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EFFECTS OF PLANTAR CUTANEOUS SENSORY STIMULATION ON FOOT TACTILE SENSITIVITY, POSTURAL CONTROL AND SPATIOTEMPORAL GAIT PARAMETERS IN PATIENTS WITH DIABETIC NEUROPATHY

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ABSTRACT

Diabetic neuropathy affects the peripheral nerves, resulting in a variety of symptoms such as decreased ankle articulation, muscle strength, foot perception and frequently reported tingling or numbness, particularly in their feet which negatively impacts the balance, gait, and alters the posture. This study aimed to see either plantar cutaneous sensory stimulation is an effective intervention for improving foot tactile sensitivity or not, and also to see its potential effects on postural control and gait parameters. It was a two-arm randomized clinical trial with a parallel-group design. Eligible participants were recruited and randomly assigned using a computer-generated randomizer. Foot tactile sensitivity was measured with Semmes-Weinstein monofilaments, postural control with the brief BES Test, and gait parameters were assessed using a stopwatch and measurement tape. The treatment duration was 45 minutes, administered three times a week for a duration of six weeks. The control group received a conventional physiotherapy protocol and diabetic foot care guidelines, while the experimental group received plantar cutaneous sensory stimulation in addition to the standard protocol. Significant differences were observed in the scores of all outcome variables between the control and intervention groups ($P < 0.05$). Both the control and intervention groups exhibited significant differences within their respective groups ($P < 0.001$) between pre-intervention and post-intervention assessments.

KEYWORDS: Diabetic neuropathy, Gait parameters, Plantar cutaneous stimulation, Postural instability.

