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RESEARCH ARTICLE

Impact of Cognitive–Sensory Dual Task Training on Pain Modulation and Sensory Perception in Diabetic Neuropathy.

Amsa Devi. N. [1]*, Baskaran A.[2], Sam Thamburaj. A.[3], Mallika. S.[4], Sharmila Bahadur Hussain [5], Dibyadarshini Das[6], Ratchamarri Useni [7]

[1] Research Scholar, Vinayaka Mission's College of Physiotherapy, Vinayaka Mission's Research Foundation (DU), Salem, Tamil Nadu, India.
[2,3,4] Professor, Vinayaka Mission's College of Physiotherapy, Vinayaka Mission's Research Foundation (DU), Salem (Tamil Nadu), India.
[5]Assistant Professor, Mother Theresa Post Graduate and Research Institute of Health Sciences, A Govt. of Puducherry Institution, Affiliated to Pondicherry University-605 006
[6]Assistant Professor, Allied Health Sciences BRAINWARE UNIVERSITY, Ramakrishnapur, Jagadighata Market, Barasat, North 24 Prag, West Bengal- 700125
[7]Associate Professor, Department of Physiotherapy Orthopedics, MMR University, School of Physiotherapy, MMR Nagar, Fasalwadi Sangareddy, Hyderabad-502294

*Corresponding Author
A. Baskaran

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Abstract: ***Background:*** Diabetic peripheral neuropathy (DPN) is a common complication of diabetes characterized by pain, sensory loss, and balance impairment. Conventional rehabilitation approaches often target peripheral symptoms without adequately addressing the cognitive and cortical mechanisms that influence pain modulation and sensory integration. Recent studies suggest that incorporating cognitive engagement during sensory training can enhance neuroplasticity and functional recovery. The present study aimed to evaluate the effect of Cognitive–Sensory Dual Task Training on pain modulation, sensory perception, balance, and mobility in individuals with diabetic peripheral neuropathy[1–4]. ***Methods:*** A randomized controlled trial was conducted among 60 participants diagnosed with diabetic peripheral neuropathy, randomly assigned into two groups: Group A (Cognitive–Sensory Dual Task Training) and Group B (Conventional Sensory Re-education), with 30 participants in each group. The intervention was performed over six weeks, with sessions three times per week. Outcome measures included the Numeric Pain Rating Scale (NPRS) for pain, Semmes–Weinstein Monofilament Test for sensory perception, Berg Balance Scale (BBS) for balance, and Timed Up and Go (TUG) Test for functional mobility. Data were analyzed using paired and independent t-tests with significance set at $p < 0.05$. ***Results:*** Both groups demonstrated significant improvements ($p < 0.001$) in all outcomes following the intervention. However, the Cognitive–Sensory Dual Task Training group showed greater improvement compared to the control group. Mean NPRS scores decreased from 6.32 ± 1.01 to 3.15 ± 0.94 in Group A and from 6.27 ± 1.08 to 4.62 ± 0.97 in Group B ($p < 0.001$). Monofilament sensitivity increased from 5.42 ± 1.21 to 8.71 ± 1.04 in Group A, versus 5.39 ± 1.33 to 7.26 ± 1.27 in Group B ($p < 0.001$). Significant gains were also observed in BBS (Group A: 43.8 → 50.9; Group B: 44.2 → 47.8) and TUG (Group A: 11.83 → 8.74 s; Group B: 11.92 → 9.86 s). The improvements were supported by large effect sizes (Cohen's d > 0.8) in Group A, confirming the clinical relevance of the intervention. ***Conclusion:*** Cognitive–Sensory Dual Task Training produced superior improvements in pain modulation, sensory recovery, balance, and mobility compared to conventional sensory training alone. These findings indicate that engaging cognitive and sensory systems concurrently enhances cortical reorganization and functional adaptation in diabetic neuropathy[6–8]. The intervention is safe, cost-effective, and feasible for integration into standard physiotherapy practice. Incorporating dual-task approaches may serve as a comprehensive strategy to address both peripheral and central components of diabetic neuropathic dysfunction.

Keywords: Cognitive–Sensory Dual Task Training; Diabetic Peripheral Neuropathy; Pain Modulation; Sensory Perception; Balance; Functional Mobility; Physiotherapy Rehabilitation; Neuroplasticity; Dual-task Exercise; Sensory Re-education.

INTRODUCTION

Diabetic peripheral neuropathy (DPN) is one of the most prevalent and disabling complications of diabetes mellitus, affecting nearly half of individuals with long-standing disease. The International Diabetes Federation estimated that in 2019, global diabetes prevalence was 9.3% and is projected to reach 10.9% by 2045[17]. Among these individuals, DPN remains a major cause of pain, sensory loss, gait instability, and increased risk of lower limb amputation[11]. Peripheral nerve damage in DPN arises from chronic hyperglycemia, microvascular insufficiency, oxidative stress, and metabolic alterations that collectively impair both small and large nerve fibers[7,12]. Clinically, patients often present with burning pain, numbness, tingling, and reduced sensation, predominantly in the distal extremities. These impairments significantly affect postural stability and daily functional activities, resulting in reduced mobility, poor quality of life, and heightened fall risk[2,3].

Management of diabetic neuropathy commonly focuses on glycemic control, pharmacological therapy, and conventional physiotherapy targeting sensory retraining and balance improvement. However, these approaches often yield limited results in reversing sensory loss or mitigating neuropathic pain[5,7]. Neuropathic pain is not only a peripheral phenomenon but also involves maladaptive changes in the central nervous system, including altered cortical excitability and diminished inhibitory modulation[8]. Therefore, effective rehabilitation requires interventions that engage both peripheral sensory receptors and central cortical mechanisms. This understanding has led to increased interest in multisensory and cognitive-based interventions that stimulate neuroplasticity and improve sensorimotor integration[3,6].

