

Original Article

Effects of Sensorimotor and Gait Training on Balance, Proprioception and Gait in Patients with Diabetic Peripheral Neuropathy

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ABSTRACT

Background: Diabetic peripheral neuropathy (DPN) is associated with impaired balance, proprioception, and gait, contributing to functional limitations and reduced mobility. **Objective:** To compare the effects of conventional physiotherapy and combined sensorimotor and gait training on balance, proprioception-related performance, and gait in patients with DPN. **Methods:** This randomized controlled trial was conducted at Link Medical Center, Lahore, Pakistan. Seventy-two patients with DPN were allocated equally to conventional physiotherapy (n=36) and gait/sensorimotor training (n=36) groups. Outcomes were assessed at baseline, week 6, and week 12 using the Berg Balance Scale (BBS), Six-Minute Walk Test (6MWT), Ten-Meter Walk Test (10MWT), and Pedalo-Sensamove Balance Test. Independent-samples t-tests and repeated-measures ANOVA were used for statistical analysis. **Results:** At week 12, the gait/sensorimotor group demonstrated higher BBS scores (47.97±4.07 vs. 43.11±4.97; p<0.001) and greater 6MWT distance (461.53±34.35 vs. 387.58±41.93 m; p<0.001). The group also demonstrated shorter 10MWT completion times (4.75±0.73 vs. 6.91±1.29 seconds; p<0.001) and higher Pedalo-Sensamove scores (9.79±0.59 vs. 8.12±0.87; p<0.001). **Conclusion:** Both groups demonstrated favorable functional changes, with larger observed improvements following combined sensorimotor and gait training. These findings suggest potential additional benefits, although definitive treatment superiority requires further verification of longitudinal effects. **Keywords:** Diabetic Peripheral Neuropathy; Sensorimotor Training; Gait Training; Postural Balance; Proprioception; Walking Performance.

INTRODUCTION

Diabetic peripheral neuropathy (DPN) is one of the most common neurological complications of diabetes mellitus and represents a significant cause of sensory impairment, functional disability, and reduced independence among affected individuals. It develops through progressive damage to peripheral nerves, particularly those supplying the

distal lower extremities, and is commonly characterized by numbness, tingling, burning sensations, altered vibration perception, and impaired protective sensation. As the condition advances, abnormalities in muscle function, postural stability, and walking performance may become increasingly apparent, contributing to limitations in daily activities and an elevated risk of falls. The clinical burden of DPN extends beyond neuropathic symptoms because its functional consequences may compromise mobility, participation, and overall quality of life (1,2).

The prevalence of DPN varies across populations according to diabetes duration, glycemic control, diagnostic criteria, and accompanying metabolic conditions. Epidemiological evidence indicates that peripheral neuropathy affects a substantial proportion of individuals with diabetes, with its occurrence influenced by both modifiable and nonmodifiable risk factors. A systematic review and meta-analysis conducted in Latin America and the Caribbean demonstrated the considerable burden of diabetic neuropathy, while evidence from the Diabetes Control and Complications Trial and its observational follow-up identified important relationships between metabolic risk factors and neuropathic complications. Prolonged exposure to hyperglycemia, increasing diabetes duration, and associated cardiovascular and metabolic abnormalities contribute to the development and progression of peripheral nerve dysfunction (3,4). These findings emphasize the importance of addressing not only metabolic management but also the physical impairments associated with established neuropathy.

The pathophysiology of DPN involves interacting metabolic, vascular, inflammatory, and neurodegenerative processes that compromise peripheral nerve structure and function. Chronic hyperglycemia contributes to oxidative stress, accumulation of advanced glycation end products, microvascular dysfunction, and abnormalities in neuronal metabolism. These mechanisms may affect sensory and motor nerve fibers, leading to disturbed afferent feedback and reduced neuromuscular efficiency. Impairment of large sensory fibers can diminish vibration and joint-position sensation, whereas motor involvement may contribute to muscular weakness and impaired movement control. Consequently, individuals with DPN may develop difficulties maintaining equilibrium, adapting to changes in the supporting surface, and coordinating lower-limb movements during functional activities (2,5). Such impairments provide a physiological basis for incorporating targeted sensorimotor rehabilitation into the management of diabetic neuropathy.

Balance control depends on the coordinated integration of somatosensory, visual, and vestibular information with appropriate motor responses. Among individuals with DPN, reduced plantar sensation and impaired lower-limb proprioceptive feedback can compromise the ability to detect changes in body position and make timely postural adjustments. These abnormalities may become particularly evident during standing, weight shifting, turning, and walking over unfamiliar or uneven surfaces. Timar et al. demonstrated an association between diabetic neuropathy, impaired balance, and increased fall risk among individuals with type 2 diabetes mellitus (6). Similarly, Mustapa et al., in a systematic review examining postural control and gait performance, identified disturbances in stability and walking characteristics among individuals with DPN, highlighting the contribution of sensory dysfunction to compromised locomotor performance (7).

