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Balance Impairment in Diabetic Peripheral Neuropathy

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Abstract. Diabetic peripheral neuropathy (DPN) is associated with impaired balance, but it is unclear whether adults with DPN have greater balance difficulty than adults with diabetes without DPN, particularly when sensory information is limited or altered. This cross-sectional study examined the association between DPN and standing balance under different sensory conditions. Data were obtained from 2,152 adults aged 40 years or older in the 2003–2004 National Health and Nutrition Examination Survey. Peripheral neuropathy was defined using monofilament testing, and balance was assessed using the Modified Romberg test. Survey-weighted logistic regression compared four groups: DPN, diabetes without DPN, prediabetes without peripheral neuropathy, and healthy controls. Models were adjusted for demographic factors and body mass index. Stata version 18.0 was used for the analyses. Few participants failed the eyes-open test on a firm surface, and failure rates did not differ significantly across groups. With healthy controls as the reference, the DPN group had higher adjusted odds of failure in the other conditions: eyes closed on a firm surface (aOR 4.43; 95% CI 2.12–9.25), eyes open on a compliant surface (aOR 10.49; 95% CI 3.18–34.57), and eyes closed on a compliant surface (aOR 2.25; 95% CI 1.47–3.45). No significant difference was found between diabetes without DPN and healthy controls. Poorer balance in DPN was thus associated with conditions that challenged vision or sensory information from the support surface. Testing these conditions may reveal deficits that are less apparent with the eyes open on a firm surface.

Keywords: Diabetic peripheral neuropathy, Postural balance, Sensory impairment, NHANES

1. Introduction

Diabetes mellitus is a growing global health problem. In 2024, its global prevalence among adults aged 20–79 years was estimated at 11.11%, with a projected rise to 12.96% by 2050 [1]. Alongside its prevalence and economic burden, diabetes affects several physiological systems that support physical function. Chronic hyperglycemia, insulin resistance, and fat infiltration within muscle can disrupt skeletal muscle metabolism and reduce glucose oxidative capacity. These changes may progressively weaken muscles, especially in the lower extremities [2]. Peripheral neuropathy also affects the sensory information needed for balance and coordinated movement. Nerve dysfunction can reduce sensory input from the lower limbs, and diabetes-related visual impairment can make it harder to perceive the surroundings and maintain body orientation [3]. As muscular and sensory function deteriorate, movement may become more difficult and less stable. The resulting mobility

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and balance problems can increase the risk of falls. Over time, daily activities may become harder to perform, physical activity may decline, and people may spend more time sedentary or lose their independence.

Diabetic peripheral neuropathy (DPN) is a distal, symmetric microvascular complication of diabetes. It involves progressive damage to peripheral sensory nerves and, in some cases, motor nerves [4]. This damage can reduce sensory feedback from the lower extremities, including plantar tactile sensation and proprioception. To maintain an upright stance, the central nervous system must continually combine visual, vestibular, and somatosensory input and produce suitable postural responses. When one source of information becomes unavailable or unreliable, the remaining sources become especially important. Reduced plantar sensation and proprioceptive input in DPN may make subtle body sway and changes in the support surface harder to detect. The postural adjustments needed to maintain balance may then be less accurate. Clinical findings are consistent with this explanation: people with DPN generally show poorer balance and mobility than healthy adults. Ullah et al. [5] reported greater static balance deficits and poorer functional mobility in DPN, including longer Timed Up and Go (TUG) completion times and less stable tandem stance. In older adults with DPN, Jimenez-Mazuelas et al. [6] found substantial dynamic balance impairment, greater concern about falling, and more functional limitations than in age-matched healthy controls.

Previous studies link DPN to impaired balance, but it remains unclear whether peripheral sensory impairment is associated with additional difficulty among adults who already have diabetes. This question is particularly relevant when sensory input is reduced or altered. Many studies have used small or clinic-based samples, with comparisons made mainly between people with DPN and healthy controls. Such comparisons show the balance deficits associated with DPN, but they do less to distinguish the contribution of peripheral sensory impairment from the other physiological and functional changes that accompany diabetes. General measures of balance performance also give limited information about what happens when a particular sensory source becomes unavailable or unreliable. Since standing balance depends on visual, vestibular, and somatosensory input, testing progressively more challenging sensory conditions may help clarify the association between peripheral sensory impairment and postural control in adults with diabetes.