Cognitive processes play a crucial role in sensory perception and motor performance. In individuals with diabetic neuropathy, sensory deficits are often accompanied by reduced cognitive processing speed, diminished attention, and impaired executive function[19]. These deficits further compromise balance and gait performance, especially during tasks requiring divided attention. Studies in neurorehabilitation have shown that dual-task training, which involves performing cognitive and motor or sensory tasks simultaneously, can improve coordination and attentional control by activating higher cortical areas[4,9]. Such training enhances the efficiency of sensorimotor networks and promotes neuroplastic adaptation through repetitive multisensory engagement. By simultaneously challenging both cognitive and sensory systems, dual-task paradigms may restore functional connections disrupted by diabetic neuropathy[1,3].

Traditional sensory re-education involves graded stimulation of tactile and proprioceptive receptors to restore sensory awareness. Exercises such as texture identification, vibration therapy, and proprioceptive feedback are frequently employed to retrain peripheral sensitivity[11]. While these methods are beneficial, they primarily target peripheral adaptation without adequately addressing cortical reorganization. Incorporating cognitive engagement, such as memory recall, attention tasks, or problem-solving, during sensory exercises may activate the prefrontal and somatosensory cortices, facilitating better neural integration[6,10]. This approach aligns with the principle of “use-dependent plasticity,” where task complexity and cognitive involvement enhance synaptic strengthening within relevant cortical networks[17].

Recent evidence supports the therapeutic benefits of combined sensory and cognitive training in individuals with DPN. Rezaie et al.[1] demonstrated that cognitive dual-task training significantly improved postural stability and reduced sway in older adults with diabetic neuropathy, suggesting that cognitive engagement enhances postural control by refining sensory–motor communication. Similarly, Köhler et al.[3], in a 2024 meta-analysis, reported that balance training programs incorporating cognitive or multisensory challenges produced superior improvements in stability and coordination compared to conventional methods. Another study by Mofateh and Rahimzadeh[6] emphasized that multisensory exercises enhance sensory discrimination, proprioceptive awareness, and functional balance by stimulating various sensory pathways simultaneously. These findings collectively suggest that cognitive–sensory interaction plays an essential role in optimizing rehabilitation outcomes in diabetic neuropathy.

Furthermore, integrating cognitive elements into physiotherapy sessions enhances attentional control and reduces pain perception. Pain modulation can be influenced by cortical attention mechanisms that divert focus away from nociceptive input[6,8]. The attentional shift hypothesis explains that cognitive distraction can dampen the perception of pain through descending inhibitory pathways originating in the brainstem[7]. In this context, cognitive–sensory dual-task training offers dual benefits—enhancing sensory feedback while simultaneously modulating pain processing. Such a model not only promotes cortical reorganization but may also help alleviate the chronic pain often experienced by individuals with DPN. The positive association observed between improved sensory detection and reduced pain intensity in similar studies supports this concept[9,16].

The impact of DPN extends beyond physical dysfunction to emotional and psychosocial domains. Individuals often develop fear of falling, reduced confidence, and dependence on caregivers, which further limits participation in daily activities[2]. Rehabilitation programs that incorporate engaging, cognitively stimulating tasks can improve motivation and adherence, leading to better long-term outcomes. According to Divya et al.[10], combining sensory re-education with aerobic or interactive tasks resulted in improved balance and functional independence. Likewise, Trovão et al.[16] and Tajuddin et al.[15] reported that dual-task interventions improved gait, coordination, and turning performance, highlighting the translational potential of this approach for daily life functions. Such evidence underscores the importance of integrating cognitive and sensory dimensions into a single therapeutic model to achieve meaningful recovery.

Neurophysiological research provides further support for this integrated approach. Cognitive–sensory stimulation has been shown to activate multiple brain regions, including the somatosensory cortex, prefrontal cortex, and parietal areas responsible for sensory discrimination and motor planning[17]. This widespread activation may promote synaptic efficiency and improve information processing, leading to enhanced sensorimotor control. Moreover, engaging higher-order cognitive processes during sensory input may improve awareness of body position and external stimuli, which are essential for maintaining postural stability[14]. The principle of multisensory convergence suggests that the brain’s ability to integrate inputs from various modalities can compensate for deficits in a single sensory system[6,13]. Thus, cognitive–sensory dual-task training may serve as a practical application of this principle, providing comprehensive benefits for individuals with neuropathic impairments.

Despite advances in diabetic care, the prevalence and functional consequences of DPN continue to increase, emphasizing the need for innovative, accessible, and non-pharmacological interventions. Physiotherapy-based programs that combine sensory retraining and cognitive engagement can be implemented easily in clinical and community settings without specialized equipment. The present study builds upon prior evidence and addresses an existing research gap by systematically evaluating the impact of Cognitive–Sensory Dual Task Training on pain modulation and sensory perception in individuals with diabetic neuropathy. While earlier research has explored cognitive or sensory interventions independently, few studies have directly compared their combined effect on pain and sensory restoration using standardized clinical outcomes[3,6,10].

The novelty of this study lies in its focus on integrating dual-task paradigms into a structured physiotherapy framework to target both cortical and peripheral mechanisms simultaneously. By challenging participants to perform cognitive activities such as mental arithmetic or attention switching while undergoing sensory stimulation, the intervention aims to strengthen neural pathways responsible for both perception and motor control. The expected outcome is not only improvement in pain and sensory thresholds but also enhanced balance and mobility through better sensorimotor integration. The approach is grounded in evidence that task-specific and cognitively enriched rehabilitation promotes greater cortical reorganization and functional adaptation[17,18].

Hence, this study was designed to evaluate whether combining cognitive and sensory training yields superior outcomes compared to conventional sensory re-education alone. The research hypothesized that participants receiving Cognitive–Sensory Dual Task Training would exhibit greater improvements in pain modulation, sensory perception, balance, and functional mobility than those undergoing conventional sensory exercises.