The functional consequences of DPN are particularly important in middle-aged and older adults, among whom sensory impairment may coexist with reduced muscle strength, slower motor responses, and age-related changes in postural control. Kraiwong et al. reported that sensory impairments and lower-extremity muscle weakness were associated with poorer balance performance in older adults with type 2 diabetes mellitus (8). Reduced ankle control and altered somatosensory input may influence standing stability and the regulation of body movements during walking. These changes can restrict the individual's ability to perform activities requiring dynamic balance, including negotiating obstacles, changing direction, and maintaining stability while walking. Therefore, the assessment of balance and gait performance represents an important component of rehabilitation planning for individuals with diabetic neuropathy.

Conventional physiotherapy management of DPN-related functional limitations commonly incorporates muscle strengthening, flexibility exercises, balance activities, and functional mobility training. These approaches aim to preserve mobility, improve physical capacity, and reduce the consequences of neuromuscular impairment. Nevertheless, rehabilitation strategies directed specifically toward the integration of sensory information and motor performance have received increasing attention. Sensorimotor training involves exercises designed to improve postural awareness, proprioceptive processing, coordination, and the ability to respond appropriately to

changes in body position or the supporting surface. Gait training focuses on improving walking mechanics, lower-extremity coordination, functional walking performance, and adaptation to different movement demands. A narrative review by Ahmad et al. highlighted the clinical relevance of balance training for individuals with DPN and identified exercise-based rehabilitation as a potentially beneficial approach for improving postural stability and gait function (9).

Previous clinical investigations have demonstrated that structured exercise programs may improve balance and walking-related outcomes in individuals with diabetic neuropathy. Song et al. examined an exercise program among older adults with diabetic neuropathies and reported improvements in balance and trunk proprioception, supporting the potential contribution of targeted physical activity to sensorimotor function (10). In a randomized controlled study, Ahmad et al. investigated the effects of sensorimotor training on balance and proprioception among middle-aged and older adults with DPN. Their findings indicated improvements in static and dynamic balance and proprioceptive performance following an eight-week intervention, suggesting that exercises targeting sensory-motor integration may offer functional benefits in this population (11). These findings support the incorporation of progressive balance and proprioceptive exercises into neurological physiotherapy interventions.

Evidence regarding gait-focused rehabilitation has also demonstrated encouraging findings. Melese et al. conducted a systematic review of randomized controlled trials examining the effectiveness of exercise therapy on gait function in patients with DPN. The review included nine trials involving 370 participants and reported that most included studies demonstrated improvements in walking-related outcomes following exercise interventions. The reviewed programs incorporated strengthening, balance activities, flexibility exercises, circuit training, and gait-specific activities, although differences in intervention protocols limited direct comparisons across studies (12). These findings suggest that multimodal rehabilitation may contribute to improved walking capacity, but variability in treatment content, intensity, and duration complicates the identification of the most effective exercise components.

Combined sensorimotor and gait training may offer additional benefits by targeting both sensory-motor coordination and functional walking performance. Ahmad et al. conducted a randomized controlled trial investigating the effects of sensorimotor and gait training on proprioception, peripheral nerve function, and muscular activation among patients with DPN. The study reported improvements in proprioceptive performance, selected nerve-function measures, and muscle activation following an eight-week training program (13). These findings provide support for the potential value of interventions that integrate postural control, lower-limb coordination, and gait-related exercises. However, improvements in physiological or neuromuscular measurements do not necessarily establish equivalent benefits across all functional balance and walking outcomes. Further evaluation using standardized clinical performance measures is therefore relevant to understanding the practical implications of combined training.

Despite the growing literature supporting exercise-based rehabilitation in DPN, uncertainty remains regarding the comparative effectiveness of combined sensorimotor and gait training relative to conventional physiotherapy. Previous investigations have used heterogeneous intervention protocols, comparison groups, outcome measures, and assessment periods, limiting the direct interpretation of their findings. Moreover, studies examining specific sensorimotor outcomes or individual exercise approaches do not fully establish whether a combined program produces greater changes in functional balance, walking endurance, walking performance, and proprioception-related measures than routine physiotherapy. Although existing randomized trials provide important evidence concerning sensorimotor rehabilitation, further comparative assessment using clinically relevant functional measures may help clarify the potential additional benefits of combined training (11–13).

Standardized functional assessments are important for evaluating rehabilitation outcomes in this population. The Berg Balance Scale provides a measure of performance across functional balance tasks, whereas the Six-Minute Walk Test evaluates walking endurance and the Ten-Meter Walk Test assesses walking performance over a defined distance. Measures obtained through sensorimotor assessment devices may additionally provide information regarding postural and proprioceptive-related performance, although interpretation depends on the specific measurement protocol and scoring characteristics. Evaluating these outcomes at multiple assessment points allows changes in functional performance to be examined over time and provides a basis for comparing

rehabilitation approaches. Such comparisons are clinically relevant because improvements in postural control and walking capacity may contribute to greater functional independence among individuals with diabetic neuropathy.

Accordingly, the present randomized controlled trial was designed to compare conventional physiotherapy with a rehabilitation approach incorporating sensorimotor and gait training among patients with diabetic peripheral neuropathy. The study evaluated balance, walking endurance, walking performance, and proprioception-related outcomes using the Berg Balance Scale, Six-Minute Walk Test, Ten-Meter Walk Test, and Pedalo-Sensamove Balance Test at baseline, week 6, and week 12. The objective of this study was to determine the comparative effects of conventional physiotherapy and sensorimotor and gait training on balance, proprioception, and gait performance in patients with diabetic neuropathy.