Using nationally representative data from the National Health and Nutrition Examination Survey (NHANES), this study examined how monofilament-defined peripheral sensory impairment was associated with standing balance under progressively more challenging sensory conditions. Modified Romberg performance was compared in adults with diabetes with and without peripheral sensory impairment. The aim was to determine whether those with sensory impairment had greater difficulty maintaining balance as visual and somatosensory information became limited or less reliable.

2. Methodology

2.1. Data source

Data were obtained from the 2003–2004 cycle of the National Health and Nutrition Examination Survey (NHANES), which included objective assessments of peripheral sensation and standing balance. NHANES uses a complex, multistage probability sampling design to obtain a representative sample of the non-institutionalized U.S. civilian population. Participants completed in-home interviews followed by clinical evaluations at mobile examination centers. Ethical approval was granted by the National Center for Health Statistics Ethics Review Board, and all subjects provided written informed consent prior to data collection.

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2.2. Study participants

The analytic sample included participants aged 40 years or older with valid balance-assessment data. Participants with missing peripheral neuropathy data were excluded. Participants with peripheral neuropathy but without diabetes, including those with prediabetes, were also excluded because their neuropathy could not be attributed to diabetes. The final analytic groups comprised participants with DPN, diabetes without DPN, prediabetes without peripheral neuropathy, and healthy controls without peripheral neuropathy. The participant-selection process is presented in Figure 1.

