quantified the omnibus effect. The original trial analysis evaluated nerve-conduction outcomes using repeated-measures analysis of variance followed by Tukey testing. Two-sided $p<0.05$ was considered significant. Analyses were performed using SPSS version 21 for the original trial, with independent verification of the BBS change-score analysis. Baseline lifestyle responses were summarized descriptively as percentages; no inferential between-group comparisons were performed for these questionnaire items.

Ethical Considerations

The study was approved by the Ethical Review Committee of Islamic International Medical College. All participants provided written

informed consent before enrollment. Study procedures were conducted in accordance with institutional ethical requirements.

RESULTS

Participant Characteristics

All 120 randomized participants were included in the available baseline and 12-week BBS dataset: 60 in control and 20 in each active-intervention group. Mean age ranged from 56.45 to 61.70 years, and women constituted 55%–65% of each group. Most participants were overweight or obese, and hypertension was common (70%–90%). Baseline characteristics are summarized in Table 1.

Table 1. Selected Baseline Characteristics by Randomized Group

Characteristic	Control n=60	SLP n=20	SLP + physiotherapy n=20	Physiotherapy n=20
Age, years	58.15±8.80	61.70±10.80	60.10±7.60	56.45±8.67
Female sex, n (%)	37 (62)	11 (55)	13 (65)	13 (65)
Overweight or obese, n (%)	50 (84)	17 (85)	18 (90)	17 (85)
Hypertension, n (%)	46 (77)	18 (90)	16 (80)	14 (70)
Current smoker, n (%)	11 (18)	6 (30)	5 (25)	5 (25)

Values are mean±SD or n (%). SLP, synchronized lifestyle modification program.

Baseline Lifestyle Patterns

The same general pattern of daily routines was evident across the four groups in the descriptive baseline questionnaire data. Between 65% and 75% of participants in each group reported waking between 09:00 and noon, and 75%–80% reported eating breakfast one to two hours after waking. A full lunch was reported by 40%–50%, whereas 20%–30% skipped lunch and 20%–40% substituted snacks. Dinner between 21:00 and 23:00 was reported by 40%–50%, while 25%–35% reported no dinner. Only 20%–30% reported regular walking or exercise; 35%–45% reported none and 25%–40% exercised occasionally. Prolonged screen exposure was also common, with 45%–60% reporting more than nine hours per day. These percentages are descriptive and were not subjected to inferential baseline comparisons.

Functional Balance

BBS scores remained essentially unchanged in the control group but increased in every active intervention group (Table 2 and Figure 2). Mean change differed significantly across groups ($F(3,116)=94.37$, $p<0.001$, $\eta^2=0.709$). Each active intervention produced greater improvement than control (all Tukey-adjusted $p<0.001$). Physiotherapy produced a larger mean improvement than SLP alone (mean difference 0.70 points, 95% CI 0.11–1.29; $p=0.013$). The difference between SLP and the combined intervention was not significant (0.25 points, $p=0.684$), nor was the difference between the combined intervention and physiotherapy (0.45 points, $p=0.195$).

Table 2. Berg Balance Scale Scores at Baseline and 12 Weeks

Group	n	Baseline	12 weeks	Mean change	Within-group p
Control	60	41.17±3.02	41.03±3.00	−0.13±0.79	0.197
SLP	20	39.75±3.32	41.45±3.33	+1.70±0.47	<0.001
SLP + physiotherapy	20	39.30±3.08	41.25±2.92	+1.95±0.51	<0.001
Physiotherapy	20	39.65±3.07	42.05±3.33	+2.40±0.82	<0.001

Values are mean±SD. Change=12-week score−baseline score; positive values indicate improved balance. Omnibus comparison of change: $F(3,116)=94.37$, $p<0.001$, $\eta^2=0.709$. SLP, synchronized lifestyle modification program.

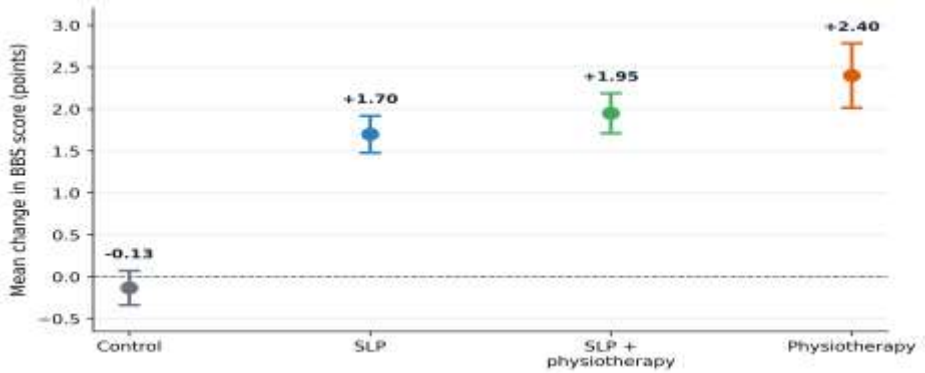

Figure 2. Mean Change in Berg Balance Scale Scores from Baseline to 12 Weeks Across the Four Randomized Groups.