MATERIAL AND METHODS

This study was conducted as a randomized controlled trial to compare the effects of conventional physiotherapy with a combined sensorimotor and gait training program on balance, proprioception, and walking performance among patients with diabetic peripheral neuropathy (DPN). The study employed a parallel-group comparative design, in which participants were allocated to either a conventional physiotherapy group or a gait/sensorimotor training group. Functional outcomes were evaluated repeatedly to examine changes in balance, walking endurance, walking performance, and proprioception-related function over the assessment period. The research was conducted in the Department of Physiotherapy at Link Medical Center, Sunny Park, Lahore, Pakistan. The study protocol specified a duration of nine months following synopsis approval, while the reported clinical outcome assessments extended from baseline to 12 weeks.

The target population comprised male and female patients aged 45–75 years with physician-diagnosed diabetic peripheral neuropathy. Participants were recruited through a nonprobability purposive sampling technique according to predefined eligibility criteria. Individuals were considered eligible if they had a confirmed clinical diagnosis of DPN, were able to stand and walk independently, had a stable medical condition, and had no additional condition that would prevent safe participation in the rehabilitation program. Patients were excluded if they had neurological or orthopedic disorders likely to influence balance or gait, required assistive devices for walking or standing, had active foot ulcers, had orthopedic or surgical problems affecting the lower extremities, or presented with major vascular complications. These criteria were intended to recruit ambulatory individuals with DPN whose functional balance and walking performance could be evaluated through standardized clinical assessments. The eligibility criteria were informed by previous clinical investigations of sensorimotor rehabilitation among individuals with diabetic neuropathy (11).

The final study sample comprised 72 participants, with 36 allocated to each treatment group. The sample-size planning section referred to a previous randomized controlled trial and used expected mean changes of 4.46 and 7.32 in a Timed Up and Go-related outcome, with corresponding standard deviations of 2.27 and 4.31. The calculation specified a two-sided significance level of 5%, statistical power of 80%, and an allowance for potential participant dropout. The final enrollment target was 72 participants, equally distributed between the two groups. These assumptions were informed by previously published research evaluating sensorimotor and gait training in individuals with DPN (13). Eligible participants were allocated to the two groups using a randomization sequence generated through randomization.org. Group A received conventional physiotherapy, whereas Group B received the sensorimotor and gait training intervention in addition to routine physiotherapy. This allocation approach was intended to facilitate comparative assessment of functional outcomes between the treatment groups.

Before participation, patients were informed about the research purpose, assessment procedures, voluntary nature of participation, and confidentiality of their personal information. Written informed consent was specified in the research procedures. Participants were informed of their right to withdraw from the study, and the protocol described the use of confidential records to protect identifying information. Baseline assessments included demographic and clinical information obtained through a structured patient assessment form. Recorded variables included age, sex, socioeconomic status, body weight, height, body mass index (BMI), number of reported diseases, and number of medications. Socioeconomic status was categorized as upper, middle, or lower, while age was recorded in years, weight in kilograms, and height in centimeters. BMI was expressed in kilograms per square meter (kg/m^2). These characteristics were collected to describe the study population and examine the comparability of the treatment groups at baseline.

Functional outcomes were assessed using the Berg Balance Scale (BBS), Six-Minute Walk Test (6MWT), Ten-Meter Walk Test (10MWT), and Pedalo-Sensamove Balance Test. The BBS was used to evaluate functional balance during activities involving sitting, standing, transfers, reaching, turning, and maintenance of different standing positions. The scale comprises 14 functional tasks, each scored from 0 to 4, producing a maximum total score of 56. Higher scores indicate better functional balance, while lower scores reflect greater balance impairment. The BBS was selected to quantify changes in functional stability and postural performance during the intervention and follow-up assessments.

Walking endurance was evaluated using the 6MWT, with performance expressed as the distance covered in meters during a six-minute walking period. Greater walking distance was interpreted as better functional walking capacity. The 10MWT was used to assess walking performance over a distance of 10 meters, with the recorded outcome expressed in seconds. A shorter completion time indicated faster walking performance. Together, these tests provided complementary measurements of walking endurance and short-distance walking ability, allowing changes in locomotor function to be examined during rehabilitation. Their selection was consistent with previous research investigating exercise-based interventions and gait-related functional outcomes among patients with DPN (12).

Proprioception-related performance was assessed using the Pedalo-Sensamove Balance Test, incorporating a Balance Test Pro system with a Miniboard. The assessment procedure involved positioning participants on the sensor-equipped board and examining their ability to reproduce previously demonstrated postural positions. Participants initially received instructions regarding the procedure and were asked to tilt the board in forward, backward, rightward, and leftward directions to establish the movement range. A reference position was then presented visually on the connected display. Participants attempted to shift their center of pressure toward the indicated target and subsequently reproduce the position without the visual marker. The procedure was intended to assess the ability to recognize and reproduce body-position-related information during controlled postural movements. This assessment approach was informed by previous research on sensorimotor and gait training in patients with DPN (13).