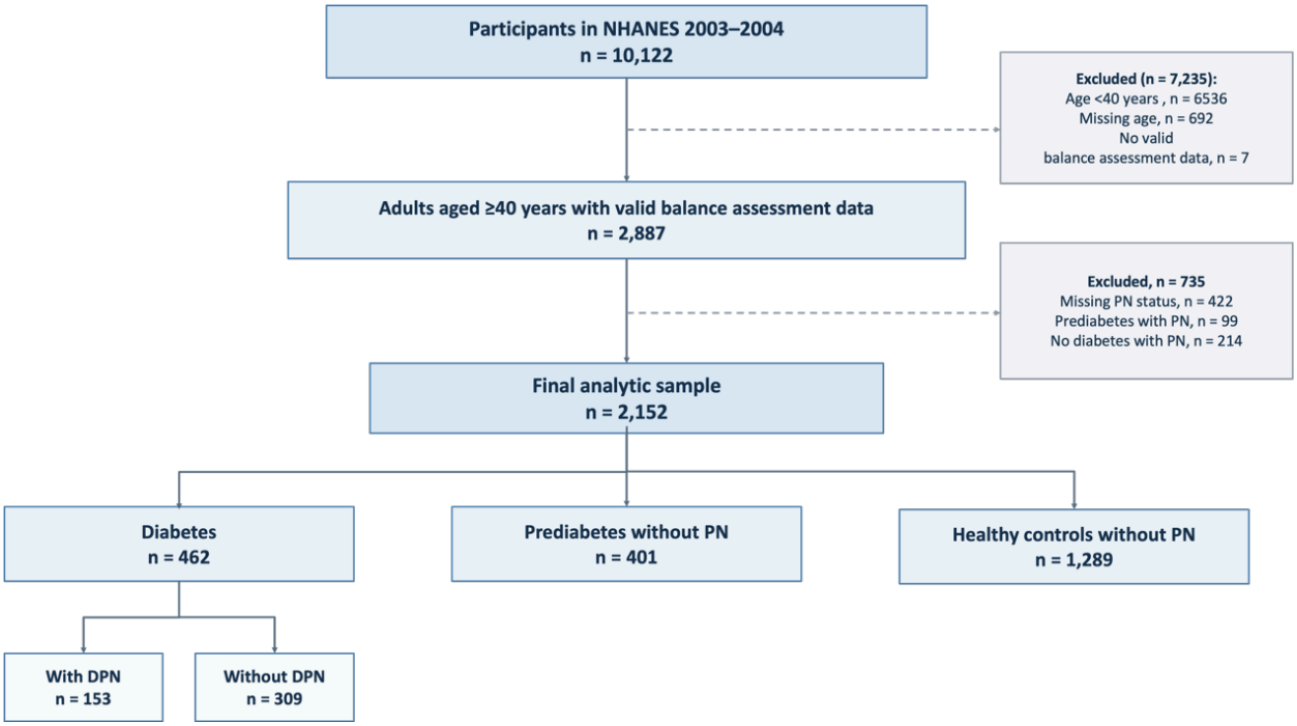


Figure 1. Participant selection flowchart. DPN, diabetic peripheral neuropathy; PN, peripheral neuropathy

2.3. Diabetes and DPN classification

Diabetes status was determined using self-reported physician diagnosis and glycated hemoglobin (HbA1c) levels. Participants who reported a physician diagnosis of diabetes were classified as having diagnosed diabetes, regardless of their HbA1c level. Among participants without a previous diagnosis, those with HbA1c <5.7% were classified as having no diabetes, those with HbA1c ≥5.7% and <6.5% were classified as having prediabetes, and those with HbA1c ≥6.5% were classified as having undiagnosed diabetes. The diabetes group included both diagnosed and undiagnosed cases [7].

Peripheral sensation was tested with a 5.07 Semmes–Weinstein monofilament delivering approximately 10 g of force. On each foot, the test sites were the plantar first metatarsal head, fifth metatarsal head, and hallux. At least one insensate site on either foot was required for classification as peripheral neuropathy. Among participants with diabetes, those who met this criterion were classified as having DPN; those with no insensate sites were classified as having diabetes without DPN [7].

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2.4. Balance assessment

The modified Romberg Test of Standing Balance was used to assess postural balance on firm and compliant surfaces [8]. The test increases sensory difficulty across four conditions: (1) eyes open on a firm surface, (2) eyes closed on a firm surface, (3) eyes open on a compliant surface, and (4) eyes closed on a compliant surface. Participants were allowed up to two trials in each condition. Conditions 1 and 2 lasted 15 seconds, while conditions 3 and 4 lasted 30 seconds. A trial was counted as a failure if the participant opened their eyes during a closed-eye trial, stepped or moved their arms or feet to maintain balance, or needed examiner assistance to avoid a fall. Each condition was analyzed separately, with performance recorded as pass or fail.

2.5. Covariates

Covariates were chosen based on earlier research and their possible relationships with DPN and balance. Age was included as a continuous variable in years, and sex as male or female. Race and ethnicity categories were Mexican American, other Hispanic, non-Hispanic White, non-Hispanic Black, and other race. Educational level was classified as less than high school, high school graduate or equivalent, or more than high school. Income level and body mass index (BMI; kg/m^2) were also included.

2.6. Data analysis

Survey-weighted multivariable logistic regression models were used to compare balance outcomes across the four study groups: participants with DPN, diabetes without DPN, prediabetes without peripheral neuropathy, and healthy controls without peripheral neuropathy. Models were adjusted for covariates. Results are presented as odds ratios with 95% confidence intervals. Statistical significance was defined as p value <0.05. Statistical analyses were performed using Stata version 18 (StataCorp, College Station, TX).

3. Results

3.1. Participant characteristics

The final analytic sample included 2,152 participants. Of these, 153 (4.7% weighted) had diabetes with peripheral neuropathy (DPN), 309 (11.1%) had diabetes without DPN, 401 (14.8%) had prediabetes without peripheral neuropathy, and 1,289 (69.4%) were healthy controls without peripheral neuropathy. Mean age differed across groups ($p < .001$), ranging from 53.3 years in healthy controls to 63.5 years in the DPN group. The DPN group also had the highest weighted proportion of men (72.8%), compared with 39.3%–45.3% in the other groups.

Race and ethnicity, educational attainment, and annual household income distributions differed across groups (all $p < .001$). Participants with DPN had the highest proportion with less than a high school education (32.9%), while healthy controls had the highest proportions with more than a high school education (58.9%) and an annual household income of at least $75,000 (32.2%). Mean BMI and HbA1c also differed across groups (both $p < .001$). Mean BMI ranged from 27.8 kg/m^2 in healthy controls to 32.0 kg/m^2 in the DPN group; mean HbA1c ranged from 5.3% to 7.4%, respectively. Participant characteristics across the four study groups are presented in Table 1.