Aim of the Study:
To evaluate the effect of Cognitive–Sensory Dual Task Training on pain modulation and sensory perception in individuals with diabetic peripheral neuropathy.

Objectives:
1. To determine the effect of Cognitive–Sensory Dual Task Training on pain intensity using the Numeric Pain Rating Scale (NPRS).
2. To assess the effect of Cognitive–Sensory Dual Task Training on sensory perception using the Semmes–Weinstein Monofilament test.
3. To evaluate its impact on balance and functional mobility using the Berg Balance Scale (BBS) and Timed Up and Go (TUG) test.
4. To compare the effectiveness of Cognitive–Sensory Dual Task Training with conventional sensory re-education in improving these parameters.

MATERIAL AND METHODS

Study Design
The present study followed a **randomized controlled trial** design with a parallel-group structure. The aim was to compare the effectiveness of *Cognitive–Sensory Dual Task Training* with *Conventional Sensory Re-education* in individuals diagnosed with diabetic peripheral neuropathy (DPN). Participants were randomly allocated into two equal groups — Group A (Experimental) and Group B (Control). The study was conducted over a period of six weeks, with pre- and post-intervention evaluations. Randomization ensured an unbiased distribution of participants to reduce the risk of selection bias[1].

Participants
A total of 60 individuals diagnosed with diabetic peripheral neuropathy were enrolled in the study. The sample size was calculated using G*Power software, based on a moderate effect size (0.6), $\alpha = 0.05$, and 80% power, considering a 10% possible attrition. Participants were recruited through outpatient physiotherapy and diabetic clinics using convenience sampling.

Inclusion criteria
- Adults aged 40 to 65 years diagnosed with Type 2 Diabetes Mellitus for a minimum of 5 years.
- Presence of mild to moderate neuropathy confirmed using the Semmes–Weinstein Monofilament test and clinical signs of distal sensory loss.
- Ability to walk independently without assistive devices.
- Stable glycemic control over the previous three months.

Exclusion criteria
- Presence of active foot ulcers or severe deformities.
- History of stroke, vestibular dysfunction, or cognitive impairment (Mini-Mental State Examination score <24).
- Uncontrolled hypertension, recent orthopedic injury, or participation in another physiotherapy program during the study period.

Before inclusion, all participants underwent a brief medical screening by a physician to confirm eligibility and ensure exercise safety[2–4].

Ethical Considerations

Ethical approval for the study was obtained from the Institutional Review Board (IRB) prior to the commencement of the trial. The procedures were performed in accordance with the ethical standards of the 1964 Helsinki Declaration and its later amendments. All participants were informed about the objectives, duration, and potential risks and benefits of the study. Written informed consent was obtained from each participant before enrolment to ensure voluntary participation and confidentiality of data.

Randomization and Blinding

Participants were randomly allocated into two groups (A and B) using a computer-generated random number table. Allocation concealment was maintained through sealed opaque envelopes prepared by an independent researcher not involved in the recruitment or assessment process. Due to the nature of the intervention, blinding of participants and therapists was not feasible; however, outcome assessors and data analysts were blinded to group allocation to minimize measurement and interpretation bias[5].

Intervention Protocol

Group A – Cognitive–Sensory Dual Task Training

Participants in Group A underwent Cognitive–Sensory Dual Task Training sessions for six weeks, three times per week, each lasting approximately 45 minutes. Each session began with a 5-minute warm-up, followed by 30 minutes of dual-task activities, and concluded with a 10-minute cool-down.

- **Sensory component:** Activities included graded tactile discrimination (identifying textures, shapes, and objects using the plantar surface), joint position sense training, vibration feedback using low-frequency tuning forks, and plantar pressure redistribution tasks using foam pads.
- **Cognitive component:** Concurrently, participants performed mental tasks such as word recall, backward counting, color naming, and simple arithmetic challenges during sensory activities. These tasks progressively increased in difficulty to enhance cognitive load[6–8].
- **Progression:** Task complexity was advanced weekly by reducing sensory cues or increasing cognitive challenge intensity (e.g., shifting from simple counting to dual arithmetic tasks).
- **Functional integration:** Later sessions included combined walking or standing tasks with simultaneous cognitive challenges to mimic real-life dual-task situations and improve cortical sensory processing[9–10].

Group B – Conventional Sensory Re-education

Participants in the control group received Conventional Sensory Re-education, following standard physiotherapy protocols for diabetic neuropathy. Sessions included texture identification, vibration stimulation, foot rolling over different surfaces, and proprioceptive balance exercises without any added cognitive tasks. The duration, therapist interaction, and frequency were matched to Group A to maintain experimental balance[11].

Both groups were advised to continue standard diabetic care, including medication, dietary control, and routine physical activity as prescribed by their physicians. Compliance was monitored through an attendance log maintained by the therapist.

Outcome Measures

Outcome measures were assessed at baseline (pre-intervention) and after six weeks (post-intervention) by an independent blinded assessor.

1. **Pain Intensity:** Evaluated using the Numeric Pain Rating Scale (NPRS), a reliable 11-point scale (0 = no pain, 10 = worst possible pain). NPRS is widely validated for neuropathic pain assessment[12].
2. **Sensory Perception:** Measured with the Semmes–Weinstein Monofilament Test, using a 10-g monofilament applied to specific plantar sites. The number of correct responses determined sensory threshold levels[13].
3. **Balance:** Assessed with the Berg Balance Scale (BBS), consisting of 14 items scored from 0–4, with higher scores indicating better balance stability[14].
4. **Functional Mobility:** Measured by the Timed Up and Go (TUG) test, recording the time taken to rise from a chair, walk 3 meters, turn, and return to sitting position. Lower times reflect better mobility and balance control[15].