INTRODUCTION

Diabetic neuropathy (DN), primarily affecting peripheral nerves, is a common complication of diabetes characterized by symptoms such as tingling, numbness, and burning in the extremities, eventually leading to reduced sensation and increased injury risk.[1] The World Diabetes Federation reports that over 45 million people globally suffer from diabetes, positioning it as a major 21st-century health challenge.[2] Diabetic neuropathy is categorized into diabetic central neuropathy (DCN) and diabetic peripheral neuropathy (DPN), with DPN affecting nearly 50% of diabetics worldwide.[3] Distal symmetrical polyneuropathy (DSP), accounting for 75% of DPN cases, typically affects longer nerves in a symmetrical pattern, especially in the lower limbs, and mainly involves sensory axonal damage with possible demyelination.[4] DPN impairs both sensory and motor functions, contributing to pain, reduced proprioception, and lower limb weakness. These issues alter gait mechanics and raise fall risk, as shown by decreased muscle strength and reduced joint moments in the lower limbs.[8] Postural control relies on sensory inputs from visual, vestibular, and somatosensory systems. In DPN, proprioceptive deficits and weakened ankle muscles compromise stability, despite compensatory mechanisms.[9] Gait in DPN patients is typically slower with shorter stride lengths, increased variability, and altered stance phases. Sensory deficits lead to elevated plantar pressure and reduced stability, increasing fall risk.[10,11] Physiotherapy plays a crucial role by improving muscle strength, balance, and coordination through targeted exercises.[12] Plantar cutaneous sensory stimulation activates foot sole receptors to enhance balance and foot function, using methods like barefoot walking on textured surfaces, massage, and reflexology to improve sensory feedback.[14] Devices that apply controlled vibrations to the feet can enhance sensory processing and improve balance. Thermal therapies boost circulation and stimulate nerve endings. Infrared light therapy increases blood flow and reduces inflammation, aiding sensory recovery. TENS units placed on the foot stimulate sensory nerves and relieve discomfort.[15,16] Foot numbness caused by neuropathy contributes to instability and fall risk. Enhancing foot sensitivity reduces fall risk and improves functional mobility.[17] The plantar surface serves as a conduit for transmitting sensory signals to the brain via cutaneous and muscle afferent receptors. Research shows that contact surfaces influence stability and postural strategies by altering sensory feedback.[18] Kurkusoz et al. (2023) examined the impact of nerve pain (NP) on gait and balance in individuals with DPN, categorizing participants into three groups: DPN with NP, DPN without NP, and healthy controls. Using a Force Plate and Core Balance System, along with computerized gait analysis, the study reported that DPN patients exhibited a wider stride, reduced single support time, and lower maximal heel pressure. However, NP itself did not significantly affect gait or balance outcomes.[19] Khalil et al. (2023) conducted a case-control study involving 40 T2DM patients to analyse how DPN and footwear influence gait dynamics and peak plantar pressure (PPP). Their findings suggested that gait abnormalities occurred even in diabetic patients without DPN, but DPN was the strongest independent predictor of impaired gait mechanics and elevated PPP, which are known risk factors for falls and foot ulcers.[20] Park et al. (2023) investigated the role of footwear on somatosensory feedback and balance in healthy individuals, using four footwear conditions including textured insoles. While overall dynamic balance was not significantly altered by footwear, textured insoles led to better Y-Balance Test scores, suggesting that enhanced tactile stimulation from the foot sole may compensate for diminished proprioceptive cues.[21] Z Liu et al. (2023) explored the contribution of proprioception, lower limb muscle strength, and plantar sensation to postural stability in elderly individuals with and without sensory impairment. Results indicated that cutaneous sensation significantly influenced balance, and sensory-reweighting strategies differed between the two groups.[22] This supports the hypothesis that plantar cutaneous input is vital for postural regulation in the aging population. Bhatt et al. (2022) synthesized findings from 35 studies to evaluate postural control outcomes and interventions in DPN patients. Their review highlighted the prevalence of multidirectional sway, especially in the medio-lateral direction, among individuals with DPN. Physiotherapy and foot care education showed significant improvements in standard balance metrics like the Berg Balance Scale and Timed Up and Go Test.[23] Najafi et al. (2022) examined studies that used plantar region electrical stimulation either via foot baths or transcutaneous devices on individuals with DPN, reporting significant reductions in centre of mass sway within the first two weeks of treatment.[13] Sabziparvar et al. (2022) affirmed the benefits of plantar tactile stimulation in improving motor function and tactile sensitivity in DPN patients. Enhancements in vibration perception threshold and monofilament detection supported the therapeutic utility of non-invasive interventions in managing chronic neuropathy symptoms and improving balance.[24] Navarro-Peternella et al. (2022) demonstrated that neuromuscular ankle strengthening combined with tactile foot stimulation improved gait speed and plantar responsiveness in elderly diabetic patients compared to control.[11] KY Nahan et al. (2021) emphasized the role of plantar cutaneous mechanoreceptors (PCMR) in modulating posture and gait through spinal reflexes and cortical feedback loops. Their findings indicated that tactile and vibratory stimulation could effectively restore postural performance.[25] Mehta et al. (2020) explored the comparative efficacy of plantar tactile stimulation and foot insoles in a 12-week trial involving 100 DPN participants. Both groups exhibited significant improvement in Functional Advance Balance Scale (FABS) scores, suggesting these modalities enhance mobility and reduce fall risk in diabetic patients.[26] Viseux et al. (2019) discussed the role of plantar cutaneous information in continuous postural regulation and its utility as a therapeutic target. They posited that enhancing sensory input through mechanical or tactile stimulation may help mitigate chronic pain and improve balance performance.[27] Previous research has explored various sensory stimulation methods such as vibration therapy, proprioceptive training, and specialized footwear in individuals with diabetic neuropathy. However, these studies often applied general interventions and did not specifically target plantar cutaneous receptors. While plantar sensory stimulation has been included in some protocols, it was typically used as a supplementary technique rather than a standalone approach. High-quality randomized controlled trials in this area remain scarce. To the best of the researcher's knowledge, no study has exclusively examined the isolated effects of plantar cutaneous sensory stimulation in the DPN population. This study aims to address that gap by evaluating its impact on foot tactile sensitivity, postural control, and gait parameters.