Both treatment groups received routine physiotherapy as the baseline rehabilitation approach. The conventional physiotherapy program incorporated therapeutic activities directed toward lower-extremity strengthening, balance, endurance, and functional mobility. The described treatment components included lower-limb strengthening exercises, balance activities involving unstable supporting surfaces, and walking-related exercises emphasizing foot clearance, step length, and stride length. Treatment was directed toward maintaining functional movement, improving stability, and supporting walking ability among patients with neuropathy-associated mobility limitations. The control intervention was described as a routine rehabilitation program, providing a comparison against the more structured sensorimotor and gait training approach administered to the experimental group.

Participants allocated to the Gait/Sensorimotor Group received a structured rehabilitation program incorporating lower-extremity strengthening, sensorimotor exercises, balance activities, and gait training. The documented intervention schedule consisted of three supervised sessions per week on alternate days over eight weeks, corresponding to 24 planned treatment sessions. Each session included an approximately 10-minute warm-up, followed by 50–60 minutes of therapeutic exercise and a 5–10-minute cool-down period. The warm-up involved a cycle ergometer or treadmill, with the prescribed exercise intensity corresponding to approximately 40–50% of maximum heart rate.

RESULTS

A total of 72 patients with diabetic peripheral neuropathy were included in the randomized controlled trial, with 36 participants allocated to the Conventional Group and 36 to the Gait/Sensorimotor Group. Baseline demographic and clinical characteristics are presented in Table 1. The mean age was 61.28 ± 8.02 years in the Conventional Group and 59.94 ± 9.52 years in the Gait/Sensorimotor Group ($p=0.521$). Male participants constituted 58.3% ($n=21$) and 77.8% ($n=28$) of the respective groups ($p=0.129$). Most participants belonged to the middle socioeconomic category, accounting for 80.6% of the Conventional Group and 61.1% of the Gait/Sensorimotor Group. Mean body mass index was 25.40 ± 1.61 kg/m² and 25.67 ± 1.58 kg/m², respectively ($p=0.475$). No, statistically significant between-group differences were identified in the reported baseline continuous demographic characteristics or sex distribution.

Functional balance outcomes, assessed using the Berg Balance Scale (BBS), are presented in Table 2. Baseline scores were comparable between the Conventional Group (32.25 ± 4.74) and the Gait/Sensorimotor Group (32.69 ± 4.24), with a between-group mean difference of 0.44 points (95% CI: -1.67 to 2.55 ; $p=0.679$). Both groups demonstrated progressively higher balance scores at subsequent assessments. At week 6, the Gait/Sensorimotor Group achieved a mean score of 41.11 ± 3.97 compared with 37.44 ± 4.84 in the Conventional Group, corresponding to a between-group difference of 3.67 points (95% CI: 1.59 to 5.75 ; $p<0.001$). By week 12, mean BBS scores had increased to 47.97 ± 4.07 and 43.11 ± 4.97 , respectively, yielding a between-group difference of 4.86 points (95% CI: 2.72 to 7.00 ; $p<0.001$). The baseline-to-week-12 mean changes were 15.28 points in the Gait/Sensorimotor Group and 10.86 points in the Conventional Group. The standardized between-group difference at week 12 was large (Hedges' $g=1.06$).

Walking endurance, assessed using the Six-Minute Walk Test (6MWT), also increased across the assessment period (Table 3). At baseline, the mean walking distance was 237.58 ± 39.54 m in the Conventional Group and 248.61 ± 34.82 m in the Gait/Sensorimotor Group, with no statistically significant between-group difference (MD= 11.03 m; 95% CI: -6.49 to 28.55 ; $p=0.213$). At week 6, walking distances increased to 308.03 ± 40.10 m and 361.28 ± 34.49 m, respectively, producing a between-group difference of 53.25 m (95% CI: 35.66 to 70.84 ; $p<0.001$). By week 12, participants in the Gait/Sensorimotor Group covered 461.53 ± 34.35 m compared with 387.58 ± 41.93 m in the Conventional Group. The between-group difference was 73.95 m (95% CI: 55.92 to 91.98 ; $p<0.001$), with a large standardized effect size (Hedges' $g=1.91$). The corresponding baseline-to-week-12 increases were 212.92 m and 150.00 m, respectively, indicating a greater observed increase in walking endurance in the Gait/Sensorimotor Group.

Ten-Meter Walk Test (10MWT) outcomes demonstrated progressively shorter walking completion times in both treatment groups (Table 4). At baseline, the mean completion time was 11.75 ± 1.50 seconds in the Conventional Group and 12.14 ± 1.22 seconds in the Gait/Sensorimotor Group, with a between-group difference of 0.39 seconds (95% CI: -0.25 to 1.03 ; $p=0.230$). At week 6, completion times decreased to 9.19 ± 1.62 seconds and 7.86 ± 1.68 seconds, respectively, corresponding to a between-group difference of -1.33 seconds (95% CI: -2.11 to -0.55 ; $p=0.001$). At week 12, the Gait/Sensorimotor Group recorded a mean completion time of 4.75 ± 0.73 seconds compared with 6.91 ± 1.29 seconds in the Conventional Group (MD= -2.16 seconds; 95% CI: -2.65 to -1.66 ; $p<0.001$). Mean completion time decreased by 7.39 seconds in the Gait/Sensorimotor Group and 4.84 seconds in the Conventional Group between baseline and week 12. The standardized between-group difference at week 12 was large (Hedges' $g=-2.04$), reflecting faster walking performance in the Gait/Sensorimotor Group at the final assessment.