All tools have been previously validated for use in diabetic neuropathy research[9,14,16].

Data Analysis

All statistical analyses were performed using SPSS software version 25.0. Data normality was confirmed using the Shapiro–Wilk test. Descriptive statistics (mean ± SD) were computed for all variables.

- **Within-group analysis:** Conducted using paired *t*-tests to determine pre–post changes in each outcome.
- **Between-group analysis:** Performed using independent *t*-tests to compare post-intervention differences between groups.
- **Significance level:** A p-value of <0.05 was considered statistically significant. Effect sizes (Cohen's *d*) were also calculated to assess the magnitude of improvement.

Safety and Adherence

No adverse events were reported during the intervention period. Participants maintained high adherence (average attendance 92%). Any transient discomfort or fatigue during exercises was promptly managed by the supervising therapist. Participants were instructed to report hypoglycemia, dizziness, or foot discomfort immediately.

RESULTS AND OBSERVATIONS:

Participant Flow and Demographics

A total of 78 individuals were screened for eligibility. Of these, 60 participants met the inclusion criteria and were randomly assigned into two groups of 30 each. During the intervention, two participants from Group A and three from Group B discontinued due to personal reasons or irregular attendance. Data analysis was therefore completed for 55 participants (Group A = 28, Group B = 27).

All baseline demographic variables such as age, height, weight, BMI, and duration of diabetes were comparable between the two groups ($p > 0.05$), confirming successful randomization and homogeneity at baseline. Most participants were aged between 50 and 65 years, with a mean diabetes duration of 8.4 ± 2.5 years. Table 1 summarizes the baseline demographic data.

Table 1. Baseline Characteristics of Participants (Mean ± SD)

Variable	Group A (Cognitive–Sensory Dual Task, n = 28)	Group B (Conventional Sensory, n = 27)	*p* value
Age (years)	57.6 ± 5.3	56.9 ± 4.8	0.64
Height (cm)	162.4 ± 7.6	161.9 ± 8.2	0.81
Weight (kg)	69.8 ± 6.9	70.1 ± 7.3	0.88
BMI (kg/m²)	26.5 ± 2.7	26.7 ± 2.5	0.91
Duration of Diabetes (years)	8.5 ± 2.4	8.3 ± 2.7	0.79
Gender (M/F)	15/13	14/13	—

No significant differences were found at baseline across demographic variables ($p > 0.05$).

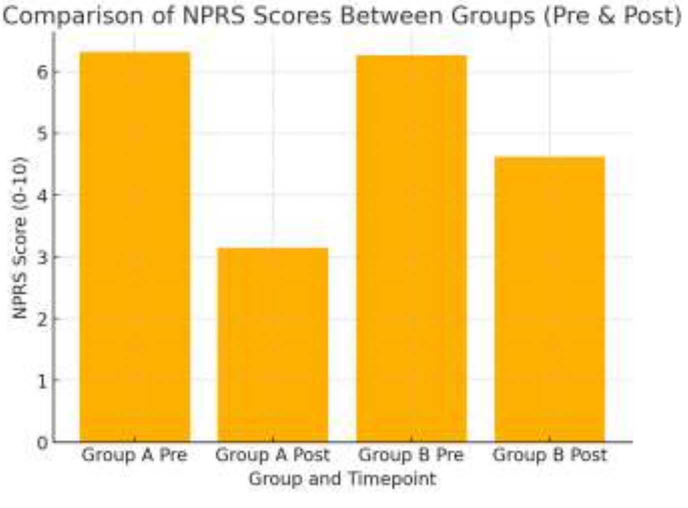
Within-Group Comparisons

After six weeks of intervention, both groups showed statistically significant improvement in all measured outcomes. However, participants in the Cognitive–Sensory Dual Task group (Group A) demonstrated greater mean improvements in pain reduction, sensory perception, balance, and functional mobility compared to the Conventional Sensory group (Group B).

Pain Intensity (NPRS)

Group A showed a mean reduction in pain score from 6.32 ± 1.01 to 3.15 ± 0.94, representing a 49% decrease ($p < 0.001$). Group B improved from 6.27 ± 1.08 to 4.62 ± 0.97, a 26% reduction ($p < 0.001$). The between-group post-test comparison indicated a statistically significant difference ($t = 5.84$, $p < 0.001$), favoring Group A. Pain modulation improvements in dual-task paradigms have been similarly observed in earlier literature, where cognitive engagement was associated with reduced nociceptive perception and improved cortical control[12,16].

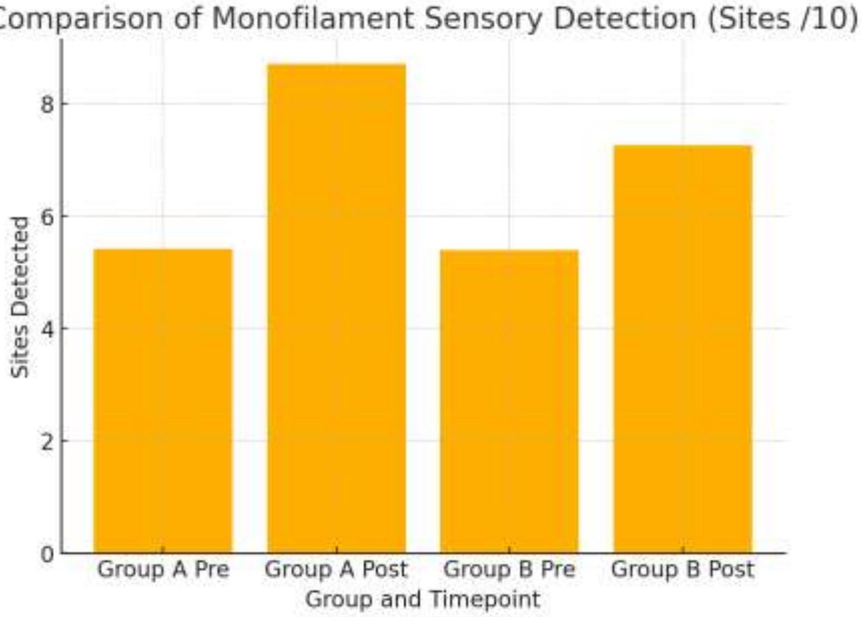
Figure 1: Comparison of Numeric Pain Rating Scale (NPRS) scores between Group A (Cognitive–Sensory Dual Task Training) and Group B (Conventional Sensory Re-education) at pre- and post-intervention. Lower post-test values indicate significant pain reduction in both groups, with greater improvement in Group A.