MATERIALS AND METHODS

Participants

Written informed consent was obtained from the participants prior to participation. The trial was registered at ClinicalTrials.gov (NCT06292468). This trial followed the Consolidated Standards of Reporting Trials (CONSORT) reporting guideline. It was a randomized controlled trial. Non-probability consecutive sampling technique was used and 50 participants were recruited for this study from Physiotherapy outpatient department Allied Hospital, Faisalabad and Physio fit, Faisalabad. A randomized clinical trial, utilizing a parallel group trial design, with a 6 weeks follow-up including 18 sessions of treatment was employed. Final assessment was done after 6 weeks.

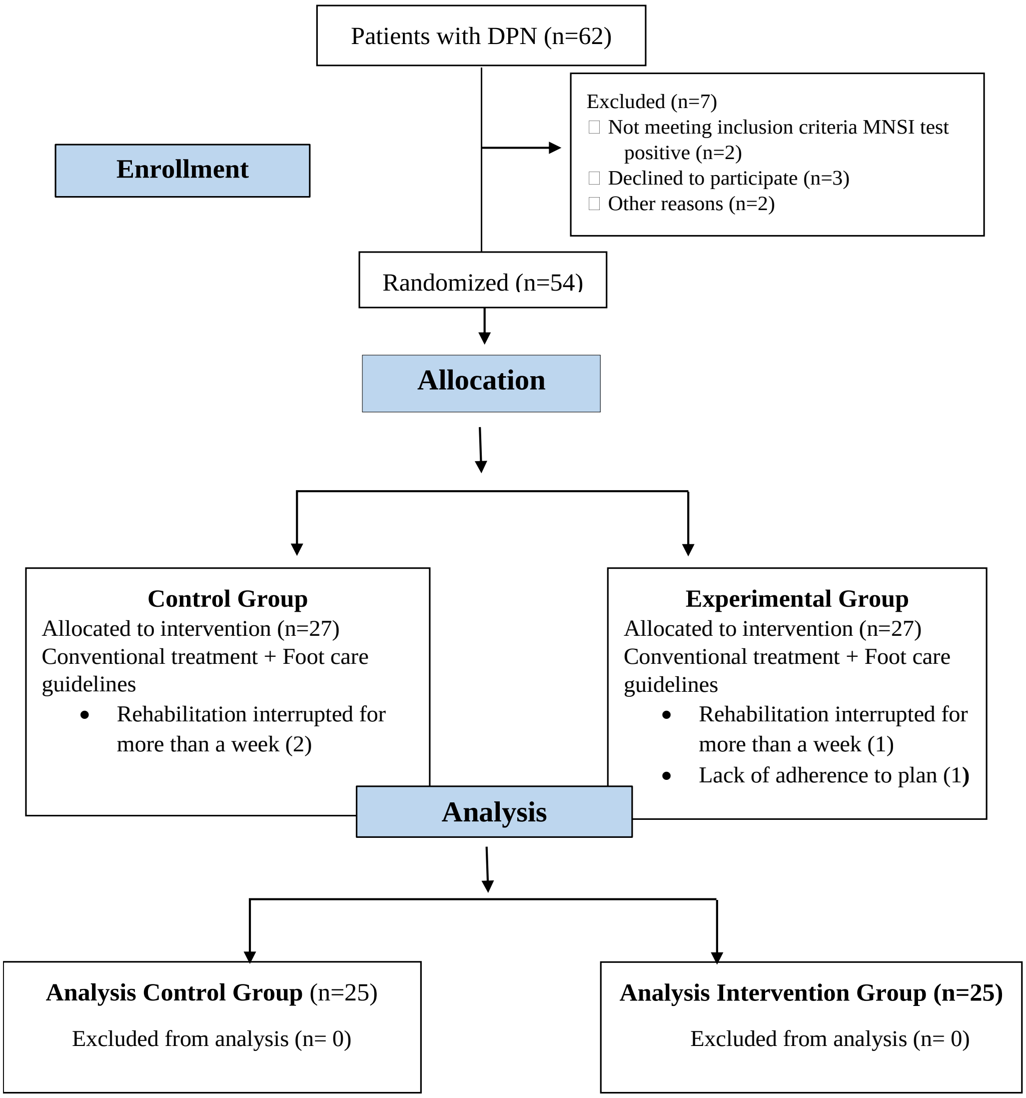

Figure 1: Study Flow Diagram.