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Table 1. Characteristics of the analytic sample by diabetes and peripheral neuropathy status

Characteristic	DPN	Diabetes without DPN	Prediabetes without PN	Healthy controls without PN	Overall	P value
Sample size, n (weighted %)	153 (4.7)	309 (11.1)	401 (14.8)	1,289 (69.4)	2,152 (100.0)	
Age, years, weighted mean (SE)	63.5 (1.4)	59.3 (0.8)	59.8 (0.6)	53.3 (0.4)	55.4 (0.4)	<0.001
Sex, n (weighted %)						<0.001
Male	104 (72.8)	134 (39.3)	179 (42.0)	607 (45.3)	1,024 (45.5)	
Female	49 (27.2)	175 (60.7)	222 (58.0)	682 (54.7)	1,128 (54.5)	
Race and ethnicity, n (weighted %)						<0.001
Non-Hispanic White	77 (74.8)	125 (66.3)	197 (69.2)	817 (83.3)	1,216 (79.0)	
Non-Hispanic Black	24 (10.2)	76 (15.4)	98 (15.7)	203 (7.5)	401 (9.7)	
Mexican American	45 (7.0)	90 (8.0)	75 (4.7)	214 (4.2)	424 (4.8)	
Other race	5 (5.7)	11 (5.9)	17 (5.5)	28 (2.9)	61 (3.7)	
Other Hispanic	2 (2.3)	7 (4.4)	14 (4.9)	27 (2.1)	50 (2.8)	
Educational attainment, n (weighted %)						<0.001
Less than high school	70 (32.9)	117 (23.2)	133 (22.1)	307 (13.1)	627 (16.5)	
High school graduate or equivalent	32 (27.0)	76 (26.2)	114 (31.4)	350 (27.9)	572 (28.2)	
More than high school	51 (40.1)	116 (50.6)	153 (46.5)	631 (58.9)	951 (55.2)	
Annual household income, n (weighted %)						<0.001
<$20,000	43 (22.0)	111 (27.1)	107 (20.7)	268 (13.4)	529 (16.4)	
$20,000-$74,999	84 (62.4)	132 (51.5)	214 (59.1)	658 (54.4)	1,088 (55.2)	
$75,000 or more	16 (15.6)	44 (21.4)	62 (20.2)	280 (32.2)	402 (28.4)	
BMI, kg/m2, weighted mean (SE)	32.0 (0.2)	31.7 (0.7)	30.2 (0.4)	27.8 (0.2)	28.8 (0.2)	<0.001
HbA1c, %, weighted mean (SE)	7.4 (0.2)	7.2 (0.1)	5.9 (0.01)	5.3 (0.01)	5.7 (0.02)	<0.001

Note. Values are presented as unweighted n (survey-weighted %), survey-weighted mean (SE), or unweighted n, as indicated.

DPN, diabetic peripheral neuropathy; PN, peripheral neuropathy; BMI, body mass index; HbA1c, glycated hemoglobin; SE, standard error.

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3.2. Balance performance across groups

Balance performance differed significantly across groups. Failure was rare in Condition 1 (eyes open on a firm surface), with no significant difference across groups (p=0.730). Failure rates remained relatively low in Condition 2 (eyes closed on a firm surface) and Condition 3 (eyes open on a compliant surface) but increased substantially in Condition 4 (eyes closed on a compliant surface), in which approximately half of the overall analytic population was unable to complete the task. Across Conditions 2 to 4, participants with DPN consistently had the highest weighted failure rates, whereas healthy controls had the lowest.