Points represent group means and error bars represent 95% confidence intervals. Positive values indicate improvement in balance. Overall between-group comparison: $F(3,116)=94.37$, $p<0.001$, $\eta^2=0.709$. Tukey-adjusted comparisons showed that each active intervention differed from control (all $p<0.001$); physiotherapy also produced greater improvement than SLP ($p=0.013$). BBS, Berg Balance Scale; SLP, synchronized lifestyle modification program.

Nerve-Conduction Outcomes

Across active groups, sensory and motor nerve-conduction means generally changed in a favorable direction: peak latencies decreased slightly, amplitudes increased, and conduction velocities increased. The largest descriptive sensory changes were observed in the combined group, including a mean bilateral peroneal sensory latency reduction of 0.07 ms, amplitude increase of 0.08 μV, and conduction-velocity increase of 0.72 m/s. Motor changes were also small; in the combined group, mean bilateral motor latency decreased by up to 0.06 ms, amplitude increased by up to 0.04 mV, and conduction velocity increased by approximately 0.43–0.47 m/s. None of the original repeated-measures comparisons demonstrated a statistically significant between-group electrophysiological effect (all $p>0.05$). Mean bilateral changes are summarized in Table 3; side-specific baseline and 12-week values are provided in Supplementary Table S1.

Table 3. Mean bilateral Change in Nerve-Conduction Parameters from Baseline to 12 Weeks

Nerve	Parameter	Control	SLP	SLP + physiotherapy	Physiotherapy
Sural sensory	Peak latency, ms	+0.02	−0.05	−0.06	−0.05
	Amplitude, μV	−0.01	+0.03	+0.05	+0.03
	Conduction velocity, m/s	−0.15	+0.29	+0.55	+0.34
Peroneal sensory	Peak latency, ms	+0.01	−0.04	−0.07	−0.04
	Amplitude, μV	−0.02	+0.04	+0.08	+0.04
	Conduction velocity, m/s	−0.21	+0.33	+0.72	+0.36
Peroneal motor	Peak latency, ms	+0.01	−0.03	−0.04	−0.03
	Amplitude, mV	−0.01	+0.02	+0.03	+0.02
	Conduction velocity, m/s	−0.59	+0.32	+0.47	+0.27
Tibial motor	Peak latency, ms	+0.01	−0.04	−0.06	−0.03
	Amplitude, mV	−0.01	+0.02	+0.04	+0.02
	Conduction velocity, m/s	−0.07	+0.43	+0.43	+0.20

Values are changes calculated from the average of right- and left-sided group means. Negative latency and positive amplitude or conduction-velocity changes are directionally favorable.

These descriptive changes were not statistically significant in the original repeated-measures analyses. SLP, synchronized lifestyle modification program.

Supplementary Table S1
Side-specific nerve-conduction results at baseline and 12 weeks. Each cell presents baseline mean±SD followed by 12-week mean±SD.