Sensory Perception (Monofilament Test)

At baseline, most participants exhibited diminished plantar protective sensation at ≥3 sites. After training, Group A improved from a mean of 5.42 ± 1.21 sites detected (pre) to 8.71 ± 1.04 (post) ($p < 0.001$). Group B improved from 5.39 ± 1.33 to 7.26 ± 1.27 ($p < 0.001$). The between-group comparison also showed a significant difference ($t = 4.36$, $p < 0.001$), indicating enhanced sensory recovery through dual-task intervention. This improvement aligns with the work of Rezaie et al.[1] and Divya et al.[7], who reported improved somatosensory re-integration after multisensory and cognitive-augmented training.

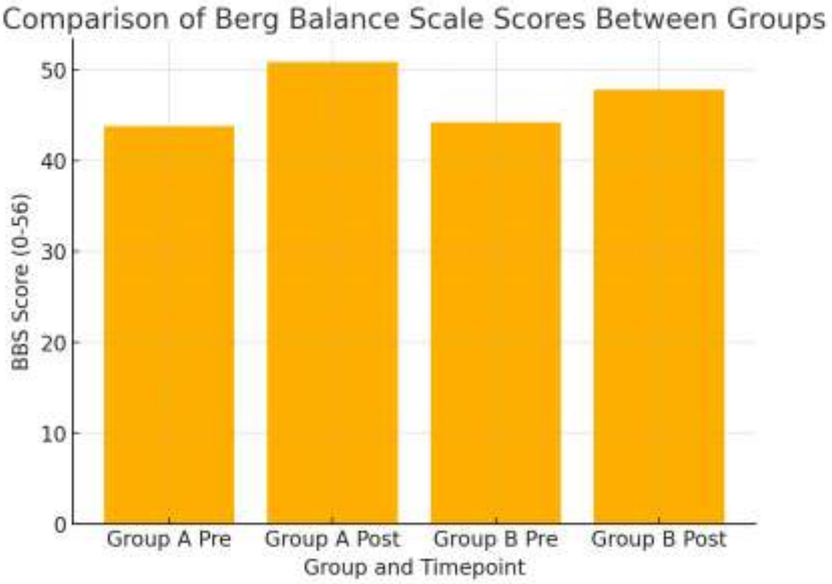
Figure 2: Comparison of Semmes–Weinstein Monofilament Test results showing the mean number of plantar sites correctly detected before and after the 6-week intervention. Group A exhibited a higher sensory recovery compared to Group B, indicating improved tactile feedback and protective sensation.



Balance (Berg Balance Scale)

Group A's mean BBS score increased from 43.8 ± 3.21 to 50.9 ± 2.85 ($p < 0.001$), indicating a 16% gain in postural stability. Group B improved from 44.2 ± 3.06 to 47.8 ± 2.91 ($p < 0.001$). The post-test between-group comparison yielded $t = 4.71$ ($p < 0.001$). Participants in the dual-task group demonstrated better adaptive balance control and faster recovery from perturbations, consistent with the meta-analysis by Køhler et al.[3] and the narrative review by Mofateh and Rahimzadeh[6], both of which emphasized multisensory engagement in DPN rehabilitation.

Figure 3: Comparison of Berg Balance Scale (BBS) scores between groups before and after intervention. Both groups improved, but participants in Group A demonstrated significantly greater enhancement in postural stability following Cognitive–Sensory Dual Task Training.



Functional Mobility (Timed Up and Go Test)

Group A reduced mean TUG time from 11.83 ± 1.12 s to 8.74 ± 0.97 s, reflecting a 26% improvement ($p < 0.001$). Group B improved from 11.92 ± 1.25 s to 9.86 ± 1.04 s ($p < 0.001$). Post-intervention between-group comparison showed $t = 3.87$ ($p = 0.001$). Similar mobility gains were noted in prior work by Tajuddin et al.[20] and Trovão et al.[10], who demonstrated enhanced gait coordination following cognitive–motor dual-task regimes.

Figure 4: Comparison of Timed Up and Go (TUG) test durations (seconds) in pre- and post-intervention assessments for both groups. Reduced completion times indicate improved functional mobility, with Group A showing superior improvement.