After adjustment for age, sex, race and ethnicity, education, household income, and BMI, the overall group effect remained significant for Condition 2 (p=0.012), Condition 3 (p=0.014), and Condition 4 (p=0.004). Compared with healthy controls, participants with DPN had higher odds of being unable to complete Condition 2 (aOR, 4.43; 95% CI, 2.12–9.25), Condition 3 (aOR, 10.49; 95% CI, 3.18–34.57), and Condition 4 (aOR, 2.25; 95% CI, 1.47–3.45). The diabetes-without-DPN group did not differ significantly from healthy controls, whereas the prediabetes-without-PN group showed higher odds of failure in Conditions 2 and 3. Adjusted associations between diabetes and peripheral neuropathy status and inability to complete balance conditions are presented in Table 2.

Table 2. Adjusted associations between diabetes and peripheral neuropathy status and inability to complete balance conditions

Balance condition	DPN, aOR (95% CI)	Diabetes without DPN, aOR (95% CI)	Prediabetes without PN, aOR (95% CI)	Healthycontrols withoutPN	Overall p value
Condition 2: Eyes closed, firm surface	4.43 (2.12-9.25)	2.11 (0.93-4.78)	2.06 (1.03-4.09)	Reference	0.012*
Condition 3: Eyes open, compliant surface	10.49 (3.18-34.57)	3.41 (0.95-12.23)	3.33 (1.02-10.90)	Reference	0.014*
Condition 4: Eyes closed, compliant surface	2.25 (1.47-3.45)	1.37 (0.98-1.92)	1.22 (0.77-1.92)	Reference	0.004**

*Note. * $p<0.05$, ** $p<0.01$; aOR, adjusted odds ratio; CI, confidence interval; DPN, diabetic peripheral neuropathy; PN, peripheral neuropathy.*
Models accounted for the NHANES complex survey design and were adjusted for covariates.
Healthy controls without PN were the reference group. Condition 1 was not modeled because of insufficient outcome variation.
An aOR greater than 1 indicates greater odds of being unable to complete the condition.

4. Discussion

Balance was compared across sensory conditions in adults with DPN, diabetes without DPN, prediabetes without peripheral neuropathy, and healthy controls. Under the least challenging condition, performance was similar across groups. Differences appeared when sensory demands increased. The DPN group showed the greatest impairment, with significantly higher odds of failure when visual or somatosensory information was limited. Adults with diabetes without DPN did not differ significantly from healthy controls, while the prediabetes group showed differences under some sensory conditions. This pattern suggests that peripheral neuropathy is associated with balance difficulty that may be missed during ordinary standing but becomes apparent when sensory input is challenged.

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Balance problems are commonly reported in diabetes, especially in people with DPN. Earlier studies found greater postural sway and instability in DPN than in diabetes without DPN or healthy controls. Some detected differences even with the eyes open on a firm surface [9, 10]. No significant group difference was found under that condition here. One possible explanation is that vision, vestibular input, and somatosensory information are all available during eyes-open standing on a firm surface. People with reduced peripheral sensation may be able to use the other inputs to remain stable. How balance is measured may also matter. Earlier studies often used force platforms to detect small changes in sway, while the Modified Romberg test records whether the required stance can be maintained. A person with DPN may therefore have some instability without failing the task. The differences under more demanding conditions suggest that DPN-related deficits become clearer as sensory information is reduced or less reliable.

Adults with DPN performed worse on the compliant surface even when their eyes remained open. This result may reflect the importance of sensory input from the lower extremities in maintaining balance. A compliant surface makes support-surface somatosensory information less reliable and places greater demands on the integration of the remaining inputs. In DPN, peripheral nerve damage has already reduced plantar tactile sensation and proprioceptive feedback [11]. Studies using similar changes in sensory conditions have also found greater instability in DPN on compliant or unstable surfaces, supporting a contribution of impaired peripheral sensory input to balance dysfunction [12, 13]. Having the eyes open did not remove the balance differences in this study. Vision may therefore be unable to fully compensate for compromised somatosensory input during more demanding tasks. Greater impairment was also seen in DPN when participants stood on a firm surface with their eyes closed, despite the relatively reliable information from the support surface. Both patterns suggest that DPN-related deficits become more apparent as sensory information becomes unavailable or less reliable and postural demands increase. Sensory weighting and postural sway were not measured directly, however, so these observations do not establish that sensory integration mechanisms were altered.