Nerve	Parameter	Control	SLP	SLP + physiotherapy	Physiotherapy
Right sural sensory	Peak latency, ms	3.71±2.16 3.73±2.17	3.72±2.20 3.66±2.17	3.63±2.15 3.56±2.11	3.76±2.23 3.70±2.19
	Amplitude, μV	1.93±1.14 1.92±1.14	2.09±1.25 2.11±1.26	1.96±1.17 2.01±1.20	1.73±1.03 1.75±1.04
	Conduction velocity, m/s	28.42±16.58 28.33±16.52	28.34±16.82 28.54±16.94	28.30±16.79 28.72±17.04	28.22±16.73 28.43±16.85
Left sural sensory	Peak latency, ms	3.68±2.14 3.69±2.15	3.71±2.20 3.67±2.18	3.62±2.15 3.57±2.11	3.72±2.20 3.68±2.18
	Amplitude, μV	1.93±1.14 1.92±1.14	2.09±1.25 2.12±1.26	1.96±1.17 2.01±1.20	1.75±1.03 1.78±1.06
	Conduction velocity, m/s	28.49±16.62 28.28±16.50	28.42±16.86 28.79±17.09	28.39±16.84 29.06±17.25	28.67±17.01 29.13±17.28
Right peroneal sensory	Peak latency, ms	3.11±1.81 3.12±1.82	3.09±1.83 3.06±1.81	3.13±1.85 3.06±1.81	3.13±1.85 3.10±1.83
	Amplitude, μV	2.11±1.23 2.09±1.21	2.12±1.25 2.15±1.27	2.11±1.25 2.20±1.30	2.11±1.25 2.15±1.27
	Conduction velocity, m/s	29.54±17.20 29.32±17.08	29.58±17.53 29.90±17.72	29.38±17.41 30.14±17.85	29.65±17.57 29.95±17.75
Left peroneal sensory	Peak latency, ms	3.12±1.82 3.13±1.83	3.09±1.83 3.04±1.80	3.13±1.85 3.06±1.81	3.13±1.85 3.08±1.83
	Amplitude, μV	2.11±1.23 2.09±1.21	2.11±1.25 2.15±1.27	2.10±1.24 2.17±1.29	2.10±1.24 2.14±1.27
	Conduction velocity, m/s	29.44±17.15 29.25±17.04	29.42±17.44 29.76±17.64	29.36±17.40 30.04±17.80	29.53±17.50 29.95±17.75
Right peroneal motor	Peak latency, ms	3.85±2.24 3.86±2.25	3.86±2.29 3.84±2.27	3.85±2.28 3.82±2.26	3.84±2.28 3.82±2.26
	Amplitude, mV	0.99±0.58 0.98±0.57	0.98±0.58 0.99±0.59	1.00±0.59 1.03±0.61	0.99±0.58 1.01±0.61
	Conduction velocity, m/s	29.33±16.49 28.25±16.45	28.29±16.76 28.59±16.94	28.36±16.80 28.67±16.98	28.34±16.79 28.53±16.90
Left peroneal motor	Peak latency, ms	3.86±2.25 3.86±2.25	3.87±2.29 3.84±2.28	3.86±2.29 3.82±2.26	3.86±2.28 3.83±2.27
	Amplitude, mV	0.97±0.56 0.96±0.56	0.95±0.56 0.97±0.57	0.99±0.58 1.02±0.61	0.97±0.58 0.99±0.59
	Conduction velocity, m/s	28.09±16.36 28.00±16.30	27.87±16.51 28.20±16.70	28.27±16.75 28.90±17.12	28.15±16.68 28.49±16.88
Right tibial motor	Peak latency, ms	3.76±2.19 3.77±2.20	3.75±2.22 3.73±2.21	3.79±2.24 3.75±2.22	3.75±2.22 3.72±2.20
	Amplitude, mV	1.05±0.61 1.04±0.60	1.06±0.62 1.07±0.63	1.04±0.61 1.08±0.64	1.05±0.62 1.07±0.63
	Conduction velocity, m/s	27.19±15.84 27.07±15.77	27.23±16.14 27.48±16.28	27.12±16.07 27.41±16.24	27.24±16.14 27.63±16.37
Left tibial motor	Peak latency, ms	3.76±2.19 3.77±2.20	3.75±2.22 3.70±2.19	3.79±2.24 3.71±2.19	3.75±2.22 3.72±2.20

	Amplitude, mV	1.05±0.61 1.04±0.60	1.05±0.63 1.08±0.64	1.04±0.61 1.08±0.64	1.05±0.62 1.06±0.63
	Conduction velocity, m/s	27.19±15.84 27.17±15.83	27.23±16.13 27.83±16.49	27.12±16.07 27.69±16.41	27.24±16.14 27.24±16.14

Cell order: baseline on the first line and 12-week value on the second line. Values are mean±SD. No original repeated-measures between-group comparison was statistically significant (all $p>0.05$).

DISCUSSION

Principal Findings

This four-arm randomized trial showed a marked divergence between functional and electrophysiological outcomes over 12 weeks. BBS scores remained essentially unchanged in the control group but improved in all three active-intervention groups. The largest mean increase occurred with supervised physiotherapy, and the physiotherapy group improved more than the synchronized lifestyle modification program (SLP) group. By contrast, no evaluated sensory or motor nerve-conduction parameter demonstrated a statistically significant between-group change. The findings therefore support a short-term functional balance benefit while providing no evidence of parallel large-fiber electrophysiological recovery.