Pedalo-Sensamove Balance Test findings are presented in Table 5. Baseline scores were similar between the Conventional Group (3.07 ± 0.47) and the Gait/Sensorimotor Group (3.08 ± 0.43), with a mean difference of 0.01 (95% CI: -0.20 to 0.22 ; $p=0.926$). At week 6, the mean scores were 5.60 ± 0.65 and 6.61 ± 0.64 , respectively, corresponding to a between-group difference of 1.01 (95% CI: 0.71 to 1.31 ; $p<0.001$). At week 12, scores increased to 8.12 ± 0.87 in the Conventional Group and 9.79 ± 0.59 in the Gait/Sensorimotor Group. The between-group difference was 1.67 (95% CI: 1.32 to 2.02 ; $p<0.001$), with a large, standardized effect size (Hedges' $g=2.23$). Baseline-to-week-12 mean changes were 5.05 and 6.71 points, respectively. The Gait/Sensorimotor Group therefore demonstrated greater observed increases in Pedalo-Sensamove scores at both follow-up assessments.

Table 1. Baseline demographic and clinical characteristics of participants by treatment group (N=72)

Characteristics	Conventional group (n=36)	Gait/Sensorimotor group (n=36)	p-value
Age (years)	61.28 ± 8.02	59.94 ± 9.52	0.521
Weight (kg)	78.78 ± 8.06	80.06 ± 7.83	0.497
Height (cm)	175.92 ± 3.48	176.44 ± 3.38	0.522
BMI (kg/m ²)	25.40 ± 1.61	25.67 ± 1.58	0.475
Number of diseases	1.89 ± 0.75	2.11 ± 0.75	0.218
Number of medications	1.53 ± 0.51	1.58 ± 0.50	0.676
Sex, n (%)			0.129
Male	21 (58.3)	28 (77.8)	
Female	15 (41.7)	8 (22.2)	
Socioeconomic status, n (%)			
Upper	4 (11.1)	7 (19.4)	
Middle	29 (80.6)	22 (61.1)	
Lower	3 (8.3)	7 (19.4)	

Values are mean $\pm$ SD or n (%). BMI, body mass index; SD, standard deviation. Continuous-variable p-values were recalculated using two-sided Welch's independent-samples t-tests from the reported aggregate data. The sex comparison uses Fisher's exact test. A socioeconomic-status p-value is omitted because some expected cell counts are small and an exact multinomial test was not performed. These baseline p-values are descriptive rather than tests of successful randomization.

Table 2. Comparison of Berg Balance Scale scores between treatment groups at baseline, week 6, and week 12

Assessment	Conventional group mean $\pm$ SD	Gait/Sensorimotor group mean $\pm$ SD	Between-group MD (95% CI)	p-value	Hedges' g
Baseline	32.25 $\pm$ 4.74	32.69 $\pm$ 4.24	0.44 (–1.67 to 2.55)	0.679	0.10
Week 6	37.44 $\pm$ 4.84	41.11 $\pm$ 3.97	3.67 (1.59 to 5.75)	<0.001	0.82
Week 12	43.11 $\pm$ 4.97	47.97 $\pm$ 4.07	4.86 (2.72 to 7.00)	<0.001	1.06
Baseline to week 12, mean change	+10.86	+15.28			

BBS, Berg Balance Scale; MD, mean difference; CI, confidence interval; SD, standard deviation. Score range: 0–56. Between-group MD is calculated as Gait/Sensorimotor minus Conventional. Confidence intervals and p-values are from two-sided Welch's independent-samples t-tests at each assessment. Hedges' g is the small-sample-corrected standardized difference. Changes are differences between reported group means, not individually estimated paired effects.

Table 3. Comparison of Six-Minute Walk Test distances between treatment groups at baseline, week 6, and week 12

Assessment	Conventional group mean $\pm$ SD (m)	Gait/Sensorimotor group mean $\pm$ SD (m)	Between-group MD (95% CI), m	p-value	Hedges' g
Baseline	237.58 $\pm$ 39.54	248.61 $\pm$ 34.82	11.03 (–6.49 to 28.55)	0.213	0.29
Week 6	308.03 $\pm$ 40.10	361.28 $\pm$ 34.49	53.25 (35.66 to 70.84)	<0.001	1.41
Week 12	387.58 $\pm$ 41.93	461.53 $\pm$ 34.35	73.95 (55.92 to 91.98)	<0.001	1.91
Baseline to week 12, mean change (m)	+150.00	+212.92			

6MWT, Six-Minute Walk Test; MD, mean difference; CI, confidence interval; SD, standard deviation. Between-group differences, 95% CIs and p-values were calculated using two-sided Welch's independent-samples t-tests. Hedges' g represents the standardized between-group difference. Baseline-to-week-12 changes were derived from the reported means.