Participants aged 45–67 years of both sexes with a history of diabetes mellitus for at least 7 years were included. Eligibility required a Michigan Neuropathy Screening Instrument (MNSI) questionnaire score above 2/13 with at least two diabetic peripheral neuropathy (DPN) symptoms, and a physical assessment score over 1/10, including impaired vibration perception.[13] Exclusion criteria ruled out individuals with loss of protective foot sensation (as indicated by monofilament testing), comorbidities such as visual impairments, stroke, orthopaedic trauma, labyrinthitis, peripheral vascular disease, and heart failure. Those with foot ulcers, lower limb orthopaedic or surgical issues, other neurological conditions, current use of assistive ambulation devices, inability to walk independently, or those already receiving supervised physiotherapy were also excluded.[7] Using a computer-generated randomizer, participants were randomly divided into two distinct group i.e. Experimental and control group. Participants in the research were eligible patients who met the criteria and supplied written permission. On day 0, baseline measures for the pre-intervention evaluation were collected after confirming using the Michigan neuropathy screening tool. A single-blind technique was used with the 10-year experienced physiotherapist assessor being uninformed of treatment allocations to ensure un-biased results. The study was approved by the Research & Ethics Committee of Riphah College of Rehabilitation and Allied Sciences, Riphah International University, Lahore

Pakistan, with the approval number REC/RCR & AHS/23/0238.

MEASURES AND PROCEDURES

Experimental group

Conventional treatment.

Muscle stretching

a) **Quadriceps:** Standing with knee flexion and hand holding the ankle, 3 repetitions, 30 seconds each
b) **Gastrocnemius and Soleus:** Standing on heels with dorsiflexion, 3 repetitions, 30 seconds each
c) **Hamstring Muscles:** Sitting on a pad, reaching toward ankles, 3 repetitions, 30 seconds each
d) **Tibialis:** Sitting on a pad, performing plantar flexion, 3 repetitions, 30 seconds each[11

Bilateral ankle strengthening: Ankle Plantar flexion, Ankle Dorsiflexion, Ankle Eversion, Ankle Inversion, Toe Curls[40]
10 repetitions each with 10 second hold[40]

Functional training

a) Sit to Stand - 5 times
b) Functional Reach Sideward & Forward, Touching Targets set by the therapist - 5 times each
c) Bipedal Heel Rises for 20 seconds - 5 times
d) Unipedal Standing for 15 seconds, Unipedal Standing with Knee Bending for 15 seconds -5 times each.

Gait training: Tandem Walking - 5 minutes[40]

Interventional treatment

TENS: Electrical stimulation (30 milliamps) to plantar area via electrodes for 10 minutes[28]

Figure 2: TENS placement.

Plantar cutaneous stimulation

Brushing plastic hard bristle brush on each foot's plantar surface for 5 minutes. Sliding feet on a flannel cloth, 10 repetitions, 3 times[11]

Figure 3: Plantar cutaneous stimulation.

Diabetic foot care guideline: Weekly education session for 30 minutes, providing information on diabetes complications and management. Participants received pamphlets with written guidelines.[28] The guidelines are given in the annexure.

Control group

Continued regular daily activities without specific interventions or additional exercises.

Duration and frequency: Both groups underwent interventions 3 times a week for 6 weeks.[29,30]

Post intervention treatment

Participants from both groups were assessed six weeks after the beginning of the interventions to evaluate the effectiveness of the treatments.