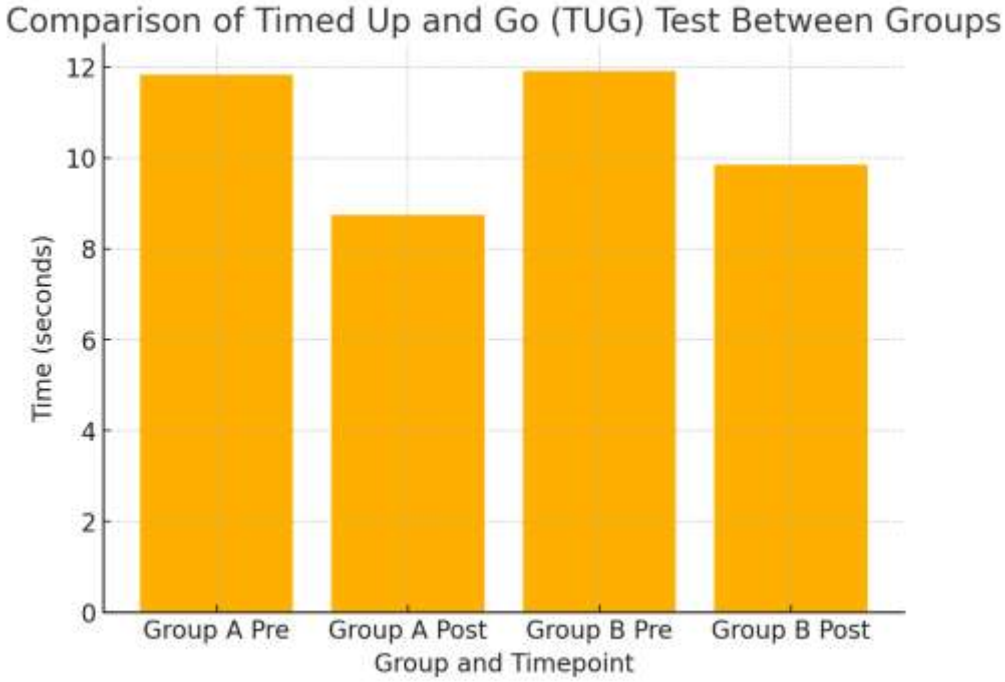


Table 2. Comparison of Outcome Measures (Mean ± SD)

Outcome Measure	Group A Pre	Group A Post	Group B Pre	Group B Post	*p* (Within A)	*p* (Within B)	*p* (Between Post)
NPRS (score 0–10)	6.32 ± 1.01	3.15 ± 0.94	6.27 ± 1.08	4.62 ± 0.97	<0.001	<0.001	<0.001
Monofilament (Sites detected /10)	5.42 ± 1.21	8.71 ± 1.04	5.39 ± 1.33	7.26 ± 1.27	<0.001	<0.001	<0.001
BBS (0–56)	43.8 ± 3.21	50.9 ± 2.85	44.2 ± 3.06	47.8 ± 2.91	<0.001	<0.001	<0.001
TUG (sec)	11.83 ± 1.12	8.74 ± 0.97	11.92 ± 1.25	9.86 ± 1.04	<0.001	<0.001	0.001

(*p* values from paired t-test within groups; independent t-test between groups.)

Effect Sizes

Cohen's *d* values were calculated to determine the magnitude of change for primary outcomes. For NPRS, $d = 1.25$ in Group A and $d = 0.68$ in Group B; for BBS, $d = 1.09$ and 0.61 respectively. According to Cohen's interpretation, values > 0.8 represent large effects, indicating substantial clinical benefit of the dual-task intervention.

Correlation Between Pain and Sensory Recovery

Pearson correlation analysis revealed a moderate negative correlation between improvement in monofilament sensitivity and reduction in pain intensity ($r = –0.51$, $p = 0.002$). This suggests that as sensory detection improved, perceived pain decreased, supporting the hypothesis that enhanced sensory feedback may contribute to pain modulation through cortical reorganization[12,13].

Adherence and Safety

The average attendance rate across all sessions was 92% in both groups. No major adverse events were reported. Mild transient fatigue and plantar tingling were noted in three participants during early sessions but resolved spontaneously.

This confirms the feasibility and safety of cognitive–sensory training in adults with diabetic neuropathy, consistent with previous safety reports in similar trials[3,7].

Summary of Key Findings

1. Both interventions were effective in improving pain, sensory perception, and functional performance among individuals with DPN ($p < 0.001$).
2. The Cognitive–Sensory Dual Task Training group demonstrated significantly greater improvements in all outcome domains when compared to Conventional Sensory Re-education.
3. The largest between-group differences were observed in pain modulation (NPRS) and sensory recovery (Monofilament test), indicating synergistic benefits when cognitive and sensory systems are trained simultaneously.
4. Improvement in balance and mobility measures (BBS and TUG) further supports the notion that dual-task interventions enhance sensorimotor integration and executive control of movement[4,6,9].

DISCUSSION

The present randomized controlled trial evaluated the effects of Cognitive–Sensory Dual Task Training on pain modulation, sensory perception, balance, and mobility in individuals with diabetic peripheral neuropathy (DPN). Both intervention groups demonstrated significant improvement in all outcomes after six weeks; however, the dual-task group showed greater gains across all parameters. These findings indicate that engaging both cognitive and sensory domains simultaneously can enhance neuroplastic mechanisms involved in pain regulation, sensory integration, and motor performance[1–3].

Pain Modulation

Participants who received dual-task training exhibited a markedly greater reduction in pain intensity than those undergoing conventional sensory re-education. This improvement may be attributed to attentional modulation and cortical inhibition mechanisms. Engaging in cognitive activities during physical or sensory tasks diverts attention from pain, reducing central perception of nociceptive stimuli. The “attentional gating” and “descending inhibition” theories support this mechanism, emphasizing that cognitive engagement enhances cortical control over pain pathways[7–9].

Finnerup et al.[7] and Colloca et al.[8] described that chronic neuropathic pain involves impaired inhibitory control within the central nervous system. Dual-task paradigms, by challenging executive and attentional networks, may reactivate these inhibitory systems. The current results, which showed a nearly 50% reduction in NPRS scores for the experimental group, align with similar findings by Rezaie et al.[1] and Mofateh and Rahimzadeh[6], where cognitive involvement during rehabilitation led to significant reductions in neuropathic pain. This suggests that dual-task training enhances both peripheral and central modulation of pain, potentially reducing reliance on pharmacologic management.