Table 4. Comparison of Ten-Meter Walk Test completion times between treatment groups at baseline, week 6, and week 12

Assessment	Conventional group mean $\pm$ SD (s)	Gait/Sensorimotor group mean $\pm$ SD (s)	Between-group MD (95% CI), s	p-value	Hedges' g
Baseline	11.75 $\pm$ 1.50	12.14 $\pm$ 1.22	0.39 (–0.25 to 1.03)	0.230	0.28
Week 6	9.19 $\pm$ 1.62	7.86 $\pm$ 1.68	–1.33 (–2.11 to –0.55)	0.001	–0.80
Week 12	6.91 $\pm$ 1.29	4.75 $\pm$ 0.73	–2.16 (–2.65 to –1.66)	<0.001	–2.04
Baseline to week 12, mean change (s)	–4.84	–7.39			

10MWT, Ten-Meter Walk Test; s, seconds; MD, mean difference; CI, confidence interval; SD, standard deviation. Between-group MD is Gait/Sensorimotor minus Conventional. Lower completion time represents faster walking. CIs and p-values are derived using Welch's independent-samples t-test. Hedges' g is the standardized between-group difference. The manuscript reports completion time, not directly measured gait speed in m/s.

Table 5. Comparison of Pedalo-Sensamove Balance Test scores between treatment groups at baseline, week 6, and week 12

Assessment	Conventional group mean $\pm$ SD	Gait/Sensorimotor group mean $\pm$ SD	Between-group MD (95% CI)	p-value	Hedges' g
Baseline	3.07 $\pm$ 0.47	3.08 $\pm$ 0.43	0.01 (–0.20 to 0.22)	0.926	0.02
Week 6	5.60 $\pm$ 0.65	6.61 $\pm$ 0.64	1.01 (0.71 to 1.31)	<0.001	1.55
Week 12	8.12 $\pm$ 0.87	9.79 $\pm$ 0.59	1.67 (1.32 to 2.02)	<0.001	2.23
Baseline to week 12, mean change	+5.05	+6.71			

MD, mean difference; CI, confidence interval; SD, standard deviation. Between-group MD is Gait/Sensorimotor minus Conventional. Estimates are derived using two-sided Welch's independent-samples t-tests and Hedges' g. Pedalo-Sensamove scoring units and direction of clinical interpretation require confirmation from the actual assessment protocol.

Overall, the reported functional outcomes demonstrated favorable changes over the 12-week assessment period in both treatment groups. The Gait/Sensorimotor Group showed larger observed changes in BBS scores, 6MWT distance, 10MWT completion time, and Pedalo-Sensamove scores. Between-group comparisons in weeks 6 and 12

were statistically significant across all four outcomes, with large, standardized differences at week 12. These results describe the observed longitudinal patterns and assessment-specific group differences without establishing a separately estimated group-by-time interaction effect.

DISCUSSION

The present randomized controlled trial compared conventional physiotherapy with a combined sensorimotor and gait training approach for improving balance, proprioception-related performance, and gait function among patients with diabetic peripheral neuropathy (DPN). The findings demonstrated favorable changes in functional performance in both treatment groups across the 12-week assessment period, with consistently greater observed improvements in the Gait/Sensorimotor Group. The most notable differences involved functional balance, walking endurance, short-distance walking performance, and Pedalo-Sensamove scores. Although these findings suggest that integrating sensorimotor exercises with gait-oriented rehabilitation may offer additional functional benefits, the magnitude and consistency of the observed differences require interpretation in relation to the study design, intervention characteristics, and statistical approach.

The improvement in functional balance observed in the present study is consistent with previous evidence supporting exercise-based rehabilitation in individuals with DPN. Ahmad et al. examined the effects of sensorimotor training on balance and proprioception among middle-aged and older adults with diabetic neuropathy and reported improvements in static and dynamic balance following an eight-week intervention (11). Similarly, Song et al. demonstrated improvements in balance and trunk proprioception among older adults with diabetic neuropathies who participated in a structured exercise program (10). These findings are comparable to the present study, in which both treatment groups demonstrated increasing Berg Balance Scale scores, with a larger observed improvement in the combined-training group. However, differences in intervention content, comparator treatment, participant characteristics, and assessment methods should be considered when interpreting agreement across studies. The present findings provide further support for investigating rehabilitation approaches that incorporate progressive postural-control and sensorimotor activities alongside conventional therapeutic exercises.

A plausible explanation for the observed improvement in balance relates to the repeated activation and coordination of sensory and motor systems during functional movement. Diabetic neuropathy may impair somatosensory feedback from the lower extremities, reducing the ability to recognize changes in joint position and respond appropriately to postural disturbances. Such impairments can interfere with the integration of sensory information necessary for maintaining stability during standing and walking. Mustapa et al. identified alterations in postural control among individuals with DPN, emphasizing the contribution of sensory dysfunction to balance limitations (7). Furthermore, Kraiwong et al. demonstrated that sensory impairment and reduced lower-limb muscle strength were associated with poorer balance performance among older adults with type 2 diabetes (8). In the present study, exercises such as tandem standing, single-leg stance, wobble-board activities, and progressive balance tasks may have provided repeated opportunities to practice weight shifting, postural adjustment, and lower-extremity coordination. These adaptations represent plausible mechanisms for improved functional performance, although the study did not directly assess neural adaptation or changes in underlying sensory pathways.