Condition 4 combined eyes-closed standing with a compliant surface. Performance worsened across all groups, and approximately half of the study population could not complete the task. Earlier studies likewise identified this combination as particularly difficult for people with DPN [10, 14]. With vision unavailable, balance depends more on vestibular and somatosensory inputs. At the same time, the compliant surface makes support-surface information less reliable, and DPN further compromises peripheral sensory feedback. Previous work has also reported more pronounced instability in DPN when visual input is removed and somatosensory information is altered [15]. Even with the high overall failure rate in Condition 4, adults with DPN were significantly more likely to fail than healthy controls. Their additional difficulty was therefore still apparent in a task that challenged the broader population. The association was smaller than in Conditions 2 and 3. High failure rates across groups may limit the ability of the task to distinguish DPN-related deficits, accounting for the smaller relative difference without implying less severe impairment.

Peripheral nerve damage may be difficult to reverse, but exercise may improve some of its functional consequences, including impaired balance. In this study, balance deficits were most apparent when vision was unavailable or support-surface sensory information was less reliable. This pattern suggests a possible role for exercises that strengthen the lower extremities and gradually increase the demands on postural control under different sensory conditions.

Trials combining balance exercises with lower-extremity strengthening have reported benefits for people with DPN. After 12 weeks of gait, balance, and functional strength training, Allet et al. [16] observed better balance and walking performance. Venkataraman et al. [17] reported improvements

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in sit-to-stand performance, ankle strength, and balance confidence after an eight-week strength and balance intervention. These results suggest that improving the muscular and functional aspects of postural control may help people with DPN remain stable even when peripheral sensory deficits persist.

Sensorimotor training may also be relevant to the differences observed across sensory conditions in this study. Interventions that include weight shifting, obstacle crossing, and visual feedback have reduced postural sway with the eyes both open and closed. Alongside conventional strength and balance exercises, these activities may allow people to practice maintaining balance as sensory information changes in availability or reliability. It is still unclear whether the improvements extend to more demanding tasks, such as standing with the eyes closed on a compliant surface.

Tai Chi and yoga may offer other ways to practice controlled weight shifting, awareness of body position, and dynamic balance. A systematic review reported improvements in balance and fall-risk measures after interventions involving weight shifting, including Tai Chi and yoga [18]. Direct comparison with conventional strength and balance programs is difficult because intervention protocols, study quality, and outcome measures differ. For people with DPN, exercises should be matched to baseline balance ability, sensory loss, and foot health, with appropriate supervision as tasks become harder. Improvements in balance and physical function have been reported, but evidence that exercise reduces actual falls in DPN remains limited. These findings support further research on training that gradually increases postural demands across sensory conditions. This study was cross-sectional and did not test an intervention, so it cannot show whether sensory-specific balance training would improve performance or which form of exercise would be most effective.

The cross-sectional design of NHANES limits what can be concluded about these associations. It cannot establish causality or show the temporal relationship between peripheral neuropathy and balance impairment. Neuropathy was identified by monofilament testing, which mainly detects loss of protective sensation and may not capture the full range or severity of DPN. The Modified Romberg test provides a clinically relevant measure of standing balance, but it does not directly measure postural sway, sensory weighting, or sensory integration mechanisms. Test duration also differed: Conditions 1 and 2 lasted 15 seconds, whereas Conditions 3 and 4 lasted 30 seconds. The longer duration of Conditions 3 and 4 means that their higher failure rates cannot be explained by sensory challenge alone. Any interpretation about reliance on particular sensory systems therefore needs caution. Adjustment for demographic and health-related factors may not have removed all confounding. Diabetes duration, glycemic control, vision, vestibular function, lower-extremity strength, medication use, and other diabetes-related complications could still have influenced the associations.

5. Conclusion

Adults with DPN had greater difficulty maintaining balance when visual or support-surface sensory input was challenged. Little difference between groups was seen under the least demanding condition. After adjustment, diabetes without DPN did not differ significantly from healthy controls, suggesting that peripheral neuropathy may be an important correlate of balance impairment beyond diabetes status alone. Testing balance under several sensory conditions may give a fuller account of the postural deficits associated with DPN than testing only under optimal standing conditions.

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