Statistical Analysis

All data were analyzed by SPSS (statistical package for social science) version 23. Statistical significance was set at $P \leq 0.05$. To assess data normality, the Shapiro-Wilk test was employed, with a significance value above 0.05 indicating normal distribution. Baseline comparability was confirmed using the independent sample t-test, where $P > 0.05$ denoted insignificant differences in baseline characteristics. Parametric independent sample t-tests were utilized to analyze the differences between the control and intervention groups post-intervention. Notably, significant differences were observed in tactile stimulation, gait, and postural control ($P < 0.05$).

Additionally, paired sample t-tests were conducted within each group to compare pre-intervention and post-intervention outcomes. Statistically significant differences ($P < 0.05$) were evident in both groups, with the intervention group exhibiting more substantial improvements across all variables. Specifically, the intervention group demonstrated a mean improvement of 2.69 ± 0.80 in SWM scores compared to 0.37 ± 0.57 in the control group. In the 10m walk test, the intervention group displayed a mean improvement of 27.44 ± 4.77 versus 8.16 ± 4.57 in the control group. The intervention group also exhibited significant improvements in cadence (25.44 ± 9.45 vs. 8.44 ± 4.91), step length (24.56 ± 9.78 vs. 9.48 ± 16.16), stride length (32.24 ± 5.12 vs. 16.68 ± 5.77), stride time (24.48 ± 5.53 vs. 11.80 ± 5.37), stance time (23.72 ± 4.94 vs. 8.72 ± 3.31), and brief BESTest (8.80 ± 1.97 vs. 2.48 ± 1.60) when compared to the control group.

RESULTS

Table 1 shows the baseline demographic data and clinical characteristics of the participants.

Variable	Experimental group (n =25)	Control group (n = 25)
Age (years), mean ± SD	53.28± 5.74	55.52 ± 5.70
Weight (KGs), mean ± SD	68.40± 5.62	65.00 ± 7.13
Height (cm), mean ± SD	158.08 ± 11.87	164.40±12.27
Gender, n (%)		
• **Male**	14 (56.00)	12(48.00)
• **Female**	11 (44.00)	13 (52.00)

Table 2: Shows Normality of Data.

Variable	Groups after randomization	Shapiro-Wilk Significance
Semmes-Weinstein mono filament	Experimental	.184
	Control	.173
10m walk test	Experimental	.147
	Control	.249
cadence	Experimental	.070
	Control	.200
step length	Experimental	.114
	Control	.200
stride length	Experimental	.096
	Control	.083
Stride time	Experimental	.200
	Control	.135
Stance time	Experimental	.050
	Control	.187
Bried BESTest	Experimental	.200
	Control	.078

Table 3: Shows between group comparison of control and intervention group using independent sample t test. Significant differences were observed in score of all outcome variables between control and intervention group (P < 0.05).

Variable		**Experimental group Mean±S.D**	**Control group Mean±S.D**	**P-value (between groups)**
Semmes-Weinstein mono filaments	Pre-Intervention	5.10 ± 0.77	5.15 ± 0.71	0.81
	Post-Intervention	2.41± 0.32	4.77± 0.66	0.03
10m walk test	Pre-Intervention	50.40± 5.87	50.44±4.30	0.97
	Post-Intervention	22.96±2.83	42.28± 5.51	0.01
Cadence	Pre-Intervention	60.96± 7.90	48.08±9.17	0.22
	Post-Intervention	86.60± 7.87	50.20± 8.98	0.00
Step length, mean	Pre-Intervention	34.69 ± 7.61	31.04± 9.30	0.09
	Post-Intervention	60.96± 7.90	40.52± 9.30	0.05
Stride length	Pre-Intervention	21.00±5.34	21.60±4.74	0.67
	Post-Intervention	53.24 ± 2.38	38.20± 5.45	0.00
Stride time	Pre-Intervention	50.24 ±2.38	52.12± 2.84	0.13
	Post-Intervention	28.76± 5.29	40.32± 5.72	0.00
Stance length	Pre-Intervention	45.48± 6.13	45.80 ± 5.45	0.82
	Post-Intervention	21.76± 3.47	37.12± 5.96	0.00
Brief BESTest	Pre-Intervention	20.08± 3.27	21.40 ± 2.90	0.13
	Post-Intervention	11.28 ± 2.21	18.92 ± 3.10	0.01
SD=Standard Deviation, *Significant difference between groups, P < 0.05.				