The findings regarding walking endurance also align with previous evidence indicating that structured therapeutic exercise may improve gait-related outcomes in patients with DPN. Melese et al., in a systematic review of randomized controlled trials, reported that exercise interventions incorporating strengthening, balance training, flexibility activities, and gait-specific exercises were generally associated with improvements in walking performance (12). The present study similarly demonstrated increases in Six-Minute Walk Test distance in both groups, with larger observed gains among participants receiving combined sensorimotor and gait training. At the final assessment, the between-group difference in walking distance was 73.95 m, with a 95% confidence interval of 55.92–91.98 m. This difference suggests a potentially meaningful functional advantage in the study population, although clinical interpretation should account for differences in baseline walking capacity, participant characteristics, and the applicability of established thresholds for clinically important change. The available evidence supports the relevance of exercise-based approaches to walking rehabilitation but does not establish an optimal training protocol applicable to all patients with DPN.

The improvement in walking endurance may reflect the combined influence of lower-extremity strengthening, repeated walking practice, and progressively demanding functional activities. Individuals with DPN frequently experience difficulties with walking stability and movement coordination because of impaired peripheral sensation and altered motor control. Repeated practice of walking activities under varying conditions may facilitate improvements in task performance, movement confidence, and the coordination required for sustained ambulation. The inclusion of treadmill walking, overground gait activities, and exercises targeting the quadriceps, hamstrings, tibialis anterior, and gluteal musculature may have contributed to these functional changes. Ahmad et al. previously reported favorable effects of combined sensorimotor and gait training on selected neuromuscular outcomes among individuals with DPN, providing a physiological rationale for integrating postural and locomotor exercises (13). Nevertheless, the present study did not measure muscle activation, nerve conduction, or physiological adaptations directly; therefore, these mechanisms remain explanatory possibilities rather than demonstrated treatment effects.

The Ten-Meter Walk Test findings provide additional evidence of favorable changes in short-distance walking performance. Both groups demonstrated reductions in walking completion time, with a more pronounced reduction in the Gait/Sensorimotor Group. At week 12, the between-group difference was -2.16 seconds, indicating faster completion of the walking task in participants receiving the combined intervention. This finding is compatible with the broader literature describing relationships between diabetic neuropathy, lower-limb sensorimotor dysfunction, and gait performance. Timar et al. demonstrated that diabetic neuropathy was associated with impaired balance and increased fall risk among individuals with type 2 diabetes (6), while Mustapa et al. identified disturbances in walking characteristics associated with neuropathic sensory impairment (7). Although these investigations were not direct comparisons of the interventions examined in the present trial, they provide a clinical context for understanding why rehabilitation directed toward walking control and postural stability may be relevant. The observed reduction in walking time may reflect improved task execution and functional locomotor performance, but the contribution of individual intervention components cannot be determined from the available data.

Changes in Pedalo-Sensamove scores were also more pronounced in the combined-training group, suggesting differences in performance on the sensorimotor assessment used in the study. Previous investigations have identified beneficial effects of sensorimotor training on proprioception-related outcomes in individuals with DPN. Ahmad et al. reported improvements in proprioceptive performance following structured sensorimotor training, while their subsequent randomized trial found favorable changes in proprioception and selected measures of neuromuscular function after combined sensorimotor and gait exercises (11,13). These observations are broadly consistent with the increases in Pedalo-Sensamove scores observed in the present study. Exercises involving unstable surfaces, controlled weight shifting, and repeated reproduction of postural positions may encourage greater awareness of body position and improved coordination of postural responses. However, the interpretation of the Pedalo-Sensamove findings depends on the scoring properties of the assessment protocol. Since improvements in device-based postural performance do not necessarily demonstrate equivalent changes in isolated joint-position sense, the results should be interpreted as proprioception-related or sensorimotor performance rather than definitive evidence of restoration of peripheral sensory function (14).

An important observation was that the conventional physiotherapy group also demonstrated favorable changes across the functional outcomes. This finding suggests that the rehabilitation activities provided to both groups may have contributed to improved performance during the assessment period. Conventional treatment included lower-extremity strengthening, balance exercises, and walking-related activities, which share functional objectives with elements of the combined intervention. Ahmad et al., in their narrative review of balance training in diabetic peripheral neuropathy, emphasized the potential role of exercise-based rehabilitation in improving balance and gait-related function (15). Consequently, the greater observed improvement in the Gait/Sensorimotor Group should not be interpreted as evidence that conventional physiotherapy is ineffective. Rather, the findings suggest that the structured combination of sensorimotor and gait-oriented activities may be associated with additional improvements beyond those observed with the conventional program used in this trial. Because some treatment components overlapped, the independent contribution of sensorimotor exercises, gait-specific training, or differences in exercise dosage cannot be isolated.

The pattern of improvement across the assessment period also warrants consideration. The reported outcomes demonstrated favorable changes at weeks 6 and 12, with between-group differences becoming more apparent

during follow-up. Progressive training may plausibly facilitate improvements through repeated task practice, improved movement coordination, and adaptation to increasing physical demands. However, the documented experimental intervention consisted of eight weeks of training, whereas outcome assessments continued to week 12. The treatment exposure and follow-up arrangements between weeks 8 and 12 are not sufficiently clear to determine whether the final outcomes represent continued supervised training effects or retention of improvements after intervention completion. Furthermore, the reported statistical comparisons primarily evaluated group differences at individual assessment points and within-group changes over time. A directly estimated and appropriately adjusted group-by-time interaction would provide stronger evidence regarding whether the trajectories of change differed between interventions. Therefore, although the observed patterns favor the combined-training group, conclusions regarding comparative longitudinal treatment effects should remain appropriately cautious (16).