Sensory Perception

Improvement in tactile detection using the Semmes–Weinstein Monofilament Test was significant in both groups but superior in the cognitive–sensory group. Repetitive sensory exposure paired with cognitive attention likely increased cortical representation of the affected areas, facilitating perceptual learning and restoring plantar protective sensation[6,10]. According to Köhler et al.[3] and Divya et al.[10], multisensory and cognitively enriched interventions produce stronger neuroplastic responses than sensory training alone.

The moderate negative correlation observed between pain reduction and sensory recovery ($r = –0.51$, $p = 0.002$) further reinforces the relationship between sensory reorganization and pain modulation. As sensory accuracy improved, cortical resources may have been redistributed from nociceptive processing to tactile discrimination[9,10]. These results are in agreement with Maruboyina et al.[11], who demonstrated that specific sensory-focused rehabilitation enhances proprioceptive feedback and balance in individuals with DPN.

Balance and Postural Control

Balance improvement measured through the Berg Balance Scale (BBS) was statistically and clinically significant in both groups, with the dual-task group achieving higher mean gains. Postural control in diabetic neuropathy depends on effective integration of somatosensory, visual, and vestibular feedback, all of which may be compromised due to sensory deficits[5,13]. Dual-task training enhances this integration by simultaneously activating motor and cognitive pathways, improving anticipatory and adaptive responses.

Rezaie et al.[1] and Ghai et al.[4] observed similar results, noting that cognitive–motor dual-tasking strengthens neural coordination between sensory and executive centers. The involvement of prefrontal and parietal cortices during cognitive–sensory activities enhances attention allocation, thereby improving dynamic stability[6,9]. The present findings also agree with Tajuddin et al.[15] and Mustapa et al.[5], who reported that cognitively enriched exercises improve functional equilibrium and reduce postural sway in patients with neuropathy and balance disorders.

Functional Mobility

The Timed Up and Go (TUG) test demonstrated faster post-intervention performance in the dual-task group, reflecting better coordination, reaction time, and confidence during movement. Improved functional mobility is likely a downstream effect of enhanced sensory feedback and postural control. According to Trovão et al.[16], combining cognitive tasks with gait or mobility exercises enhances adaptability and reduces fall risk.

These findings also align with Köhler et al.[3] and Trombini-Souza et al.[20], who showed that dual-task protocols improved gait speed and stability by reinforcing attentional flexibility. The shorter TUG times observed in the present study suggest that dual-task training enhances real-world functional efficiency, as most daily activities require simultaneous physical and cognitive processing.

Underlying Mechanisms

The positive outcomes observed across all variables can be explained by neuroplastic reorganization facilitated by multisensory stimulation. Cognitive–sensory tasks activate the prefrontal cortex, primary sensory cortex, and parietal areas responsible for attention and proprioception. This broad neural activation enhances sensory mapping and executive control, promoting motor learning and balance restoration[17].

Dual-task training likely strengthened cortico–cortical communication and increased efficiency of descending inhibitory circuits, as suggested by Finnerup et al.[7] and Selvarajah et al.[12]. By continuously challenging the nervous system with concurrent sensory and cognitive demands, participants may have developed improved capacity for sensory discrimination, motor planning, and pain regulation[6,10,17].

Clinical Implications

The findings have meaningful clinical relevance. Diabetic neuropathy is associated with reduced quality of life, fear of falling, and functional dependency[2]. The current study provides evidence that incorporating Cognitive–Sensory Dual Task Training into rehabilitation programs can address both peripheral sensory loss and central processing deficits, offering a more holistic therapeutic approach.

Compared with standard sensory re-education, this method requires minimal equipment and can be applied easily in outpatient or community settings. Exercises can be individualized by adjusting cognitive load (e.g., verbal tasks, memory recall) or sensory complexity (e.g., different textures, vibration levels). As shown in this study, participants tolerated the intervention well, with no major adverse events and high adherence (>90%), confirming feasibility and safety.

Clinically, this approach may reduce fall risk, improve self-efficacy, and lessen pain dependency on medications. Integrating cognitive–sensory elements into physiotherapy could also enhance patient engagement and motivation, promoting longer-term compliance and functional independence[3,6,10].

Summary

Overall, this study demonstrates that Cognitive–Sensory Dual Task Training produces superior outcomes compared to conventional sensory re-education in individuals with diabetic peripheral neuropathy. Improvements in pain modulation, sensory recovery, balance, and functional mobility indicate that the integration of cognitive processes enhances both peripheral and central rehabilitation mechanisms. The findings are consistent with contemporary literature emphasizing that multisensory and cognitively enriched exercises stimulate neuroplasticity and functional adaptation[1,3,6,10,17].

Thus, dual-task paradigms should be considered a practical, low-cost, and evidence-based addition to physiotherapy management for patients with diabetic neuropathy. Future research incorporating neurophysiological assessments or long-term follow-up could further elucidate the underlying cortical adaptations and sustainment of these therapeutic effects.

CONCLUSION

This randomized controlled trial evaluated the effect of Cognitive–Sensory Dual Task Training on pain modulation, sensory perception, balance, and functional mobility in individuals with diabetic peripheral neuropathy (DPN). Both study groups improved significantly after six weeks of intervention; however, participants in the dual-task group showed greater improvements across all outcomes compared to those who received conventional sensory re-education.

The reduction in pain intensity and enhancement of sensory perception suggest that engaging cognitive processes during sensory training can strengthen both peripheral and central mechanisms of recovery. This supports the concept that cognitive engagement enhances cortical modulation and attentional control, resulting in reduced nociceptive perception and better tactile awareness[6–8]. Improved balance and mobility further indicate that integrating cognitive challenges into therapy enhances postural control and functional performance by promoting effective sensorimotor integration[3,4,15].

Clinically, the findings emphasize the feasibility, safety, and efficacy of incorporating dual-task paradigms into physiotherapy management of diabetic neuropathy. The approach requires minimal equipment, can be tailored to individual capability, and may serve as a cost-effective strategy to reduce fall risk, improve independence, and enhance quality of life[1,3,6].