Functional Balance Response

The balance response is biologically and clinically plausible. DPN compromises plantar sensation, proprioception, distal strength, ankle mobility, and the timing of corrective responses, all of which can destabilize standing and gait.[5,6] The physiotherapy program directly targeted several of these modifiable constraints through aerobic, resistance, flexibility, and balance exercises. Repeated practice may improve lower-limb force production, anticipatory and reactive postural strategies, coordination, and the use of remaining sensory information. Recent reviews similarly conclude that physical rehabilitation can improve balance outcomes in people with DPN, although intervention protocols and certainty of evidence vary.[8–10,16–18] A recent randomized study of computer-based balance exercise also reported improvements in balance-related outcomes, although its protocol and population differ from the present trial.[20] The larger mean gain with physiotherapy than with SLP is consistent with the specificity of training: participants repeatedly practiced the physical capacities most closely represented in BBS tasks. However, the absolute changes were modest—approximately 1.7 to 2.4 points across active groups.

Lifestyle Intervention and Timing-Conscious Care

The baseline questionnaire provides important context for the SLP response. Late waking and breakfast, late or omitted evening meals, low levels of regular walking or exercise, and prolonged screen exposure were common across groups. These patterns identify practical targets for diabetes self-management and help explain why a structured program was relevant to this cohort. They should not, however, be interpreted as independent predictors of balance or as mechanisms of treatment response: the questionnaire was administered before randomization, the items were summarized descriptively, and no mediation analysis was performed.

SLP was a multicomponent, timing-conscious package rather than an isolated dietary or circadian intervention. A standardized written core coordinated hydration, meals and snacks, daily walking, and sleep, while the baseline interview allowed counseling to address each participant's routine. Weekly calls and follow-up review were intended to reinforce adherence and preserve delivery fidelity. SLP alone improved BBS relative to control, but because the components were delivered together and were not evaluated as mediators, the balance response cannot be assigned to meal timing, walking, sleep advice, hydration, or any other single component. The larger gain with physiotherapy is consistent with the greater task specificity of progressive balance and exercise training.

The dietary schedule can therefore be viewed as a pragmatic attempt to strengthen feeding-fasting cues. Water on waking, breakfast at approximately 09:00, planned daytime meals and snacks, and dinner at least two hours before sleep were intended to replace irregular or late eating with a more consistent daily pattern. Aligning nutrient exposure with the habitual active phase may reduce a mismatch between meal-related insulin demand and circadian variation in β-cell responsiveness.[21,22] This interpretation concerns the timing and regularity of the prescribed diet, not a unique effect of fruit, green tea, whole grains, or another individual food.

The synchronized or timing-conscious interpretation nevertheless remains provisional. Recent work links sleep and circadian characteristics with glycemic control and diabetes complications, but a systematic review of altered sleep timing found heterogeneous and inconclusive glycemic effects. [13,14] The present trial did not measure insulin or C-peptide secretion, continuous glucose profiles, sleep or activity objectively, chronotype, circadian phase, or meal timing relative to dim-light melatonin onset. Adherence to the prescribed eating schedule was also not quantified. Circadian alignment of β-cell insulin release is therefore a biologically plausible rationale for the SLP, not a demonstrated mediator of its BBS effect.

Electrophysiological Response

The nonsignificant NCS findings contrast with the directionally favorable mean changes seen in several active groups but are compatible with the variable literature. Recent reviews report possible exercise-related improvements in selected nerve-function or conduction outcomes, yet substantial heterogeneity remains across nerves, protocols, participants, and measurement methods. [11,12,15,18,19] The present trial's active arms were small, multiple electrophysiological endpoints were examined, and no single NCS outcome showed a reliable between-group effect. Directional changes should therefore be treated as exploratory rather than as evidence of nerve regeneration.

Several explanations may account for the null between-group comparisons. NCS primarily reflects the physiology of large myelinated fibers and does not directly quantify small-fiber function, postural integration, muscle strength, or motor learning. [3,4] In established DPN, detectable axonal regeneration, remyelination, or reversal of distal conduction abnormalities may require longer exposure than 12 weeks. Supporting this temporal interpretation, a 12-week high-intensity interval-training study improved cardiovascular autonomic function but did not change somatosensory nerve function or structure. [19] Small biological changes may also be obscured by limb temperature, electrode placement, technical variability, and between-person differences in baseline neuropathy. A null result in this setting means that the study did not demonstrate a treatment effect on the tested NCS measures; it does not prove that neural physiology was unaffected.