Baseline demographic characteristics provide additional context for interpreting the results. Both groups had broadly comparable mean ages, BMI values, and reported numbers of comorbid conditions and medications; however, the proportion of male participants was greater in the Gait/Sensorimotor Group. Although this difference was not statistically significant in the reported comparison, sex-related variation in physical characteristics and functional performance may influence rehabilitation outcomes. Moreover, diabetes duration, neuropathy severity, glycemic control, and relevant sensory or motor deficits were not adequately characterized in the reported baseline data. These factors are clinically important because the functional consequences of diabetic neuropathy may vary according to disease severity and accompanying metabolic or neurological impairment. Previous research has emphasized that diabetic neuropathy is influenced by multiple clinical and metabolic factors and that its manifestations can differ considerably across affected populations (17,18). The absence of detailed baseline neuropathy characteristics therefore limits the ability to determine whether the observed treatment differences were consistent across clinically relevant patient subgroups.

From a clinical perspective, the findings support consideration of structured sensorimotor and gait-oriented activities as potentially useful components of physiotherapy management for ambulatory patients with DPN. Rehabilitation programs that combine lower-extremity strengthening, progressive balance challenges, postural-control tasks, and walking practice may address several functional limitations commonly associated with neuropathic impairment. Improved balance and walking performance may be particularly relevant to activities requiring independent mobility, transfers, and navigation of different environments. Nevertheless, the present study did not directly evaluate fall incidence, health-related quality of life, community participation, or long-term disability. Accordingly, improvements in the measured functional outcomes should not be equated with demonstrated reductions in falls or sustained improvements in everyday participation. Existing evidence indicates that balance impairment and functional limitations contribute to the clinical burden of DPN, supporting further investigation of rehabilitation approaches that address these concerns (19,20).

The study has several methodological strengths, including its randomized comparative design, incorporation of an active rehabilitation comparator, repeated assessment of functional outcomes, and use of established clinical measures for balance and walking performance. Assessment of both walking endurance and short-distance walking ability provided complementary information regarding functional mobility, while the inclusion of a sensorimotor assessment extended the evaluation beyond conventional gait measures. The use of an independent assessor, described as blinded to treatment allocation, was also intended to reduce assessment-related bias. These features strengthen the clinical relevance of the study and provide a useful framework for evaluating functional responses to rehabilitation in patients with DPN (21,22).

However, several limitations should be considered when interpreting the findings. The sample was recruited from a single rehabilitation setting using purposive sampling, which may limit generalizability to patients with different levels of neuropathy severity, functional dependence, or healthcare access. Individuals requiring walking aids or presenting with certain neurological, orthopedic, or vascular complications were excluded, further restricting applicability to more severely affected populations. The relatively modest sample size limits the precision of subgroup comparisons, while the imbalance in sex distribution and incomplete characterization of diabetes-related clinical variables may contribute to residual uncertainty. The intervention descriptions also indicate overlap between conventional physiotherapy and combined sensorimotor and gait training, making it difficult to determine which treatment components were responsible for the observed differences. Furthermore, allocation

concealment, intervention adherence, participant attrition, and adverse-event reporting were insufficiently detailed. The primary longitudinal treatment effect was not clearly established through a reported group-by-time analysis, and the clinical interpretation of the Pedalo-Sensamove score requires confirmation of its measurement properties. These limitations reduce certainty regarding the magnitude, reproducibility, and generalizability of the observed comparative effects (23,24).

Further randomized controlled trials should employ clearly differentiated and reproducible intervention protocols, adequate allocation concealment, comprehensive reporting of participant flow, and standardized assessment procedures. Future investigations would also benefit from detailed characterization of neuropathy severity, diabetes duration, glycemic status, and relevant comorbidities, together with analyses that account for baseline outcome values and repeated measurements. Larger samples and longer follow-up periods would help establish whether improvements in balance, walking endurance, and sensorimotor performance are maintained after supervised rehabilitation ends. Incorporating patient-centered outcomes, including falls, functional independence, and quality of life, may further clarify the practical relevance of these interventions. Overall, the present findings suggest that combined sensorimotor and gait training may be associated with greater functional improvements than the conventional physiotherapy program used in this study. However, confirmation through rigorously reported comparative analyses and more clearly characterized intervention protocols is necessary before definitive recommendations regarding treatment superiority can be made (25).

CONCLUSION

The findings of this randomized controlled trial demonstrated improvements in balance and walking performance in both the conventional physiotherapy and combined sensorimotor and gait training groups among patients with diabetic peripheral neuropathy. However, the combined training group exhibited greater observed improvements in Berg Balance Scale scores, Six-Minute Walk Test distance, Ten-Meter Walk Test completion time, and Pedalo-Sensamove scores over the 12-week assessment period. These findings suggest that integrating sensorimotor exercises with gait-oriented rehabilitation may offer additional functional benefits compared with conventional physiotherapy alone. Nevertheless, uncertainties regarding intervention delivery and longitudinal treatment-effect estimation limit definitive conclusions about treatment superiority.

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