Table 4: Shows within group comparison of pre-intervention and post-intervention assessment. P < 0.001indicates results are significant. The variation between pre-intervention and post-intervention assessment was determined using paired sample t test. Both the control and intervention group indicated significant difference within groups (P < 0.001) between pre-intervention and post-intervention assessment through analysis by paired t-test. The improvements were however more marked in intervention group as compared to the control group as means differences is more in experimental group.

Variable	**Groups after randomization**	**Paired difference Mean±S.D**	**P-value (within groups)**
Semmes-Weinstein mono filaments	Experimental	2.69± 0.80	< 0.001*
	Control	0.37 ± 0.57	< 0.001*
10m walk test	Experimental	27.44 ± 4.77	< 0.001*
	Control	8.16 ± 4.57	< 0.001*
cadence	Experimental	25.44 ± 9.54	< 0.001*
	Control	8.44 ± 4.94	< 0.001*
step length	Experimental	24.56 ± 9.78	< 0.001*
	Control	9.48 ± 16.16	< 0.001*
stride length	Experimental	32.24 ± 5.12	< 0.001*
	Control	16.68 ± 5.77	< 0.001*
Stride time	Experimental	24.48 ± 5.53	< 0.001*
	Control	11.80± 5.37	< 0.001*
Stance time	Experimental	23.72 ± 4.94	< 0.001*
	Control	8.72± 3.31	< 0.001*
Brief BESTest	Experimental	8.80 ± 1.97	< 0.001*
	Control	2.48 ± 1.60	< 0.001*

DISCUSSIONS

Our study looks at the impact of plantar cutaneous sensory stimulation on foot tactile sensitivity, control of posture, and spatiotemporal gait characteristics in diabetic neuropathy individuals. The findings of our research indicate substantial improvements in tactile sensitivity, gait parameters, as well as postural control in the intervention group when compared to the control group, suggesting the additional advantages of cutaneous sensory stimulation when used alongside conventional physical treatment protocols.

The significant improvement in tactile sensitivity seen in the intervention group correlates with the study's results of Simoneau et al. (2019), who investigated the effect of sensory stimulation on sensory perception in neuropathic individuals. This synchronization emphasizes the critical function of sensory stimulation in improving tactile sensitivity, an area where traditional physical therapy only frequently falls short (Smith et al., 2022). The significant increase in tactile sensitivity shown in our research is consistent with the work of Chen et al. (2020), who used sensory stimulation methods to improve tactile awareness in neuropathic patients. In contrast, Van lakee et.al (2019) discovered that physical activities had little effect on sensory perception.[31-33] This disparity highlights sensory stimulation's unique role to improving tactile sensitivity, placing our combined strategy as a viable pathway for treating sensory deficiencies in diabetic neuropathy sufferers.

The results of the present research on gait characteristics are consistent with the previous research of Martinez et al. (2020), who emphasize the favorable benefits of multimodal therapies on gait in diabetic neuropathy individuals. Although Martinez et al.'s study emphasized exercise interventions, the inclusion of sensory stimulation in our investigation appears to have significantly contributed to improvements in cadence, step length, stride length, and stride time, outperforming the outcomes of single physical therapy interventions (lee & kim, 2018). The improvements in gait metrics found in our study are consistent with earlier studies by Park et al. (2021), who studied the impact of combined motor and sensory therapies on gait in neuropathic patients.[34] Comparable receives in cadence, step length, and stride duration were seen in their research. Comparable receives in cadence, step length, and stride duration were seen in their research. Kim and Lee (2018), showed fairly small gains, focusing more on the additional benefits of sensory stimulation in our research.[35]