Interpreting Functional–Electrophysiological Discordance

The separation between BBS and NCS responses highlights why both outcome types are useful. Balance emerges from sensory input, central integration, musculoskeletal capacity, learned movement strategies, attention, and confidence. Improvements in any of these domains can raise BBS performance even when distal large-fiber conduction is unchanged. Conversely, a small electrophysiological change may not translate into an observable functional gain. Functional and NCS endpoints should therefore be interpreted as complementary indicators rather than interchangeable measures of recovery.

STRENGTHS AND LIMITATIONS

Strengths include the randomized four-arm design, direct comparison of two nonpharmacologic strategies and their combination, concurrent assessment of a clinically interpretable functional outcome and objective bilateral electrophysiological measures, and consistent directional coding of NCS change. The verified participant-level BBS dataset permitted analysis of individual change rather than reliance on group means. The baseline lifestyle assessment adds local behavioral context, and the detailed protocol and questionnaire supplied as appendices improve intervention transparency and reproducibility. Several limitations are important. First, BBS and NCS were secondary outcomes, and the unequal 3:1:1:1 allocation left only 20 participants in each active arm, limiting precision for active-treatment comparisons and increasing the possibility of false-negative NCS results. Second, the 12-week follow-up may have been sufficient for neuromuscular adaptation but too short for stable electrophysiological remodeling. Third, the lifestyle questionnaire was investigator-developed, and evidence of reliability or construct validity was not available. Its interviewer-administered self-report items are vulnerable to recall and social-desirability bias, and several broad response categories limit measurement precision. Lifestyle behaviors were not reassessed at 12 weeks. Although standardized materials, follow-up review, and weekly calls supported fidelity, adherence was not captured with a validated quantitative measure; mechanisms, behavioral change, and dose–response relationships therefore could not be tested. Fourth, the study did not assess

falls, gait speed, fear of falling, patient-reported function, strength, or quality of life; statistical improvement in BBS cannot therefore be assumed to represent broader clinical benefit. Fifth, the absence of a prespecified DPN-specific threshold for meaningful BBS change limits interpretation of the modest score gains. Sixth, numerous NCS parameters were explored without adjustment for multiple comparisons, and the electrophysiological change values were derived from bilateral group means rather than analyzed from participant-level repeated measures. Finally, the single-center Pakistani cohort and eligibility criteria may limit generalizability to patients with different neuropathy severity, comorbidity profiles, or access to supervised rehabilitation.

Clinical Implications

These results support adding structured functional assessment to DPN care and research. A 12-week supervised, progressive program that includes balance, strengthening, flexibility, and aerobic exercise may improve task-based balance even when standard NCS measures remain unchanged. [7–10,16–18,20] This does not justify replacing neurological examination or electrophysiology with the BBS; each addresses a different clinical question. A brief assessment of meal timing, walking, sleep, hydration, and screen exposure may help clinicians identify counseling targets, but it should complement rather than replace task-specific rehabilitation. Rehabilitation should be individualized to foot integrity, vision, cardiovascular status, hypoglycemia risk, and baseline fall risk, with appropriate supervision and progression. [3,7] Timing-conscious lifestyle advice may be incorporated within broader diabetes self-management, but the independent effects of its components and of circadian synchronization remain unproven. Future multicenter trials should use larger balanced groups, validated lifestyle instruments, blinded outcome assessment where feasible, objective adherence and sleep–activity monitoring, participant-level longitudinal NCS analysis, and follow-up long enough to examine falls, sustained function, and neural change.

CONCLUSION

Synchronized lifestyle modification, physiotherapy, and their combination improved BBS performance relative to control over 12 weeks in adults with type 2 diabetic peripheral neuropathy. Electrophysiological parameters showed small favorable directional changes but no significant between-group effects. Functional balance may respond earlier than large-fiber nerve conduction; however, the modest absolute BBS gains and limitations of the available NCS data require cautious interpretation.

Declarations

Ethics approval and consent to participate: Approved by the Ethical Review Committee of Islamic International Medical College; all participants provided written informed consent.
Trial registration: ClinicalTrials.gov identifier NCT04813146.
Consent for publication: Not applicable; no identifiable participant information is presented.
Data availability: Deidentified data may be requested from the corresponding author subject to institutional and ethical approval.
Supplementary materials: Supplementary Appendix A provides the detailed SLP intervention protocol, and Supplementary Appendix B reproduces the baseline Lifestyle Assessment Questionnaire.

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