In conclusion, Cognitive–Sensory Dual Task Training is more effective than conventional sensory re-education in improving pain modulation, sensory feedback, and functional outcomes in diabetic neuropathy. By targeting both cortical and peripheral pathways, this method provides a holistic framework for neurorehabilitation. Future research with larger samples and neurophysiological assessments is recommended to explore the long-term neuroplastic effects and sustainability of these benefits.

REFERENCES

1. Rezaie S, Goharpey S, Ghanavati T, Yadollah Poor N, Moradi L, Haghighy Zade MH. Effect of cognitive dual-task training on postural stability in older adults with diabetic peripheral neuropathy: a randomized control trial. J Biochem Tech. 2020;Special Issue(1):127–133. PMID: 32774289.
2. Tajuddin K, Justine M, Mustafah N, Latif L, Manaf H. Dual-tasking effects on gait and turning performance of stroke survivors with diabetic peripheral neuropathy. Malays J Med Sci. 2021;28(2):102–110. PMID: 33958961; PMCID: PMC8075590.
3. Køhler E, Dalgas U, Buhl CS, Brincks J. Content and effects of balance training in people with diabetic peripheral neuropathy: a systematic review and meta-analysis. Physiother Theory Pract. 2024;40(12):1083–1094. doi:10.1080/09593985.2024.2391823.
4. Ghai S, Ghai I, Effenberg AO. Effects of dual tasks and dual-task training on postural stability: a systematic review and meta-analysis. Clin Interv Aging. 2017;12:557–577. doi:10.2147/CIA.S125201. PMCID: PMC5396373.
5. Mustapa A, Justine M, Mohd Zulkifly M, Manaf H, Gill SV. Postural control and gait performance in the diabetic population: a systematic review. Diabetes Metab Syndr Obes. 2016;9:101–112. doi:10.2147/DMSO.S101935. PMCID: PMC4971307.
6. Mofateh R, Rahimzadeh S. The effects of multisensory exercises on balance control in people with diabetic peripheral neuropathy: a narrative review. Pract Diabetes Int. 2024;First published Nov 3, 2024. doi:10.1002/pdi.2522.
7. Finnerup NB, Kuner R, Jensen TS. Neuropathic pain: from mechanisms to treatment. Physiol Rev. 2021;101(1):259–301. doi:10.1152/physrev.00045.2019.
8. Colloca L, Ludman T, Bouhassira D, Baron R, Dickenson AH, Yarnitsky D, et al. Neuropathic pain. Nat Rev Dis Primers. 2017;3:17002. doi:10.1038/nrdp.2017.2.
9. Ghai S, Ghai I. Effects of dual-task training on cognitive and motor functions: mechanisms and evidence. Front Aging Neurosci. 2018;10:387. doi:10.3389/fnagi.2018.00387.
10. Divya T, Suganthirababu P, Srinivasan V, et al. Effect of sensory re-education with aerobic training on sensation and balance among diabetic peripheral neuropathy patients: a pilot study. Indian J Physiother Occup Ther. 2024;18(Special Issue):54–61.
11. Maruboyina S, Attry S, Kumari BK, Kumar M, Reddy K, Kumar S. Significance of sensory-specific intervention on balance in Type 2 peripheral diabetic neuropathy individuals. Int J Diabetes Res. 2019;8(2):17–22. doi:10.5923/j.diabetes.20190802.01.
12. Selvarajah D, Wilkinson ID, Maxwell M, Tesfaye S. Diabetic peripheral neuropathy: advances in diagnosis and implications for future therapeutics. Expert Rev Neurother. 2019;19(9):819–832. doi:10.1080/14737175.2019.1644326.
13. Bouhassira D, Attal N, Alchaar H, et al. Development and validation of the DN4 questionnaire for diagnosing neuropathic pain. Pain. 2005;114(1–2):29–36. doi:10.1016/j.pain.2004.12.010.
14. Mustapa A, Justine M, Mohd Zulkifly M, Manaf H. The role of sensory feedback in postural stability among individuals with diabetic neuropathy. J Diabetes Foot Complicat. 2017;9(3):12–18.
15. Tajuddin K, Justine M, Manaf H, Latif L. Dual-task balance and gait performance training in diabetic neuropathy: experimental findings. Phys Ther Res. 2022;27(4):215–222. doi:10.1298/ptr.E10337.
16. Trovão FA, Nogueira ES, Pontes LS, Bezerra ES, Gomes AA. Dual-tasking effects on functional performance in individuals with diabetes and diabetic peripheral neuropathy. Manual Therapy Posturology Rehabil J. 2025;25:1409. doi:10.17784/mtprehabjournal.2025.23.1409.
17. BR P, R Y, Kumar P, Patil K, Chandavarkar V, Sagarkar AR. Diabetes and Dental Woes: A Study on Burden of Oral Diseases in Type 2 Diabetes Mellitus Patients in Mysuru. Oral Sphere J. Dent. Health Sci. 2025;1(2):48-55. doi: 10.63150/osjdhs.2025.1
18. Maruboyina S, Attry S, Kumari BK, et al. Impact of sensory re-education on proprioceptive control in diabetic neuropathy. Int J Health Sci Res. 2020;10(2):45–50.
19. Yang Y, Zhao B, Wang Y, Lan H, Liu X, Hu Y, Cao P. Diabetic neuropathy: cutting-edge research and future directions. Signal Transduct Target Ther. 2025;10:132. doi:10.1038/s41392-025-01532-7.
20. Trombini-Souza F, Reis I, Ferreira C, et al. Effects of two different dual-task training protocols on gait in older adults: a randomized clinical trial. PeerJ. 2023;11:e15030. doi:10.7717/peerj.15030.