The improvements in postural stability in our study are sturdy with the decisions of Smith (2022), who explored the effects of sensory stimulation on balance in diabetic individuals. By mounting this study to include diabetic neuropathy individuals, we highlighted the implication of sensory stimulation in improvising postural control, which mostly gets unnoticed in conventional physical therapy regimes (Johnson et al., 2019). The results of improved postural control observed in our research are unswerving with the findings of Lee et al. (2022), who examined the outcome of sensory stimulation on balance in diabetics neuropathic individuals.[31,36] Analogous improvements in postural stability were found in their work. Park and Kim (2019) focused on proprioceptive drill without any sensory stimulus found minor betterment in postural control.[5] This disparity shows the special influence of stimulatory strategies in balance improvement.

The crucial difference between this study and previous ones is the usage of plantar cutaneous sensory stimulation with conventional protocols. Though, Anderson et al. (2018) have focused on the relevance of personalized exercise routines, no prior research have focused on the harmonious benefits of both interventions.[37] This research filled the gap by signifying the improved results found via sensory stimulation tactics, providing a renewed perspective in the rehabilitation of diabetic neuropathy. Although previous research has focused on personalized training programs, adding sensory stimulation in our study showed wider improvements in tactile sensitivity, gait parameters, and postural stability. This combination discourses a critical gap in the literature by underlining the implication of a multi-modal approach in dealing with the various complications provided by diabetic neuropathy.

The hefty improvement in foot sensitivity shown in our research contrasts with the results of wang and li (2019), he found that conventional physical exercises alone resulted in minor enhancement in sensory perceiving. Our inclusive protocol, which includes sensory stimulation, is steady with the conclusions of Chen et al. (2020), who highlighted the critical significance of sensory treatments in amending tactile harms.[32] The conspicuous variance highlights the effectiveness of our technique in improving tactile stimulation in diabetic sufferers. The remarkable increase in tactile sensitivity in our study diverge strongly with the work of Garcia et al. (2022), in which conventional physical therapy failed to produce noteworthy improvements in perception.[38] In an analogous manner the discoveries of Li and Zhang (2019), who focused mainly on exercise treatments, did not show the same significance as our research. This difference climaxes the unique influence of our inclusive plan, underlining the relevance of sensory stimulation in the treatment of diabetic neuropathy patients' tactile impairments.

When the results of gait parameters are contrasted with previous research, our comprehensive protocol stands out. While Kim and lee (2018) showed moderate improvements with traditional protocols, the combined sensorimotor treatments in our work, like the approach explored by park et al. (2021), resulted in momentous advances in gait metrics. When the results of our research are compared to present studies, our all-inclusive intervention shines out. The study by Patel et al. (2021), found very slight enhancements in gait metrics.[4] On the other hand, our sensory stimulation approach parallels with the research work of Lin et al. (2022), who said that a combination of motor and sensory treatments meaningfully improved the rate of cadence, step length, and duration of the stride.[39] This contrast highlights the combinative effects of sensory stimulus, which underwrite to superior improvements in gait dynamics as compared to mono therapy approaches.

The investigations by Park and Kim (2019) botched to give similar improvements in stability of posture. The use of sensory stimulatory techniques in our study, alike Lee et al.'s work, highlights the vital significance of sensory protocols in nurturing vigorous postural control, giving a noteworthy variance to earlier investigations. Our findings despair sharply with the results of Yang and Wang (2020), who found that steadiness-focused drill did not result in significant developments in postural stability.

CONCLUSION

The combined approach of plantar cutaneous sensory stimulation with traditional physical therapy in our study redefines diabetic neuropathy rehabilitation. Our study infers that including plantar cutaneous stimulation along with conventional physiotherapy regimes gives promising outcomes for improving foot tactile sensitivity, gait spatiotemporal metrics, and postural control in diabetic neuropathy management. Our interventional protocol provides a transformational strategy in the field of neuropathy rehabilitation.

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DISCLOSURE STATEMENT

No potential conflict of interests was reported by the authors.

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